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Contents

Foreword

There has long been a need to review the present knowledge on the quality of sorghum grain, especially since it is one of the major food grains of 700 million people living under impoverished conditions in the semi-arid tropics.

To meet this need, ICRISAT hosted an International Symposium on Sorghum Grain Quality in October 1981 at ICRISAT Center near Hyderabad, India. It was sponsored by the USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL), the Indian Council of Agricultural Research (ICAR), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Participants interested in sorghum as a food who attended the Symposium represented diverse disciplines: food technology, home economics, nutrition, breeding, biochemistry, food processing, engineering, pathology, and economics, and the topics included the existing knowledge on preparing sorghum as a food, its grain structure and deterioration, milling and laboratory methods for evaluating and improving food quality, nutrition, consumer acceptance, marketing, and quality standards.

A wide range of sorghum grain types is used to prepare different solid and liquid foods such as porridges, leavened and unleavened breads, snacks, beverages, and beer. However, there are two major disadvantages of sorghum as a food—the problems of nutrient uptake, and the constant drudgery involved in hand pounding and hand grinding to make sorghum flour.

Sorghum grain quality is a complex subject. Only in recent years have nutritionists and millers studied the problems associated with sorghum. To replace hand processing, several pilot projects using machines for pearling and grinding are under way in some locations in Africa.

Increasingly, plant breeders are developing new varieties and hybrids. For successful adoption of new cultivars by farmers, consumer acceptance is an essential requirement. We need more information on why sorghum is accepted or rejected as a food, and work still needs to be done to develop laboratory tests to screen sorghum for food quality.

But much has already been accomplished. Progress has been made in such diverse fields as the description of food preparations and the quantification of quality; pearling and milling technology; and nutrition. The identification of genes that contribute to high lysine has spurred interest in nutrition. There has also been increased research on tannins.

Forty-two papers were presented and discussed at this unique Symposium and recommendations for future action were formulated and are included in these Proceedings. We hope that the Symposium will stimulate more intensive and wider ranging research on sorghum grain quality, and that these Proceedings will serve as a useful reference for food-related studies on sorghum in the 1980s.

L. D. Swindale
Director General

Inaugural Session

Chairman: E. R. Leng **Rapporteur: K. Anand Kumar**

Welcome Address

J. C. Davies*

On behalf of INTSORMIL, ICRISAT, and ICAR, it gives me great pleasure this morning to welcome you to this Symposium on Sorghum Grain Quality and to extend a cordial welcome to ICRISAT and Hyderabad. To those of you who have joined us from the far-flung corners of the globe, the Workshop Committee trusts that you had pleasant journeys, and that they were not too exhausting in view of the strenuous program prepared for you here. You have come to Hyderabad at certainly one of the best times of the year weatherwise, and also at a time of great significance in the Hindu calendar—a time to take stock and to look afresh at things of the past and to make plans and resolutions for the years ahead. It is also an opportune time, in that the prolongation of the rains and their amount this year has demonstrated very forcibly to us at ICRISAT, yet again, the importance of the subject in hand. It is particularly appropriate that papers include some on grain deterioration and quality as it affects cultivar acceptance. These considerations will, I feel sure, be well reflected in your deliberations over the next few days of interaction, discussion, and formulation.

When a small workshop on the quality of sorghum grain was first considered about a year ago, we at ICRISAT welcomed that idea as it added another dimension to the Sorghum in the Eighties Symposium, already well into the planning stage. At that time we did not quite visualize the intense interest and enthusiasm that has resulted in this excellent attendance this morning. As you see from the program, the sessions planned range over topics as varied as physical grain characteristics and quality of boiled sorghum in relation to starch; they include presentations on diverse food products from the traditional *teau* of Mali, to the *tortillas* of Mexico and the *rotis* of India. It is notable that a full session on consumer acceptance is to be held.

We are particularly pleased to welcome so many young scientists actively working in the quality field from developing countries and indeed to see so many old friends who have worked for years on the subject. We know that the interaction between the participants can only be of great benefit in our mutual endeavors to improve the quality of life of the peoples who are habitual consumers of sorghum the world over.

The diversity of the program and the participants is also reflected in the city of Hyderabad, a historic city in the state of Andhra Pradesh, where cultures and peoples have intermingled and met over the centuries. We know that you will find the traditional hospitality of Hyderabad and India to your liking. I hope that your full schedule will allow you to sample not only the quality of sorghum, but also the quality of Hyderabad. I wish you all a pleasant stay, a useful conference, and a fruitful outcome of your deliberations. If we, as the Symposium Committee, can do anything to assist, please do not hesitate to ask. Have a good day.

* Director for International Cooperation, ICRISAT.

Opening Address

E. R. Leng*

I should like to add on behalf of INTSORMIL my welcome to that already expressed by Dr. Davies. I am sure that this workshop will develop much useful information and contribute a great deal to understanding the need for attention to grain quality in sorghum improvement. The genesis of this workshop was with Dr. Rooney, who took the initiative—even before INTSORMIL was funded—to organize a meeting of sorghum workers interested in food products and grain quality related to them. When we began to discuss plans for "Sorghum in the Eighties," it was soon decided to hold the grain quality workshop just prior to the major symposium; this plan has been carried out, and the present workshop is the result.

Sorghum grain quality, as compared to that of other cereals, is a peculiarly complex matter. Sorghum has a very wide variety of food uses as well as those for animal feed or industrial use. The variety of food products made from sorghum is very wide compared to the range of products from other major cereals. It will be a chief objective of this workshop to delineate this range of products and to arrive at a determination of principal quality factors for each major class of product. This is likely to be a difficult but very interesting task.

Again I hope that our deliberations go well and that useful results emerge from this workshop.

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The Importance of Food Quality in Sorghum Improvement Programs

H. Doggett*

Sorghum improvement programs in the semi-arid tropics (SAT) are concerned in the main with the grain for human food. The acceptability of the stover (stubble) as fodder for cattle is a consideration to be remembered, but it is incidental to the main breeding program. Breeders have always concentrated on improving yield, and in more recent years stability of yield. However, in the past, too little stress was laid on grain quality.

Grain quality may be conveniently divided into cryptic quality and evident quality.

Cryptic Quality

The argument for working on nutritional value is based on the fact that the farmer is producing the grain for food. If plant breeders can improve the quality of that food, then this should be done subject to yield and yield stability being maintained. For the same effort, the farmer gets the same quantity of better food.

We are fortunate in having the comprehensive review by Hulse et al. (1980) to help us in assessing grain quality needs. Their summaries of analyses show that there is considerable variation in sorghum for levels of protein, lysine, lipids, carbohydrates, fiber, calcium, phosphorus, iron, thiamine, and niacin, and also in the isoleucine : leucine ratio. Provided that suitable analytical techniques are available, any of these nutrients could be the subjects of successful plant breeding programs. Are any of them worthwhile? Hulse et al. (1980) point out that the lysine content of sorghum is among the lowest of any of the cereal grains, and they note the great importance of sorghum in the diets of the peoples of the SAT.

They recommend that research be continued to stabilize a higher-than-average lysine content in combination with an average (say 10 %) protein content. There can be no question but that their recommendation is correct; the protein is being produced in any case and if more of it could be utilized for food without the need to supplement with another food containing abundant lysine, so much the better.

The initial optimism that this would prove possible has not yet been justified. The Ethiopian high-lysine types were only of use as immature grains; the P721 mutant seems more hopeful, but at the present time it is not possible to recommend any good sources of high lysine that do not have undesirable pleiotropic effects for use in ordinary breeding programs. The effects of recurrent selection on this character have not yet been tried seriously, to my knowledge. Gebrekidan in Ethiopia is using the dented grains of the local high-lysine types as indicators of crosses in a recurrent selection program, since plump seeds on such heads are hybrid seed, not selfs. It will be interesting to see in due course whether any plump seeded high-lysine types occur.

Of the other cryptic quality factors, the leucine:isoleucine ratio appears to be important, but there are no quick screening techniques such as the UDY system that would make a breeding program possible at present. It will be realized that nutritional factors—the cryptic characters—have to take their place in the list of priorities among all the yield and yield characters needed. It is not possible to breed for everything at once.

Evident Quality Characters

Two evident quality characters are the presence of tannins in the grains and grain mold damage to the grains.

The tannin situation is governed very largely, but not entirely, by the grain-eating bird population. This is particularly true in Africa with the *Quelea* birds, which descend on the small grain

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crops like locusts. The tannins in sorghum are polyphenols, which render the grain astringent and unpalatable, especially in the green stage. In some varieties, the astringency diminishes on ripening, until it almost disappears. Such sorghums can be ground into flour and used for food in the normal way, although the product is colored, often quite strongly.

This provides the only character that plant breeders can use to select for better grain quality among the bitter sorghums of the bird areas. To be useful, the bird population needs to be small enough at the grain-ripening stage for damage levels to be acceptably low. High tannin levels result in low digestibility and reduced protein efficiency ratio levels.

Such high tannin sorghums therefore present problems of utilization that have been largely solved by the people dependent upon them. Germinating the sorghum grain in wood-ash is said to reduce the tannin content, and this process is the basis of much of the beer-making found in Africa. In some regions, special brewing sorghums are grown that have high polyphenol contents, and no doubt flavor is a consideration in this situation, although the malting germination is still done in moist wood-ash. For areas where the sorghum grains are predominantly brown, beer is often the method of using the grain for food. Westerners think of the tannins as improving the flavor of the beer, whereas in Africa the manufacture of the beer is one method of reducing the tannins and improving the digestibility of the proteins. Some people obtain much of their nourishment from these beers, which contain a lot of solids.

Grain molds are another source of grain deterioration which the plant breeder can do a great deal to reduce. The ICRISAT grain mold resistance program has succeeded beyond my original expectations, and mold resistance should be a component of any food quality program where grains are liable to ripen in some seasons under conditions that favor grain mold development.

Food Quality

Attention has already been drawn to areas that have special problems of bird incidence and or grain molds that have an overriding influence on the type of sorghum grown. The people have had to learn to use those sorghums for food, and their standards of good or bad are relative within those grain types.

When these constraints are absent, the conventional wisdom in Africa was to associate good food quality with clean, white, cream, or even yellow corneous grains, often shiny with a thin pericarp. This character is less important where the pericarp is removed by pearling with a pestle and mortar, as is frequently done in Africa. Color is also important, as minor damage can result in a pinkish color in the prepared food. Plants lacking this pigment (tan plants) were therefore chosen. The very corneous grains were harder to grind, and one was never certain whether this character was desired primarily for food quality or for grain storage. Plant breeders looked first at the plant, then at the grain. They bit the grain to judge hardness, presence of a testa, and the amount of corneous endosperm and appearance. That simple procedure determined which plants had "quality" grains.

Another achievement of the past 5 years has been the classification of sorghum food types on a worldwide basis and correlations of food types with grain characteristics. Keeping quality and food quality have to go together in some areas, so cooking methods have been developed to suit the grain types that store well. Looking at the data on the corneous endosperm scores, those with a very corneous endosperm are used for the thick-paste products, i.e., the *tô* and *ugali*. These foods belong to areas where grain storage is a problem. At the other extreme, *injera* belongs to the cool highlands, where such problems are not so severe. *Tortillas* are a food of the highlands of Central and South America originally, the main maize-growing zones, cooler also, and needing only a low percentage of corneous endosperm. At present, *roti* comes lower in the corneous score scale, but this could well be revised upwards later. *Kisra* seems to be a compromise: perhaps literally a compromise. The ancient people on the eastern side of Africa grew their sorghum in the highlands where no doubt they developed the fermented bread. Moving into the lowlands, they needed better keeping quality, so a more corneous endosperm. Perhaps we do not yet have a sufficient understanding of the grain that makes good *kisra*. In the tables I have seen of a comparison of 25 cultivars, the highest score for *kisra* for any cultivar is 2.1. A lower score indicates a higher quality. All the other forms achieve at least one 1.0 rating, except for *tortilla*, which received 1.2 for CSH-5 (The *ugali* comparison is incomplete, only 11 of the 25 cultivars were tested).

The milling information also favors the harder grains; the *injera* types cannot be expected to mill well, while the Dobbs types underline what had already been realized—that the prospects of milling off a bird resistant testa are not good. We need harder grains, and if these had been obtained the milling losses would probably still have been unacceptably high, because so much has to be removed from the outer layers of the grain.

Pearling and Milling

Work has been in progress over the past few years to study the pearling and grinding of sorghum grain. IDRC supported a project at Maiduguri in Nigeria to try out small-scale pearling and grinding machinery; this was followed by work in Botswana, and an active program has continued. It would seem from the viewpoint of the plant breeder that we must learn how to handle the existing popular grain types, but in due course the best types for mechanical handling will be identified and can be bred into the breeding programs.

Plant Breeding

Turning to the plant breeding considerations, yield and quality will always be the primary objectives of our programs. Before a new cultivar is released to farmers, it is important that its food quality should have been properly evaluated by people through tasting and cooking tests. It may be necessary to sacrifice a little yield in favor of better quality; we all know the situation in which the improved cultivar is grown for sale and the traditional type retained for food. There is a trade off; this can only be balanced up by those involved in the production and consumption of grain.

Our programs must be matched to the local needs. It is no good aiming for a white corneous grain type in bird areas, unless one has first identified a part of the season into which a short-duration type might fit, when the birds have moved elsewhere to nest. If we are in brown-grained sorghum areas, how is the grain used for food? Do the local types become less astringent as they ripen? If so, we must see that this character is in our good lines. Is the grain germinated in the course of preparing beer or food? If so, under what conditions? In damp wood-ash? Our lines must be as good as the local cultivars when subjected to these same treatments.

In many other areas, the old system of looking at plant color, grain color, pericarp, absence of a testa, and proportion of corneous endosperm while selecting in the field will sort out a great deal of the material. Later, more refined small-scale tests can be done, and we can expect ICRISAT to come up with the most useful of these tests for the particular food type popular in each area. A testing panel of local sorghum eaters should be assembled to test the products before they go to the multiplication stage.

I suspect that, with both *injera* and *kisra*, small-scale tests will be needed that involve actually making the final product and a standard local type for comparison.

Storage

Lastly, how do our potential new lines keep in store? There are two main methods of storage: threshed grain, and unthreshed heads. The pests of the former are the rice weevil-*Tribolium* complex. There are various ways of estimating losses from these. I always used net bags containing 100 grains each, buried in a tin of weevilly grain each tin being a replication. The damaged grains were counted every fortnight. Ten replications were used and also two local cultivars as controls. The whole head system of storage can be simulated by hanging heads on wires in a room where there is some Angoumis grain moth (*Sitotroga*) infested grain spread out on the floor. Again, use plenty of replication, compare with two checks, and count at intervals.

Conclusions

1. Make sure that your new lines will yield equally well as, or better than, the farmer's cultivars *under the conditions he actually uses*, but are much more responsive to good management than his types.
2. Ensure that your new lines are of acceptable quality for preparing the local food or drink.
3. Ensure that your new lines will keep in storage reasonably well when compared with local cultivars.

Reference

HULSE, J. H., LAING, E. M., and PEARSON, O. E. 1980. Sorghum and the millets: Their composition and nutritive value. IDRC, Ottawa, Canada: Academic Press. 997 pp.

Session 2

Traditional Food Preparations and Their Quality Parameters

Chairman: L. W. Rooney

Discussant: L. R. House
Rapporteur: K. Anand Kumar

Evaluation of *Tô* Quality in a Sorghum Breeding Program

S. Da, J. O. Akingbala, L. W. Rooney, J. F. Scheuring, and F. R. Miller*

Summary

A procedure for cooking tô from less than 10-g sorghum flour has been perfected and used in evaluating several sorghums from the International Food Quality Trials and from ICRISAT sorghum breeding programs in Upper Volta and Mali for tô quality.

The method is effective in separating sorghums of good, average, and poor tô-making properties. The results compare favorably with traditional large quantity tô evaluation methods currently in use in ICRISAT, Mali, and Upper Volta. The method is relatively simple and will reduce time and effort in screening for good tô quality sorghums.

Tô is a staple food in most parts of Africa, South of the Sahara. *Tô's* other names include *teu, tuo, tuwo, ugali,* and *asidah. Tô* is prepared from rice, maize, millet, or sorghum depending on taste, cost, custom, geographical areas, and/or availability of grains.

In 1975, the ICRISAT station in Kamboinse, Upper Volta, initiated its breeding program with short growing cycle sorghums to combat the successive Sahelian drought experienced in previous years (Pattanayak et al. 1976). These varieties had some improved agronomic characteristics that promised to improve grain yields over the local varieties. However, some of the grain produced was not suitable for *tô* making, therefore the grain was unacceptable to Voltaic consumers. The realization that *tô* quality of sorghum was important stimulated the Sorghum Improvement Program in Upper Volta to evaluate potential new sorghum varieties for *tô* quality as well as agronomic properties, disease, and insect resistance. Thus, cooking trials were initiated by ICRISAT at Kamboinse, Upper Volta, in 1977 to evaluate *tô* quality.

* Da and Akingbala are graduate students; Rooney is Professor, Cereal Quality Laboratory; and Miller is Associate Professor, Sorghum Breeding, Soil and Crop Sciences, Texas A&M University, College Station, Texas 77843, USA; Scheuring is a Cereal Breeder, ICRISAT, Bamako, Mali.

The *tô* of Upper Volta is generally made from sorghum flour prepared by hand decortication of the grain to remove the bran (pericarp). The decorticated grain is ground into flour by additional hand pounding in the mortar with a pestle. The flour is cooked in water that is acidified by adding extracts of tamarind or juices of lemons. The pH of the *tô* is about 4.5. The flour to water ratio varies but is usually about one part flour to four parts of water. The *tô* is allowed to cool about 1 hr after cooking before it is consumed with a sauce composed of numerous ingredients including tomatoes, okra, or gumbo, chilies, cow pea leaves, cow peas, and amaranthus. The exact ingredients used vary with the season, availability, and cost. The *tô* sauce is an important source of protein, minerals, vitamins, and other nutrients required to improve the nutritional value of the *tô*.

Tô with sauce is the major staple food consumed in Upper Volta, although a significant proportion of the sorghum grown there is used to produce beer. Other foods from sorghum, such as *cous cous* and *fura*, comprise only a small proportion of the total grain consumed. Thus, for sorghum quality, *tô* is the major food use that must be considered.

Characteristics of Sorghum Suitable for *Tô*

The *tô* quality of sorghum in Upper Volta is affected by the milling properties of the grain, by the cooking properties of the flour, and by the acceptability of the fresh and stored *tô*. The general appearance of the grain is important. Sorghums that are easily decorticated by hand pounding in a mortar and pestle are desirable. Thus, sorghums with a thick pericarp and a corneous endosperm are preferred. A promising experimental line, 940, from the ICRISAT Upper Volta program, was too floury and had poor milling properties that resulted in poor decortication and low yields of the decorticated grain. Grains should be mold free since a moldy grain has poor milling properties and produces bad tasting *tô*.

The consumer wants *tô* with a firm paste that holds together and does not crumble under finger pressure. It must not stick to the fingers, teeth or roof of the mouth when eaten. Firmness and nonstickiness should remain constant when *tô* is stored overnight before consumption. Some varieties of sorghum produce fresh *tô* with acceptable quality; but after storage it turns soft and sticky and is not acceptable by consumers. Yellow or white *tô* color is preferred, but pink, red, or gray *tô* with good texture is also well accepted. Bland flavor is preferable.

The objectives of this paper are to review how *tô* is produced and consumed traditionally and to present laboratory techniques developed to evaluate the firmness, stickiness, and color of *tô* made from sorghums with varying quality. The potential use of these techniques in a breeding program is discussed. This was approached by developing laboratory procedures for decortication and milling of sorghums into flour. Then, a laboratory procedure was developed for cooking small flour samples into *tô* similar to that obtained by the traditional process. This new procedure was used to cook *tô* from several sorghum varieties from the ICRISAT and International Food Quality Trial (IFQT) programs. Results from the objective methods developed for *tô* texture measurements were compared with those from subjective methods used in ICRISAT stations of Kamboinse, Upper Volta, and Mali.

Material and Methods

Sorghum Samples

Several kg of grain from varieties grown at Kamboinse in Upper Volta were used to obtain preliminary information that was required to develop the laboratory procedures described in this paper. Kamboinse Local and S-29, known for their good milling properties and good *tô* quality, and 940 sorghum that had poor milling and poor *tô* quality were supplied by Dr. Pattanayak and colleagues at ICRISAT in Kamboinse, Upper Volta. In addition, sorghums with thick and thin pericarps were used as parents in an incomplete diallel cross program. The sorghums with a thick pericarp were BTx3197 and BTx623 from the Texas Agricultural Experiment Station. Sorghums with a thin pericarp used in the crossing program were 77CS2, CS3541, and TAM428. All of the sorghums had white or colorless pericarps without pigmented testa. Grain from heads of the F_2 of nine crosses was obtained. The crosses were:

BTx623 × CS3541	BTx623 × TAM428
TAM428 × CS3541	CS3541 × TAM428
CS3541 × 77CS2	BTx623 × 77CS2
BTx3197 × CS3541	77CS2 × CS3541
BTx3197 × TAM428	

Fourteen sorghum samples from ICRISAT Mali and 25 International Food Quality Trials (IFQT) sorghums grown at ICRISAT Center, Hyderabad, India in the postrainy seasons of 1979 and 1980 were evaluated for *tô* quality. These samples were highly diversified in kernel size, endosperm texture, endosperm type, pericarp color, chemical composition, and food qualities.

Milling Procedures

Techniques for milling sorghums from 5 g to several kilogram are available. Those techniques that we have found useful are presented here.

Micro Methods

A 10 g sample from the parents and the F_2 generation was pearled in a modified Udy cyclone mill (Shepherd 1979) at 1500 rpm for a period of 15, 30, 45, 60, and 90 sec. The pearled grain, bran, and fines from the bran were sieved and collected separately and then weighed to evaluate ease of pearling of these sorghums. Then the pearled grain was milled in a Udy cyclone milf to pass through a 2.4 mm screen opening and used in cooking *tô*. This technique can be used to mill grain samples from individual heads.

Semimicro Methods

A 100 g sample was pearled in a Strong Scott barley pearler fitted with a carborundum wheel for 1 min. The pearler was modified for a continuous pearling operation. Then, a seed blower was used to separate the decorticated grain from the pericarp and fines. The clean decorticated grain was milled into flour with an Udy hammermill equipped with a cyclone collector device to allow flour to pass through a modified 5.78 mm screen. Two large openings were made in the sieve to obtain a flour particle size that was similar to the one milled in Upper Volta by hand decortication followed by grinding into flour with an attrition mill.

Cooking Procedure

A small-sample *tô* cooking procedure was standardized for acid and alkali *tô* (Fig. 1). The products from the laboratory procedure compared favorably with *tô* from Upper Volta and Mali in texture, pH, taste, and acceptability.

Acid *Tô* (pH 4.6)

A 9.5-g flour (dwb) was made into a slurry using 20 ml distilled water. Twenty milliliters of water were measured into a 150 ml beaker, 1 ml lemon juice concentrate (Realemon brand, Borden Inc.-T, Columbus, Ohio 43215, USA) was added. Then

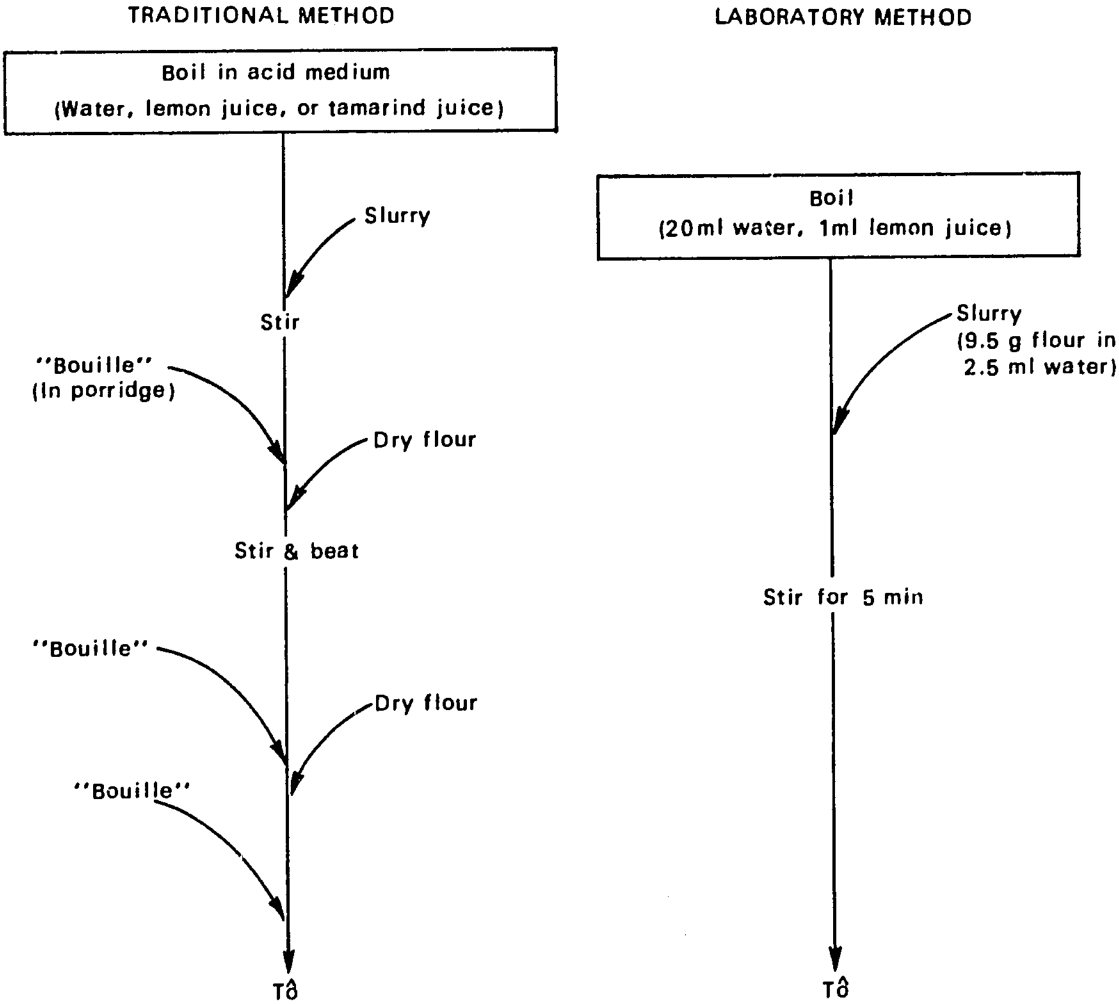


Figure 1. Traditional and laboratory methods of tô *preparation.*

the mixture was heated on an electric hot plate (model HP-A1915 B, Type 1900, Therodyne Sybron Corp., Dubuque, Iowa, USA) at maximum temperature until boiling. Then the flour slurry was poured into the boiling acid solution with continuous stirring to prevent lumps. Water (5 ml) was used to rinse all the flour into the boiling solution. The slurry was cooked for 5 min, then poured into two 10 ml beakers, and set aside for testing. *Tô* from one of the beakers was tested after 1 hr at room temperature (fresh *tô*) and the other after 24 hr storage (stale *tô*). Storage temperature and relative humidity were usually maintained at 44° C and 70% relative humidity. They were varied in some experiments.

Alkali *Tô* (pH 8.8)

Flour, 9.5 g (dwb), was made into a slurry as described for the acid *tô*, then poured into a boiling alkali solution (45 g KOH in 200 ml H_2O or 0.07 M solution). The beaker containing the flour slurry was rinsed into the boiling alkali with 5 ml distilled water and the mixture was cooked for 5 min with continuous stirring. After cooking, the *tô* was poured into two 10-ml beakers and set aside for testing as in the acid *tô*.

Cooking at Different pHs

The laboratory cooking procedure was modified for cooking *tô* at different pHs. Flour, 9.5 g (dwb), was mixed with 45 ml of the pH adjusted solution and cooked for 8 min on an electric hot plate set at the maximum heating capacity. *Tô* was cooked at pH 3.0, 4.0, 5.5, 7.6, 8.0, and 9.0 using this procedure.

Quality Evaluation

Tô texture was evaluated by objectively measuring its stickiness and softness properties. Texture was evaluated in the fresh and stale *tô* to observe its keeping quality. The color of fresh and stale *tô* was measured with a Gardner color meter equipped with an XLIO-CDM transmission attachment (Gardner Laboratory Inc., Bethesda, Maryland, USA).

Softness

Tô was removed from the beaker and cut into six slices with an egg slicer. The top and bottom slices were discarded. The remaining four slices were divided into two (11.0-mm thick) sets of two slices each. The softness of each set of slices was measured with a precision penetrometer (Serial No. 11-Y-12, Precision Scientific Co., Chicago, Illinois, USA) calibrated in 0.1-mm divisions and equipped with a one-quarter size (8.3 g) penetration cone (Fig. 2a). The *tô* sample on a hard flat surface was placed under the cone and the cone

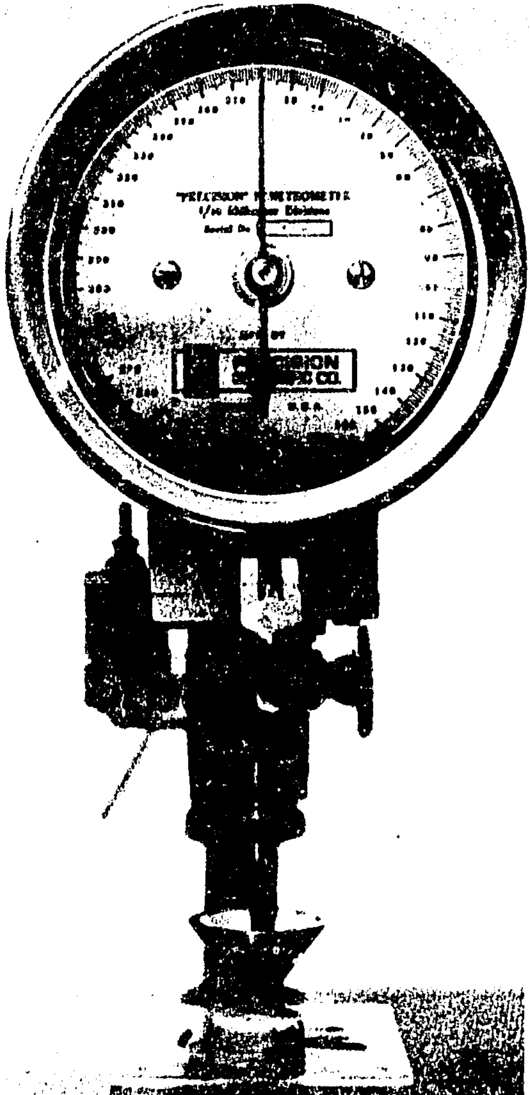


Figure 2a. Precision penetrometer for measuring tô *softness.*

was lowered until the tip just touched the surface of the *tô*. Then the cone was released by a lever and allowed to free fall into the *tô* (Fig. 2b). The penetration of the cone into the *tô* was read on a dial calibrated in 0.1 mm, 2 sec after the fall of the cone. The cone penetrated deeper into a soft *tô* than it did into a firm *tô*.

Stickiness

The stickiness of *tô* was measured by a method similar to that described by Kumar et al. (1976) for measuring the stickiness of bread crumb. *Tô* stickiness was measured on the same slices used in the softness determination. The stickiness of each slice was determined. The apparatus used for measuring *tô* stickiness is presented in Figure 3a. It consists of a double pan balance, a burette, a laboratory Big Jack (Precision Scientific Co., Chicago, USA) and a water trough. Two 10-ml beakers are placed on the left scale and an aluminum disk is attached to its bottom with a rod. A water trough made of an aluminum dish is placed on the right scale pan. The water trough balances the weight of the two small beakers, the rod, and the disc. To measure *tô* stickiness, the balance pointer is zeroed by addition of water to the small beakers. Then, a slice of *tô* on a flat surface is raised on the laboratory jack until it touches the disc under the left pan. A good contact between the *tô* surface and disc surface is assured by tapping the disc lightly with a dissecting needle. The balance pointer, displaced from zero by the contact between the *tô* and the disc surfaces, is zeroed again by raising or lowering the jack. Then water is added from the burette into the trough at the rate of 15 ml/min. The pointer is deflected by the addition of water to the trough. When the weight of the water overcomes the adhesion of the metal disc-*tô*-interface, the disc

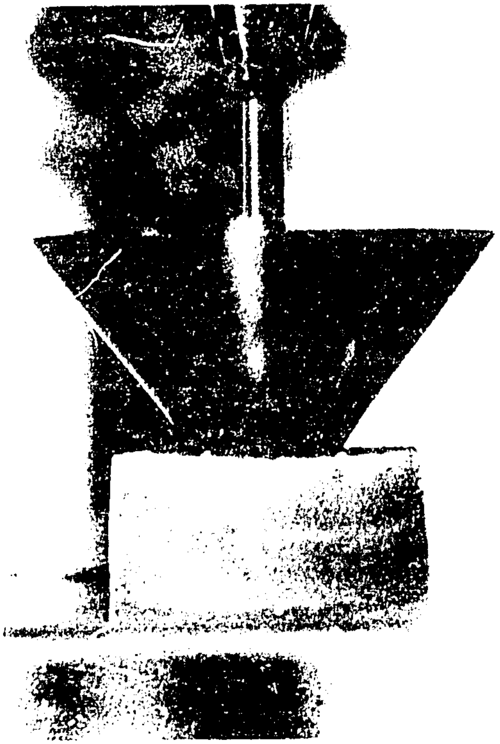


Figure 2b. Cone has penetrated tô *after being allowed to free fall into it.*

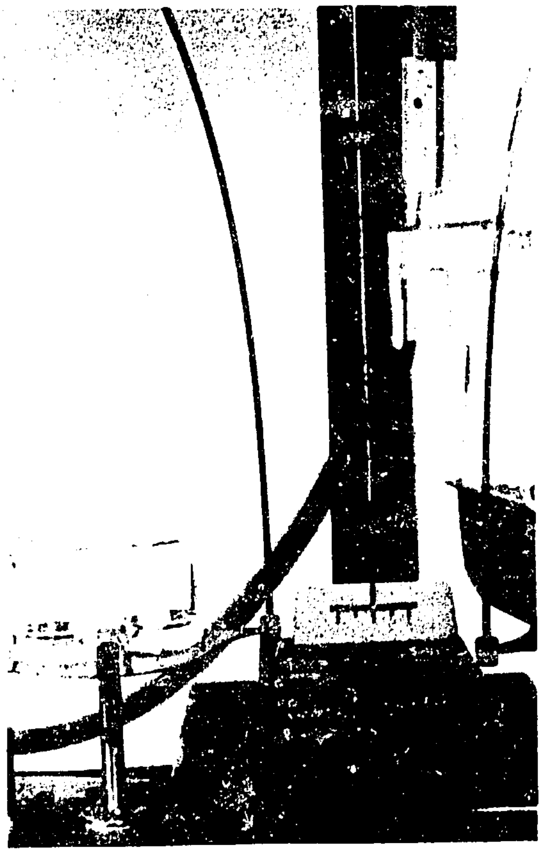


Figure 3a. Double pan balance for measuring tô *stickiness.*

separates from the *tô*. The separation of the disc from the *tô* brings the pointer deflection to an abrupt end as the pointer goes off the scale (Fig. 3b). The position of the pointer on the scale just before the break, is reported as *tô* stickiness. After each determination, the disc is wiped with wet tissue and dried. The higher readings indicate *tô* that has the greater stickiness.

Defining *Tô* Quality

A good *tô* is a firm and nonsticky to the fingers, the teeth, or the roof of the mouth. A *tô* with good texture has a stickiness reading of less than 3.0 and a firmness value of less than 7.0 mm by our method of stickiness and firmness measurement. *Tô* with an intermediate textural quality has a stickiness of 3.0 to less than 4.0, a firmness of 7.0 to less than 8.0 mm; a *tô* with poor texture has a stickiness of greater than 4.0 and firmness reading of 8.0 mm and above. On storage, a good quality *tô* should not soften, become more sticky, nor undergo weeping.

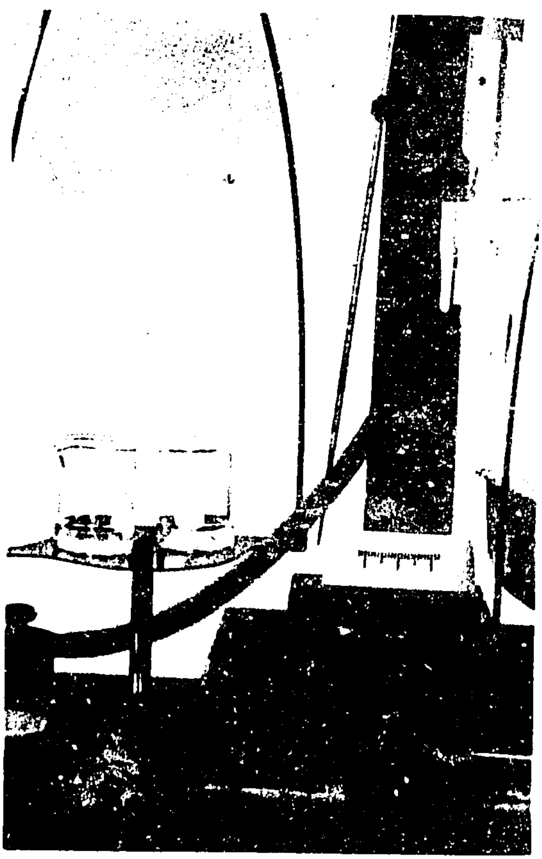


Figure 3b. Disc has separated from the tô and the balance pointer has gone off the scale.

Results and Discussion

Milling

The mean yields of the milling fractions from sorghum samples with thick mesocarp and samples with thin mesocarp are presented in Table 1 and Figure 4. At 15-sec pearling, 3.3% of the kernel was removed as bran in sorghums with a thick mesocarp compared with about 1% in those with a thin mesocarp. The mean yield of the endosperm was 90.0±2.1% in the thick mesocarp sorghum and 93.9±2.7% in the thin mesocarp sorghum at 30-sec pearling. These data (Table 1, Fig. 4) show that the thick pericarp is removed quickly at the beginning of pearling. Then the relative rates of removal are similar for both thick and thin pericarp. Others (Rooney and Sullins 1969; Scheuring 1980; Scheuring et al. 1977; and Shepherd 1981) have reported that sorghums with a thick mesocarp are easier to

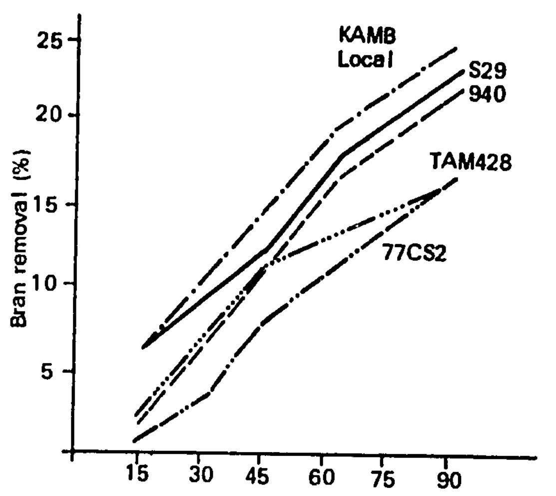


Figure 4. Percentage of total bran removed during pearling.

decorticate than sorghums with a thin mesocarp. The binomial frequency distribution for the milling yields of grain from F_2 heads of sorghum is presented in Figure 5. In this cross, involving thin and thick mesocarp parents, the Udy mill allows a clear discrimination among the segregating thin and thick mesocarp progenies.

Malian Sorghums

Acid *Tô*

Softness in the fresh acid *tô* ranged from 4.95 in Keninke to 8.35 mm in line 9289 with a mean of 6.26 ± 0.88 mm (Table 2). The mean softness for

Table 1 Mean yields (%) of milling fractions from sorghums with thick and thin paricarp.

Fraction	Pericarp	Time in seconds 15	30	45	60	90
Decorticated grain n = 5 range	Thick	95.4 ± 1.9 93.0–97.2	90.0 ± 2.1 87.5–92.1	85.1 ± 5.6 81.0–88.4	81.8 ± 3.3 77.7–86.8	75.3 ± 3.0 71.7–80.0
Decorticated grain n = 2 range	Thin	98.3 ± 1.2 97.4–99.1	93.9 ± 2.7 92.0–95.8	90.0 ± 2.4 88.3–91.7	86.8 ± 1.3 85.9–87.7	81.9 ± 0.2 81.7–82.0
Bran > 420 μ n = 5 range	Thick	3.3 ± 1.4 1.6–5.0	4.9 ± 0.7 4.0–5.9	6.1 ± 0.6 5.5–6.8	7.0 ± 1.0 5.4–8.2	10.0 ± 3.3 7.5–15.8
Bran > 420 μ n = 2 range	Thin	0.8 ± 0.5 0.4–1.1	2.3 ± 1.1 1.5–3.0	4.5 ± 0.3 4.2–4.7	5.4 ± 0.1 5.3–5.5	6.9 ± 0.9 6.2–7.5
Fines < 420 μ n = 5 range	Thick	1.4 ± 1.0 0.5–3.1	3.8 ± 1.4 2.8–6.3	6.8 ± 1.6 5.2–9.5	9.8 ± 2.3 7.0–12.9	14.0 ± 1.7 11.4–15.8
Fines < 420 μ n = 5 range	Thin	0.8 ± 0.6 0.4–1.2	2.9 ± 1.2 1.7–4.1	5.5 ± 2.0 4.1–6.9	7.0 ± 1.5 5.9–8.0	10.3 ± 0.4 10.0–10.5

Table 2. Textural Properties of Acid *tô* from Mali sorghums.

Variety	Stickiness[a] Fresh *tô*	Stale *tô*	Softness[b] (0.1 mm) Fresh *tô*	Stale *tô*
940-S	2.3 ± 0.3e	3.4 ± 0.1 c	71.4 ± 2.7b	73.3 ± 1.1b
CE-90	2.9 ± 0.1c	2.8 ± 0.3d	63.8 ± 1.1de	64.5 ± 1.4c
36 80-2	3.1 ± 0.1c	4.1 ± 0.2b	63.5 ± 8.8de	78.3 ± 2.5a
9-5	2.3 ± 0.1e	2.2 ± 0.1efg	57.3 ± 0.4f	58.8 ± 3.9d
38-3	3.0 ± 0.0c	3.4 ± 0.2c	68.8 ± 1.1bc	74.0 ± 4.2b
65 30	3.8 ± 0.1b	3.5 ± 0.4c	64.0 ± 2.8de	72.5 ± 5.0b
SPV-35	2.0 ± 0.0f	2.0 ± 0.0fgh	54.3 ± 3.9fg	54.8 ± 0.4e
VS 702	3.0 ± 0.0c	2.3 ± 0.2ef	66.0 ± 1.4cd	54.8 ± 0.4e
VS 701	3.1 ± 0.4c	2.3 ± 0.1e	62.0 ± 0.7e	59.5 ± 0.7d
9289	6.0 ± 0.0a	5.1 ± 0.1a	83.5 ± 0.7a	79.5 ± 1.4a
E35-1	2.1 ± 0.1f	1.9 ± 0.3gh	56.3 ± 1.8f	58.0 ± 2.1de
WAxNigerian	3.0 ± 0.0c	1.8 ± 0.1h	62.3 ± 6.1e	56.5 ± 0.7de
Keninke	2.0 ± 0.0f	1.1 ± 0.1i	49.5 ± 4.2h	42.8 ± 1.8g
S-29	2.4 ± 0.2e	1.0 ± 0.0i	53.8 ± 2.5g	48.0 ± 2.1f

a. Stickiness was mean of two replicates with four observations in each.
b. *Tô* softness (0.1mm) was mean of two replicates with two observations each.
Note: Means with the same letter are not different at the 5% level of significance.

the stale acid *tô* is 6.25 mm and was not significantly different from that of the fresh acid *tô*. However, this did not indicate stability in softness of the *tô* samples. *Tô* from S-29, Keninke, WAxNigerian, 9289, and VS702 firmed up considerably upon storage while *tô* from 36/80-2, 38-3, and 65/30 softened upon storage. The firmness of acid *tô* from the other sorghums did not change appreciably with storage.

Stickiness was slightly lower in stale acid *tô* with a mean of 2.6 ± 1.2, than in the fresh *tô* (mean = 2.9 ± 1.0). The range was also lower in stale (1.0 – 5.1) than in fresh *tô* (2.0 – 6.0). Most of the acid *tô* was in the nonsticky to intermediate stickiness range. *Tô* from sorghum line 9289 was the only acid *tô* with a stickiness value greater than 4.0.

Overall, CE-90, 9-5, SPV-35, VS702, E35-1, WAxNigerian, Keninke, and S-29 make good quality acid *tô*; 9289 makes poor quality *tô* while the other Malian sorghums make intermediate quality acid *tô*.

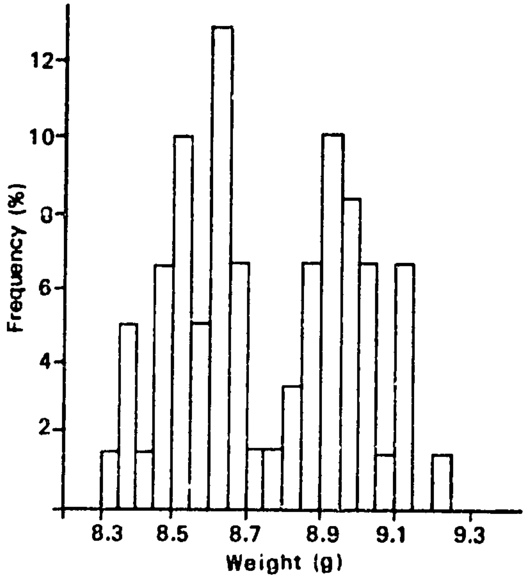


Figure 5. Frequency distribution for milling yields of grain from F_2 sorghum heads of CS3541 × BTx623.

Alkali *Tô*:

The softness and stickiness rating of alkali *tô* from the Malian sorghums are presented in Table 3. Softness ranged from 5.68 to 9.90 with a mean of 8.53 ± 1.29 mm in the fresh and 5.33 to 9.43 with a mean of 7.39 ± 1.08 mm in the stale alkali *tô*. Only three sorghums made alkali *tô* with acceptable firmness. These were Keninke and S-29 with good firmness, and WAxNigerian with inter-

Table 3. Textural properties of alkali *tô* from Mali sorghums.

Variety	Stickiness[a]		Softness[b]	
	Fresh *tô*	Stale *tô*	Fresh *tô*	Stale *tô*
940-S	4.2 ± 0.1d	4.1 ± 0.1c	95.5 ± 2.1bc	74.5 ± 9.2bcd
CE-90	3.6 ± 0.5e	3.1 ± 0.3e	82.5 ± 3.9d	59.0 ± 2.8g
36/80-2	6.1 ± 0.2a	5.3 ± 0.0b	97.3 ± 6.7a	77.8 ± 11.0b
9-5	5.2 ± 0.3c	4.1 ± 0.1c	89.8 ± 6.7c	72.0 ± 6.4bcd
38-3	5.3 ± 0.2c	4.1 ± 0.2b	99.0 ± 4.2a	80.0 ± 6.4b
65/30	5.8 ± 0.0ab	5.0 ± 0.2b	96.0 ± 2.8ab	89.5 ± 12.1a
SPV-35	3.3 ± 0.1e	3.3 ± 0.5de	75.8 ± 1.8a	70.8 ± 10.6cde
VS 702	4.4 ± 0.7d	4.1 ± 0.3c	82.3 ± 1.8d	77.5 ± 0.7b
VS 701	5.7 ± 0.1abc	4.2 ± 0.3c	93.0 ± 2.8bc	77.3 ± 6.0bc
9289	5.5 ± 0.4bc	5.8 ± 0.4a	99.5 ± 6.4a	94.3 ± 1.1a
E35-1	4.6 ± 0.3d	3.6 ± 0.5d	84.5 ± 9.2 c	75.3 ± 3.2bcd
WAxNigerian	3.3 ± 0.5e	3.3 ± 0.0def	73.5 ± 3.5e	67.8 ± 1.1def
Keninke	2.1 ± 0.2f	2.5 ± 0.0g	56.8 ± 1.8g	53.3 ± 5.3h
S-29	3.2 ± 0.3e	2.9 ± 0.1ef	68.5 ± 3.5f	65.3 ± 1.1f

a. Stickiness was mean of two replicates with four observations each.

b. *Tô* softness (0.1 mm) was mean of two replicates with two observations each.

Note: Means with the same letter are not different at the 5% level of significance.

mediate firmness property. However, CE-90 firmed up considerably during storage from a very soft *tô* to a very firm *tô*. The stale alkali *tô* was generally firmer than the fresh alkali *tô*.

All the Malian sorghum samples except Keninke produced moderately sticky to a very sticky alkali *tô*. Sorghums CE-90, SPV-35, WAxNigerian, and S-29 produced moderately sticky *tô* and the remaining sorghums very sticky *tô*. The stickiness of *tô* from these sorghums decreased upon storage. Only Keninke and S-29 made alkali *tô* with acceptable textural properties. *Tô* from the other sorghums was too soft and or too sticky and some also had poor storage properties. Our results were comparable with the data obtained in Mali on the alkali *tô* from these sorghums. The only exception was in the storage property of *tô* from E35-1. Our observation was that alkali *tô* from E35-1 firmed up upon storage. However, results from Mali indicated that it softens upon storage (Scheuring 1980). The difference in observation might be due to differences in the method of evaluation, i.e., subjective in the Mali study and objective in our laboratory. The observed differences could also result from the different procedures used in cooking and in the particle size indices of the flours. In ICRISAT Mali trials, *tô* was cooked until optimum cooking was observed. In our experiments, *tô* was cooked at a constant time (5 min) that was optimum for most of the sorghums. The differences in storage temperature, humidity, etc., could also result in the observed differences in keeping quality of *tô* from E35-1 by the two laboratories.

Tô Quality of Sorghums from the IFQT

Table 4 contains a summary of the stickiness properties of *tô* from sorghums from the International Food Quality Trial (IFQT) crops of 1979 and 1980. A summary of the firmness properties of these sorghums for the 1979 and 1980 crop seasons is presented in Table 5.

The acid *tô* from the IFQT sorghums were generally nonsticky with a mean stickiness of 2.3 ± 0.6 and 2.2 ± 0.8 in the fresh and stale acid *tôs* of the 1979 samples, and 2.5 ± 0.9 and 2.3 ± 0.6 as the mean stickiness of the fresh and stale *tôs* from the 1980 samples. There were no significant differences in the means of the fresh and stale *tô* stickiness. The mean stickiness of acid *tô* from the 1979 crop was comparable with that of the 1980 crop.

The alkali *tôs* from these sorghums were stickier than the acid *tôs*. The mean stickiness of the fresh alkali *tô* from the 1979 IFQT sorghums, 4.1 ± 0.6, was significantly different from the mean of 3.2 ± 1.0 observed for the *tô* from the 1980 IFQT sorghums. However, the mean stickiness of stale *tô* from the 1979 and 1980 IFQT sorghum crops was not significantly different. The stickiness of alkali *tô* was generally reduced upon storage.

Of the sorghum varieties tested, IS7055 makes an acceptable intermediate quality acid *tô*, while the quality of P721, IS158, WS1297, and Dobbs is poor. Only varieties M35-1, M50297, IS2317, IS7035, and Oaga-Market-1 make good-quality *tô*. The samples P721, WS1297, Dobbs, and IS158 had poor acid *tô* textural properties, while the remaining samples would produce intermediate-quality *tô* upon cooking. The textural properties of *tô* were not significantly correlated with the Brabender viscoamylograph cooking

Table 4. Means for stickiness of *tô* from the 1979 and 1980 IFQT sorghums.

Description	Fresh *tô*	Stale *tô*
1979 Acid *tô*	2.3 ± 0.6	2.2 ± 0.8
n = 24 range	1.5-4.1	1.0-4.4
1980 Acid *tô*	2.5 ± 0.9	2.3 ± 0.6
n = 23 range	1.5-5.4	1.3-3.8
1979 Alkali *tô*	4.1 ± 0.6	2.8 ± 0.7
n = 24 range	2.9-5.7	1.6-4.2
1980 Alkali *tô*	3.2 ± 1.0	2.7 ± 0.7
n = 23 range	2.0-6.9	2.1-5.3

Table 5. Means for firmness of *tô* from the 1979 and 1980 IFQT sorghums.

Description	Fresh *tô*	Stale *tô*
1979 Acid *tô*	76.5 ± 9.3	70.5 ± 10.2
n = 24 range	65.8 95.5	56.5-93.3
1980 Acid *tô*	63.2 ± 9.4	58.5 ± 6.9
n = 23 range	49.0 80.3	46.8-79.0
1979 Alkali *tô*	5.5 ± 8.8	83.5 ± 9.4
n = 25 range	67.5 96.8	64.8-103.0
1980 Alkali *tô*	76.6 ± 8.1	67.8 ± 8.5
n = 23 range	61.3-94.3	56.3-83.8

properties of the flour. This was due to the high and low pH at which the *tô* was cooked compared with the neutral pH at which the amylograph was run. However, *tô* stickiness and softness are highly correlated in all the sorghums evaluated. A non-sticky *tô* is also a firm *tô* and a sticky *tô* is usually soft.

Tô Colors

Tô colors ranged from white in *tô* from sorghums with white pericarp and no testa, to dark purple and dark brown in sorghums with purple or brown testa. The dark colors of *tô* from sorghums with a testa were caused by acid and alkali hydrolysis of the condensed tannins to form colored pigments.

Storage of *tô* did not significantly change the color (Fig. 6). However, color lightness "L" was reduced and there was an increase in the yellow and red hues when *tô* was cooked in alkali instead of acid. The differences in intensity of red and yellow colors in *tô* was due to the difference in intensity of color pigments produced when acid and alkali react with polyphenols in the flour.

Effect of pH on *Tô* Texture

Figures 7 and 8 summarize the effect of pH on the softness of *tô* from the seven sorghum varieties we

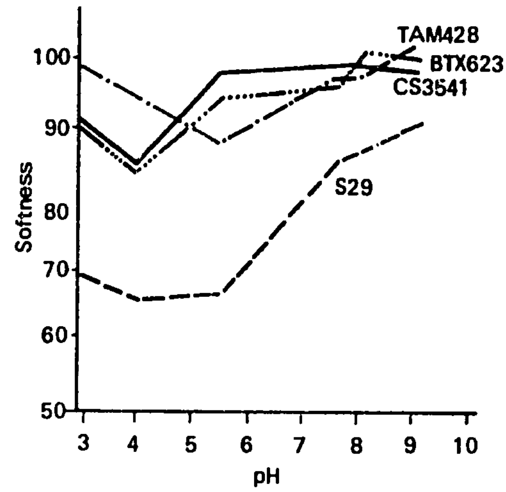


Figure 7. Effect of pH on tô *softness.*

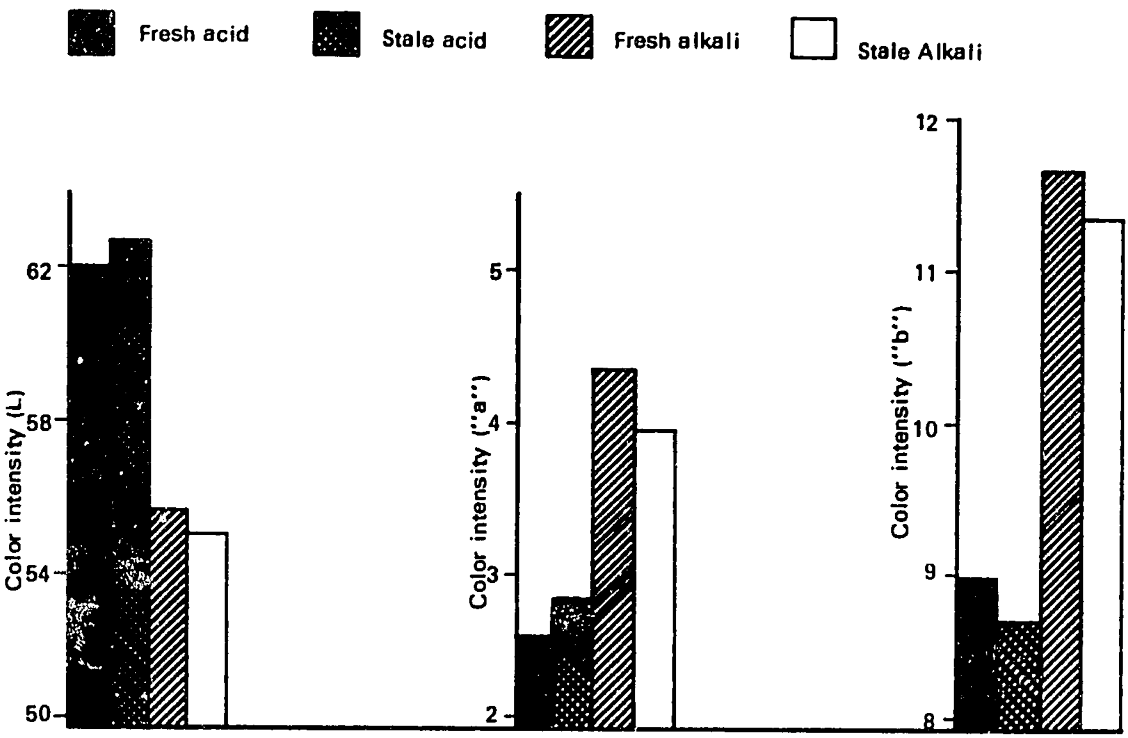


Figure 6. Effect of pH and storage on tô *color.*

used for breeding. The effect of pH on the stickiness of *tô* from these sorghums is presented in Figures 9 and 10. The softness and stickiness properties of *tô* from these and other sorghums are highly correlated, i.e., *tô* that is low in softness (firm) is also nonsticky and vice versa. Different sorghum varieties perform differently under different pH conditions. However, a general trend can be established from our observations. At pH 3, *tô* from all of the samples evaluated, except S-29 and Kamboinse (Local), was soft and sticky. The texture of most of the *tô* was best, i.e., firm and nonsticky, between pH 4.0 and 5.5 and then texture deteriorated as pH increased for these seven sorghums. Therefore, the best pH for *tô* preparation would be between 4.0 and 5.5. While we are not completely certain of all that is happening in this complex system, we know that the effect of pH on the retrogradation properties of starch is responsible for most of the observed differences in texture. The rate of starch retrogradation is dependent on the molecular weight of amylose and can be increased by partial hydrolysis. However, excess acidity reduces the rate of retrogradation as it reduces the molecular weight of the amylose (Whistler and Johnson 1948; Lansky et al. 1949). A higher molecular weight of amylose than optimum also reduces the rate of retrogradation. The pH that produced the highest rate of retrogradation as indicated by *tô* firmness in most of the sorghums used for *tô* was between 4.0 and 5.5. Protein swelling and denaturation might also have some effect on the texture of sorghum *tô*.

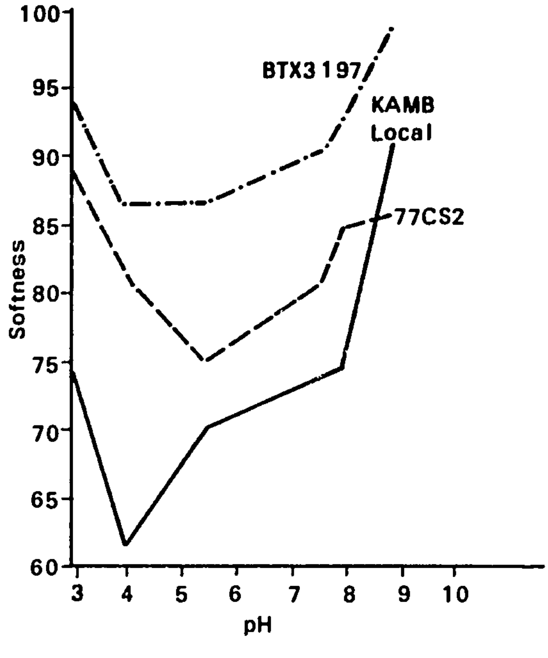


Figure 8. Effect of pH on tô *softness.*

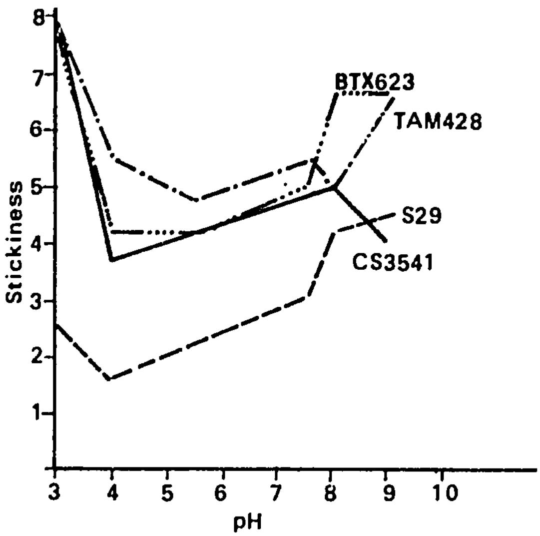


Figure 9. Effect of pH on tô *stickiness.*

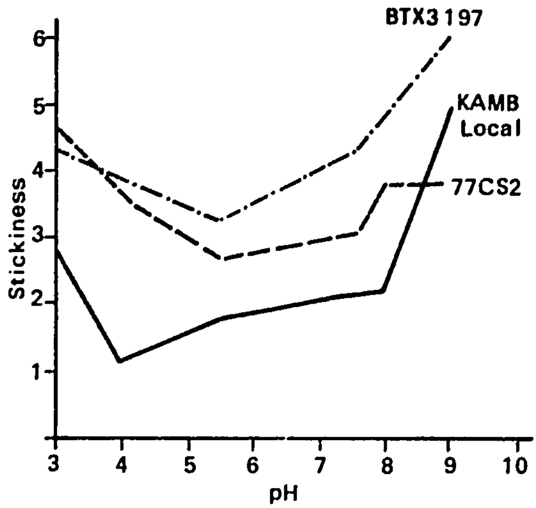


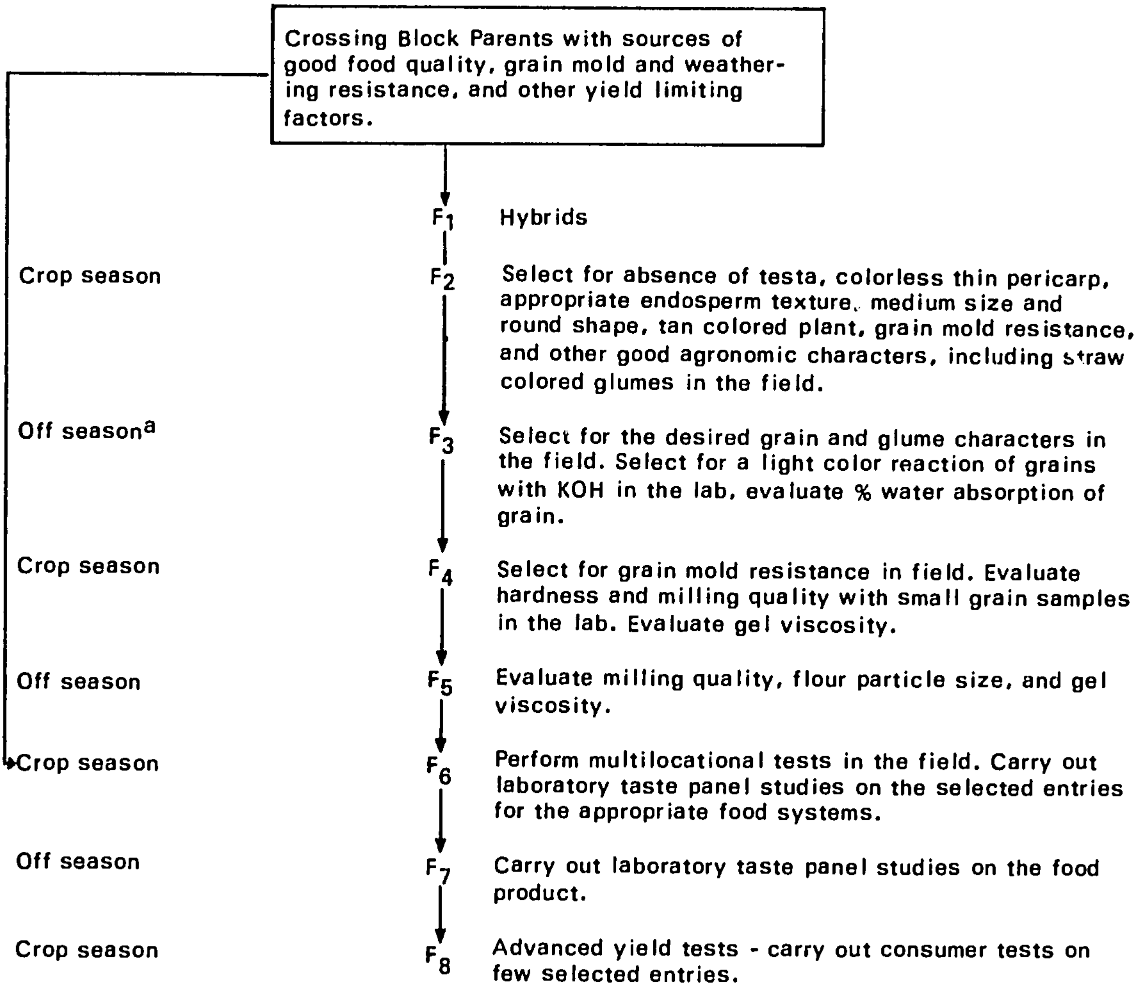
Figure 10. Effect of pH on tô *stickiness.*

Use of Small-scale *Tô* Testing in a Breeding Program

The effectiveness of techniques for pearling, milling, and testing small grain samples has been demonstrated. This technique is geared towards the evaluation of a single head of sorghum in *tô* textural properties, and having some grain left for planting if the properties of *tô* are desirable. The diagram in Figure 11 illustrates how the technique will speed the rate and reduce the work involved in breeding sorghum for *tô*.

Conclusion

A technique for the making and testing of *tô* on a small scale from small grain samples has been developed and tested on several sorghum samples. The effectiveness of the technique was demonstrated by the similarity of the results obtained by this and other methods utilizing large quantities of grain in the laboratories of ICRISAT Mali and Upper Volta. We believe that this technique can save time, energy, and resources if applied in a breeding program.



[a] In the tropics, photosensitive material selection for some desirable agronomic characters (height) cannot be done in the off season.

Figure 11. A proposed scheme for use in a breeding program to select for good food quality.

Acknowledgment

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Sorghum Alkali *Tô*: Quality Considerations

J. F. Scheuring, S. Sidibe, and A. Kante*

Summary

Sorghum alkali tô quality studies over 3 years in Mali have revealed four quality criteria that must be considered when selecting new varieties and hybrids destined for alkali tô consumption. These criteria in increasing order of importance are taste, color, texture, and keeping quality.

Sorghums with a colored testa or a yellow pericarp often make tô with astringent taste.

Tô color is greatly affected by pH. It lightens in acid pH while alkali pH levels result in dark colors especially gray, yellow, and red. Very dark red or gray tô color is unacceptable. Grain weathering can cause unacceptable dark tô colors from varieties whose clean grain makes light tô color. The color of tô can be evaluated from samples prepared in a 20-g mini-test.

Sticky or dense tô texture is unacceptable. Tô with poor texture also has poor keeping quality. The elimination of varieties whose tô has poor keeping quality will assure the elimination of tô with poor texture.

Overnight keeping quality depends on gel stability. Tô that weeps water overnight becomes mushy. Acceptable tô remains firm after overnight storage. Whereas acid pH enhances keeping quality, alkali pH makes many tô gels unstable. The keeping quality of some varieties changes drastically with small alkali pH increments. Local Guineense varieties remain stable across the pH range from 4 to 9. These varieties also maintain acceptable tô keeping quality even from weathered grain. A 20-g mini-test has been designed to accurately predict tô keeping quality.

Tô is the Malinké name for a flour gel product that is a common food with only slight regional modifications from Sénégal to Ethiopia. In the Sudanian zone of West Africa, *tô* is the principal cereal food. For at least 20 million people in semi-arid Africa, *tô* serves as the principal form of carbohydrate intake, and the accompanying *tô* sauce serves as the principal source of proteins, minerals, and vitamins.

Tô can be prepared from a wide variety of cereal carbohydrate sources such as sorghum, pearl millet, maize, rice, and even wild grasses. In the Sudanian zone, sorghum and millet *tô* are the most common because they are the dominant cereals.

The pH of sorghum *tô* varies regionally in Africa. In most parts of Africa, it is prepared simply with water and flour. However, for reasons unknown to us, in Upper Volta *tô* is acidified to approximately pH 4.6 by the addition of tamarind, lemon, or sour gruel; and in Mali *tô* is raised to pH 8.2 by the addition of wood or peanut hull ash extract. We frequently find sorghums that make acceptable *tô* at acid or neutral pH but fail to make an acceptable *tô* at basic pH levels. This paper summarizes our efforts over the past 3 years to define alkali *tô* quality and to develop tests that identify potential sorghum varieties and hybrids with acceptable alkali *tô* quality.

Preparation

Dehulling

In Mali and Upper Volta, sorghum grain is dehulled before it is prepared into *tô*. Traditionally, a wooden mortar and pestle are used to dehull the

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grain. Washed grain is directly placed into the mortar where it is pounded with the pestle. From time to time, water is sprinkled on to the grain while the pericarp and germ are removed. For 2 kg grain lots, we have measured quantities of 400–600 ml water added during the dehulling process.

Dehulling time varies with endosperm hardness and pericarp thickness. Among local grains of comparable endosperm hardness, we have found an inverse relationship between pericarp thickness and mortar-and-pestle dehulling time. For 2 kg seed lots, we measured dehulling times of 11.0, 19.8, and 27.7 min for grains with very thick, thick, and thin pericarps, respectively.

We have found that yields of dehulled grain after traditional dehulling are consistently around 70% for local Malian and Voltaic varieties. Recently, mechanical dehullers have become popular in urban neighborhoods in Mali and Upper Volta. We have found a remarkable similarity in endosperm yield of the mechanical dehullers compared with the mortar and pestle. The extent of bran and germ removal is comparable for both methods.

Cooking

Measurements were taken for three preparations of *tô* at Boulkassambougon (Mali) prepared by three different women using a local Keninke sorghum. Each woman was given 2 kg (1.35 kg dry weight) of freshly milled sorghum flour that had been dehulled with about 30% bran removal before reduction to flour. The flour was sifted through a sieve with 1-mm mesh openings.

Flour proportions, water volumes, lime weights, pH, and cooking times were measured during *tô* preparation. The following is a summary of the preparation. Preparation data from four different *tô* preparations at Boulkassambougon, Mali, are presented in Table 1.

1. Four liters of water are brought to the boil in a metal pot over a fire.

2. About 650 ml cool water is mixed with 10 g of wood ash extract and about 750 g (500 g dry weight) sorghum flour in a calabash or bowl. The flour was previously passed through a sieve with 1-mm mesh openings. The mixture is stirred until

Table 1. Measures of flour, water, pH, and time from four *tô* preparations in Mali.

	Sample I	Sample II	Sample III	Sample IV
Flour[a] (g)				
Flour used in bouillie (Step 2)	474	474	541	496
Flour added during whipping (Step 4)	686	736	809	744
Total flour used in *tô*	1160	1210	1350	1240
Water (ml)				
Original pot water (Step 1)	4000	4000	4000	4000
Water used for making bouillie (Step 2)	600	650	650	633
Total water used for *tô*	4600	4650	4650	4633
Alkali (g)				
Alkali dissolved in bouillie (Step 2)	10	10	10	10
pH				
Bouillie	8.9	9.0	8.9	8.9
Tô during whipping	8.2	8.2	8.2	8.2
Time (min)				
Bouillie cooking (Step 2)	8	8	8	8
Whipping (Step 4)	8	10	9	9
Final cooking (Step 5)	12	12	12	12
Total cooking time	28	30	29	29

a. Flour weights are expressed as dry weights (6% moisture).

homogeneous and then swirled into the boiling water in the pot. The boiling gravy is stirred for about 8 min until it thickens. At that point the gravy is called "bouillie" (French). The bouille is sometimes consumed as a thin porridge.

3. The heat of the fire is diminished by removing several pieces of wood. About 1300 ml of bouillie is removed from the pot and put aside in a calabash.

4. About 1125 g (750 g dry weight) sorghum flour is added, a handful at a time, to the boiling bouillie in the pot. After each addition of flour, the paste is vigorously whipped with a flat wooden spoon. When the paste thickens too much for easy whipping, a small amount of bouillie from the calabash is added. The addition of flour followed by whipping and addition of bouillie continue until the bouillie is finished and the paste is homogeneous and very thick. This step takes about 9 min.

5. All large pieces of wood are removed from the fire and only small embers are allowed to remain. The thickened paste is covered and allowed to cook over the low heat for about 12 min.

6. The *tô* is removed from the fire, uncovered, and scooped into serving bowls where it is allowed to cool and set for at least 1 hr before eating.

Quality Criteria

During the past 3 years, we have run acceptability panel evaluations on hundreds of *tô* samples prepared from sorghums in the International Sorghum Food Quality Trial, the regional ICRISAT West African trials, and our own multilocational observation trials in Mali. In summary, we have found the following four important quality criteria, which are listed in ascending order of importance: taste, color, texture, and overnight keeping quality. We have tried to define each quality criterion and develop tests to predict acceptability using only small grain lots.

Taste

Although taste is the least understood of the criteria we have studied, it is also, in our opinion, the least significant. We have encountered considerable difficulty in getting reliable results from taste panels. *Tô* color and texture influence taste for most panelists. When panelists can see the *tô*, unacceptable red *tô* is said to have bad taste. When panelists are blindfolded, pasty or runny *tô* repulses them so much that they confound unacceptable texture with unacceptable taste.

Unacceptable taste can mean several different sensations. The astringent taste of many sorghums with a colored testa are clearly disliked. We have been surprised to find that many yellow pericarp sorghums (Patcha Jonna and IS-9985) also make *tô* with a slight, but definite astringency. Since *tô* is eaten with a sauce, there should be no strong after-taste to the *tô* itself. The variety P-721 has an overwhelming after-taste that is clearly unacceptable.

There are only rare cases when clearly unacceptable taste is coupled with acceptable color, texture, and keeping quality. For the sake of efficiency, we have decided to postpone taste tests until after we have screened breeding lines and hybrids for the more objective qualities of color, texture, and keeping quality.

Color

Depending on variety and grain quality, sorghum *tô* can vary in color from white to reddish black. The *tô* of many introduced varieties is yellow. Since maize *tô* is also yellow and highly relished, shades of yellow are readily acceptable. In general, the shades above a value of 4 in hues of 7.5 YR, 10 YR, and 2.5 Y in the Munsell Soil Color Charts (1975) are acceptable. Pale red is generally acceptable, but weak and dusky red are not. Children are particularly repulsed by red *tô* color. In Bamako during the 1972–74 drought, *tô* made from American aid sorghum was red and was commonly served only at night so that children could not see the color.

The pH level plays an important role in determining color. Acid *tô* color is always lighter than alkali *tô*. Increments of pH above neutral bring out yellow and red hues. The variety E35-1 is very pale brown acid *tô*, but yellow alkali *tô*. The local sorghum "nio-fionto" makes white acid *tô*, but alkali *tô* is gray.

Grain weathering can elicit abrupt *tô* color changes. At pH 8.2 the *tô* of unweathered grain from hybrids of ATx623 and A296 females is either pale yellow or very pale brown. Weathered grain of those same hybrids make weak red *tô* from ATx623 parentage and dusky red *tô* from A296 parentage.

Hybrids from A2077 and A2219 females, both tan plant varieties, maintain similar yellowish *tô* color from both sound and weathered grain. However A296 also has tan plant color and the *tô* made from its weathered grain is dark red. Plant color does not seem to be related to *tô* color. All the local Keninke Malian sorghums have purple plant color; yet, even if the grain is splotched from weathering, it always makes light *tô*.

Tô color can be reliably predicted from samples prepared in the 20-g mini-test described later in the discussion on keeping quality. Also we have successfully predicted alkali *tô* color using a modified procedure described by Khan et al. (1980) for predicting sorghum *tortilla* color. Five grains of sorghum are digested overnight in 5 ml water and 1 pellet of sodium hydroxide. The color of the jelly-like mass formed after digestion roughly approximates the yellow or red hues of alkali *tô*.

When a colored testa is not present in the grain, the color of mini-test samples prepared from whole grain accurately reflects the color of alkali *tô*. However, when a colored testa is present, we have found it necessary to use dehulled grain to approximate true *tô* color.

Texture

Since *tô* is eaten by hand, the texture is very important for *tô*-eaters. The gel should be stiff, but not dense. A person should be able to dip in his fingers, scoop out a piece, and readily manipulate the piece with the forefingers and thumb without the gel adhering to the fingers. Likewise, while chewing the *tô*, it should not stick to the teeth.

Some well defined sorghum types have consistently poor *tô* texture. The *tô* from waxy sorghums like IS158 and BTx615 never forms a gel. The *tô* consistency is like a thick gruel. Amylograph peak viscosity of waxy sorghum flour is substantially lower than normal sorghum flour (4.7). That means the swelling of the flour and thus gel formation is inhibited.

Most soft-textured sorghum grains make sticky *tô*. Feterita sorghums as well as the soft-seeded ICRISAT Upper Volta varieties, 940 and 940S, all make sticky *tô*.

We have consistently observed that poor texture is related to an instability of the gel. Every time a *tô* has poor texture, it also has poor keeping quality. We have found no exception to that rule.

Since we have found many sorghums with good texture but with poor keeping quality, we have decided to focus our varietal screening efforts on keeping quality. By selecting against sorghums with poor keeping quality, we are confident that we are also eliminating those with poor texture.

Keeping Quality

Tô is usually prepared in the afternoon and served as an evening meal. The leftover *tô* is stored overnight in a dish covered by a cloth to prevent desiccation. The next morning the *tô* is either reheated or eaten cold. The leftover *tô* should still be firm enough to withstand reheating without falling apart. The *tô* of most local varieties, particularly the Keninkes (Snowden's "*Guineense gambicum*") have that trait of gel stability which insures the successful overnight storage of the *tô*. If *tô* is mushy or soft after overnight storage, it is emphatically rejected. *Tô* decomposition is due to the instability of the gel.

As recently described by Tanaka (1981), a gel is a tangled network of solid polymers immersed in a liquid medium. If for any reason the equilibrium of the solid *tô*-liquid phase network is disrupted, the liquid and solid lose their intimate association and an exudation of the liquid occurs. That process is called syneresis. The equilibrium of starch gels is particularly sensitive to the pH level.

We have found that the *tô* of many introduced sorghum varieties and hybrids is unstable. The *tô* becomes soft or mushy after overnight storage. A film of water exudate forms on the surface of the gel. Often the *tô* decomposition is accompanied by a drop in pH from 8.2 to less than 7.2. The decomposed *tô* frequently has a repulsive taste as well as an unacceptable texture. There is no question concerning the unacceptability of such *tô*. Mushy *tô* does not require the consensus of an evaluation panel.

Sidibe (1980) has developed a laboratory micro-test which has enabled us to accurately predict the *tô* keeping quality of 20-g grain lots. The procedure is as follows:

1. Twenty g of whole grain are milled for 90 sec in a Salton Quick Mill.
2. The flour is mixed with 125 ml warm water in a 200-ml beaker. The beaker is placed in a boiling hot water bath with the water level at about 5 cm. We use a deep skillet as our hot water bath.
3. A small amount of local wood ash extract is added to the gravy and stirred for a few minutes. By constant monitoring with a pH meter, the desired pH concentration is reached by adding small quantities of wood ash extract.

4. The paste is stirred for 25 min until it becomes very stiff.

5. After cooking, the *tô* is removed from the beaker and placed in a small metal bowl. At that point the *tô* color can be evaluated.

6. The bowl is covered with a piece of paper and the *tô* stands overnight. Night time temperatures range from 25 to 28°C.

7. The next morning the *tô* is turned upside down and is evaluated for firmness, using a scale of 1 to 5, with 1 as most firm and 5 as gruel-like. A score of 3 or higher indicates an unacceptable keeping quality.

In our laboratory we run 18 micro-test samples per day. When the demand becomes greater, we will eventually be able to run up to 50 samples per day. Our check varieties are Tiemarifing for consistently good keeping quality, and E35-1 for consistently poor keeping quality.

Generally, acidity enhances sorghum *tô* stability. Frequently we find sorghums with unstable *tô* at pH 8.2 but stable *tô* at acid pH concentrations. The variety E35-1 is a good example. Figure 1 illustrates the firmness of overnight-stored E35-1 *tô* that has been prepared at various pH concentrations.

At all acid pH concentrations the *tô* remains firm. The *tô* decomposes at alkali pH levels. The variety E35-1, however, has excellent fresh *tô* texture at all pH concentrations. Upon storing, the alkali *tô* of E35-1 is unstable.

In 1979 we grew a yield trial of 15 test varieties that had been selected by our colleagues in Upper Volta. We prepared Malian *tô* (pH 8.2) from each variety and found that 11 out of the 15 varieties gave mushy *tô* after overnight storage (ICRISAT/Mali Annual Report 1979). Only 2 out of the 11 varieties were unstable when their acid *tô* was tested in Upper Volta.

Until recently we have prepared our large and micro-scale *tô* samples at pH 8.2, because that is the pH concentration we have found in *tô* throughout Mali. However, both in large-scale and in micro tests we have found some sorghums that give contradictory results—sometimes the stored *tô* was very firm, sometimes very mushy. The variety BTx623 and hybrids of ATx623 are good examples of that inconsistency. When we prepared BTx623 at various pH concentrations, we found that the vicinity of pH 8.2 was a critical concentration where *tô* stability was suddenly lost. At pH concentrations above and below pH 8.2, the stored *tô* was firm. It is evident that our approximation of pH 8.2 is not always accurate in our *tô* preparations. Figure 2 illustrates the keeping quality of BTx623 at various alkali pH concentrations.

Since *tô* stability can rise and fall in response to relatively slight pH changes, we have recently decided to run our micro test preparations at various pH increments instead of doing several replications at a single pH concentration (pH 8.2). That procedure gives us an idea of the gel stability across a range of alkali pH concentrations. The *tô* of the best Keninke local varieties remains firm and

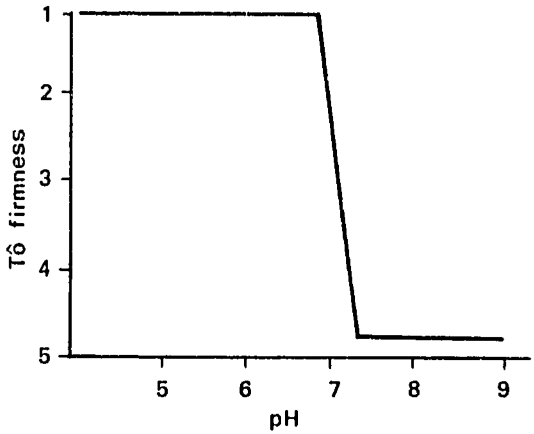

Figure 1. Overnight keeping quality (firmness) of tô *prepared from E-35-1 sorghum at various pH concentrations.*

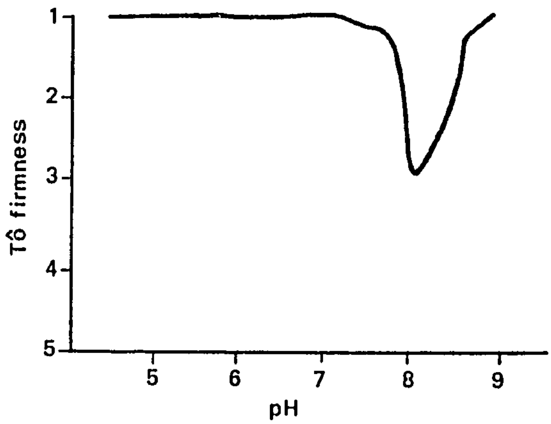

Figure 2. Overnight keeping quality (firmness) of tô *prepared from BTx623 sorghum at various pH concentrations.*

relatively unchanged at pH increments between 7.0 and 8.8.

Grain weathering has an enormous influence on alkali *tô* keeping quality. Weathered grain is usually soft and floury. The rapidity and extent of weathering are enhanced by low soil fertility and postfloral drought. Both of those situations are the rule rather than the exception in Malian agriculture.

When the grain is weathered, the *tô* of most introduced sorghums loses its gel stability. Overnight-stored *tô* becomes mushy. Many weathered local sorghums also lose gel stability, but their overnight-stored *tô* is usually soft and not mushy. There are some local sorghums that, continue to make a stable *tô* even when the grain is filled during drought and under other stresses. This is the case with Tiemarifing, a local Keninke sorghum which has been popular in Mali for the past 30 years because of its respectable yields and its quality stability.

In the 1980 season, we grew identical hybrid observation nurseries at four Malian locations. The grain was weathered in increasing order at these locations: Samé, Baramandougou, Cinzana, and Sotuba. The *tô* keeping qualities of various entries from that test are listed in Table 2.

Table 2. *Tô* (pH 8.2) keeping quality of sorghum hybrids grown at different locations.

	Tô keeping quality[a]			
Hybrid	Samé	Baramand-ougou	Cinzana	Sotuba
A296 × MR-376	–	1	3	5
A296 × MR-183	–	1	2	5
A296 × SPV-315	–	1	2	5
A2077 × MR-184	–	1	1	3
A2077 × MR-384	–	2	1	4
A2077 × MR-383	–	1	1	3
A2219 × MR-169	–	2	1	3
A2219 × MR-386	–	1	1	3
A2219 × MR-392	–	1	1	2
ATx623 × M62740	2	4	4	–
ATx623 × M60312	5	4	5	–
ATx623 × M61108	4	4	4	–
Tiemarifing	–	1	1	1

a. 1 = most firm; 3 to 5 = unacceptable quality (5 = gruel-like).

The Tiemarifing grain grown at the Sotuba station was tested for keeping quality at alkali pH increments between 7.0 and 8.8. The overnight-stored *tô* was very firm at all pH levels.

There is no question that varietal screening for *tô* keeping quality should be carried out on grain lots that have been grown under a variety of field conditions. In our breeding program, we screen early generation materials from grain lots obtained from multilocational observation nurseries. More critical screening will be carried out on grain lots obtained from multilocational yield trials.

Conclusion

We have begun a large crossing program involving local Keninke sorghums and high-yielding introductions. Keninke B-line crosses have been made to assure the incorporation of acceptable *tô* quality into seed parents of F_1 hybrids. Very soon our program will generate both varieties and hybrids that carry Keninke parentage. With the *tô* quality information and screening tests now at hand, we expect to make rapid progress in the identification of high-yielding varieties and hybrids with acceptable alkali *tô* quality.

Appendix. The International Sorghum Food Quality Trial, 1979–1981

Fresh grain lots of the 25 trial entries were sent from ICRISAT Center to Mali in 1979, 1980, and 1981. Lot sizes of the first 2 years varied from 1 to 2 kg and in the 3rd year the lot size was 150 g. The grain of all 3 years was clean and sound. In 1979 and 1980 the grain of each entry was prepared into alkali *tô* under normal household conditions. The *tô* qualities of color, texture, taste, and keeping quality were evaluated by a panel of at least five persons. In 1981 the samples were prepared at six pH levels in the 20 g mini-test and evaluated for keeping quality after overnight storage.

The 3-year summary of results is given in Table 3. The data are fr[illegible] three different *tô* preparations and three different grain lots of each entry.

In the trial there were five entries with colored testa grain; WS1297, IS2317, IS7035, Dobbs, and IS7055. Each of those varieties in at least 1 year had unacceptable *tô* color and/or *tô* taste. It is

Table 3. Summary of results for alkali *tô* prepared with grains from the International Sorghum Food Quality Trial, 1979–1981.[a]

Entry	Color 1979	Color 1980	Texture 1979	Taste 1979	Taste 1980	Overnight keeping quality 1979	1980	1981 pH 7.0	pH 7.4	pH 7.8	pH 8.0	pH 8.4	pH 8.8
M35-1	1	2	1	1	1	1	1	1	1	1	1	1	1.5
CSH-5	1	1	1	1	2	1	1	1	1	1.5	2	2	2
M50009	1	1	5	5	2	5	2	1	1	1.5	1.5	1	1
M50013	1	1	1	1	2	1	5	1	1	1.5	1.5	1.5	1
M35052	1	1	1	1	2	1	5	1.5	1.5	1	4	2	1.5
M50297	1	1	1	1	3	1	3	1	1	1.5	1.5	2	1.5
CO4	1	1	1	1	1	1	1	1	1	1	1	1.5	1
Patcha Jonna	1	1	1	1	3	1	1	1	1	1	1	1	1
Mothi	1	1	3	5	1	5	2	1	1	5	3	2	1.5
E35-1	1	1	1	1	2	5	4	1	1	1	1	1	1
IS-158	1	2	5	1	5	5	5	5	5	5	5	5	5
WS-1297	1	3	1	1	2	1	1	3	4	5	5	5	5
Swarna	1	2	1	1	2	1	3	2	2	2	2	2	2
S-29	1	1	1	1	1	1	1	1	1	1.5	2	1.5	1.5
S-13	1	1	1	2	3	1	1	1	4	4	4	5	5
P-721	1	1	5	5	2	5	3	4	5	5	5	5	5
IS-2317	1	2	1	1	3	1	1	3	2.5	2	2.5	4	4
IS-7035	1	5	1	1	1	1	1	1.5	1.5	2	1.5	1.5	1.5
IS-9985	1	2	1	2	4	1	1	2	2	3	5	5	5
IS-8743	3	2	1	1	1	5	5	1	1	2	4	2	1.5
Dobbs	5	5	1	5	1	1	1	2	2	1	3	3	3
CS3541	1	1	1	1	2	5	1	2	1	1.5	1.5	5	5
Segaolane	1	1	2	1	3	1	2	1	1	1	1	1	1
Market-1	1	1	1	2	1	1	1	1	1	1.5	1.5	1	1
IS-7055	1	3	1	1	3	1	5	3	5	5	5	3	2.5

a. Quality data is on a scoring scale of 1–5, with 1 as best quality and 5 as poorest quality. Scores of 3 or higher are considered unacceptable.

interesting that the *tô* taste of IS7035 was judged excellent in both years.

There was one waxy endosperm variety in the trial, IS-158. As discussed in the preceding text, the *tô* texture and keeping quality of IS-158 were poor. The *tô* never formed a gel.

The high-lysine opaque endosperm variety, P721, had unacceptable *tô* texture, taste, and keeping quality.

Some varieties had poor quality in 1 year and excellent quality in another year. The contrasts were particularly marked for keeping quality in several varieties. The varieties S-13 (CE-67), CS-3541, and the four ICRISAT varieties all had contrasting keeping quality in different years. The quality inconsistency of S-13 is well known in West Africa. We have seen additional cases of year-to-year variation in CS-3541 and ICRISAT varieties in Mali.

The variety E35-1 has been our best check variety for poor *tô* keeping quality. In both 1979 and 1980 the E35-1 *tô* became mushy overnight. However the 1981 lot gave perfectly stiff *tô* at six contrasting pH levels. The 1981 grain was much bolder than any E35-1 grain lot we have previously studied. It is possible that optimal growing conditions altered the endosperm composition enough to improve the keeping quality. We do not expect to find such growing conditions in Mali.

There were four varieties and the hybrid CSH-5 that made acceptable *tô* in all 3 years and with all three grain lots. The varieties Market-1 and S-29 are both West African local sorghums. In this group of entries, they can be considered as the two local check varieties.

The variety CO4 is used in India to prepare a local *tô*-like product called *sankati*. We were impressed by the fact that the red pericarp of CO4 did not alter the *tô* color acceptability. The pericarp pigmentation was sufficiently removed during dehulling. The consistently good *tô* quality of CO4 suggests that crosses between West African *Guineense* sorghums and Indian *Sankati* sorghums may offer a large array of derivative varieties with acceptable *tô* quality.

The *tô* of the Indian *rabi* sorghum, M35-1, and the Indian hybrid CSH-5 was consistently good. Unfortunately, M35-1 does not grow well during the Malian rainy season. CSH-5 grows very well but the female parent is difficult to produce in Mali. The female parent of CSH-5, 2077B, has been crossed with West African B-lines to obtain seed parents with acceptable *tô* quality.

The International Sorghum Food Quality Trial has been an instructive exercise. We have obtained the following information concerning alkali *tô* quality:

1. Sorghums with grain containing a colored testa are likely to produce *tô* with unacceptable color and/or taste.
2. Waxy endosperm sorghum produces a *tô* with no gel consistency.
3. Many sorghum varieties exhibited large year-to-year *tô* quality differences.
4. Some red pericarp sorghums can produce *tô* with excellent color.
5. Sorghums that are used for gel foods similar to *tô* are likely to produce acceptable *tô*.

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Bogobe: Sorghum Porridge of Botswana

M. B. Boling and Nancy Eisener*

Summary

Bogobe, *the sorghum porridge of Botswana, is prepared from fermented and nonfermented sorghum meal. Grain color and texture of the meal produced are important characters contributing to the quality of the porridge. Mechanical dehulling and grinding of grain are becoming important since these operations eliminate a considerable amount of hand labor and generally increase the quality of meal produced.*

Sorghum is the staple food of Botswana and is preferred over maize, millet, and wheat by most Botswanians. Eisener (1977) reported in a survey of the Southern and Southeastern Districts of Botswana that 96% of the people interviewed indicated that they eat sorghum. Of these, 89% eat it daily and the other 11% eat it two to three times weekly. It is consumed as porridge, *bogobe* (pronounced Bō hō bē), and as beer, *c[illegible]huku*, or *bojalwa*.

Bogobe is made from fermented and nonfermented sorghum meal. Fermented *bogobe*, a soft porridge is known as *motogo wa ting* or "*ting*". A firm nonfermented *bogobe* is called *mosokwane*. Ting is usually eaten in the evening and morning and *mosokwane* eaten for lunch. A variation of *mosokwane* exists (Labovitch 1977) in which a small amount of wheat flour and sugar is added to sorghum meal before boiling into porridge. This porridge is called *mageu*. Both fermented and nonfermented *bogobe* may be eaten with meat and vegetables.

Grain Preparation

Traditional Method

Grain is prepared daily for making porridge by stamping with a mortar and pestle. The steps followed are:

1. Winnow grain to remove loose chaff.
2. Wash grain and leave wet.
3. Stamp grain in a mortar with a pestle to remove pericarp. The time required varies with the type and amount of grain, but a full mortar requires 20 to 30 min.
4. Winnow stamped grain to separate pericarps from grain.
5. Stamp grain again to grind it into a meal of coarse texture.
6. Spread meal to dry until used for making porridge.

Machine Preparation

Macfarlane and Eisener of the IDRC Sorghum Milling Project conducted extensive research in Botswana on the use of machines for dehulling and grinding sorghum grain during the years 1976–1979. Machine dehulling using an IDRC/PRL Batch Dehuller gave extraction rates of 65% to 90% depending on the hardness of the grain and presence or absence of a pigmented subcoat. Grain was then passed through a Hippo Hammermill to produce a mixture of different particle sizes. The processed sorghum meal was packaged and marketed through retail outlets in Gaborone. Demand far exceeded supply. In a market survey, Eisener (1977) reported that more than half of the people interviewed indicated a "willingness to stop pounding and purchase on a regular basis" the prepared sorghum meal.

Smaller versions of the above equipment are now being operated successfully in several villages by Rural Industries Promotions of Botswana.

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Porridge Preparation

Ting (*Motogo wa ting*)

This fermented porridge requires a starter that is made by fermenting a small quantity of sorghum meal in water for 48 hr. The recipe and procedure for making ting is given below.

Ingredients:
30 g starter
300 g sorghum meal
1500–1800 ml water

1. Mix starter with dry sorghum meal.
2. Add 250–300 ml of lukewarm water.
3. Stir to make a slurry.
4. Cover and let ferment for 24 hr.
5. Boil 1500 ml of water.
6. Add fermented meal to boiling water and stir frequently.
7. Cook for 12–15 min.

Mosokwane

This firm, nonfermented porridge contains a mixture of one part of sorghum meal to four parts water and is made in the following manner:

1. Boil the water.
2. Add meal to boiling water, stirring frequently.
3. Cook for 20–30 min.

Quality Parameters

Grain characteristics that appear to contribute to good *bogobe* are difficult to measure. For example, Eisener (1977) reported that 62% of the people surveyed indicated that they preferred porridge made from white grain, but 34% preferred colored grain. Botswana consumes a lot of colored grain because enough white grain is not available. Most grain produced in the country has a white or red pericarp with no subcoat, but rarely is enough produced to satisfy demand. Thus a large portion of the country's grain requirement is imported, mainly from the Republic of South Africa. Practically all of the grain sorghum grown in South Africa that enters the commercial market is from hybrids based on colored U.S. germplasm. As a result, Botswanians have a high tolerance for porridge made from colored grain and are not moving away from sorghum consumption in favor of other processed grain because of color or status.

Texture of the meal produced by the grain appears to be more important than color. Eisener (1977) found that 86% of the people preferred a medium to coarse texture while only 12% preferred a fine texture. Therefore, a grain with a hard, corneous endosperm is desired. Grains with a large proportion of soft, floury endosperm have been found to produce a texture totally unacceptable for making *bogobe*. Eisener (1977) reported that using a 20-mesh screen for grinding grain produced a meal of coarse, acceptable texture.

International Food Quality Experiment

The Department of Agricultural Research, Botswana participated in an international food quality experiment sponsored by ICRISAT in 1979. Since personnel in the IDRC Sorghum Milling Project had more expertise in the subject, they were asked and readily agreed to conduct the experiment using the facilities and personnel from their project. The objective of the experiment was to evaluate various sorghum varieties for making *bogobe*.

Procedure

Twelve sorghum varieties from ICRISAT and two local control varieties were used in the experiment.

1. First, a group of older farmers were shown samples of the grain and asked to make observations.

2. After this initial observation, grain samples were dehulled in the IDRC PRL Batch Dehuller until an acceptable amount of bran was removed. A group of local women made this determination by visual inspection. Extraction rates were determined by weight.

3. Dehulled grain was then ground in a Hippo Hammermill to produce a coarse meal. The meal was then divided into two samples.

4. One sample was made into *motogo wa ting* and the other made into *mosokwane*. Porridge was prepared and served on 2 different days to the cook and to 10 other people. They were asked to rate the porridge as acceptable or not acceptable.

Results

A summary of comments on visual inspection of the grain is given in Table 1. A point of interest is that the farmers were able to indicate those varieties that were not suitable for making porridge. This was verified by the taste trials.

Results of mechanical dehulling are given in Table 2. Extraction rates ranged from 65 to 90% with most samples between 80% and 90%.

A summary of porridge taste test results is given in Table 3. An attempt was made to separate the "taste experience" into various components such as "mouth feel" and "aftertaste". This concept is foreign to most of the evaluators who look upon eating as a "total experience." Therefore no objective evaluation could be made. Also a rating scale of 1 to 5 for taste could not be used since people either liked the taste or disliked it. The concept of gradients of acceptability does not exist. Generally those grains that have been found to make good *chapati, tô,* or *kisra* also make an acceptable *bogobe.*

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Table 1. Comments on visual inspection of the grain.

Sample	Tswana name	Comments
CSH-5	*Sebathane*	Very good for porridge.
Segaolane		Many people grow this variety.
S-13		Grain grows tall.
M-35052		Grain is planted early.
Swarna		Samples differ because they are from different people.
Control White	*Bogalane*	Very good for porridge. Porridge very white. Good Tswana sorghum.
CO4	*Mmatshaane*	Not well known. Grows medium height. Makes good porridge.
S29	*Tswana Mabele*	It has no name. Makes good porridge.
IS-9985	*Terrakoba*	Head of grain bends over. Not Tswana variety. Good for porridge.
IS-7055 Dobbs	*Maidi*	Not good for porridge. Grown for sweet reed. Fed to cattle or chickens. Grows very tall. Good for beer.
E35-1	*Tsipikgolo*	Grows tall with a large head. Not well known. Makes white porridge. Meal tastes very good.
Control Red	*Show*	This is not Tswana sorghum. It grows very short. Porridge is all right to eat.

Tabe 2. Mechanical dehulling results.

Sample	Dehulling time (min)	Extraction rate (%)	Dehulling characteristics
White Control	1	87	Excellent
Red Control	1.5	83	Traces of bran on kernels
Swarna	1	88	Excellent
CSH-5	1	90	Excellent
E35-1	1	65	Good but soft grain
IS-7035	1	90	Few broken grains, some bran still on kernels
S-29	1	89	Excellent
IS-7055	1.5	83	Kernel breakage 50%, soft grain, some bran still on kernels
C04	2	73[a]	Kernel breakage 50%
M35052	1	86	Excellent
Dobbs	1	82	Good but some not dehulled
IS-9985	1	83	Good, 30% broken grain
Segaolane	1	82	Excellent
S-14	1	89	Excellent

a. After 1.5 min of dehulling, the grain seemed to have all the bran removed; however the women said it should be dehulled again. In the last 30 sec the grain began to break. As a result, the sample was overprocessed.

Table 3. Summary of porridge taste test.

	Motogo wa ting		*Mosokwane*		
Sample	A[a]	NA[b]	A	NA	Comments
Control White	X		X		Appealing white porridge.
Control Red	X		X		Does not produce good fermented meal.
Swarna	X		X		Appealing white porridge.
CSH-5	X		X		Slight complaints on taste.
E35-1	X		X		Sample became very sour, but was still acceptable.
IS-7035		X	X		Porridge had a disagreeable taste when fermented.
S-29	X			X	Disliked color; would use only as last resort.
IS-7055		X	X		Disliked color; would use only as last resort.
C04	X		X		This was one of the most popular samples; color very appealing.
M35052	X		X		Appealing white porridge.
Dobbs		X		X	Unacceptable color and taste.
IS-9985	X		X		Acceptable.
Segaolane	X		X		Acceptable.
S-13	X		X		Appealing white porridge.

a. A = Acceptable.
b. NA = Not acceptable.

Sankati Quality Evaluation of Sorghum Cultivars

D. S. Murty, H. D. Patil, and L. R. House*

Summary

Sorghum sankati *is a type of thick porridge consumed in South India and is prepared by cooking coarse flour/grits from either dehulled grain or whole grain. Domestic methods of* sankati *preparation and consumption are described. Thirty sorghum cultivars were evaluated for* sankati *quality by using taste panels at two locations. Grain with intermediate and hard endosperm texture and a white/creamy pericarp produced* sankati *with the preferred qualities.*

Sankati (Telugu) is a type of thick porridge made from sorghum (*Sorghum bicolor* L. Moench) in several parts of South India. It is called by different names in various regional languages, e.g., *mudda* (Telugu), *mudde* (Kannada), and *kali* (Tamil). Sorghum *sankati* is consumed in the Rayalaseema tracts of Andhra Pradesh, the southern tracts of Karnataka, and all over Tamil Nadu. There is no authentic information on the extent of *sankati* consumption. However, keeping in view the dietary habits in various regions, we estimate that in the state of Tamil Nadu, about 60 to 70% of sorghum consumed is taken in the form of *sankati*. In Andhra Pradesh, approximately 50% of the sorghum produced is eaten as *sankati* while in Karnataka approximately 30% of the sorghum is consumed as *sankati*. On the basis of the statewide sorghum production figures (Government of India 1980), we estimate that approximately 15 to 20% of the sorghum produced in India is consumed in the form of *sankati*. It is eaten by adults as well as children from the age of 4 years. *Sankati* is usually consumed with a range of side dishes such as sauce, *dhal* from pulses, pickles, chutneys, butter milk, curd, curries, etc. Pushpamma and Geervani (1981) reported the nutrient composition of sorghum *sankati*. Pearl millet (*Pennisetum americanum* Leeke) and finger millet (*Eleucine coracana*) grains are also used for the preparation of *sankati*.

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Domestic Methods of *Sankati* Preparation

Milling

Traditionally, sorghum grains are dehulled in a stone mortar with a wooden pestle after moistening the grain. The endosperm (mostly broken) that is recovered after washing the grain is either used directly for cooking or dried and ground to a coarse flour in a rotary stone mill. The bran and washes are fed to animals. However in recent years, the dehulling process has been generally given up and is only occasionally practiced. Increased urbanization and the availability of electrically-powered flour mills have prompted consumers to use grits from whole grains to save time and avoid cumbersome processing. Whole grains are either ground to grits in rotary stone mills, or are taken to flour mills and a mixture of grits and coarse flour is obtained. The milled product is sifted with a very coarse sieve (comparable to U.S. standard mesh 20) to separate fines from grits. Coarse bran pieces are removed by winnowing.

Cooking

A 1 : 3 proportion of sorghum grits/flour and water is generally used for preparing *sankati*. Water is allowed to boil in a vessel and the grits are added to the boiling water coupled with stirring. After about 10 min the fines are added to the cooking medium followed by stirring. The cooking process continues for 3 more min; the vessel is removed from the fire. *Sankati* is poured onto a moist plate and is frequently made into balls of 10-cm diameter by hand. *Sankati* is eaten either fresh or stored overnight submerged in water or buttermilk. A *sankati* that is light in color and slightly sweet in taste is preferred. It should not be sticky or pasty. *Sankati* should remain firm when stored in water so as to allow eating by hand. It should not disintegrate into small pieces. Consumers prefer a *sankati* that is similar to cooked rice in texture.

Sankati Quality Evaluation

The *sankati* quality of 30 sorghum cultivars (25 of them were chosen for the International Sorghum Food Quality Trials, 1980), was evaluated at two different locations, Bhavanisagar (Tamil Nadu) and Anantapur (Andhra Pradesh), with the aid of farm women. Standard methods to prepare and evaluate *sankati* were determined after interviewing a large number of consumers, mostly farm workers. The following procedure was adopted for preparing *sankati* at the two locations:

1. Grain samples (300 g) were dried to a moisture level of about 10% and were ground to grits on a carborundum stone grinder (Milcent size D-2, 0.5 HP) by suitable uniform pressure adjustments. The mixture of grits and coarse flour was sifted on a Ro-Tap Shaker with a U.S. standard 20 mesh sieve. The grits and the fines were kept separate.

2. The samples were cooked on an electric stove. Three hundred ml of water was boiled in a vessel and 50 g grits were added to the water followed by stirring. Additional quantities of hot water were added as required. Just before the grits were completely cooked, the fine flour (50 g) was added to the cooking medium followed by stirring. *Sankati* was removed from the stove after a semisolid consistency was obtained which took approximately 2 min. The total quantity of water uptake and the cooking time were recorded.

3. *Sankati* samples were scored for color, taste, and texture on a scale of 1 to 5 (1 = good) by a panel of six farm women 1 hr after the *sankati* was prepared. Keeping quality of *sankati* was evaluated after overnight storage. At Bhavanisagar, *sankati* samples were submerged in water and left overnight while at Anantapur they were placed individually in a cloth wrap and left in a pot. The samples were evaluated for keeping quality next morning on a scale of 1 to 5 (1 = good).

Average scores for various quality characters of *sankati* obtained at the two locations are presented in Table 1. Traditionally, consumers use mostly yellow and red pericarp sorghums for *sankati* preparation, since these are widely grown in South India, although white pericarp types are also utilized for the same purpose. The yellow and red pericarp grain types are characterized by a medium to thick pericarp, 10 to 20% corneous endosperm confined to the periphery, and a large part of floury and slightly sweet endosperm. Their milling quality in terms of pericarp removal by the mortar-and-pestle method is good. However, the endosperm gets broken and losses in the process of washing are considerable. When the grains are milled in a flour mill to grits, some coarse bran gets separated and is rejected by winnowing. On the average, among the 30 cultivars studied the water uptake of grits from corneous grains was slightly higher. They also took more time for cooking. The range of variation for color, taste, texture, and keeping quality was broad. The cultivars CO4 and Patcha Jonna represent the local varieties of Tamil Nadu and Andhra Pradesh and their *sankati* acceptability scores were good. However, the panelists generally preferred a white colored product. *Sankati* from brown, or sorghums with a subcoat, was disliked because of poor color and bad taste. In general, white grain types with a medium to hard endosperm texture were preferred. *Sankati* made from grain samples of cultivars CSH-5, M500013, M50297, and Mothi was good for all the organoleptic qualities and proved better than the local yellow and red pericarp types. At Anantapur, *sankati* with a moderate hardness or firm texture was preferred while at Bhavanisagar, a moderate soft product was acceptable. These differences illustrated the variation in regional preferences for *sankati* texture.

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Table 1. ***Sankati*** **quality characters of 30 sorghum cultivars chosen for the International Sorghum Food Quality Trials.**

Genotype	Endo-sperm texture	Water uptake[a] (ml)	Time for cooking[a] (min)	Color[b] A[c]	Color[b] B[c]	Color[b] Mean	Taste[b] A	Taste[b] B	Taste[b] Mean	Texture[b] A	Texture[b] B	Texture[b] Mean	Keeping quality[b] A	Keeping quality[b] B	Keeping quality[b] Mean
M35-1	3	328	7.5	1.3	2.5	1.9	1.6	2.0	1.8	2.9	2.1	2.5	3.0	2.0	2.5
CSH-5	2	323	9.3	1.0	1.7	1.3	1.3	1.4	1.3	1.6	1.8	1.7	2.5	1.3	1.9
M50009	2	340	11.0	1.1	1.8	1.4	1.3	2.1	1.7	1.7	2.3	2.0	3.0	3.1	3.0
M50013	2	349	11.3	1.2	1.8	1.5	1.8	1.8	1.8	1.0	2.0	1.5	1.4	2.1	1.7
M35052	2	325	11.3	1.0	1.7	1.3	1.3	2.3	1.8	2.8	2.3	2.5	2.3	2.4	2.3
M50297	2	325	10.8	1.3	1.9	1.6	1.5	2.0	1.7	1.5	2.2	1.8	1.5	2.2	1.8
P-721	4	325	8.3	2.9	2.7	2.8	3.3	3.0	3.1	4.2	3.5	3.8	4.3	4.0	4.1
CO-4	3	318	8.8	4.4	3.0	3.7	2.6	2.0	2.3	2.1	2.1	2.1	2.0	2.8	2.4
Patcha Jonna	3	323	10.3	4.0	3.9	3.9	4.1	4.2	4.1	2.5	2.3	2.4	2.2	1.9	2.0
Mothi	2	335	10.5	1.0	1.6	1.3	1.7	1.8	1.7	1.9	1.8	1.8	1.9	2.1	2.0
E35-1	1	325	9.8	1.1	1.5	1.3	1.44	2.8	2.1	1.2	3.2	2.2	1.7	2.8	2.2
IS158	3	349	7.3	1.3	1.9	1.6	4.8	2.4	3.6	4.9	3.4	4.1	4.8	4.3	4.5
WS-1297	4	313	7.3	4.2	4.1	4.1	3.8	3.2	3.5	3.6	3.1	3.3	3.6	3.1	3.3
Swarna	2	328	9.3	2.8	3.1	2.9	2.0	2.8	2.4	1.8	2.3	2.0	1.3	2.9	2.1
S-29	1	325	9.3	1.1	2.2	2.6	1.4	2.6	2.0	1.5	2.1	1.8	1.2	2.7	1.9
S-13	1	328	9.0	1.1	1.6	1.3	1.3	2.5	1.9	1.5	2.7	2.1	1.1	2.9	2.0
IS2317	3	300	5.8	4.2	4.1	4.1	3.7	3.5	3.6	2.3	3.2	2.7	2.4	3.5	2.9
IS7035	3	313	9.5	4.8	4.9	4.8	3.8	4.0	3.9	3.4	4.0	3.7	2.4	4.0	3.2
IS7055	3	313	7.0	4.1	4.7	4.4	4.2	3.2	3.7	3.4	3.1	3.2	2.0	3.1	2.5
IS9985	3	313	9.0	3.0	3.6	3.3	2.3	2.6	2.4	2.8	2.3	2.5	2.6	2.3	2.4
IS8743	3	325	8.5	4.0	4.6	4.3	3.5	2.7	3.1	2.8	2.7	2.7	2.4	2.7	2.5
Dobbs	4	323	6.0	4.1	4.8	4.4	4.0	2.9	3.4	3.0	2.4	2.7	2.9	2.1	2.5
CS3541	2	346	10.0	1.3	1.6	1.4	1.4	2.4	1.9	1.5	2.3	1.9	1.9	2.6	2.2
Segaolane	2	325	11.0	2.4	2.1	2.2	1.7	3.2	2.4	2.3	2.9	2.6	2.1	2.5	2.3
Market-1	1	335	10.0	1.7	1.9	1.8	1.5	2.7	2.1	1.3	2.7	2.0	1.6	2.4	2.0
Gato-1001	4	300	8.3	3.6	3.9	3.7	2.9	3.1	3.0	2.3	3.6	2.9	2.9	2.8	2.8
Awash-1050	3	356	12.5	4.1	2.4	3.2	4.2	3.2	3.7	3.1	3.9	3.5	2.4	3.2	2.8
SPV-352	2	325	9.5	1.0	1.5	1.2	1.5	1.9	1.7	1.7	1.8	1.7	1.7	2.7	2.2
Kanye standard	4	331	9.8	4.5	4.0	4.2	3.5	3.9	3.7	3.2	4.4	3.8	3.4	4.5	3.9
Langi langa	3	349	11.3	2.0	2.5	2.2	2.2	3.2	2.7	2.5	2.8	2.6	2.6	2.0	2.3
Mean	2.6	327	9.3	2.5	2.8	–	2.5	2.7	–	2.4	2.7	–	2.4	2.8	–
SE	0.16	2.4	0.3	0.2	0.2	–	0.2	0.1	–	0.2	0.1	–	0.1	0.1	–
Range	1–4	300–356	5.8–12.5	1.0–4.8	1.5–4.9	–	1.3–4.8	1.4–4.2	–	1.2–4.9	1.8–4.4	–	1.1–4.8	1.3–4.5	–

A = Anantapur; B = Bhavanisagar

a. Average of two independent observations at each of 2 locations, Anantapur and Bhavanisagar.

b. Color, taste, texture, and keeping quality were scored by the taste panelists on a scale of 1 to 5 (1 = good). The taste panel consisted of five farm women at Bhavanisagar and six at Anantapur. Values presented are averages of two independent observations made on two different weeks.

Sorghum *Ugali*

S. Z. Mukuru, J. N. Mushonga, and D. S. Murty*

Summary

Ugali *(Kiswahili language) is a thick porridge popular in Eastern and Southern Africa and is prepared using flour from whole or dehulled grains. Traditional methods of* ugali *preparation and consumption are described.* Ugali *quality characteristics of 61 sorghum cultivars, including those of the International Sorghum Food Quality Trials, were evaluated by taste panels. It was observed that a light colored* ugali *with least tackiness was the most desirable. In general, cultivars with corneous grains and high breaking strength produced* ugali *with the most desirable texture and keeping quality.*

Sorghum and millets are the traditional staple cereals in most countries of Eastern and Southern Africa and used to be the only cereals grown until the introduction of maize about 50 years ago. Maize is now extensively grown in the whole region especially in fertile and high rainfall areas. Sorghum and millets are, however, still the favored traditional cereals and are especially important in areas with relatively poor soils, and low and unreliable rainfall. All these cereals are similarly consumed in a variety of ways but the most important and widespread method of consumption as food is in the form of flour that is mixed with hot water and cooked into a stiff paste or thick porridge. An equally large percentage of sorghum and millets are used in the preparation of a wide range of traditional alcoholic and nonalcoholic beverages.

The cooked stiff porridge that is prepared from all the cereals is commonly known as *ugali* (Kiswahili language) in Kenya, Uganda, and Tanzania; *sof* or *mafo* in Somalia; *nsima* in Malawi and Zambia and *sadza* in Zimbabwe. It is also called by several other different names in tribal dialects throughout the entire region. For convenience and ease of presentation, we will refer to all the cooked stiff porridges (neutral pH) prepared from sorghum as *ugali*.

Today most *ugali* is made from maize, but sorghum *ugali* still enjoys considerable importance and popularity among the rural poor for whom it is an important dish. In this paper, we will attempt to describe some of the traditional methods of grain processing and *ugali* preparation noting significant variations if any in some countries of eastern and southern Africa. We will also present the results of taste panel evaluations carried out at ICRISAT Center on *ugali* prepared from several different sorghum cultivars and discuss their quality variations.

Grain Types Used

A wide range of sorghum grain types are used in the preparation of *ugali*. However, the white-seeded and highly corneous grains where available are preferred by most people in several countries. In Uganda, Rwanda, and parts of Western Tanzania, the brown-seeded high tannin sorghum grain types are most common and are used for *ugali* preparation as well as for brewing traditional beers. In Zimbabwe, all the brown-seeded grains with testa are used for brewing while the white or red-seeded types without testa are preferred for *ugali*.

Grain Processing

Traditional methods of sorghum grain processing are similar and are largely dependent on the grain

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types used for *ugali*. Sorghum grain processing is generally carried out by women. The white or red-seeded and highly corneous grains without testa are usually dehulled to remove the pericarp before they are ground into flour. Traditional sorghum grain dehulling generally involves pounding the soaked or damp grain in a wooden mortar with a pestle and winnowing to separate the dehulled grain from bran. The highly corneous grains are preferred because they are much easier to dehull and give higher recovery rates of dehulled grain. In Malawi, the grain is soaked in water for 1-2 hr before pounding it lightly to remove the pericarp. In Tanzania, a little water is added to the grain in the mortar and then pounded vigorously, followed by winnowing. This process is repeated until the pericarp is completely removed. The white-seeded grains with a floury endosperm as well as the brown-seeded high tannin types, which also have a soft endosperm, are not dehulled. However they are usually lightly pounded dry and winnowed before grinding into flour.

The traditional dehulling is hard work and consumes much time for the housewives thus restricting the amount of grain that can be processed and utilized. As far as we know, no suitable mechanical dehullers are available in these countries that could be used to process sorghum to produce dehulled grains of similar quality as the traditionally dehulled grain.

The dehulled or whole grain is then finely ground into flour on traditional grinding stones. The grinding stones consist of a small flat stone on a larger rectangular stone. The grain must be clean and sufficiently dry to produce flour of high quality. Grinding is always carried out by experienced women who try to produce finely milled flour. Small-scale mechanical grinders have been introduced in some areas, usually for maize, and these are becoming popular for sorghum as well. For many people in rural areas where mechanical grinders are not available or who cannot afford the prices charged for grinding, traditional grinding on stones is still the practice.

In Zimbabwe, the dehulled damp grain is sometimes roasted in a clay pot to dry before grinding it into flour. This is believed to improve the flavor of the *ugali* produced. In Tanzania, the dehulled grain is sometimes soaked in water for 1-2 days after which it is dried and ground into flour. This improves the whiteness of the flour. In the northern and eastern parts of Uganda, western Tanzania, and Kenya, the brown-seeded grains are mixed with a little dry cassava, finger millet or maize and the mixture is ground into flour.

Ugali Preparation

The traditional preparation methods for *ugali* in most countries are basically similar. A clay pot is used to boil an estimated amount of water, depending on the size of the family and the amount of flour available. When the water starts boiling, a little flour is sprinkled on the surface of the water and heating is continued. As soon as the water begins boiling again, most of the flour is poured into the pot and allowed to cook for about 2 min. After this one-fourth to one-half of the hot slurry is removed and kept in a separate container. The remaining boiling water and flour in the pot are vigorously mixed with a wooden stick, which has a cylindrical handle and a flat end. Additional slurry or flour is added as required until *ugali* with the right consistency is obtained. Then the *ugali* in the pot is allowed to continue cooking on a reduced fire for an additional 4-5 min. The *ugali* is removed from the pot into baskets made for this purpose, as *ugali* kept on plates becomes watery after some time. The whole process of *ugali* preparation might take up to 20 min.

In northern Uganda, tamarind water or mango or lemon juice is added to boiling water to improve the taste and flavor of *ugali*. In Kenya, lemon juice or milk may be added to boiling water. *Ugali* is usually served with beans or peas, vegetable soup, meat or fish stew, etc.

To prepare a high quality *ugali*, the flour used should be ground from clean grain free of mold and weevil damage.

A good *ugali* should not contain any lumps. When eating *ugali* one should be able to take pieces of it with the fingers without the *ugali* sticking to the fingers or teeth while eating. After *ugali* has cooled, a thin crust forms on the surface, but the *ugali* inside should be soft but not sticky and should be able to keep in a similar condition for up to 24 hr.

Ugali Quality Differences

At ICRISAT, sorghum *ugali* preparation methods were standardized with the help of trainees from Kenya familiar with sorghum *ugali* (Murty and House 1980). Whole grain samples of sorghum were ground to a moderately coarse flour using a carborundum stone grinder (Milcent-Size D2) powered by 0.5 hp motor. Flour samples were sieved with a U.S. standard 35 mesh sieve and the throughs were used for *ugali* preparation.

Four hundred and fifty ml of tap water were heated on an electric hot plate. As soon as the water started boiling, flour was added in increments coupled with vigorous stirring with a wooden laddle. Further quantities of flour were added as required until a thick well cooked paste was formed devoid of any lumps. The *ugali* was then removed from the heater and allowed to cool. The whole process took 10-12 min. The amount of flour required to produce *ugali* with the desired consistency and texture was recorded.

Twenty-nine standard sorghum cultivars were evaluated for their *ugali* quality in 1978 and 1979. *Ugali* for each variety was prepared following the standard preparation methods described above. The *ugali* was scored by trainees from Kenya for the most important quality characteristics, i.e., color, taste, texture, and keeping quality on a scale of 1 to 5 where 1 represented good and 5 poor quality. Five trainees in 1978 and six different trainees in 1979 were used to score all the *ugali* prepared from the same seed lots of the 29 cultivars. The sorghum grain of 25 cultivars was white, pale yellow, or cream color while the grains of the remaining four cultivars had a red pericarp without a testa.

The amount of flour added to 450 ml of water to make *ugali* varied from 200 to 300 g among the sorghum cultivars. The endosperm texture score and breaking strength (kg) of grain samples from the 29 cultivars together with their *ugali* quality characteristics are presented in Table 1. The *ugali* quality scores of the sorghum cultivars varied considerably from variety to variety even though 80% of them were white. The average scores obtained in 1978 generally agreed with those obtained in 1979. The results indicated that light colored *ugali* without tackiness was the most desirable. Light yellow colored and slightly sweet *ugali* was often compared to maize *ugali*. The cultivars E35-1, M35-1, IS-5341, IS-6928, and CSH-5 obtained the best scores. It is interesting to note that IS-1475 obtained desirable scores despite having a red pericarp. In general, cultivars with corneous grains and high breaking strength produced *ugali* with the most desirable texture and keeping quality.

Grain samples of an additional 11 cultivars of the International Sorghum Food Quality Trials (ISFQT) 1979, and 21 cultivars obtained from Mr. Pinto, sorghum breeder, Kenya were evaluated for their *ugali* qualities in 1979 and 1980 (Tables 2 and 3). Cultivars E35-1, Swarna, and M35-1 from the ISFQT and four cultivars from Kenya; 2219A × Lulu-D, 2KX17 B 1, Serena-1-2W, and 2KX17 6 produced the best *ugali* products. Cultivars with a red pericarp and testa obtained poor scores for *ugali* color. Cultivars 2KX17/B/1 and Lulu-D needed the least amount of flour (163 and 169 g, respectively) for the standard preparation.

References

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Vogel, S., and Graham, M. 1979. Sorghum and Millet: Food production and use. Report of a workshop held in Nairobi, Kenya, 4-7 July 1978. Ottawa, Ontario, Canada: IDRC. 64 pp.

Table 1. Variation for *ugali* quality as assessed by two different groups of taste panels in the years 1978 and 1979.[a]

Genotype	Grain[c]		Color appeal[b]			Taste[b]			Texture[b]			Keeping quality[b]		
	Endosperm texture	Breaking strength (kg)	1978	1979	Mean	1978	1979	Mean	1978	1979	Mean	1978	1979	Mean
CSH-5	2	9.5	1.6	2.1	1.8	1.6	1.7	1.6	1.5	1.9	1.7	1.4	2.2	1.8
E35-1	1	13.2	1.2	1.7	1.5	1.3	2.2	1.8	1.1	1.8	1.5	1.4	2.5	1.9
Swarna	3	10.6	3.6	2.9	3.2	3.2	3.0	3.1	2.5	2.2	2.4	2.6	2.4	2.5
IS-2550	2	8.8	1.7	2.2	2.0	2.1	2.3	2.2	2.7	1.9	2.3	4.4	2.9	3.4
IS-1475	3	7.5	2.0	3.2	2.6	2.5	2.6	2.5	1.2	1.9	1.6	1.5	2.4	2.0
IS-5341	1	10.2	1.2	1.7	1.5	1.5	2.0	1.8	1.3	2.0	1.6	2.0	2.7	2.4
IS-1457	3	7.4	3.3	2.9	3.1	2.2	2.5	2.3	1.6	2.1	1.8	2.0	2.5	2.2
IS-1070	3	7.0	3.1	2.7	2.9	2.7	1.5	2.1	2.2	1.7	1.9	2.4	2.6	2.5
IS-11025	3	8.4	1.2	2.3	1.7	1.7	2.6	2.2	1.7	2.3	2.0	2.2	2.0	2.1
M35-1	3	8.6	1.1	1.5	1.3	1.2	2.0	1.6	1.2	2.0	1.6	1.3	2.0	1.6
SC-423	2	8.0	2.2	2.3	2.3	2.2	2.8	2.5	2.0	2.8	2.4	1.0	3.0	2.2
2219B	2	8.7	1.4	2.1	1.7	1.7	1.8	1.8	1.6	1.8	1.7	2.0	2.2	2.1
8272-1	3	8.9	1.8	1.9	1.9	2.0	2.2	2.1	2.0	2.2	2.1	1.9	2.5	2.2
SC-108-3	2	10.0	2.8	2.6	2.7	2.1	2.3	2.2	2.0	2.3	2.2	3.1	2.8	2.4
$UChV_2$	2	10.0	2.1	2.6	2.4	2.5	2.5	2.4	1.8	2.5	2.2	1.5	2.2	1.8
Vidisha-60-1	3	7.3	2.8	3.3	3.0	2.8	2.5	2.7	2.3	2.1	2.2	2.4	1.8	2.1
Improved Saoner	3	8.1	2.7	2.7	2.7	2.2	2.7	2.4	1.8	2.5	2.2	2.4	1.8	2.1
IS-1122	3	6.7	4.7	3.7	4.2	2.9	2.2	2.5	2.9	2.0	2.4	3.5	2.5	3.0
IS-9530	3	10.0	3.9	3.2	3.5	2.3	2.7	2.5	2.7	2.2	2.4	2.6	2.6	2.6
IS-6928	2	11.0	1.2	1.7	1.5	1.2	2.8	2.0	1.2	1.9	1.6	1.0	2.8	1.9
E187	3	9.6	1.9	2.9	2.4	3.0	2.3	2.6	2.6	2.3	2.5	2.4	2.3	2.4
BG-137	3	10.2	3.7	3.5	3.6	2.5	2.6	2.5	2.7	2.6	3.0	3.0	3.0	3.0
SC-110-14	3	9.4	2.1	2.9	2.5	2.0	3.3	2.6	2.0	2.8	2.4	2.7	3.2	2.9
IS-4582	3	8.5	2.7	2.5	2.6	2.7	2.7	2.7	2.1	2.2	2.2	2.0	2.5	2.2
IS-4242	3	9.6	2.8	2.7	2.8	1.7	2.4	2.0	1.8	2.3	2.1	1.0	2.2	1.6
E6954	2	11.0	1.8	2.1	2.0	1.8	2.4	2.1	1.7	2.1	1.9	1.5	2.2	1.9
SPV-101	3	10.5	2.3	2.7	2.4	2.3	2.4	2.4	1.9	2.4	2.1	2.0	2.3	2.1
TAM-428	3	8.2	2.4	2.3	2.4	2.1	2.6	2.3	1.8	2.0	1.9	1.6	2.4	2.0
BP-53	3	8.1	3.0	3.0	3.0	3.1	2.3	2.7	2.2	2.1	2.1	2.0	2.4	2.2

a. The panelists were Kenyans and each panel consisted of 5 to 6 members. Values represent averages of the independent scores of the panelists.

b. Color appeal, taste, texture and keeping quality of the *ugali* product were scored by each panelist independently on a scale of 1 to 5 where 1 = the best and 5 = very poor.

c. Endosperm texture was scored by examining 10 grains and noting the approximate amount of corneous endosperm. 1 = 80–100% corneousness, 2 = 60–80% corneousness, and 3 = 40–60% corneousness. Breaking strength of 10 grains was independently noted on a Kiya Grain Hardness Tester.

Table 2. *Ugali* quality characters of sorghum cultivars from the ISFQT.[a]

Genotype	Color of grain	Color[b] appeal	Taste[b]	Texture[b]	Keeping quality[b]
CSH-5	White	2.0	2.4	2.1	2.5
M50009	White	2.3	2.9	2.5	2.4
M50013	White	2.2	2.9	2.2	2.8
M50297	White	2.2	2.3	2.0	2.8
CO4	Red	3.2	2.4	2.6	2.5
E35-1	White	2.0	1.9	2.0	2.8
WS-1297	Red with testa	4.0	3.1	3.5	3.8
Swarna	White	2.2	2.1	2.1	1.9
IS-7035	Red with testa	4.0	3.0	2.9	2.4
CS-3541	White	2.3	2.7	2.3	2.3
Segaolane	White	2.4	2.5	1.8	2.6

a. The panelists were Kenyans and each panel consisted of 5 to 6 members. Values represent averages of the independent scores of the panelists.

b. Color appeal, taste, texture, keeping quality of the *ugali* product were scored by each panelist independently on a scale of 1 to 5, where 1 = the best.

Table 3. Grain and *Ugali* quality properties of sorghum varieties from Kenya.

	Grain					Ugali				
Genotype	Color	Endosperm[a] texture	100 grain wt (gm)	Breaking[a] strength (kg)	Flour quantity (g)	Color appeal[a]	Cooking quality[b]	Taste[a]	Texture[a]	Keeping quality[a]
CK 60AxSB65	Strong brown	4	2.44	5.1	205	4.4	1	3.4	3.1	3.0
8M51AxLulu-1	White	3	2.42	5.2	202	1.8	1	2.6	2.4	2.6
IS10406xLulu-D	White	3	2.55	6.1	212	1.2	1	1.1	2.0	3.4
2219AxLulu-D	Pale yellow	3	2.47	6.0	208	1.3	1	1.6	1.6	2.5
5D × 135/13/1/3/1	Reddish yellow	4	2.37	6.2	175	3.2	2	3.6	3.5	2.6
Katimum AxSB65	Reddish brown	3	2.32	4.8	204	3.3	2	2.9	3.0	3.4
KAFAxSB65										
KX17/3/1	Pale yellow	2	2.39	8.0	163	2.4	1	2.0	2.3	2.6
2KX71/3	Pale yellow	3	2.84	7.9	176	2.6	1	2.5	3.0	3.0
2KX76/752	Very pale brown	2	2.17	7.2	184	3.3	1	2.7	2.9	2.7
2KX76/325	White	2	2.51	6.5	177	3.2	1	3.1	2.8	3.3
Tx430	Brown yellow	3	2.74	6.1	192	4.6	2	4.0	3.4	3.4
10x5/41/1	White	3	2.33	5.9	179	1.5	1	4.4	1.8	2.8
SERENA-12-W	White	2	2.53	7.3	194	1.7	1	1.7	2.3	2.4
Makueni Local	Pink	5	2.06	5.1	191	3.2	2	3.2	2.8	2.6
2KX17/5	White	2	2.60	8.3	170	2.6	1	2.3	2.2	2.6
2KX17	White	2	2.83	9.1	196	1.9	1	2.3	2.4	2.4
2KX17/6	Pale yellow	3	2.55	9.1	196	1.9	1	2.4	2.6	1.8
Muvenba Local	Light brownish	3	3.09	10.2	176	4.2	2	2.9	3.0	2.5
Lulu-D	White	3	2.30	6.2	169	1.6	1	2.3	2.3	2.4
SERENA	Reddish yellow	2	1.92	6.8	201	4.1	2	3.3	2.9	2.6
E525HR	Reddish yellow	5	2.14	5.6	183	4.5	2	3.4	2.9	3.3

a. See footnote in Table 1 for methods.

b. Cooking quality was subjectively evaluated by skilled women on a scale of 1 to 3, where 1 = good.

Traditional Sorghum Foods in Nigeria: Their Preparation and Quality Parameters

A. Tunde Obilana*

Summary

Ogi, a smooth, creamy, free-flowing thin porridge and tuwo, a soft, binding thick porridge are two major staple foods prepared from sorghum in Nigeria. The processing of sorghum into these two dishes is compared in detail. The nutritional quality and consumer preference for traditional and laboratory methods of processing sorghum is compared. Consumers prefer sorghum ogi and tuwo prepared from traditionally processed flour and paste. Irrespective of nutritional qualities, they prefer soft white or cream-colored grain without a subcoat, which gives a high percentage of ogi recovery and a light color ogi or tuwo with good keeping quality.

In the savanna and semi-arid regions of Nigeria, sorghum and millets are very important food commodities. For most areas, they are the staple foods. Sorghum is grown in the wetter area while millet is grown in the very dry part. About 50% of the total area devoted to cereal crops (i.e., rice, sorghum, millet, and wheat) in Nigeria is occupied by sorghum. The area, estimated at 6.1 million hectares, is located mostly between latitudes 8° N and 13° N. Total sorghum production in 1978 in Nigeria was 4.8 million tonnes.

Presently 95% of Nigerian sorghum production is consumed as human food with differential preference for certain varieties. Sorghum consumption for food is mainly in the form of flour or paste processed into two main dishes: *ogi* or *akamu*, a thin porridge, and *tuwo*, a thick porridge. Other dishes that are sometimes made from sorghum include a number of deep-fried snacks, steamed dumplings, and other snacks.

The consumption pattern, grain processing, preparation method, product appearance, storage, evaluation, and consumer acceptability of *ogi* and *tuwo* will be discussed with special attention to factors affecting the quality of sorghum.

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Traditional Sorghum Foods

Thin Porridge

Ogi, kamu and *akamu* are popular names given to the thin porridge from wet-milled, fermented sorghum. Several other common names are given to the finished product based on three main factors: use of various additives in the *ogi*, mode of preparation, and mode of serving the dish, either hot or cold (Table 1).

Information on the product and its derivatives of variations was reviewed and described by Vogel and Graham (1979) and Maigida, Home Economics Section, Ahmadu Bello University, Zaria. They discussed the preparation and storage of both traditional and exotic foods made from sorghum. Industrial and laboratory procedures useful for *ogi* production from sorghum and its consequent properties have been described (Banigo and Muller 1972; and Akingbala et al. 1981a). Maize was processed into *ogi* and its properties were evaluated at Moor plantation, Ibadan (Chinwuba and Okparanta 1962; and Eijinatten 1965).

Ogi is the most common porridge eaten by Nigerians from the coast to the extreme northern boundaries of the country. Sorghum *ogi* is the most popular in the savannas where sorghum is mostly grown, and maize *ogi* is more popular in the

Table 1. The major food uses of sorghum in Nigeria.

Popular name of product	Description of product	Regional language
Ogi and its variations:[a]		
Ogi	Thin porridge served hot	*Yoruba*
Kamu	Thin porridge served hot	*Hausa*
Akamu	Thin porridge served hot	*Ibo*
Kunu	Watery *kamu*, served cold	*Hausa*
Kunu zaki	Watery *kamu* with sweet potato flour or sugar, served hot or cold.	*Hausa*
Kunu tsamia	Watery *kamu* soured with tamarind	*Hausa*
Koko	Watery *ogi* or *kunu* with tiny lumps of flour to add texture, served hot.	*Hausa* and *Yoruba*
Eko	Solidified cold *ogi* wrapped in leaves	*Yoruba*
Kafa	Solidified cold *ogi* wrapped in leaves	*Hausa*
Agidi	Solidified cold *ogi* wrapped in leaves	*Ibo*

a. From observations on consumption patterns, *tuwo* has little (potash or tamarind) variation within and across the regions where it is largely consumed.

southern forests and derived savannas. Overall, sorghum *ogi* is the most extensively consumed in Nigeria, although it has been relatively less studied than maize *ogi*. The nutritional implications and potential of sorghum and millet as food have been discussed (Oke 1976; Vogel and Graham 1979).

Thick Porridges

In the northern parts of the Nigerian savanna where sorghum production is greatest, the thick porridge *tuwo* is more extensively consumed than *ogi*. *Tuwo* is usually a molded or shaped solid processed from dry-milled nonfermented whole grain flour. It exhibits little variation across different places and forms the major source of food for the main meal. The only other important thick porridge is *dalaki* which is made from wet-milled, fermented, cracked sorghum grains. The resulting paste (starch) is dried and repounded into flour before cooking. Cracked sorghum grains can occasionally be used per se to make a related product called *saino*.

Consumption and Consumer Preference

Ogi is the most extensively consumed thin-porridge breakfast food in Nigeria. It is usually taken hot with *akara* or *kose* (fried bean cake or bean balls) and also with *olele* or *moinmoin* or *dan wake* (steamed bean paste or pudding). In this combination, it is eaten by everybody including young and old, men and women, rich and poor, sick and healthy. *Ogi* is prepared especially for weanlings, infants, new mothers, and sick people by adding milk or *nunu* to the cooked *ogi* and cooking it for an additional time. Fortification is necessary to replace protein lost during *ogi* preparation and to improve the nutritive value of *ogi* for these special groups. Supplementation with a protein source to prevent kwashiorkor in children was indicated by Nicol (1954). The Federal Institute of Industrial Research has succeeded in blending industrially made *ogi* flour with soyflour to make a product called soy-ogi which is available in limited quantities in a few supermarkets (Akinerele et al. 1970).

Daily consumption patterns for *ogi* and *tuwo* and consumption as a percentage of sorghum production are shown in Tables 2 and 3, respectively. A few subregional studies have been conducted to determine consumption patterns and consumer preferences for *ogi* and *tuwo* (Steckle and Ewanyk 1974; Simmons 1976). However, nothing has been documented for the whole savanna region of Nigeria where sorghum is extensively cultivated. Consequently, information in Tables 2 and 3 has been put together from several personal observations and communications. The general picture of the importance of these products as human food in these areas is, however, very clear.

Kamu or *ogi* is eaten at both breakfast and lunch while *tuwo* is eaten mainly at lunch and dinner, except in the northern Guinea savanna which is the heart of sorghum production. Thus, irrespective of the region, *ogi* or *kamu* is the most important breakfast dish while *tuwo* becomes more important at lunch time and is almost the exclusive food for dinner. The amount of calories taken via these two dishes is very substantial and highly sustaining. Cereal crops contribute 42% of the calories from all foodstuffs in Nigeria (Oke 1976); of all the cereals, sorghum contributes about 50% of the calories in Nigeria and 73% of the calories in the savanna regions (Simmons 1976). Since most of the sorghum cultivated is consumed in the form of either *ogi* or *tuwo*, it follows that the consumers obtain about 50% and 73%, respectively, of all their required calories from sorghums. Recently, there has been an increasing demand for maize, rice, and bread in the savanna regions. This shift in consumer preference toward food items in limited supply will surely cause a significant shift in the consumption of sorghum used in *ogi* and *tuwo*. The expected shift would of course vary in frequency and amount between and within the different ecological zones.

In terms of the percent of sorghum produced, consumption of *ogi* and *tuwo* (Table 3) show definite relative trends across the four savanna ecological zones in Nigeria. *Tuwo* is most important ranging from 70% of the sorghum cultivated in the Sudan savanna to 45% in the northern Guinea savanna. In contrast, *ogi* consumption increases from 20% in the Sudan savanna to 35% in the southern Guinea savanna. The demand for sorghum grain for use in poultry feed is increasing. Thus the amounts of *ogi* and *tuwo* consumed as a percent of the total sorghum produced will de-

Table 2. Consumption pattern of *ogi* and *tuwo* with their variation in daily meals.

Region	Breakfast	Lunch	Dinner
Sahel and Sudan Savanna	*Kamu Kosai*	*Tuwo*/stew *Kunu* (snack)	*Tuwo*/stew
Northern Guinea Savanna	*Kamu* or koko *Kosai* *Tuwo* stew	*Tuwo*/soup *Kamu*/*Kosai*	*Tuwo*/stew
Southern Guinea Savanna	*Koko* or *Kamu Kosai* *Eko* or *Kafa Dan wake* or *Moinmoin* or *Olele*	*Tuwo*/soup or stew	*Tuwo*/stew

Table 3. Consumption of *ogi* (*kunu or kamu*) and *tuwo* as a percentage of sorghum production.

	Region			
Product	Sahel and Northern Sudan Savanna[a] (%)	Sudan Savanna (%)	Northern Guinea Savanna (%)	Southern Guinea Savanna (%)
Ogi / *Kunu* / *Akamu*	10	20	30	35
Tuwo	85	70	60	45
Others: (beer and beverages)	5	10	10	20

a. Most of the *ogi* and *tuwo* consumed in this zone are prepared from millet.

crease. This shift, although intensified by the increasing use of maize, wheat, yams, and cassava foods will be at a slow pace.

Grain Processing

Sorghum may not be dehulled to produce *tuwo* in certain localities. However, during *ogi* preparation the grain is dehulled during the wet-milling process. In some parts of Nigeria, commonly among the Hausa, almost always sorghum grains are dehulled before any further processing. Housewives claim that when grains are processed without dehulling, the resulting food (especially *tuwo*) is tough, nonelastic and nonbinding unlike normal *tuwo* texture. Use of whole ground sorghum causes the *tuwo* color to be unacceptably dark or brown due to the presence of either dark-colored flecking on the pericarp, or the presence of pigments in the subcoat. Some tribes that do not dehull grains before milling, solve the expected problems by adding potash to the food during cooking. The potash is obtained by leaching wood ashes with water. Generally, sorghum is dehulled prior to use. After dehulling, dehulled grains are made into flour (dry milling) via different methods, depending on the food dish to be prepared and available resources.

Dehulling

Dehulling of the grains need the following equipments: deep mortar and pestle, winnower (*matankadi*), some water, a fairly large container, and a flat surface or mat for drying.

The method involves putting sorghum into the mortar. The grains are moistened by sprinkling water on them (about 120 cc of water to one *mudu* of grains). The damp grains are pounded with the pestle to loosen the bran until dehulling of all grains is complete; the dehulled grains are winnowed using *matankadi*, a local winnower woven with grass or raffia, to remove the bran. The winnowed, dehulled grains are put into a large container and washed with water until clean.

The method described is a domestic procedure used by all housewives in the areas where dehulling is done. There is very little, if any, machine dehulling done in Nigeria as mechanical dehullers are not available. Grains used in the dehulling process are naturally dried to moisture contents as low as 6–9% moisture. This is possible because sorghum is left to dry in the field and then harvested in the dry cold "Harmattan" seasons. The sorghum is stored, mostly on the head, in storage bins of clay or strengthened soil covered with thatched grass covers for aeration. Portions of the heads are threshed as needed.

Dry Milling

Dry processing of sorghum for flour is done in three ways: (a) by using a grinding stone, (b) by pounding with the wooden mortar and pestle, and (c) by using a commercial grinder or mill.

Grinding Stone Method

The dehulled grains are washed and spread on a mat to dry. Portions are taken after drying and ground between the mother stone and top hand stone into a fine powder. The powder (flour) is sieved intermittently until all grain particles pass through the sieve. The grinding stone consists of a large rectangular slab (50 cm long and about 30–40 cm wide) with a smooth or slightly rough surface, and a cylindrical hand grinding stone which is as long as the width of the slab. Considerable energy is required to grind the sorghum.

Pounding Method

The dehulled grains are washed, excess water is drained out, and the washed grains are left to temper for 1–3 hr without additional water. Soaking softens the grains. When the grains are soft enough, portions are put in the mortar and pounded with the pestle. The pounded grains are sieved, at intervals, until all are pounded into flour.

Commercial Milling Method

The dehulled grains are washed, drained, and dried by spreading on a mat or mats. Then the dried, dehulled grains are dry milled using the machine grinder or mill. The most common models of such mills are the Premier Grinding Mill which uses electricity, and the Amuda Grinding Mill which uses a diesel engine. Both mill models range from small (No. 1A) through the medium (No. 2A) to the large (No. 3A). The electric mills are more common in urban areas while the diesel mills are common in the smaller towns and villages. The diesel mills use the R. A. Lister diesel engine (of Dursley, England) usually with 8 hp and 850 rpm for all sizes of mills. The principle of milling is attrition between stone or steel plates.

The extent of use of any of these methods vary within and among the regions. However, for immediate household use in small quantity, the grinding stone is still used. On the whole, across all regions the pounding method is still the most widespread and the flour produced from the mortar still more preferred because it is lighter, tastier, and produces better quality *tuwo*. The flour qualities from the different methods have not been evaluated scientifically.

Wet Milling

Like the flour processing, paste processing from dehulled grains using wet milling is achieved by two methods: (a) using a grinding stone, and (b) machine grinding or milling. Unlike flour processing however, paste processing goes through two phases—the grinding or milling phase followed by the straining phase. The grinding phase produces a rough paste which contains both starch and chaff (pericarp plus bran) while the straining phase produces the smooth paste containing mainly starch and protein, the chaff having been sieved off, dried, and then fed to livestock.

Grinding Stone Method

The dehulled grains are soaked in cold water overnight (about 24 hr) to soften and ferment. The duration of soaking depends on the physical characteristics of the sorghum varieties used. Usually, overnight soaking is for softer, floury grains while harder, corneous grains would have to be soaked for 24 to 48 hr. Then the grains are washed and ground to a coarse paste. The pounding method in a mortar is not used for paste processing.

The Straining Process

The slurry of ground grain is screened through a sieve which usually consists of a muslin cloth. The muslin removes mainly the bran glumes and other coarse particles which are referred to as chaff. Straining procedures are tedious and time consuming. The slurry that passes through the muslin consists of starch, endosperm chunks, and parts of the germ depending upon the extent of the grinding procedure. The strained material is allowed to stand for 5–6 hr and the water is poured off leaving sufficient water to cover the settled paste. In some areas the steep and wash waters are used to cook the paste into *ogi*. Use of the processing water in *ogi* preparation makes the *ogi* more nutritious and tasty. For instance, more than 50% of the minerals was leached into the steep and wash water during *ogi* processing of sorghum (Akingbala et al. 1981a) and maize (Akintele and Bassir 1967; Oke 1967). A laboratory procedure used by Akingbala et al. (1981a) is presented in Figure 1. The wet paste can be stored under water for a few hours and is sold in the markets.

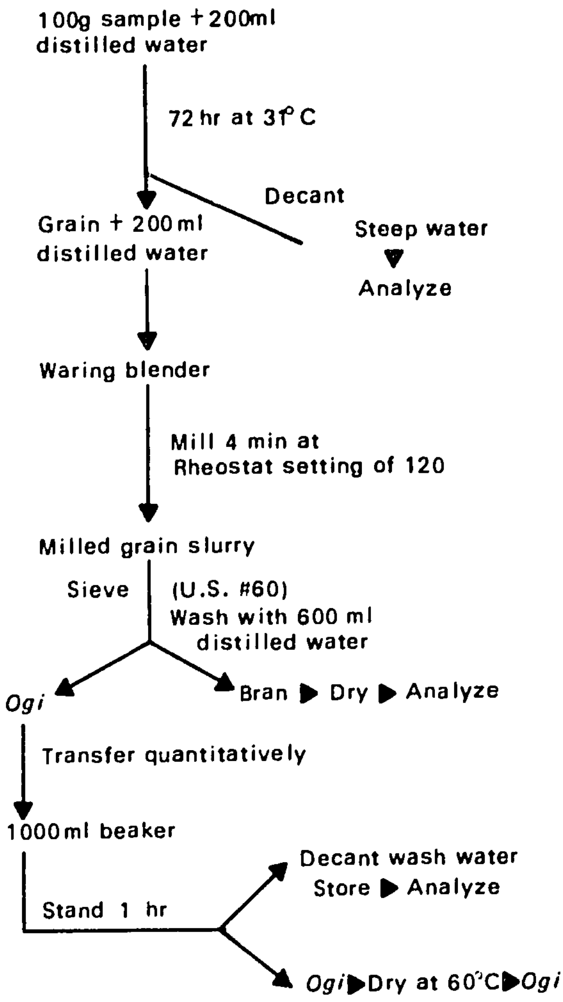

Figure 1. Procedure for laboratory preparation of ogi *(from Akingbala et al. 1980).*

General Sorghum Milling

The processing of flour or paste from sorghum can be achieved without dehulling the grains. Even among the people that commonly dehull, the practice is fast fading out because the homemaker no longer has time for the tedious job of hand dehulling. In addition, labor is becoming more expensive and less available than 10–20 years ago. Due to this increased demand on time and labor, the homemaker washes the grains, soaks them overnight (about 12 hr), and processes for either flour or paste.

The increasing demand for sorghum flour and paste for *ogi* and *tuwo* preparation makes it imperative to develop industrial-scale mechanical dehullers and mills. The effect of such agro-industrial establishments on quality and acceptability of finished products—flour, dried paste, *ogi*, and *tuwo*—must be considered. Comparative experimental evaluations of industrial and traditionally processed products for color, texture, taste, and storage properties are needed. Another implication is the acceptance or nonacceptance of improved sorghum varieties for making *ogi* and *tuwo* paste and flour, industrially. High-yielding varieties with a dark subcoat will not be acceptable unless machine dehullers are available to reduce the problems of dehulling. Alternatively, varieties with no undercoat will have to be developed as is being done presently.

To increase the consumption of *ogi* and *tuwo*, convenient methods of processing the flour and paste have to be developed. Several new pilot commercial mills, capable of dehulling and milling sorghum for preparation of these traditional foods, are needed.

Formulae for Traditional Preparation of *Ogi*

Ogi is prepared from paste (endosperm fractions) prepared by wet milling as already described. The ingredients include approximately two tablespoons of the wet sorghum paste and 6 cups of water. The paste is mixed to a smooth, thin consistency in two tablespoons of water. Then the paste is poured into boiling water with continuous stirring until the paste gelatinizes. The bowl is covered with a lid and cooked for an additional 2 min. The thin porridge can be sweetened as desired. The porridge is consumed immediately without storing.

Kafa, *eko* or *agide* are made similarly except the water is reduced and the porridge is a stiff, solid mass that is served with soup, stew, or vegetables.

Preparation of Sorghum *Tuwo*

The flour from dehulled or whole sorghum is mixed with water and cooked into a thick stiff porridge that is eaten with a soup (sauce) composed of vegetables, meat, and other items depending upon the availability of the ingredients. The basic formula consists of four cups of flour and nine cups of water. Most of the water is brought to boiling. The remaining cold water is used to make a paste of the flour. Then the paste is added to the boiling water. This prevents lumps from forming. The mixture is stirred vigorously and small amounts of flour are added to prevent lumps from forming. The thick porridge is cooled and consumed immediately; any leftovers are stored overnight.

Several varieties of *tuwo* exist. Sometimes potash (leachate from wood ashes) is added to the boiling water. At other times, the leachate from tamarind (acid) is added to the cooking water. These variations in *tuwo* formation are similar to those observations of stiff porridge being made with alkali, acidic, and neutral water in other parts of Africa. It is not known how extensively acid (tamarind) and alkali (potash) are used to cook sorghum in Nigeria.

Other Sorghum Products

Sorghum is used to produce beverages, beer, and snacks. These are beyond the scope of this discussion.

Product Appearance and Storage

Ogi is a free-flowing, thin, fermented porridge with a creamy consistency and smooth texture. Across the whole of the region, light colored *ogi* is preferred with bland to sour taste. The light color results from the color of the grain used, the most preferred being white or cream (more); while yellow grains are also used. The major variation of *ogi*, *eko* or *kafa* or *agidi*, the cold set form usually wrapped in leaves or left in bowls, is similar in appearance and aroma except that it is firm but soft to the touch and almost exclusively white in color. Being free flowing, the *ogi* takes the shape of the bowl or container in which it is served; while *eko* or *kafa*, being solid, is shaped according to the way it is wrapped in leaves while hot.

The stiff porridge, *tuwo*, is solid, soft to the touch, slightly elastic, and binding. It is molded into a round shape prior to serving. Mostly, the light colored *tuwo* (white, cream, or yellow) is preferred.

Traditionally, *ogi* is not normally stored. What is prepared is totally consumed at a sitting. When it is left overnight, it becomes watery and loses its smooth, creamy consistency. When fermented porridge is stored it is a solid gel in the form of *eko* or *kafa* wrapped in leaves or covered in bowls. When wrapped in leaves, these products are safely and traditionally stored in locally woven baskets (with grass or raffia) or large calabashes, for up to 2 or 3 days depending on the quality of the preparation. When stored, *eko* (*kafa*) is not expected to change in texture, consistency, flavor, and aroma. These are preferred characteristics of good *eko* or *kafa*. The product that undergoes changes with reference to these preferred storage qualities is unacceptable.

Tuwo is stored "naked" in the bowls or calabashes in which it was served or in the cooking pots. These containers are covered and storage is commonly overnight. Keeping quality parameters that are traditionally preferred in this region include: retention of moisture, softness with firmness, elasticity, color, and flavor. If after overnight storage, the *tuwo* cracks indicating dryness due to loss of moisture, and becomes hard, the product is unacceptable.

Product Evaluation and Consumer Acceptability

In Nigeria, all sorghum varieties developed for production must have consumer acceptability for food in addition to high yield, disease and insect resistance, and adaptability to the specific ecological zones. Consequently, improved varieties of sorghum must be evaluated for *ogi* and *tuwo* food quality. In this region, food evaluations are done on varieties already tested and identified as elite in terms of high agronomic performance. Only those that prove palatable to the consumers are acceptable. However, acceptability for food does not necessarily mean acceptability for production across this region. The latter factor is dependent on the interaction of several other factors including socioeconomic considerations. For instance, tall sorghums are preferred because of the stalks, which are used for many essential purposes. Thus, dwarf or semidwarf varieties with acceptable grain color and food quality may be rejected.

Considering sorghum grains alone however for *ogi* and tuwo, evaluation of the product should be for: (a) palatability and acceptability, and (b) nutritional quality. These two evaluation parameters would vary in ranking with genetic variation among sorghum varieties.

Evaluation for Palatability and Acceptability

Palatability and acceptability (P and A) tests are based on visual, sensory, and tactile selection traits of the *ogi* or *tuwo* by the consumers themselves. It is a gross evaluation of the actual properties of the prepared *ogi* or *tuwo* as consumed compared with laboratory tests which are mainly visual and chemical. P and A tests have been done mostly on *tuwo* and maize *ogi* and very little on sorghum *ogi*. This aspect of product evaluation for sorghum *ogi* needs immediate attention as soon as collaborators are available to work with the sorghum breeder using his improved varieties.

Evaluation Procedure for *Tuwo*

The procedure used here is field evaluation rather than laboratory evaluation. The assessment parameters include: color of product; texture to test for roughness or smoothness, hardness/softness, elasticity/brittleness, wetness/dryness; and keeping or storage qualities to test for color changes, stability of desired texture and cracking of *tuwo* samples, and changes in taste.

The field trials of *tuwo* quality of new varieties are set up within the framework of the National Accelerated Food Production Project (NAFPP). The best high-yielding varieties released by the breeder for each specific zone are planted in minikit trials for the acceptability test. After other desirable traits of plant height, standability, and grain yield have been recorded, a cooking trial is conducted by housewives. Table 4 shows the varieties tested in minikit trials for 2 years in two ecological zones. *Tuwo* is prepared in the traditional way by housewives on grain from the minikit trials. *Tuwo* is prepared a day before the

Table 4. Sorghum varieties evaluated in *tuwo* palatability and acceptability tests in two ecological zones in 1979 and 1980.

Ecological zone	Variety tested	Description	Ranking
Northern Guinea Savanna	L.187	Yellow, floury-flint, improved cross-bred	Acceptable
	SK5912	Yellow, flint, improved natural mutant from local variety	Not acceptable
	FFBL	White, floury, improved selection from local variety.	Acceptable
	Local	Unimproved farmer's variety	Check
Northern Sudan Savanna, and Sahel	B.E.S.	Yellow, floury-flint, improved selection from local variety	Acceptable
	H.P.3	White, with brown flecks, floury, adapted exotic variety. Has subcoat.	Not acceptable
	H.P.8	White with fewer brown flecks, floury, adopted exotic variety. Has subcoat.	Not acceptable
	Local	Unimproved farmer s variety.	Check

test day and it is stored overnight to evaluate storage qualities. *Tuwo* is also prepared fresh on the test day.

Usually, farmers' field days organized by the NAFPP extension agronomist are used for the palatability tests. On the day of the tests, 10 farmers (all males) are randomly chosen for the taste panel. The *tuwo* is tasted with and without soup. The essence of this procedure is to obtain actual nonmeal taste evaluation of the *tuwo* per se for the different varieties with and without soup. The second tasting with soup is expected to be biased due to a confounding effect between the *tuwo* and the soup. First, all 10 tasters taste the *tuwo* without soup and their opinions are recorded as acceptable or not acceptable. Second, the dish is tasted with the popular soup used in the village and acceptability is recorded. The different varieties of *tuwo* are identified as 1 to 4 or any number tested. Then the tasters are asked their reasons for accepting or rejecting. Some give critical answers on physical properties of the *tuwo*, while a few simply say the taste is not right compared with that made from the local variety. Most of the time the local is always selected plus one or two of the improved varieties. In addition, the tasters are guided by interviewers through questions like: "Is the sample tasted as good as, better than, or worse than the same dish prepared at home? Why do you or don't you like the sample? Is it because of color, texture, looks, keeping quality, or a combination?" Finally, the varieties tested are ranked for *tuwo* quality and acceptability. The final ranking of varieties adapted to the northern Guinea and northern Sudan savannas is shown in Table 4, compared with the respective locals. The thin porridge, *ogi*, can also be evaluated similarly.

Field P and A tests just described are very subjective. The consumer evaluation and consequent ranking of varieties could be affected by several confounding factors. These include choice of taste panelists and site of tests, age and sex variation, food appearance, and hunger effect. These tests can be made more valid by: (a) choosing taste panel members who are familiar with the food, (b) selecting male and female adults for the panel, and (c) conducting the taste panel at such time as to avoid exceptionally hungry taste panel members.

In field P and A tests, opinions usually differ on which *tuwo* is better than the other. Opinions differ across the region and within each subregion as shown in the ecological zones in which P and A tests have been done in Nigeria. However, white sorghum kernels followed by yellow or cream types are mainly preferred across the region. Brown and red grains or white grains with a subcoat are in most cases rejected and not used for these main staples. These dark-colored grains are however cultivated for beverages and beers. Housewives do prefer the soft floury and floury-flinty grains to hard flinty grains, which are harder to pound.

Evaluation for Nutritional Quality

Grains of 16 improved sorghum varieties from Nigeria were analyzed for proximate tannin, and amino acid content (Okoh et al. 1981). Insignificant differences were observed among the varieties for ash, crude fiber, fat, and total carbohydrate content. In contrast, the crude protein and tannin content showed considerable variation, ranging from 9.3% (in short Kaura SK5912) to 14.9% (in L538) for protein, and 0.09% (in SK5912) to 0.22% (in YG5760) for tannin content. These varieties need to be evaluated for their *ogi* and *tuwo* nutritional qualities. To do this, close collaboration is needed between the breeder, the biochemist, food scientist, and home economist.

Ogi has been successfully prepared using a laboratory procedure by Akingbala et al. (1981a) as shown in Figure 1. Its physical, chemical, and sensory evaluation has also been reported (Akingbala et al. 1981b). They have also shown differences in *ogi*-making properties of different sorghum varieties, and the properties were compared with those of maize and millet (Banigo and Muller 1972).

Mean *ogi* composition from seven sorghum cultivars was 84.3% starch, 8.3% protein, 2.5% fat, 0.53% ash, and 1.3% soluble sugars (Akingbala et al. 1981a). Because of the mode of processing of sorghum into *tuwo*, via dry milling of whole grain, its nutritional quality is expected to be significantly better than that of *ogi*. *Tuwo* protein, fat, ash, and soluble sugar content are higher, while the content of starch is low compared with *ogi* (inferred from Akingbala et al. 1981a).

Yield, physical, chemical, morphological, and cooking properties of laboratory-prepared *ogi* were significantly affected by the variety of sorghum. However, the laboratory procedure produced *ogi* with a higher fat content and darker color than that *ogi* prepared in a traditional manner because the germ and pericarp were ground finer in the laboratory procedure. More information is required on commercial and scientific preparation of *ogi* and *tuwo* from improved high-yielding varieties with good quality. Correlations of these quality assessments with simple morphological traits will go a long way in aiding selection programs for food quality. The difficulty encountered presently is that none of these nutritional and food quality traits were adequately correlated with morphological plant traits and worse still with taste parameters.

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Sorghum *Injera* Preparations and Quality Parameters

Brhane Gebrekidan and Belainesh GebreHiwot*

Summary

Injera *is a leavened, flat and round, Ethiopian traditional bread made from cereals. Sorghum is second only to tef as the preferred cereal for* injera. *The best quality sorghum* injera *is made from the dehulled grain. Since sorghum dehulling machines are not available to the Ethiopian housewife, the job is all done by the tedious, traditional mortar-and-pestle method. Recipes, cooking procedures, and equipment for* injera *preparation are given in the paper. The major sorghum* injera *quality parameters discussed in the paper are color, "eyes", texture, taste, overall appearance, and storability. The poor storability of sorghum* injera *compared to that of tef is considered a major problem. The use of composite flours of sorghum with tef or barley is the traditional solution to this problem. Results of international and national experiments have established varietal differences for the major quality attributes of sorghum* injera.

All the major cereals grown in Ethiopia are traditionally used for making *injera*. Of all the cereals, tef (*Eragrostis tef* [Zucc.] Trotter) is reputed to make the best quality *injera*. Next to tef, sorghum (*Sorghum bicolor* [L.] Moench) is the most preferred cereal for making this traditional bread of Ethiopians.

Injera is the undisputed national bread of Ethiopians. Signifying the importance of *injera* in the daily diets of Ethiopians, the daily prayer of the average person would include "... Give us this day our daily *injera*. ..."

Injera normally means a leavened, round flat bread found in most Ethiopian homes. However, because of its traditional popularity and the prominent role of this product in the diets and cultures of Ethiopians, the word *injera* in Ethiopia often has broader connotations signifying one's job or way of earning a living.

Popular Names

In the various vernacular languages of Ethiopia, *injera* has different names. In Oromigna it is *bidena*, but in Tigrigna it is known as *taita*. In Guragigna it is often called *tabita* while in Wolaytigna it is *solo*. *Injera* is, however, an *Amharic* word and by far it is the most widely used and understood designation for leavened breads consumed in Ethiopia.

Ethiopian Sorghum Foods

Nearly all of the 1 million metric tons of sorghum grain produced annually in Ethiopia are used for human consumption. Of this, about 80% is used for making *injera*. Home-brewed beverages take an estimated 10% of the national sorghum production. The rest of the sorghum grain produced in the country goes into making porridge (*genfo*), unleavened bread (*quitta*), boiled whole grain (*nifro*), roasted grain (*kolo*), and animal feed.

The different kinds of foods, except *injera*, made from sorghum grain are consumed as snacks or as special meals. However, where *injera* is traditional it is normally used everyday by the whole family for the three daily meals. Adults and children over 2 years of age normally take *injera* as a staple. Between the ages of 12 and 24 months, weanlings are normally introduced into *injera* particularly in the rural areas and among low income groups. Children are normally fed *injera* in the form of *fitfit*

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which is a mixture of broken pieces of *injera* and *wot* (sauce). It is also fed as *injera* and *wot*, as normally served to adults.

Chemical Compositions of Sorghum *Injera*

Comparative chemical compositions of *injera* from the major Ethiopian cereals have been reported (Ethiopian Nutrition Institute 1980). Table 1 gives the chemical composition of 100 g *injera* from sorghum, tef, maize, finger millet, barley, and wheat.

The *injera* of the different cereals differs little in chemical composition. The moisture content of *injera* of any cereal is above 50%. The mean protein content reported across all the cereals is about 4.8% with sorghum reportedly having the highest protein (7.1%) in the *injera*. Whether or not the reported range of protein will generally hold with changes in varieties of each crop needs further investigation and confirmation. The identifications of varieties analyzed for each cereal have not been given. Agren and Gibson (1968) reported that sorghum *injera* has only 3.0% protein. The discrepancies in the protein content of sorghum *injera* appear due to varieties and sampling variations. The existence of varietal difference in protein content in *kisra*, fermented Sudanese bread similar to *injera*, has been reported (Tinay et al. 1979). In the whole-grain chemical analysis of the major cereals grown in Ethiopia, sorghum has been reported to have a comparatively low protein content among the cereals (Angren and Gibson 1968). Other unusually high values in *injera* chemical composition (Table 1) are the extremely high calcium content of finger millet *injera* and the iron content of tef *injera*.

Injera and *Wot*

Injera is seldom consumed alone. It is often taken with some kind of stew. The general name of the stew that is served with *injera* is *wot* (Amharic). Small pieces of *injera* are taken by the fingers and dipped into the *wot* bowl and used for picking up the *wot* for eating. The major source of protein and other noncarbohydrate nutrients for the traditional consumers of *injera* and *wot* is mainly the *wot*. *Wot* can be made from meat, pulses, vegetables, or their combinations. Various types of *wot* are recognized, the major ones being *shiro* (pea flour), *kikh* (split lentils, broad bean, or pea), vegetables, *doro* (chicken), egg, beef, mutton, and fish. Though these are the major ingredients of *wot*, most recipes would include red pepper, onion, butter or oil, and spices. Milk and milk products

Table 1. Analysis per 100 g of *injera* of each of the major cereals grown in Ethiopia.

	Sorghum	Tef	Maize	Finger Millet	Barley	Wheat	Mean
Food energy (calories)	193	162	185	172	167	172	175.17
Moisture (%)	52	59.8	54.0	56.1	58.0	57.4	56.22
Protein (g)	7.1	4.2	5.0	3.8	3.5	5.4	4.83
Fat (g)	0.6	0.6	0.7	0.3	0.3	0.9	0.57
Carbohydrate (g)	39.8	33.9	39.6	38.4	37.5	35.6	37.47
Fiber (g)	0.9	1.7	0.7	4.0	0.9	0.9	1.52
Ash (g)	0.5	1.5	0.7	1.4	0.7	0.7	0.92
Calcium (mg)	10	64	27	169	16	28	52.33
Phosphorus (mg)	111	129	120	103	128	135	121.00
Iron (mg)	3.5	30.5	2.1	17.3	4.2	3.3	10.15
B-Carotene Equiv., (mcg)	0	0	Trace	Trace	0	0	0
Thiamine (mg)	0.17	0.21	0.14	0.14	0.12	0.14	0.15
Riboflavin (mg)	0.08	0.07	0.06	0.01	0.05	0.09	0.06
Niacin (mg)	1.7	0.8	0.7	0.2	3.0	2.4	1.47
Ascorbic acid (mg)	0	1	2	1	0	1	0.83

SOURCE: Ethiopian Nutrition Institute. 1980.

may also be served along with *injera* and *wot*. The normally sour *injera* and the spicy *wot* create a food taste combination that is considered ideal by Ethiopians depending on this staple.

Processing—Dehulling and Grinding

The processing of the grain for making *injera* goes through several stages. Initially, inert materials are handpicked, and chaff and other impurities are winnowed. If the grain appears dirty or appears moldy as a result of pit-storage, it is washed. In most parts of the country, the cleaned grain is soaked and pounded in a wooden mortar and pestle to remove the bran. After sufficient pounding, the bran is winnowed off to leave clean dehulled grain. The bran and cracked grain winnowed off are used as poultry feed. In some areas, whole grains, without dehulling, are taken to the grinding mill. However, in most parts of the country, sorghum for *injera* is dehulled and it is generally accepted that dehulling does improve the *injera* quality. Though dehulling is known to improve the *injera* quality, it is also known that the overall nutritional quality of the dehulled grain is negatively affected (Reichert and Young 1977).

The dehulling of sorghum in Ethiopia is often done at home by the housewife. The grain is soaked in cold or hot water for 10 min. Immediately after soaking, excess water is drained off the grain. A small quantity (about 2–3 kg) of the wet grain is placed in the traditional wooden mortar and pounded with the pestle by women until the bran is removed. The dehulled grain is allowed to dry in the sun after which it is winnowed to remove the bran. Grinding normally follows dehulling and winnowing.

In Ethiopia, machines for dehulling sorghum are not available to housewives. Recently, the PRL/RIIC sorghum dehuller machine (Eastman 1980) has been introduced to Ethiopia from Canada. This machine is currently under test at Nazreth by the Institute of Agricultural Research and the Ethiopian Sorghum Improvement Project. Since the PRL/RIIC dehuller has been extensively tested on sorghum in Botswana (Eastman 1980; Forrest and Yaciuk 1980) so far it has been found very effective and efficient at Nazreth also. There appears to be a growing interest in mechanically dehulled sorghum in Ethiopia, not only for *injera* making but also for sorghum/wheat composite flour for making regular bread (Wakjira and Guttu 1980).

Sorghum grinding is done both at home and by commercial mills. At home the equipment used is simply two pieces of stone (*wofcho* and *mej*) in which the sorghum grains are crushed into flour. This is achieved by the constant back and forth riding of the small stone (*mej*) on top of the big one (*wofcho*) with the continuous crushing pressure and weight of the *mej* and the grinding woman, who at the same time constantly feeds the sorghum into the mill. The dimension of *wofcho* and *mej* normally used at homes would be about 80 cm × 40 cm and 20 cm × 20 cm, respectively. The grinding surfaces are periodically sharpened by a hard stone or a suitable hammer.

In towns and large villages, machine grinding services at reasonable costs are normally available. After machine grinding, the housewife would sieve the flour to remove grits and coarse materials before preparing the dough. The mills used are stone attrition types. Two equal sized round pieces of stone are used for milling; one stone on top of the other rotates to grind the sorghum grain. The bottom stone is stationary and the diameter is about 1 m.

Sorghum *Injera* and its Preparation

Formula

A standard formula, where a starter from previously used container is used, is given below. If no starter is available, the modified formula given by Vogel and Graham (1979) is suitable.

A. Preparation of the Dough

INGREDIENTS:

Sorghum flour 4.5 kg
Ersho (starter) 500 cc (fermented thin yellowish fluid saved from previously fermented dough.)
Water 2000 cc

METHOD:

Using a traditional sieve, sift the flour into a large bowl to remove any foreign materials.

Add 1 liter of water and knead well by hand.

Stir in the *ersho* (starter).

Add the rest of the water gradually and knead well.

Transfer the dough into a previously used *buhaka* (dough container).

Cover and let stand for 48 hr.

B. Baking the *Injera*

INGREDIENTS:

Sorghum flour 1600 g
Water 4200 cc

METHOD:

Sift the flour into a large bowl.

Heat 1700 cc of the water to boiling.

Pour the boiling water over the flour and mix well with a wooden spoon or smooth stick. Let the mixed batter stand until it cools to 55° C.

Add to the fermented dough in the *buhaka*.

Add the rest of the water (2 liters) into the *buhaka* (dough container) and mix well.

Let stand until bubbles of air form (about 1 hr).

After a half hr start to heat the clay griddle *metad*.

Sprinkle ground rapeseed over the *metad* and polish with a folded piece of clean cloth. Dust away all the rapeseed flour and start baking *injera*.

To bake the *injera*, pour the batter onto the hot greased *metad* using a circular motion from outside towards the center to make a circular *injera*. When holes begin to form on top of the *injera*, cover with the *akenbalo* (*injera* griddle lid) and bake for 2–3 min. Use about a half liter of batter for each *injera*.

Grease the *metad* with the rapeseed flour or oil between each baking. Repeat the process until the dough is used up.

The yield is 31 *injeras* each weighing 390 g.

Cooking Medium

Metad (the *injera* griddle made of clay) is used to bake *injera*. *Metad* is supported by *gulicha* which are three stones placed at equal distance around the open fireplace to form corners of a triangle.

The *metad* is heated to a medium to high temperature before baking starts and this temperature is maintained throughout the baking time. Firewood from trees found in the vicinity, usually *Eucalyptus* in the highlands and *Acacia* in the lowlands, is used to heat the *metad*. Sorghum stalks are also used for this purpose in sorghum-growing areas. Dried leaves, dried dung, and sawdust are often used as source of heat. In the cities, electric *metads* are now being introduced and are spreading fast.

Equipment and Cooking Utensils Needed for *Injera* Baking

The major equipment used in *injera* baking (Fig. 1) is the *metad*, which is a round, smooth, clay griddle generally 55–60 cm in diameter. A good quality *metad* is perfectly flat with a slightly raised ridge around the edge so that it produces *injera* of consistent thickness and also fits properly with the *akenbalo* (the *metad* cover).

The *akenbalo* is a light weight circular and cone-shaped *metad* cover with a handle on the apex of the cone. It is generally made from straws or bamboo and plastered with mud or dung. It fits the *metad* perfectly so that no steam escapes during baking until the *injera* is cooked well. The *metad* cooks the bottom surface and the steam cooks the top of the *injera*.

Buhaka is a clay, enamel, metal, or wooden container with a cover where the dough is kept to ferment for a few days. *Masesha* is a clean-folded piece of cloth used in greasing and polishing the *metad*. The batter is poured off a tin or calabash container called *mazoria*. *Sefied* is a flat basket made from grass straw and is used to remove *injera* from the *metad*, after baking.

Messob is the *injera* basket made from straw. It is cylindrical in shape and has a flat bottom. It has a conical-shaped lid which fits the *messob* perfectly. Different types of *messob* are used for storage of *injera* and for serving a group of people at a time.

Some Variations in *Injera* Preparation Across Regions

In addition to the preparation methods explained in the formula given above, variations are that after fermentation the dough is thinned down by adding *absit* and water. *Absit* is a gruel prepared by mixing a part of the additional water that is required to thin down the dough and a small portion of the fermented dough together and cooking the mixture for about 10 min. The gruel is cooled to a temperature of about 46° C and added to the fermented dough. More water is added to get the right consistency batter.

For the recipe given, preparation of *absit* for a

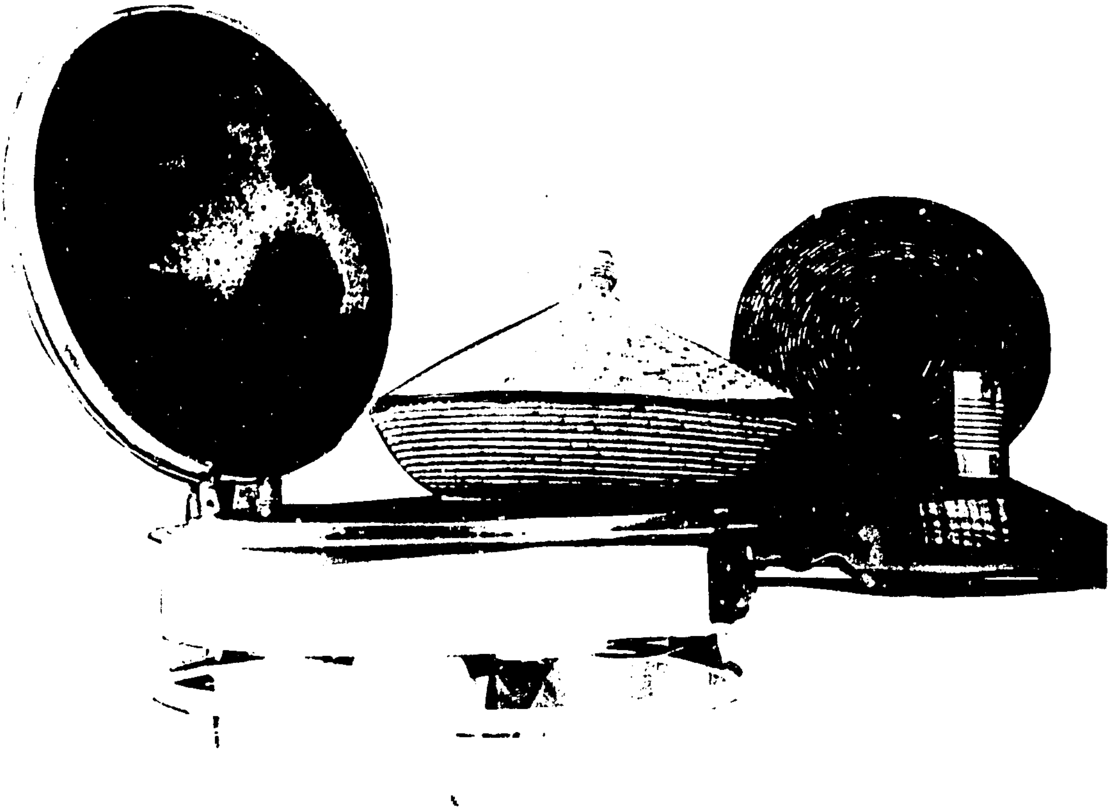

Figure 1. Equipment used in the baking and storage of injera.

variation would therefore be:

Ladle out 800 g of the fermented dough.

Add 350 ml of water and mix well.

Boil 765 ml of water and stir the dough and water mixture into it.

Cook while stirring constantly for 10 min.

Remove from heat. Cool to a temperature of about 46° C.

Add the cooked dough (*absit*) to the fermented dough in the *buhaka*. Mix well with a long clean stick, ladle, or clean hand.

Add 2 liters of water and mix well.

Let stand about 50 min to allow the batter to rise. Bake.

Another variation is to wait a few hours after the initial dough is mixed, and then one-fourth of it is cooked thoroughly until it reaches the consistency of porridge. The cooked dough is added back to the initial dough, mixed well, and left overnight to ferment. The dough is thinned with warm water and baked.

Physical Characteristics and Quality Attributes of *Injera*

In physical appearance, a typical *injera* is normally round in shape and measures about 60 cm in diameter. Normal *injera* is thin, or about 6 mm thick. The front side of a good quality *injera* has uniformly spaced honeycomb-like "eyes", each measuring about 4–5 mm in depth and 4 mm in diameter (Fig. 2). About 4 *injera* eyes are contained per cm^2 of *injera* surface.

Injera with large unevenly spaced eyes or those with tiny eyes are both considered poor quality. While the former signifies insufficient fermentation, the latter signifies too much *absit* in the dough. The backside of *injera* is normally smooth and devoid of eyes. Good quality *injera* is soft and pliable in texture enabling the consumer to wrap and pick up *wot* and *injera* with the fingers to eat. A good *injera* is also spongy and can be folded without cracking. A nonpowdery, soft appearance

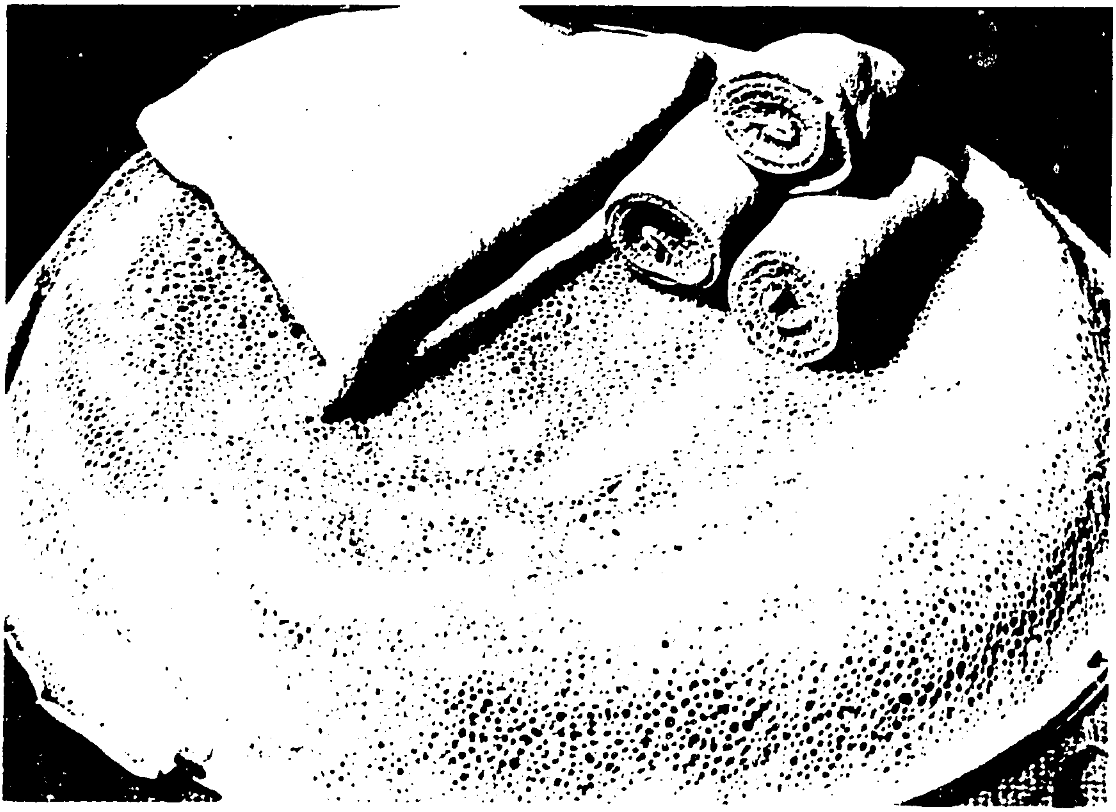

Figure 2. Injera—*rolled, folded, and spread. (Photograph. W. G. Menbere, Ethiopian Nutrition Institute.)*

is also characteristic of a good quality *injera*. Poor quality *injera* is brittle, crumbles easily when handled, looks powdery and dry, or sticky and rusty brown on the back.

The color of *injera* could generally be whitish, cream, reddish-brown, or brown depending on the color of the sorghum flour used. The most preferred kind of *injera* is whitish or cream in color, has a soft and pliable texture for as long as 3 days after its preparation, is relatively thin, and has uniformly spaced medium sized eyes. The backside of *injera* must be smooth, not sticky and should not look rusty or brown with burns. Good quality *injera* does not fluff off and stick to the fingers when it is handled.

In taste, good *injera* must be slightly sour to have the desired taste combination with the spicy *wot*. *Injera* made from dough that has not been sufficiently fermented has sweetish taste and is not considered good for eating with *wot*. This type of *injera* is called *allegna*. When there is an urgent need for *injera* and the housewife cannot wait until sufficient fermentation has taken place, she would normally make *allegna injera*. *Injera* made from overfermented dough is too sour and is undesirable for food.

The quality of *injera* is influenced to a large extent by the fermentation process and the length of time for fermentation. In tef, the primary agent of fermentation of the *injera* dough has been identified as the yeast *Candida guilliermondii* (Cast) Langeron and Guerra (Stewart and Getachew 1962). The primary agent responsible for sorghum *injera* dough fermentation has not been reported. There is no commercially available yeast that can be used for sorghum dough fermentation to prepare *injera*.

Regional Preference for *Injera*

Preference for *injera* quality appears to vary from region to region, and also from urban to rural areas. Though the two cereals most preferred for *injera* are tef and sorghum, which of the two is preferred in a given region, appears to depend on the traditional food habit of the area. In general, the predominant crop of a region is the preferred *injera* cereal for the region. In urban areas, *injera* of medium thickness, lighter color, and large size is preferred. In rural areas, thick *injeras* of large diameter are often consumed. In terms of color preference, white grains, red grains, grains with subcoat, and brown grains would be ranked in the order mentioned.

Eating in Groups

Injera and *wot* is customarily eaten in a group. The group sits around the circular *injera* basket in which several layers of *injera* are placed. After *wot* is poured into the center of the basket, each person tears off a piece of *injera*, dips it into the *wot* and eats (Fig. 3). It is common for people sitting around the *messob* to feed each other as a sign of friendship and generosity. This is often done by the hostess to her guests after they have had their fill.

Storage

In most parts of Ethiopia, since sufficient *injera* to last for 3 days' consumption of the family is baked by the housewife at a time, it must be stored. Normally, a straw basket (*messob*) with tight cover, big enough to hold several layers of *injera* piled flat on top of one another, is used for storage. *Injera* made from only sorghum flour has poor storability. To improve this quality, sorghum is often mixed with tef and or barley for making *injera*. Since *injera* is normally stored for 3 days under room temperature, the most significant changes that take place in storage are molding and drying of the product. In cool and highland zones,

Figure 3. Group eating of injera *and* wot. *(Photograph: W. G. Menbere, Ethiopian Nutrition Institute.)*

molding in storage is not as severe a problem as it is in lower altitude warmer areas. Dried and brittle *injera* is not convenient for eating with *wot*. Therefore, preferred *injera* keeping quality parameters are softness, nonbreakability, and freedom from mold. Eventhough one would expect variability in sorghums for *injera* keeping quality, no work has been done to screen sorghums for this important character. The use of composite flour has been the only traditional method of tackling this problem. In our germplasm collections and surveys of sorghum food traditions in Ethiopia, we have not found reliable information on whether or not sorghum keeping quality is a varietal characteristic. However, our laboratory evaluations of various sorghum varieties have repeatedly shown that there are significant varietal differences in storage quality (Table 2).

Laboratory Procedures for *Injera* Preparation

The Ethiopian Nutrition Institute has an experimental kitchen where tests are run on new and indigenous foods and their acceptability evaluated

Table 2. Results of *injera* evaluations of selected sorghum varieties in an international food quality experiment conducted at Alemaya, Ethiopia, 1980.

Variety	Amount of water added, liter kg	Number of *injera* per kg of flour	Softness after 48 hr	Color of *injera*	Taste of *injera*	Overall desirability of *injera* and general remarks
M35-1	2.24	6.2	Soft	White	Very good	Good overall
CSH-5	2.68	7.2	Soft	White	Good	Good overall
M50009	2.55	6.2	Soft	White	Very good	Trace of bitter taste
M50013	2.20	6.0	Dry	Bright white	Good	Tastes and looks like maize *injera*
M35052	2.39	6.5	Dry	White	Poor	Has maize taste
M50297	2.36	5.8	Dry	Yellowish	Poor	Dries too fast
P721	2.33	5.9	Dry	Yellowish	Bad	Too brittle and bad
CO4	2.35	6.2	Very soft	Reddish	Very good	Very good overall desirability and appearance
Patcha Jonna	2.16	6.4	Dry	Yellow	Poor	Has taste of wheat
Mothi	2.28	6.2	Dry	White	Poor	Maize taste, too brittle
E35-1	2.46	5.7	Medium	Bright white	Fair	Average appearance and acceptability
WS-1297	2.36	5.6	Very soft	Brownish	Excellent	Similar to tef *injera*
Swarna	2.67	6.7	Soft	White	Very good	Good appearance and taste
S-29	2.39	5.8	Dry	White	Poor	Very bad "eye" quality
S-13	2.86	6.5	Dry	Bright white	Fair	Similar to maize *injera*
IS2317	2.34	6.2	Dry	Reddish	Bad	Very bad "eye" quality
IS7035	2.48	5.6	Dry	Reddish	Very good	Eyes are as good as tef
IS7055	2.57	6.5	Dry	Reddish	Bad	Very bad "eyes"
IS9985	2.36	6.5	Soft	White	Very good	Good overall
IS8743	2.45	6.9	Soft	Reddish	Very good	Similar to tef and overall good quality
CS3541	2.67	6.0	Dry	White	Poor	Overall poor
Segalone	3.05	6.4	Soft	Brownish	Good	Overall good
Ouga-Market	2.51	6.9	Dry	White	Bad	Has bad aroma and taste but good "eye" quality
IS158-OP	2.30	Not suitable for making *injera* at all, does not make "eyes"				
Dobbs	2.89	"	"	"	"	" " "
Mean	2.48	6.26				

by a trained taste panel. In this laboratory, standardized formula of *injera* are prepared and evaluated for three characteristics, i.e., appearance, texture, and taste.

Appearance

This characteristic would be rated good (1) if the shape is properly round and the top surface has uniformly distributed eyes of 4-5 mm in diameter and closely located to one another. There should be no blind spots on the surface. The general appearance should be rich and not powdery. The backside should be smooth and not browned. On the other hand, a rating of 5 (poor) would be given for appearance if the circumference is jagged, if the top surface is powdery and or cracked, if eyes are too large or tiny and are irregularly placed, and if the backside is browned.

Texture

A rating of 1 is given for texture if the *injera* is of medium thickness (4-6 mm) and is soft, spongy, and resilient. The *injera* should be soft enough to cut a piece easily with the fingers but resilient enough so that it does not crack or crumble when folded or used to wrap around *wot* portions when eating. The texture should not be gluey or stick to the fingers when handled. A rating of 5 is given for texture of *injera* that is too thin, dry, brittle, or leathery. Sorghum *injera* becomes drier and more brittle as the number of days of storage increases.

Taste

Injera taste is rated good (1) if it has a slightly sour pleasing taste that goes well with the spicy *wot*. On the other hand, too sour or sweet taste would get it rated 5. The laboratory procedure for preparing and evaluating *injera* differs from common practice in that the formulae used are standardized. Measured amounts of ingredients are used and the product derived is predictable and repeatable. The evaluation for different characteristics is also systematically done by a trained taste panel. In common practice, the baking of *injera* is skill oriented having been passed from mother to daughter for years. Estimated amounts of ingredients are used and the end-product can vary from household to household, or from one time to another.

Injera Quality Experiments

As part of the international network on the evaluation of the same set of sorghum varieties for making different sorghum foods, the Ethiopian Sorghum Improvement Project evaluated 25 sorghum varieties for making *injera* at Alemaya, Ethiopia, in 1980. They were all grown and milled at Hyderabad, India, and sent to us by ICRISAT for evaluating them for *injera*. The samples had been ground in a stone mill and the flour was of whole grain.

The results of the experiment are given in Table 2. The amount of water needed to bring the batter to the desired consistency for pouring in the *injera* griddle ranged from 2.2 to 3.0 liter kg of sorghum flour. The number of *injeras* of 55 cm diameter that could be baked from 1 kg of flour ranged from 5.2 to 7.2. Other factors being equal, the greater the number of *injeras* that could be obtained per kg of flour, the more desirable a variety is. What special characteristics of the grain or flour of a given variety are positively correlated with making a larger number of *injera* is not clear. It is often said that housewives consider the larger water-absorbing capacity of a given kind of sorghum as being more desirable. One would expect that this would be associated with the number of *injeras* obtained from a variety. However, the data in Table 2 do not bear this out. There appears to be no association between the amount of water needed and the number of *injeras* obtained. More information is needed to determine why some sorghum flours produce more kilogram of *injera* than others.

Since softness of the *injera* after a day or more of storage is critical, the 25 international varieties were evaluated for this characteristic. They ranged from varieties that were rated very soft to those labelled dry after 48 hr of storage in the traditional *injera* storage basket. The two varieties that produced very soft *injera* after 48 hr of storage were CO4 and WS1297. Thirteen of the 25 varieties produced *injeras* that were too dry (Table 2). The *injera* could not be rolled well and it could not conveniently be used for picking up the *wot*.

The colors of the *injeras*, in the order of consumer preference, were: white, yellow, red, and brown (Table 2). If softness and eye quality are acceptable, *injera* color is a characteristic that is often tolerated by the consumer.

Evaluations of taste and overall desirability of the *injera* of each variety were done (Table 2). Nine varieties receiving good ratings for taste and overall desirability were M35-1, M50009, CO4, WS1297, Swarna, IS7035, IS9985, IS8743, and Segaolane. Considering color of *injera* also, the overall best three varieties were M35-1, Swarna, and IS9985.

Two varieties, IS158-OP and Dobbs, were found totally unsuitable for making *injera*. The *injeras* from these varieties were completely without eyes and it was difficult to remove their *injeras* from the baking pan. Other varieties that had very bad eyes and were relatively unsuitable for *injera* were P-721, S-29, IS2317, and IS7055.

Evaluation of taste and overall desirability was done by a taste panel of five adults whose traditional staple is sorghum *injera*.

Based on the results of this experiment it was not, in general, possible to associate the physical appearance of the sorghum kernel with the quality of *injera* it could make. Some sorghums with apparent visual good grain quality made *injera* of poor quality. It would be of interest to investigate in detail what component of sorghum of different varieties contributes to keeping quality, softness, eye quality, and taste of its *injera*. The significance of endosperm texture in determining the quality of *injera* remains to be investigated further.

Tests on Local Varieties

A series of *injera* baking trials on selected Ethiopian sorghums were conducted at Alemaya and a summary of the results obtained from these experiments as means of 10 trials is given in Table 3. The samples were dehulled using the traditional mortar and pestle. The dehulled grains were milled mechanically in a stone attrition mill found in the Alemaya area of eastern Ethiopia.

The number of *injera* of 55-cm diameter that could be made from 1 kg of flour ranged from 4 to 7.5 with most varieties making 5. Variety WS 1297, which made the largest number of *injeras* (7.5), also took the most amount of water/kg of flour. On the other hand, variety Gato 994, which took a relatively large amount of water, made the

Table 3. Summary of results of *injera* evaluation tests on 15 Ethiopian sorghum varieties and a tef check, conducted at Alemaya, 1974.

Variety	a	b	c	d	e	f	g
WS1763	6	2.6	3.7	3.8	3.8	4.2	Brown
Gato 994	4	2.7	4.2	4.0	3.4	4.0	Brown
Gato 1001	5.5	2.5	3.2	3.6	3.6	4.0	Brown
Awash 1050	5	2.5	2.6	2.6	2.9	2.3	Straw
Adi-Ugri 149	5	2.6	3.1	2.9	3.7	2.6	Straw
Alemaya 70	5	2.5	3.2	3.3	3.3	2.3	Straw
Jijdasola 781	5	2.6	3.4	3.4	2.8	2.9	Straw
WS1297	7.5	2.9	3.5	4.0	3.0	3.0	Brown
Hirna 305	5	2.5	2.8	3.4	3.3	3.4	Light red
Dedessa 1057	5	2.5	3.1	2.7	2.6	3.3	Brown
Al-477	5	2.6	3.4	2.9	3.1	3.3	Light red
Hirna 547	5	2.5	2.8	2.7	3.2	3.0	Light red
Babile 1033	5.5	2.7	3.1	2.8	2.6	3.4	Brown
Jijwegere 935	5	2.5	3.3	3.1	3.3	3.4	Straw
WS1509	5	2.4	3.1	3.1	3.2	2.9	Red
A-53 (Tef Check)	5	2.6	2.6	2.4	1.9	2.9	Straw
Mean	5.2	2.6	3.2	3.2	3.1	3.2	

a. Number of *injera* of 55 cm diameter obtained per kg of flour.
b. Total amount of water, in liters, needed per kg of flour.
c. "Eye" quality, 1 = best and 5 = worst.
d. Quality of back side of *injera*, 1 = best and 5 = worst.
e. Softness of *injera* after 24 hr storage, 1 = best and 5 = worst.
f. Overall desirability, 1 = best and 5 = worst.
g. Color after 24 hr of storage.

least number of *injeras*/kg of flour.

Scores for eye quality, backside desirability, softness, overall desirability, and color are given in Table 3. Varieties that had the best eyes in these series of trials were the A-53 tef check entry, Awash 1050, and Hirna 305. The eyes of the *injeras* of these varieties looked like honeycomb throughout and did not have blind areas. The varieties with the poorest *injera* characteristics were Gato 994 and WS1763. These varieties had very few, poorly developed eyes. Both of these varieties are among the highest grain yielders of the highland sorghums (Gebrekidan 1973). However, because of their unacceptability for *injera*, they have been discarded from production.

The best scores for the quality of the backside of the *injera* and its softness after 24 hr of storage were given to the tef entry. No sorghum entry approached the softness of the tef entry.

The overall desirability score was given by a panel of five adults who normally eat sorghum. The panel gave the best overall desirability score to Awash 1050 and Alemaya 70. Both of these varieties are high-yielding and have been released for the highland sorghum zones. Even though tef is considered as best for *injera* by most Ethiopians, the results of this series of trials bear out that this is apparently true only in traditionally tef-eating areas. The tef variety A53 used here is one of the best varieties and it was scored as only average for overall desirability. Taste has weighed heavily in the overall desirability score of the panel. This is understandable because the taste panel members were all traditional sorghum eaters.

Composite Flours for *Injera*

The most serious reservation by the traditionally tef-eating community in substituting sorghum with tef for *injera* is often linked to the poorer storability of sorghum and the relative brittleness and dryness of its *injera* after storage. To improve this shortcoming of sorghum, many housewives mix the sorghum flours with that of tef or barley. The *injera* made from such a composite flour has much improved softness and pliability compared with sorghum alone. Experiments on such composite flours for the making of *injera* were done at Alemaya. In areas where sorghum and tef production overlap, composite flours are used to extend the tef. On the other hand, where sorghum is the dominant crop of an area, very little composite flour is used for *injera* preparation. In general, in urban areas, composite flours are used more than in rural areas.

The results of these experiments have shown that the keeping qualities and softness of the *injera* are improved a great deal by the addition of 20–50% tef or barley. Even those sorghum varieties with the poorest storability quality have been improved substantially by the addition of tef and barley flours to the sorghum.

In this connection it is worth mentioning that a pulse that is often used in composite flours for *injera* is fenugreek (*Trigonella fenum*). This pulse improves not only the physical characteristics of the *injera* but also its nutrition. The broad area of composite flours for *injera* making has been inadequately investigated. Also, the traditional preparation methods is an area that needs further attention and detailed scientific investigations.

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Kisra Quality: Testing New Sorghum Varieties and Hybrids

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Summary

Kisra, *a thin pancake-like leavened bread made from whole sorghum flour, is the staple diet of most people in the Sudan. Sorghum grain for* kisra *is traditionally cleaned, processed, and ground at home. Repeated grinding using a local grindstone is practiced to produce fine flour. Today most of the sorghum is processed by commercial attrition mills available in most villages and towns. In both local and commercial milling, the resultant flour is not sieved. There is no standard recipe available for* kisra *preparation. A thick paste is prepared by mixing flour with water in varying proportions. The paste is left to ferment for 12–24 hr and thinned to desirable consistency by the addition of more water just before baking. A good quality* kisra *should peel off the baking pan as one piece with no holes, well set, and not scorched. It must also be white, soft, moist, and supple in texture.*

Eleven new sorghum varieties and eight promising experimental hybrids were compared for kisra *making quality with popular local varieties in two separate experiments. A group of five panelists, men and women who regularly consumed* kisra, *served as judges. Results showed that not all cultivars selected on the basis of conventional evident grain quality parameters make good* kisra. *Some sorghum cultivars with pearly, yellow grains were identified for making acceptable* kisra, *but the local sorghums with white chalky pericarp and without subcoat were rated the best by the panelists. There was, however, no significant association between other physical grain properties and* kisra *quality as determined by the panelists. Color and texture of* kisra *stood out as the most important criteria determining quality.*

Kisra is a thin pancake-like leavened bread made from whole sorghum flour. It is the predominant staple diet of most people in the sorghum-growing regions of the Sudan. *Kisra* supplies the main dish in the usual type of Sudanese meal. At its best, it is usually served with stews (*mulah* or *tabbikh*) and other side dishes, or at the simplest level it is served with a relish or sauce or even with just water and condiments (salt and chilies). Typically, *kisra* is served regularly for at least one of the three meals of the day. In rural areas, *kisra* may be substituted by a stiff porridge called *lugma* (asida) as the main dish of any meal, while in urban homes wheat bread is replacing *kisra* to a great deal. Ironically, the price of home-grown sorghum is often higher than imported wheat. In addition, the fast flourishing bakeries are rendering relief for the women thus providing more leisure time or time to take care of other home activities. Nevertheless, random enquiries to urban men indicated that, given the choice, a good *kisra* meal with *mulah* and other associated dishes is still a real treat for all classes of people including various age groups.

Depending on the income of the family, children can start consuming a *kisra* diet as early as 2 years of age. In the absence of other products of choice, children from poor families are of course trained to consume *kisra* earlier than those in well-to-do families. In both cases, however, *kisra* for children is served in a different manner than to adults. Instead of serving stew and other dishes separately to be used for dipping the *kisra*, children are often served with *kisra* broken into pieces and soaked in sauce or simply in water to make a pap called *mos* which is drunk with or without sugar. Then, as children develop the necessary dexterity and learn the etiquettes that go with sharing meals in groups, they join the adults at all meals.

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Grain Processing

Sorghum is marketed down to the retail level and made into flour by the consumer. Traditionally, the grain is processed at home by the family or by hired labor using a local grindstone. However, in view of the steadily increasing number of mills in towns and villages, very little sorghum is processed and milled at home today. Detailed information on home processing of sorghum for *kisra* in typical traditional households is documented by Culwick (1951).

First, the grain is cleaned to remove the earth that comes with it from the storage pits, and the husk. This is typically done by pouring the grain into a wide-mouthed container half-filled with water and, squeezing and rubbing the grain and floating off the chaff. After a brief soaking, the grain is sun-dried for a few hours. Culwick (1951) estimated the husks, mud, and other trash washed out of the grain amounted to about 4% by weight and another 4% of light grain was removed. Furthermore, processing losses of about 12%, not attributable to any particular fraction of the grain, occurred in Culwick's estimation. The finished flour, therefore, represented 80% of the original weight of the grain brought from storage or from the market.

After the grain is thus thoroughly cleaned, it is coarsely ground using local grindstone to make *derish*, which is then finely ground to taste, by repeated grinding (usually three) using the same grindstone. It is preferred that the flour be made as fine as possible. Sieving is not ever made.

Today most of the grain is taken to the now ubiquitous stone mills for grinding. The miller does not take the responsibility to clean the grain. The sample is thrown into the mill in the form brought in by the customer. When samples are brought in from the farm villages, they are usually cleaned properly at home beforehand; whereas urban consumers purchasing grain from the market employ *Fellata* women in the grain markets or at the mills to hand-pick and winnow out loose husks. Sieving is not practiced with flour resulting from mills.

Kisra Preparation

There is no ready-made recipe available for *kisra*. Though the basic equipments necessary are simple and their elaborations very few, detailed procedures do vary slightly from region to region, village to village, and even from household to household within the same village. Many times the same woman is unable to make the same quality of *kisra* from one day to the next, using samples from the same batch of sorghum flour. Several factors including quality of flour, room temperature, quality of starter, conditions of cooking utensils, fermentation time, and heating temperature of the baking sheet (*saj*) all affect the quality of *kisra* produced. With this in mind, the general method of *kisra* preparation utilized by most housewives is as follows:

A thick paste, *ajin*, is prepared by mixing, on an air-dry basis, 60% flour and 40% water (Culwick 1951). The *ajin* is left to stand fermenting for approximately 12–24 hr, by which time it had developed a sour taste. Just before baking, the *ajin* is further diluted to a thin batter by the addition of more water at the rate of 50 cc water to 100 g paste. Again, these proportions are not universal standards. For example, in preparations made at our laboratory the women used a larger quantity of water to make a thin *ajin* and diluted it to batter the next day with less than 1 : 2 proportions (Tables 1 and 2).

An open fire utilizing wood, sorghum stalk, or charcoal is used to heat the baking pan. A sheet of metal (*saj*) or fired clay (*doka*) of variable size is used for baking *kisra*. The baking pan is heated and then rubbed with a damp oily cloth (usually sesame oil is used) before spreading the batter. The oil facilitates smooth and even spreading of the batter, protects against scorching, and helps the *kisra* to peel off in one piece. The baking pan is set on stones in the case of an open fire, or directly on the burning charcoal neatly piled up on the local burner, *mangad*. The woman sitting before the baking pan pours out a small container full of the batter along the length of the hot pan. Then using the indispensable *gargariba* (a dry piece of palm leaf) dipped in water, she swiftly spreads the batter into a very thin layer by using quick, smooth sideways movements. In about 1 min, the *kisra* is done and ready to be peeled off, and the pan is rubbed again with the oily cloth before spreading the next lot of batter.

A good quality *kisra* should peel off the baking pan as a fine smooth wafer (*taraga*) in one piece with no holes; well set but not scorched; and supple, not breaking readily on handling and folding (Culwick 1951). It must be white in color, soft, moist but not spongy in texture. Though most

Table 1. Flour: water proportions, number, and weight of *kisra* produced—Experiment I.

Entry	Wt of flour (g)	Quantity of water (cc)		Wt of *kisra* % of flour	No. of *kisra*
		Initial	At baking		
M62455	600	775	200	139	9.0
M62466	600	775	225	161	9.5
A3638	570	720	230	137	8.3
A5835	570	730	230	136	8.3
Cr.43/36	550	675	250	165	9.0
Cr.54/19	400	500	200	166	6.7
Cr.37/18	400	500	250	158	6.3
Cr.49/15	550	675	250	176	8.5
M62496	575	575	175	160	9.0
A9057	575	575	175	-	7.0
Cr.36/44	550	675	250	164	9.5
Safra	400	500	230	165	6.0
Dabar	450	550	250	178	7.5
Wad Fehal	450	540	200	148	7.3
Tetron	450	550	250	173	7.8
Mean	513	621	224	159	7.9

families prepare enough *kisra* for daily consumption, a good quality *kisra* if covered well should, under local climatic conditions, be soft and moist enough to eat the next day.

Testing New Sorghum Varieties and Hybrids for *Kisra* Quality

Experiment I

Eleven new sorghum varieties and four locals were evaluated for *kisra* quality during the winter of 1979/1980. All of the entries (Table 1) except local entries Safra, Wad Fehal and Tetron were harvested from plots grown under similar conditions on an irrigated farm at the Gezira Research Station, Wad Medani during kharif 1979.

Experiment II

Eight promising experimental hybrids and three local varieties evaluated for *kisra* quality (Tables 2 and 3) during kharif 1981 were from one hybrid yield trial conducted during kharif 1980. Local varieties Dabar and Feterita Ombinin were also harvested from the same season's crop grown at the same farm, while the variety Tetron was a market sample. All samples were stored under similar condition until evaluation for *kisra* started.

Methods

In both these experiments, grain moisture measurements were not taken. However, after samples were kept for 3-7 days under direct sun, it is assumed that the moisture levels on all samples would have been constant. Local varieties Dabar, Tetron (Experiments I and II), and Wad Fehal (Experiment I) were included as checks for their acclaimed popularity as good *kisra* makers, whereas the variety Feterita Ombinin (Experiment II) was said to be known for making poor *kisra*.

Grain samples from all entries were properly cleaned following traditional methods and taken to a nearby commercial stone mill for grinding. Each sample was preceded with one-half kilogram of its own subsample to avoid a mix-up between samples. In both experiments, the details of grain processing, batter preparation, and baking were as described in the text above.

Data on 100-seed weight, corneousness of grain, *kisra* baking ease, acceptability and keeping quality were collected in Experiment I. An attempt was made to sort out preference or acceptability into color, texture, and taste in Experiment II.

Table 2. Flour: water proportions, number, and weight of *kisra* produced—Experiment II.

Entry	Wt of flour (g)	Quantity of water (cc)		Wt of *kisra* % of flour	No. of *kisra*
		Initial	At baking		
Dabar	250	400	150	195	5.0
Tetron	250	400	97	167	4.3
ATX 623 × Su.Cr.54: 18/17	250	400	105	172	4.3
ATX 623 × Karper 1755	250	400	100	181	4.3
ATX 623 × Karper 551	250	400	117	168	4.3
A IS10360 × Su.Cr.36: SC/70	250	400	130	174	4.5
A CK74 × Su.Cr.65: 30/27	250	400	150	176	4.7
A IS10454 × A1700	250	400	140	166	4.0
CSH-5	218	340	142	168	4.0
ATX 623 × Karper 473	250	400	93	176	4.8
Feterita Ombinin	250	400	93	181	4.5
Mean	247	395	120	432	4.4

Table 3. Grain and *kisra* properties of selected experimental hybrids and some local cultivars—Experiment II.

Entry	Grain		*Kisra*				
	100-seed wt (g)	Corneousness score[a]	Baking ease[b]	Color[b]	Texture[b]	Taste[b]	Keeping quality[b]
Dabar	2.97	3.0	2.0	1.5	1.9	2.1	2.1
Tetron	2.89	3.0	1.7	1.3	2.0	2.0	2.2
ATX623 × Su.Cr.54: 18/17	3.25	2.0	3.0	2.9	3.0	2.7	2.8
ATX623 × Karper 1755	2.61	3.0	3.0	3.1	2.6	2.8	3.2
ATX623 × Karper 551	2.92	2.0	3.7	3.3	3.4	3.0	3.3
IS 10360A × Su. Cr. 36: 80/70	2.74	2.0	4.0	3.7	3.4	3.2	2.8
ACK74 × Su.Cr.65: 30/27	2.42	2.0	4.0	3.8	3.4	3.7	3.3
IS10454A × A1700	2.91	2.0	3.7	3.0	3.1	2.9	2.0
CSH-5	3.00	2.0	4.0	2.4	4.0	3.1	3.6
ATX623 × Karper 473	2.75	3.0	1.3	3.4	2.4	2.8	2.7
Feterita Ombinin	2.39	5.0	1.3	4.5	2.8	3.1	3.6

a. 1 = Completely corneous; 5 = completely floury.
b. 1 = Excellent; 5 = very poor.

Corneousness was visually scored by cutting a few seeds into halves with a razor blade and the proportion of vitreous and opaque endosperm scored on a scale of 1 to 5, where 1 = completely corneous and 5 = completely opaque. *Kisra* baking ease was determined by the woman hired for making the *kisra* as she spread the batter on the baking pan. Acceptability, color, texture, taste, and keeping quality were all scored by a panel of five members on a scale of 1 to 5, where 1 = excellent, 2 = very good, 3 = good, 4 = poor, 5 = very poor. Keeping quality was determined by folding two or three *kisra* wafers (*taragat*) wrapped with polyethylene plastic for 24 hr and scored by the same group of panelists on how well the *kisra* remained fresh, moist, and supple. Although different panelists were assembled separately for each experiment, the group included men and women who regularly consume *kisra* in their respective households. In both experiments, four different runs (baking) were made essentially amounting to four replications and the resultant data were then summarized over the four runs and five panelists.

Results and Discussion

Data from Experiment I comparing *kisra* preparation from new sorghum varieties vs local sorghum cultivars are given in Tables 1 and 4. The results of *kisra* testing of agronomically superior sorghum hybrids (Experiment II) are presented in Tables 2 and 3.

A single wafer (*taragat*) of *kisra* from the cultivars tested weighed approximately 100 g, but cultivars seemed to vary in their water-retaining capacity (Tables 1 and 2). Depending on the kind of paste (*ajin*) prepared, the total weight of *kisra* produced from a sample of flour is roughly equal to that of the weight of flour plus water at initial mixing (Culwick 1951) or water added at baking (Tables 1 and 2). Therefore, in addition to the quality of *kisra* they make, cultivars tend to differ in quantity of product they make as well.

Murty and House (1980) compared physical properties of sorghum grain with *kisra* quality and acceptability in the 1979 International Sorghum Food Quality Trial and showed good association between soft endosperm texture and good quality *kisra*. The list of cultivars tested in both Experiments I and II did not include a wide range of variability for physical properties of grain, as the main purpose of the experiments was to evaluate promising varieties and hybrids for their *kisra*-making quality and not so much to identify the parameters associated with good or poor *kisra*. Therefore, the grain properties (100-seed weight and corneousness score) in the cultivars that we evaluated do not seem to have any significant association with *kisra* properties judged by our panelists. On the other hand, even within the narrow range of germplasm tested, corneousness scores appear to have a negative association with housewives' preference (baking ease). Cultivars with highly vitreous grains were consistently rated as below average for baking ease while those with less vitreous or opaque endosperms were rated as

Table 4. Grain and *kisra* properties of selected sorghum varieties—Experiment I.

	Grain		Kisra		
Entry	100-seed weight (g)	Corneousness score[a]	Baking ease[b]	Accepta-bility[b]	Keeping quality[b]
M 62455	2.37	3	2.0	3.0	2.5
M62466	2.89	3	3.0	3.3	3.2
A3638	2.49	2	4.3	4.4	4.0
A5835	2.76	2	4.0	4.3	5.0
Cr.43/36	2.00	3	2.5	3.2	4.0
Cr.54/19	2.11	3	1.3	1.9	1.3
Cr.37/18	2.50	3	3.0	2.8	2.7
Cr. 49/15	2.61	3	1.0	2.5	1.0
M62496	2.18	2	2.0	2.8	3.0
A9057	2.17	2	4.0	4.7	4.0
Cr.36/44	2.16	2	3.0	3.3	2.0
Safra	4.00	3	2.3	3.0	3.0
Dabar	3.0	3	1.8	2.3	3.2
Wad Fehal	4.18	3	1.8	1.9	1.5
Tetron	2.71	3	1.3	1.8	1.3

a. 1 = Completely corneous; 5 = completely floury.
b. 1 = Excellent; 5 = very poor.

above average (Tables 4 and 3). In fact we found that the baker's remarks at the time of baking was a reliable and predictive judgment corresponding very closely with general acceptability of the *kisra* (Table 4) or with one or the other good *kisra* determining traits, i.e., color, texture, taste, or keeping quality (Table 3).

Color and texture of *kisra* stand out as the most important criteria determining acceptability. A good quality *kisra* must be white in color, soft, moist, and supple in texture. Sorghum cultivars with pearly, yellow grains did make good acceptable *kisra* but the local sorghums with white chalky grains without a subcoat (Tetron, Dabar, and Wad Fehal) were rated the best. It was interesting that the local variety, Feterita Ombinin (chalky white with subcoat) that was included as a "bad" check was not detected as poor by the panelists except for color and keeping quality. Surprisingly it was actually scored favorably high on the most critical criterion of baking ease (Table 3).

Keeping quality (how well *kisra* remains fresh, moist, and supple for at least overnight) is an important criterion. However, since most families prepare *kisra* for each day, a high-yielding sorghum cultivar should not be rejected if it rates well on color and texture. Taste of *kisra* was understandably the most difficult trait for the panelists to judge. As a fermented product, *kisra* taste and flavor are bound to be detectably affected by outside agents more than the inherent nature of the grain. Hence unless otherwise contaminated, *kisra* from various grains will maintain a similar kind of taste, flavor, and aroma that would be difficult to differentiate by panelists.

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Sorghum *Roti*: I. Traditional Methods of Consumption and Standard Procedures for Evaluation

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Summary

Roti *(an unleavened bread) is the most popular sorghum food consumed in India. The traditional methods of milling, dough and* roti *preparation are described in detail. Standard procedures for the dough and* roti *evaluation evolved at ICRISAT are outlined.*

Sorghum (*Sorghum bicolor* L. Moench) is one of the major coarse grains used for human consumption in the semi-arid tropics and is the staple diet for millions of people, providing the bulk of the calories, proteins, vitamins, and minerals. In India, it is consumed in several forms like *roti* (Hindi—an unleavened bread), *chorru* (Tamil) or *annam* (Tamil, Telugu—boiled grain), *sankati* (Telugu) or *mudde* (Kannada—thick porridge), and *kanji* (Tamil, Telugu—thin porridge) (Ayyer 1944; Rachie 1963; Subramanian and Jambunathan 1980).

A consumer survey of sorghum grain utilization methods was conducted in 171 villages of India belonging to seven states (Subramanian and Jambunathan 1980) and the information compiled for *roti* are reviewed in this paper along with those reported by others. In the central parts of India, which account for most of the sorghum production, *roti* is the most popular sorghum food. It is consumed in rural as well as urban areas; it is served in middle-class hotels of some of the towns. Although precise statistics are not available, on the basis of sorghum grain production figures published by the Government of India (1980) and the dietary habits of the people in various regions, we estimate that approximately 70% of the sorghum produced in India is consumed in the form of *roti*. However, in the state of Maharashtra, more than 95% of the sorghum produced is consumed as *roti*. In the states of Gujarat, Rajasthan, and Madhya Pradesh, *roti* is by far the most important sorghum food product. In Karnataka and Andhra Pradesh, sorghum *roti* is a major portion of the diet for a large segment of the population living in the dry tracts.

Sorghum *roti* is known by various names in the different languages of India: *chapati* (Hindi), *bhakri* (Marathi), *rotla* (Gujarati), *rotte* (Telugu), etc. *Roti* is consumed by children from the age of 2 years as well as adults (Subramanian and Jambunathan 1980). It is eaten at breakfast, lunch, and supper and is frequently stored overnight. Farmers generally carry *rotis* prepared early in the morning to the fields for lunch. *Rotis* are generally stacked in a pile wrapped in cloth and stored in perforated baskets. Occasionally, they are sun-dried and stored for more than a week.

Roti is consumed with several side dishes depending upon the socioeconomic status of the consumer, e.g., cooked vegetables, *dhal*, meat, milk, curd, buttermilk, pickles, *chutneys*, sauce, etc. (Subramanian and Jambunathan 1980). *Rotis* are softened with milk or buttermilk before feeding to old people and children.

Swaminathan et al. (1976) and Pushpamma and Geervani (1981) reported the nutrient composition of sorghum. The average nutrient composition of sorghum *roti* is given in Table 1. Pushpamma and Geervani (1981) have reported the vitamin B losses during the process of *roti* preparation.

Consumers prefer white/pale yellow colored, dense and round grains, free from colored spots for *roti* preparation (Murty et al. 1979). Grains of the traditionally grown cultivars *Maldandi* and *Dagdi*

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Table 1. Nutrient composition of sorghum *roti* (per 100 g)

Calories	292
Protein (g)	8.0
Fat (g)	1.2
Carbohydrate (g)	61.8
Ash (g)	2.3
Fiber (g)	2.9
Calcium (mg)	67.8
Iron (mg)	5.3
Thiamine (mg)	0.17
Riboflavin (mg)	0.16
Niacin (mg)	0.80

SOURCE: Pusphamma and Geervani 1981.

are popular and fetch the maximum price in the market.

Domestic Methods of *Roti* Preparation

Milling

Until a few decades ago, whole sorghum was ground to a moderately fine flour in hand-operated rotary stone mills. During the last few decades, about 90% of the milling has been done by small electrical or diesel-operated disc or plate mills (*chakki*) that mill small quantities of grain for consumers (Subramanian and Jambunathan 1980). Generally, enough grain to last the family for a week is milled each time. Usually, flour is not stored more than a week. The flour is sifted through a sieve comparable to U.S. standard 20 mesh and the overs comprising mostly bran and coarse particles are fed to animals. Usually 95-99% extraction is obtained. In some places the flour is used as such without sifting for dough preparation. Particle size distribution of the flour from grain samples of five cultivars ground in four village mills is given in Table 2. The particle size of the flour varies depending upon the mill, grinding pressure, grain sample, etc.

Dough Preparation

Housewives generally use the following procedure for *roti* preparation: Approximately 50 g flour are mixed with 50 ml of warm water in increments and is kneaded by hand on a smooth wooden board (5–7 cm high) into a dough (Subramanian and Jambunathan 1980). As the dough attains proper consistency, it is made into a 6-cm diameter ball and pressed by hand into the form of a circular disc. The disc is placed on the wooden board and flattened by fast and deft hand strokes into a thin circle. Small quantities of dry flour are used as dusting flour to eliminate stickiness during handling. *Roti* size varies from 12 to 25 cm in diameter and 1.3–3.0 mm in thickness depending upon the region. In the villages, farm workers prefer thick *rotis* since they lose moisture slowly and can be stored longer. A creamy white, sticky dough with a characteristic sorghum aroma is preferred.

Sorghum flour is made into a dough occasionally by substituting sugarcane juice, jaggery (a kind of brown sugar) water, milk, etc. for water (Subramanian and Jambunathan 1980). Sometimes finely sliced vegetables, spices, salt, etc., are mixed into the *roti* dough. Sorghum flour is also mixed with that of other grains like green gram, chickpea, and wheat in different proportions. When the dough is made by mixing sorghum with other grains and vegetables, the *rotis* are called by various colloquial names. In some restaurants, small quantities of dough are stored overnight in water and used the next day in small bits to mix with fresh flour to make dough.

Baking

Baking methods vary with the socioeconomic status of the family. In the villages, normally, three stones are arranged in a triangular form and an iron or earthen pan is placed on the stones. The fire is manipulated to give enough heat to the pan (Subramanian and Jambunathan 1980). Permanent hearths made out of mud into semicylindrical structures are also used. Baking temperatures are usually around 300–325° C. The *roti* is placed on the hot pan. Small quantities of water are sprinkled on top of the *roti*. Alternatively, the *roti* is moistened with a wet cloth. When the underside is cooked (normally in 30–40 sec) the *roti* is turned over. The *roti* is removed from the pan after a minute and is placed near the fire, with the unmoistened side exposed to limited heat from the fire that completely puffs the *roti*. In urban and semiurban areas, coal and gas stoves and electric grills are used for baking *rotis*.

Table 2. Particle size distribution of sorghum flour obtained from four Indian village mills.[a]

Cultivar	Percent flour retained on the sieve (U.S. mesh)					100 through
	20	45	60	80	100	
Village Mill-I						
M35-1	0.4	13.1	18.7	14.6	6.6	46.0
CSH-8	0.6	10.0	12.6	12.4	8.5	55.2
Village Mill-II						
Market Sample-1	1:3	6.1	29.8	28.7	16.3	17.4
Market Sample-2	0.4	4.4	24.9	27.7	19.6	21.3
Village Mill-III						
M35-1	0.10	6.20	17.48	17.25	8.82	49.78
	0.12	6.18	16.56	17.00	7.90	50.80
Mean	0.11	6.19	17.02	17.13	8.36	50.29
SPV-354	0.12	5.64	14.93	18.83	9.90	50.59
	0.15	5.47	15.28	17.15	10.82	51.08
Mean	0.14	5.56	15.11	17.99	10.36	50.84
Village Mill-IV						
M35-1	0.12	5.10	18.28	16.80	10.70	48.39
	0.10	4.74	18.00	17.62	9.30	50.10
Mean	0.11	4.92	18.14	17.21	10.0	49.23
SPV-354	0.11	4.70	16.37	15.94	11.70	50.70
	0.10	4.96	15.90	16.25	11.52	50.96
Mean	0.10	4.83	16.14	16.10	11.61	50.83

a. Observations recorded on village mills I and II were based on one sample whereas those on village mills III and IV were based on two samples.

Standard Laboratory Procedures

As mentioned earlier, there are several variations in the domestic methods of *roti* preparation. In order to evaluate *roti* quality of grain samples in the laboratory, *roti* preparation methods were optimized so that they would simulate the domestic methods to the extent possible and yet were controlled enough to reveal significant differences between samples for dough and *roti* quality.

Evaluation of Grain, Dough, and *roti* Characters

The following standard procedures and rating scales were used at ICRISAT to evaluate grain samples for *roti* quality.

1. Grain samples were dried to a moisture level around 10%. In addition to the dough and *roti* characters, it was found useful to record some physical properties of the grain sample including endosperm texture, (on a scale of 1 to 5, where 1 = 100% corneous), color, density (by water displacement), breaking strength (using KIYA Hardness tester), 100-grain weight, and percentage water absorption of grain after 5 hr of soaking in water.

2. Grain, dough, and *roti* colors were compared with Munsell soil color charts and the matching Hue, Value, and Chroma notations were recorded. Rooney et al. (1980) have used a Hunter Laboratory Color Difference Meter for measuring *tortilla* colors and the device could be useful for distinguishing *roti* colors.

3. All grain samples (300 g) were ground with a Milcent (Size 2) Domestic electric flour mill equipped with two vertically placed carborundum grinding stones. A standard grinding-pressure adjustment suitable to grind samples of M35-1 grain was used for all test samples. Small samples of grains were ground with a Udy cyclone mill. The flour was sifted using a U.S. standard 35 mesh

sieve and the throughs were collected to prepare *roti*.

4. A flour sample of 30 g was taken and kneaded into a dough using 25–30 ml water in small increments. The volume of water required to make a dough of satisfactory consistency (subjectively judged) with 30 g flour was recorded.

5. The kneading quality or stickiness of the dough was scored subjectively on a scale of 1 to 3, where 1 = good, 2 = average, and 3 = poor.

6. The dough sample was pressed by hands into a thick disc and rolled to a uniform thickness of 1.7 mm on a smooth laminated board with raised edges using a wooden rolling pin. Four to five g of dry flour was used to prevent the dough from sticking to the board or the pin. The flattened dough was cut into a 17-cm diameter *roti* with a circular die.

7. The rolling quality of the dough was evaluated by using another flour sample and measuring the diameter of the *roti* obtained by continuous rolling with a pin until the *roti* breaks.

8. *Rotis* were baked on an Indoleum pan heated by an electric hot plate and the temperature of the baking pan was maintained at 290–320° C with the help of a dial thermometer. Flattened dough discs of 17-cm diameter were placed on the hot pan. They were sprayed with 1–2 ml of water. *Roti* was turned after 30 sec and again after 1.5 min. The *roti* was removed after it was satisfactorily cooked and puffed showing two separate layers.

9. For routine samples, *rotis* were evaluated by the research technician in the laboratory. Selected samples were evaluated later by a trained taste panel. Keeping quality of the *rotis* was scored for two rotis for each test sample after 5 hr of storage at room temperature in perforated plastic trays. A *roti* was folded around a dowel stick (10 × 2 cm) and the extent of resistance to breakage was observed and scored on a scale of 1 to 5. *Rotis* with good keeping quality could be folded around the stick without any breakage. Storing *rotis* in a Percival Incubator at 30° C and 20% RH for 2 hr followed by rating for keeping quality was a satisfactory test.

Evaluation of Organoleptic Qualities

We found that a trained taste panel could evaluate the organoleptic quality of *rotis* more efficiently than randomly picked tasters. Initially, 20 traditional sorghum consumers were selected for taste panel studies and triangular taste trials were conducted with their help following the methods suggested by Larmond (1977). Each panelist was given three *rotis*, two from the same grain sample and the third from a different one. The panelists were asked to identify the odd sample. Six panelists, who identified the odd samples consistently, were trained further and were used to evaluate the test material. A good *roti* should be smooth, soft, and slightly sweet with a characteristic sorghum aroma (Murty et al. 1979). The trained panelists were asked to evaluate taste, texture, aroma, and overall acceptability of the *rotis*. Sample *rotis* from five cultivars were given to the taste panelists along with that of a blind check. Each day five to six panelists participated in the tests. Finally an average of the scores obtained from the panelists was considered for the evaluation of each individual test entry. Selected samples were replicated over 3 different weeks. The following scales were used for the various organoleptic parameters.

Taste: 1-good; 2-fair; 3-average; 4-bad; and 5-very bad.

Texture: 1-very soft; 2-soft; 3-average; 4-hard; and 5-very hard.

Aroma: 1-pleasant; 2-moderate; and 3-unpleasant.

Keeping quality: 1-good; 2-fair; 3-average; 4-bad; and 5-very bad.

The texture of *roti* could also be evaluated by using an Instron Tester to measure the force required to deform a *roti* and calculate the strain, stress, and modulus of elasticity, which reflect the softness and elastic nature of the *roti* (Waniska 1976).

Dough and *roti* quality characters of 15 sorghum cultivars evaluated using the standard procedures outlined here are presented in Table 3. These procedures were also used to screen a large number of breeding progenies followed by a trained taste panel evaluation of selected lines (Murty et al. 1981). However, more basic studies on the dough and *roti* properties of sorghum might lead to the development of rapid screening procedures useful to breeders. There is a need to develop simple, economic and reliable equipment to measure the textural properties of dough and *roti*.

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Table 3. Grain, dough, and *roti* quality[a] characteristics of 15 sorghum cultivars.[b]

Cultivar	Grain					Dough			Roti				
	Color[c]	Corn-eous-ness	Weight (g/100)	Breaking strength (kg)	Water Absorp-tion (%)	Water required (ml)	Kneading quality	Rolling quality (cm)	Color[c]	Taste	Tex-ture	Aroma	Keeping quality
M35-1	5Y 8/4	3	4.24	7.7	18.1	26.1	1.0	23.7	5Y 8/4	1.3	1.5	1.0	1.5
CSH-8	5Y 8/4	3	4.05	6.5	26.4	25.6	1.0	23.0	2.5Y 8/2	2.0	2.0	1.8	2.0
CSH-6	2.5Y 8/4	2	3.67	9.7	20.7	26.5	1.0	22.0	5Y 8/2	1.7	2.0	1.2	2.7
CSV-5	5Y 7/4	3	3.06	7.6	23.8	25.1	1.5	20.5	5Y 7/4	2.0	2.6	1.6	3.5
BG-30	2.5Y 6/4	3	5.16	7.0	32.4	25.2	1.5	21.3	5Y 7/4	2.9	2.8	2.5	3.5
IS-7943	2.5Y 7/6	3	5.64	9.6	37.0	26.1	1.0	22.8	5Y 7/3	3.0	1.8	1.5	3.2
CK60B	2.5Y 8/2	3	3.16	7.0	20.9	28.0	1.5	20.5	2.5Y 7/2	2.4	2.1	1.8	3.0
T-SS-47	2.5Y 6/6	3	4.02	8.6	23.8	28.3	2.0	20.3	5Y 7/4	2.3	2.2	1.4	4.1
IS-12611	5Y 8/2	2	4.64	11.0	22.7	30.9	1.0	22.2	5Y 8/2	1.6	1.5	1.2	3.0
P721	5Y 8/2	5	2.51	6.8	32.7	25.7	3.0	18.1	2.5Y 7/2	3.7	3.3	2.7	4.0
IS-1098	2.5Y 7/6	4	3.15	6.0	37.5	24.3	1.5	20.7	2.5Y 7/2	2.5	3.2	1.5	2.5
M36082	5Y 8/2	1	2.61	10.0	22.7	30.3	1.0	22.8	5Y 8/4	1.4	2.0	1.0	3.0
IS-2328	5Y 8/4	2	3.12	12.4	29.0	26.1	1.2	22.6	5Y 8/4	2.2	2.7	1.7	3.7
PJ33K	2.5Y 8/4	3	5.01	8.8	25.1	27.1	1.0	22.2	2.5Y 8/2	2.2	1.9	1.4	2.7
IS-11024	5Y 8/6	3	7.63	11.0	28.9	24.4	1.0	22.6	5Y 7/2	2.4	2.4	1.5	3.5

a. Methods and rating scales as menti^ned in the text.
b. Grain samples were obtained from postrainy season harvest of 1978, ICRISAT Center.
c. All color grades belong to white and yellow shades of Munsell.

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Sorghum *Roti*: II. Genotypic and Environmental Variation for *Roti* Quality Parameters

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Summary

Grain, flour, dough, and roti *quality characters of a large number of sorghum cultivars were evaluated in the laboratory by using standard methods.* Roti *quality of 422 genotypes of different pericarp colors and endosperm texture were evaluated with the help of a trained taste panel. The range of variation for the various quality parameters under study was broad even among cultivars with pearly white grains. Pericarp color, endosperm type, and endosperm texture had significant effects on* roti *quality. Corneous grains, in general, exhibited more density and breaking strength, lower percent water absorption, and better dough and* roti *quality.*

Significant effects for season, year, and genotype × year interaction were recorded for grain, dough, and roti *quality parameters. The effect of the nitrogen fertility level on* roti *quality was insignificant. However, a considerable effect of soil moisture stress on dough characters was noticed. Wet weather leading to grain deterioration caused the most significant effect on* roti *quality.*

The flour particle size index (PSI) varied among cultivars and was associated with endosperm texture. Grinding methods were found to have a profound effect on flour properties.

Correlation coefficients between the grain, dough, and roti *quality characters of 167 cultivars with pearly white grains were studied. None of the characters was strongly enough correlated with* roti *quality to be used as an indirect assessment, although several of them were statistically significant. Good* roti *producing grain types exhibited, on the average, a colorless thin pericarp, 60–70% corneous endosperm, less than 24% water absorption of grain, and flour PSI around 65. Grains with 100% corneous endosperm produced* rotis *with a hard texture and unsatisfactory keeping quality, while floury grain types produced a poor dough and* rotis *with poor flavor and keeping quality. The implication of these results in breeding programs involved in improving* roti *quality are discussed.*

Sorghum (*Sorghum bicolor* L. Moench) production in India has increased steadily in the last decade, particularly in the state of Maharashtra. Much of this increase has been attributed to the adoption of improved cultivars and cultural practices by the farmers (Government of India 1969, 1980). However, market surveys carried out by ICRISAT economists point out that prices of improved cultivars/hybrids were significantly lower than the traditionally grown cultivars (Parthasarathy and Ghodake 1981). Rao et al. (1964), Madhava Rao (1965), and Ananthararaman (1968) found that the dough and *roti* qualities of the high-yielding hybrids were much inferior to those of the local cultivars. Viraktamath et al. (1972) and Desikachar (1977) reported varietal differences for culinary quality in sorghum, which showed that traditionally grown cultivars possessed relatively superior culinary properties over recently developed cultivars.

Information is scanty on the extent of genetic variation for *roti* quality attributes in sorghum. Breeders have been empirically selecting pearly white or yellow bold grain types. However, experience has shown that all the white/yellow

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grains do not produce equally good *rotis*. Anantharaman (1968) observed considerable variation for *roti* quality among 27 hybrids with pearly white grains. Waniska (1976) studied the dough and *roti* properties of some nonwaxy cultivars and found significant differences associated with endosperm texture of the grain.

A series of sorghum *roti* quality tests were conducted at ICRISAT with the objective of obtaining precise and detailed information on:

1. The genotypic differences between cultivars with pearly white grains for various quality attributes of the grain, flour, dough, and *roti*.
2. The effects of environmental factors like crop season, soil fertility, and moisture on the grain and consequently on the *roti* quality attributes.
3. The properties of the grain and flour that affect *roti* quality and that could be used for an indirect assessment of *roti* quality.

The experiments were aimed to obtain information that could contribute to a rational basis for the establishment of suitable quality-testing procedures to be applied in sorghum improvement programs.

Methods Used for *Roti* Evaluation

The methods followed for the preparation and evaluation of *rotis* were generally the same as those described by Murty and Subramanian (1981) for use in laboratories. Grain and *roti* colors were compared with Munsell Soil Color Charts (1975) and the Hue, Value and Chroma of matching shades were recorded. Grain samples were ground with a Milcent (Size 2) Domestic electric flour mill equipped with two circular carborundum grinding stones (50-cm diameter × 6 cm). A standard pressure adjustment suitable to grind grain samples of Indian sorghum cultivar M35-1 was used for all test samples. The following characters of the grain, flour, dough, and *roti* were recorded for the test entries (Murty and Subramanian, 1981):

Grain:
- (a) Color
- (b) Weight (g/100)
- (c) Density of grain (weight/volume) by water displacement method
- (d) Endosperm texture score on a scale of 1 to 5 (1 = 0-20% floury, 5 = 81-100% floury)
- (e) Breaking strength (kg) with a Kiya Hardness Tester
- (f) Percent water absorption of the grain after soaking in water for 5 hr at room temperature

Flour:
- (a) Flour particle size index (PSI) (Waniska 1976).

Dough:
- (a) Water required (ml) to make dough from 30 g flour
- (b) Kneading quality score (1 to 3)
- (c) Rolling quality (diameter in cm)

Roti:
- (a) Color
- (b) Taste
- (c) Texture
- (d) Aroma
- (e) Keeping quality

Organoleptic qualities of *rotis* from samples of a preliminary or routine nature were scored in the laboratory by a research technician. *Rotis* from selected samples were evaluated by a trained taste panel of five members. *Rotis* made from the grain samples of either the most preferred cultivar, M35-1, or the commercial hybrids i.e., CSH-5 and CSH-6 were included as blind checks. *Roti* taste, texture, and keeping quality were scored on a scale of 1 to 5 (1 = good) while kneading quality of the dough and *roti* aroma were scored on a scale of 1 to 3 (1 = good). Keeping quality of the *rotis* was scored by the technician after 5 hr storage at room temperature.

Genetic Variability for Grain, Dough, and *Roti* Quality Characters

Approximately 4000 grain samples belonging to accessions from the World Collection and breeding lines in F_5 and F_6 generations, were evaluated in the laboratory for the various grain, dough, and *roti* quality characters. These studies indicated a broad range of variability for the various characters studied. A selected set of 422 genotypes of diverse origin and grain color were evaluated with the aid of the trained taste panel, and replicated observations were made for each quality parameter under study. The range and mean for 12 of the characters studied are presented in Table 1. They reflect a broad range of variation for all the characters observed, except grain density. Physical characters of the grain—endosperm texture, breaking strength, and percent water absorption—showed a broad variation. The dough quality characters—water required for dough, kneading quality score, and rolling quality—showed a moderate variation. The range of the organoleptic quality scores was also wide and varied from 1 to 5.

The color of the *roti* could bias the panelist during the organoleptic evaluation in favor of a lighter colored product. *Roti* color, aroma, and taste were often affected by pigmentation on the pericarp (Table 2). White grains with dark-colored spots on the pericarp produced dark-colored dough and *rotis*. Brown grains and white grains with a subcoat produced *rotis* with a dark color and were bitter in taste. The range of variation for *roti* quality parameters among visually similar and good grain types is of more significance, since pigmentation on the grain is controlled by major genes (Rooney et al. 1980) and

Table 1. Variability for grain, dough, and *roti* quality attributes in sorghum.

Attribute	Mean ± SE	Range	
		Maximum	Minimum
Grain:			
Endosperm texture	2.5 ± 0.03[a] (2.5 0.05)[b]	5.0 (4.0)	1.0 (1.0)
Grain weight (g/100)	3.49 ± 0.043 (3.43 0.048)	7.63 (5.27)	2.04 (2.04)
Breaking strength (kg)	8.4 ± 0.09 (8.9 0.15)	14.6 (14.6)	0.8 (5.5)
Density	1.26 ± 0.002 (1.23 0.002)	1.38 (1.32)	1.002 (1.119)
Water absorption (%)	25.3 ± 0.23 (26.3 0.38)	43.1 (42.1)	12.4 (14.4)
Dough:			
Water for dough (ml)	27.9 ± 0.12 (27.2 0.17)	38.9 (37.5)	20.9 (20.9)
Kneading quality	1.2 ± 0.02 (1.1 0.02)	3.0 (3.0)	0.5 (0.5)
Rolling quality (cm)	22.0 ± 0.06 (22.3 0.08)	27.8 (25.4)	15.2 (16.2)
Roti:			
Taste	2.3 ± 0.03 (2.0 0.04)	5.0 (3.5)	1.0 (1.0)
Texture	2.2 ± 0.02 (2.2 0.04)	4.5 (4.0)	1.0 (1.0)
Aroma	1.4 ± 0.02 (1.4 0.03)	3.0 (3.0)	1.0 (1.0)
Keeping quality	2.8 ± 0.03 (2.6 0.04)	5.0 (4.5)	1.0 (1.0)

a. Values obtained from observations on 422 genotypes with various kernel colors.
b. Values in parentheses were obtained from observations on a subset of 167 genotypes with pearly white kernels.

Table 2. Mean properties of grain, dough, and *roti* quality characteristics of 25 sorghum cultivars grown in the postrainy season at ICRISAT Center over 2 years, 1979 and 1980.

		Grain				Dough			Roti					
Genotype	Color[a]	Corneous-ness	Weight (g/100)	Breaking strength (kg)	Water absorp-tion (%)	Water required (ml)	Kneading quality	Rolling/ spreading (cm)	Color[a]	Taste	Texture	Aroma	Keeping quality	PSI[b]
M35-1	P. yellow	3.5	3.80	7.4	17.8	26.2	1.1	22.3	White	1.6	2.1	1.4	2.0	61.9[c]
CSH-5	P. yellow	2.0	2.35	7.4	20.1	26.6	2.1	22.4	White	1.8	2.0	1.2	2.3	65.8
M50009	P. yellow	2.0	2.79	8.2	25.5	27.6	1.2	21.9	P. yellow	2.2	2.4	1.4	2.5	74.2
M50013	P. yellow	2.0	2.79	9.1	26.6	27.1	1.2	21.5	White	2.1	2.3	1.4	2.4	75.3
M35052	P. yellow	2.0	2.59	7.4	27.1	26.1	1.2	22.6	P. yellow	1.9	2.2	1.3	3.0	69.8
M50297	P. yellow	2.0	3.14	9.5	23.9	28.7	1.2	21.9	P yellow	2.0	2.2	1.3	2.7	71.2
P721	White	5.0	2.39	6.5	32.9	28.6	3.0	17.0	P. olive	2.9	3.1	2.1	3.9	51.6[c]
CO-4	Red	3.0	2.96	6.6	23.2	25.6	1.2	22.5	L. yellow brown	2.7	2.5	1.8	3.3	50.6
P. Jonna	Yellow	3.0	3.33	7.1	22.7	25.4	1.3	22.6	Olive yellow	3.4	2.5	2.2	3.4	69.4[c]
Mothi	P. yellow	2.0	3.18	9.6	22.8	28.8	1.2	23.0	P. yellow	1.7	2.2	1.5	2.8	72.7[c]
E35-1	White	1.0	3.57	14.4	23.1	23.2	1.0	23.4	White	1.8	2.2	1.4	2.8	73.4
IS-158	White	Waxy	3.29	6.5	21.9	22.8	0.5	25.5	P. yellow	3.3	1.4	2.1	3.7	61.6
WS-1297	L. gray (testa)	4.5	3.89	6.5	27.1	27.6	1.8	21.6	Weak red	3.3	2.5	2.4	3.5	37.7
Swarna	P. yellow	2.0	3.85	8.7	22.6	27.1	1.0	22.9	White	1.9	2.2	1.3	2.6	47.6
S-29	White	1.5	2.64	8.1	23.2	26.4	1.0	23.1	White	1.7	2.5	1.4	3.2	81.4[c]
S-13	P. yellow	1.0	2.35	10.2	26.3	27.9	1.0	23.1	P. yellow	2.1	2.4	1.2	3.1	80.5[c]
IS-2317	L. Gray (testa)	3.0	3.60	9.0	30.5	28.0	1.0	22.7	G. brown	3.1	2.7	2.4	3.4	74.1[c]
IS-7035	White (testa)	3.0	3.14	6.7	26.6	28.3	1.3	22.0	Weak red	3.2	2.8	2.5	3.4	64.1
IS-7055	R. brown (testa)	3.5	2.99	7.3	35.3	29.6	2.5	19.1	R. brown	3.4	2.9	2.4	3.1	75.0
IS-9985	Yellow (testa)	3.5	6.65	9.9	22.1	29.8	1.7	21.2	White	2.5	2.4	1.9	2.6	71.3[c]
IS-8743	Dark yellowish brown (testa)	3.0	2.80	7.0	25.3	27.4	1.2	22.3	R. brown	3.2	2.9	2.4	3.1	70.4
Dobbs	P. yellow	4.0	2.43	9.8	41.7	32.8	3.0	17.6	R. brown	3.7	3.3	2.7	3.9	62.2
CS-3541	P. yellow	2.0	2.82	8.6	25.9	29.1	1.3	21.7	P. yellow	2.0	2.6	1.4	3.2	81.7[c]
Segaolane	P. yellow	2.0	2.76	6.8	20.6	26.3	1.1	23.0	White	1.9	2.2	1.3	3.1	70.6
Market-1	White	1.0	2.78	8.8	21.3	26.2	1.1	22.9	White	2.2	2.5	1.4	3.0	81.1[c]
CD 5%		0.0	0.14	0.7	1.7	1.4	0.2	0.80		0.3	0.3	0.2	0.4	3.7

a. Color comparisons were made with Munsell's soil color charts (1975): P = Pale; L = Light; G = Gray; R = Red.

b. PSI = Flour particle size index.

c. Values are based on 1-year observations.

can be manipulated through breeding techniques with relative ease. Therefore, data from a subset of 167 genotypes with white, creamy white, and pale yellow grains were separately examined from that of the whole set of 422 genotypes (Table 1). The range of variation observed for the various quality parameters within the pearly white grain group was as broad as that present in the whole set (422) of material studied. This observation confirms the scope for selection and improvement through breeding in the pearly white group.

In addition to the pericarp color and pigmentation, endosperm texture of the grain had a bearing on *roti* quality. The 422 genotypes were grouped under five endosperm texture classes, and the mean values of the quality characters of these five groups were examined (Table 3). The mean properties of corneous grains showed that, in general, their density and breaking strength were higher, percentage water absorption was lower, and dough and *roti* quality were scored better than that of floury grains. Waxy grains produced excellent dough, but *rotis* of poor quality.

Variation for *Roti* Quality in the ISFQT

A set of 25 genotypes with different kernel colors and endosperm textures was chosen as common test material for the 1979 and 1980 International Sorghum Food Quality Trials (ISFQT). They were evaluated for various *roti* quality parameters with the aid of the trained taste panel. The cultivars were tested for two consecutive years using harvests from April 1979 and April 1980, and for each of the years the cultivars were evaluated in a randomized and replicated design over two to three different weeks. Due to restricted quantities of grain, PSI was evaluated for only some genotypes. Twenty cultivars could be evaluated in two replications for the two consecutive years. Mean observations over years and weeks for each of the quality parameters studied are presented in Table 2. An analysis of variance of the data for 1979 and 1980 indicated highly significant variation between cultivars for all the quality parameters (Tables 4a and 4b). The coefficients of variation were all under acceptable limits, although they were relatively high for *roti* texture and keeping quality. Variation due to years was statistically significant for 100-grain weight, grain breaking

Table 3. Quality properties associated with endosperm texture of the 422 sorghum cultivars.

Character	80–100% corneous (17)[a]	60–80% corneous (213)	40–60% corneous (165)	20–40% corneous (23)	0–20% corneous (4)
Grain weight (g 100)	3.12 ±0.206	3.28 ±0.041	3.67 ±0.074	4.44 ±0.314	2.92 ±0.304
Breaking strength (kg)	9.7 ±0.51	9.1 ±0.12	7.8 ±0.12	7.0 ±0.27	4.7 ±1.17
Grain density	1.24 ±0.008	1.24 ±0.001	1.23 ±0.002	1.2 ±0.008	1.1 ±0.035
Water absorption (%)	23.6 ±0.73	25.1 ±0.27	25.2 ±0.40	28.3 ±1.52	28.0 ±2.70
Water for dough (ml)	27.8 ±0.59	28.1 ±0.15	27.7 ±0.20	27.6 ±0.62	26.5 ±0.33
Kneading quality[b]	1.0 ±0.00	1.2 ±0.02	1.1 ±0.03	1.6 ±0.15	2.6 ±0.21
Rolling quality (cm)	22.6 ±0.19	22.0 ±0.08	22.2 ±0.10	21.0 ±0.41	18.5 ±1.36
Roti taste[b]	2.2 ±0.18	2.0 ±0.03	2.4 ±0.05	3.2 ±0.17	3.8 ±0.27
Roti texture[b]	2.2 ±0.11	2.1 ±0.03	2.2 ±0.04	2.8 ±0.13	3.0 ±0.24
Roti aroma[b]	1.2 ±0.05	1.3 ±0.02	1.6 ±0.0[illegible]	2.0 ±0.13	2.5 ±0.18
Roti keeping quality[b]	2.7 ±0.11	2.8 ±0.04	2.8 ±0.05	3.1 ±0.16	3.8 ±0.38

a. Numbers in parentheses indicate the number of genotypes evaluated in the endosperm texture group.
b. Kneading quality of the dough and *roti* aroma were evaluated on a scale of 1 to 3, while *roti* taste, texture, and keeping quality were evaluated on a scale of 1 to 5 (1 = good).

Table 4a. Analysis of variance (mean sums of squares) for various *roti* quality parameters in randomized block experiments replicated over 3 weeks with the aid of a trained taste panel of five members, 1979.

Source of variation	Quality parameters: Grain: Weight (g/100)	Grain: Breaking strength	Grain: Water absorption (%)	Flour: PSI	Dough: Water for dough (ml)	Dough: Rolling quality	*Roti*: Taste	*Roti*: Texture	*Roti*: Aroma	*Roti*: Keeping quality
Weeks	0.01	0.26	0.66	18.04	0.57	1.42	0.15	0.09	0.03	0.06
Cultivars	2.36**	9.77**	92.64**	77.27**	16.65**	6.50**	1.54**	0.44**	0.78**	0.98**
Error	0.00	0.38	1.05	8.09	2.68	0.71	0.06	0.09	0.03	0.16
n	25	25	25	14	19	19	19	19	19	19
CV%	1.5	7.7	3.9	5.2	0.9	3.8	9.7	12.4	9.9	12.8

** Significant at 1% probability level.

Table 4b. Analysis of variance (mean sum of squares) for some grain, flour, dough, and *roti* quality characters of 20 sorghum genotypes grown at ICRISAT Center in 1979 and 1980.

Source	df	Quality parameters: Grain: Corneous-ness	Grain: Weight (g/100)	Grain: Breaking strength (kg)	Grain: Water absorption (%)	Flour: PSI	Dough: Water required (ml)	Dough: Kneading quality	Dough: Rolling/spread-ing	*Roti*: Taste	*Roti*: Texture	*Roti*: Aroma	*Roti*: Keeping quality
Replications	1	0.00	0.02	0.21	3.29	111.50**	0.08	0.05	1.72*	0.40*	0.56**	0.18**	0.75**
Years	1	0.80**	0.60**	13.72**	35.17**	7769.69*	0.00	1.51**	12.21**	0.04	0.07	0.12**	0.59*
Genotypes	19	3.06**	3.09**	13.68**	112.60**	582.16**	15.77**	1.11**	7.30**	2.02**	0.42**	1.19**	0.90**
Genotypes × years	19	0.17**	0.05**	1.39**	4.79**	279.66**	2.76**	0.26**	0.95**	0.20**	0.07	0.08**	0.18*
Experimental error	39	0.00	0.01	0.23	1.38	10.41	1.03	0.02	0.32	0.06	0.07	0.03	0.09
CV(%)		0.0	3.0	5.6	4.6	5.0	3.6	11.7	2.6	10.0	10.4	9.2	9.9

* Significant at 5% probability level. ** Significant at 1% probability level.
df for PSI: Replications-2, year-1, genotypes-13, genotypes × years-13, and experimental error-54.

strength, percentage water absorption, dough kneading and rolling qualities, *roti* aroma, and keeping quality. Genotype × year interaction was highly significant for several of the characters studied. The *roti* quality characters showed significant effects of the replications. However, when the 1979 data were analyzed separately using data obtained on three replications, the replication effects were not significant. The cultivars M35-1 and CSH-5 were the best for *roti* quality characters, while S-13, CS-3541, and E35-1 were average. Cultivar P721 exhibited the poorest *roti* quality.

Roti Quality of Rainy- and Postrainy-Season Harvests

Grain quality problems of the rainy-season crop, particularly when the sorghum is caught in late rains, need not be overemphasized. The grain becomes discolored, moldy, and is frequently unfit for human consumption. Over the last few years, 1500 grain samples of breeding progenies in F_5 and F_6 generations originating from rainy and postrainy seasons were screened routinely for desirable *roti* quality, using the postrainy-season harvest samples of M35-1 as checks. The objective was to identify lines combining less grain deterioration and desirable *roti* quality in the rainy season as well as the postrainy season. Grain, dough, and *roti* quality characters of some selected lines grown in the rainy and postrainy seasons are presented in Table 5. It was observed that grains from the rainy season harvest frequently showed reduced grain weight and breaking strength, increased percentage water absorption, and relatively poor organoleptic properties. It should be pointed out that the data presented pertains to those entries that were mostly selected for better *roti* quality and grain mold resistance in the rainy season and better *roti* quality in the postrainy season. If a random sample of lines were to be evaluated for their *roti* quality in rainy and postrainy seasons, the seasonal effects on the quality parameters could be more pronounced.

In our experience, grain samples of check variety M35-1, obtained from Mahol and Bijapur (M35-1 is grown in Central India only in the postrainy season), exhibited superior *roti* quality over samples of the same variety harvested in the same season at ICRISAT Center (Murty et al. 1981). This difference was probably due to the lower humidity and hotter climate that prevailed during the postrainy season in Mahol and Bijapur. The luster and color appeal of the grain, and consequently that of the *roti*, depend on the temperature, relative humidity, and rainfall during the grain-filling period of the crop. At ICRISAT Center, preliminary screening was carried out using postrainy-season harvests and selected lines were carried forward to the rainy season. Selection for *roti* quality in the rainy season was carried out with due weightage to the maturity of the cultivar and the extent of grain deterioration.

Effect of Nitrogen Fertility

In order to quantify environmental effects on quality parameters and establish optimum grain-sampling procedures, a series of experiments were carried out to determine the effect of nitrogen application, moisture stress, and grinding methods on the *roti* quality of the grain harvest. Six sorghum cultivars—M35-1, SPV-351, SPV-393, CS-3541, E35-1 and P721—were grown in a split plot design with four levels of nitrogen application (0, 60, 120, and 200 kg/ha) as main plots with three replications. The experiment was conducted in the postrainy season under irrigation on black soils. Available N, P, and exchangeable K contents of the top 1 m soil profile before the application of N were 24 ppm, 1.45 ppm, and 163 ppm, respectively. Half of the N dose was applied to the crop in the form of urea 6 days after emergence, and the rest was applied similarly 25 days after emergence. Grain samples were analyzed for various grain, dough, and *roti* quality characters, and the results of the analysis of variance are presented in Table 6. Differences due to cultivars was the major source of variation for all the characters, while variation due to the N level was significant only for plot yield, and percentage water absorption. An examination of the mean values of the attributes for the four levels of N application indicated that most of the differences were due to the 0 level of nitrogen vs the 60,120, and 200 kg N application. The organoleptic qualities—*roti* taste, texture, aroma and keeping quality—as rated by the taste panelists were not significantly affected by N application.

Effect of Moisture Stress

Grain samples were obtained from a split plot

Table 5. Grain, dough, and *roti* quality characteristics of 15 sorghum cultivars grown in the rainy and postrainy seasons at ICRISAT Center.

		Grain				Dough		*Roti*				
Cultivar	Origin[a]	Endo-sperm texture	Weight (g/100)	Breaking strength (kg)	Water absorp-tion (%)	Water required (ml)	Rolling quality (cm)	Color[b]	Taste	Texture	Aroma	Keeping quality
SPV-350	R1977	2	3.34	8.7	25.9	27.2	23.0	5Y 8/2	1.5	1.8	1.2	2.0
	K1978	3	2.85	8.0	25.5	28.5	23.0	2.5Y 8/2	2.4	2.3	1.4	3.2
SPV-351	R1977	2	3.10	9.5	27.9	25.3	22.2	5Y 8/3	1.6	1.8	1.6	2.0
	K1978	3	2.36	6.6	23.3	30.8	21.4	5Y 8/2	2.0	1.7	1.5	2.5
SPV-354	R1977	2	3.42	13.5	29.4	27.1	22.1	5Y 8/2	3.0	2.0	1.0	3.5
	K1978	2	3.35	11.6	24.7	31.5	22.3	2.5Y 8/2	1.8	1.6	1.2	2.2
SPV-386	R1979	2	3.19	8.1	25.9		23.2	5Y 8/2	1.7	1.7	1.3	2.2
	K1978	3	2.90	7.8	28.0	29.6	22.6	5Y 8/2	2.8	3.0	1.0	3.0
SPV-387	R1978	1	3.16	11.6	18.7			5Y 8/2	2.0	2.2	1.0	2.6
	K1980	2	2.68	11.7	22.6			5Y 8/3	2.3	2.2	1.0	2.3
M66118	R1978	2	2.96	7.4	23.0			5Y 7/4	2.2	2.5	1.0	2.2
	K1979	3	3.44	9.8	28.3	29.1	22.7	5Y 6/4	2.2	2.8	1.7	2.8
M62455	R1978	2	3.03	8.9	23.1			5Y 8/4	3.0	3.0	1.0	3.2
	K1979	3	2.74	9.3	25.6	30.1	20.1	5Y 7/3	2.2	1.9	1.7	2.5
M62404	R1978	2	3.53	11.2	23.7			5Y 7/4	2.8	2.7	1.0	2.6
	K1979	3	2.58	8.7	22.0	30.8	19.1	5Y 6/3	2.4	2.5	2.0	2.5
M62522	R1978	2	3.54	9.4	19.3			5Y 7/4	2.5	2.7	1.0	2.4
	K1979	3	2.51	6.5	19.4	26.5	20.2	5Y 8/3	2.4	2.4	1.8	3.0
M62557	R1978	2	3.28	7.8	20.8			5Y 8/3	2.2	2.2	1.0	2.2
	K1979	3	2.77	8.4	22.3	27.2	19.7	5Y 6/3	2.3	2.7	1.7	3.0
M62637	R1978	3	3.16	9.3	17.7			5Y 8/3	2.0	2.0	1.0	2.4
	K1979	3	2.96	6.7	18.7	29.5	23.2	5Y 7/2	2.2	2.3	1.8	2.5
M66172	R1978	2	2.98	9.7	25.4			5Y 8/4	2.0	2.2	1.0	2.7
	K1979	2	2.96	8.8	27.7	26.4	20.1	5Y 7/3	1.7	2.4	1.6	3.0
CSH-5	R1979	2	2.73	7.0	19.8	26.2	22.6	5Y 8/2	1.9	2.1	1.0	2.3
	K1980	3	2.85	7.0	20.3			5Y 7/3	2.5	2.5	1.5	2.9

CSH-6	R1979	2	3.25	9.0	18.3		23.9	5Y 8/3	1.7	2.1	1.2	2.2
	K1980	2	2.25	6.9	25.7	29.3	19.0	5Y 6/4	2.3	3.0	1.5	2.8
CSV-4	R1979	2	3.19	9.2	22.8		23.5	5Y 8/2	2.0	2.1	1.2	2.4
	K1980	2	2.69	8.5	23.4			5Y 7/3	2.5	2.5	1.5	2.6
M35-1	R(Bijapur)	3	3.80	9.0	18.2	25.6	24.5	5Y 8/3	1.2	1.8	1.2	1.9
Mean	$\bar{R}$	2.00	3.19	9.3	22.8				2.1	2.2	1.1	2.5
	$\bar{K}$	2.66	2.73	8.4	23.8				2.3	2.4	1.5	2.7
SE diff.		0.16	0.113	0.6	1.3				0.6	0.5	0.2	0.5

a. R = Postrainy season, K = Rainy season.
b. Colors represent hue and chroma values given in Munsell's Soil Color Charts (1975). All values belong to white and pale yellow colors of different shades.

Table 6. Analysis of variance (mean sum of squares) of quality characteristics of sorghum from a split plot design experiment with four levels of N application.

		Quality parameters									
		Grain			Dough		*Roti*				
Source	df	Weight (g/100)	Breaking strength	Water absorption (%)	Water required (ml)	Rolling quality	Taste	Texture	Aroma	Keeping quality	Plot yield
Blocks	2	0.207	1.54	3.90	10.66	13.50	0.03	0.08	0.17	0.19	0.00
Nitrogen levels	3	0.061	0.59	11.77*	4.36	1.31	0.12	0.10	0.14	0.02	0.45*
Error (a)	6	0.117	0.86	1.80	2.19	0.98	0.07	0.07	0.04	0.06	0.07
Genotypes	5	5.807**	65.52**	536.16**	5.66**	69.56**	3.95**	3.30**	1.33**	1.23**	2.20**
Genotypes × nitrogen	15	0.037**	0.41	3.96	1.10	0.70	0.05	0.03	0.01	0.10	0.08
Error (b)	40	0.003	0.49	3.80	1.22	0.49	0.05	0.03	0.02	0.10	0.07
CV% (b)		1.8	8.3	6.4	3.6	3.2	10.8	8.4	8.8	12.0	16.8

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

experiment in which the effect of moisture stress on the crop was studied. The experiment involved a comparison of crop performance of ten genotypes in the postrainy season under satisfactory irrigation and very restricted irrigation. The average yield reduction in the stress plots was 38.5% of the control plots. Grain samples were cleaned thoroughly from chaff, poorly filled grain, and poorly filled grain attached with glumes. Grain, dough, and *roti* quality characters were studied using clean and normal plump grains. An analysis of variance of the data (Table 7) showed that variance due to moisture stress was large for endosperm texture, 100-grain weight, percentage water absorption, water for dough, and rolling quality of dough. However, these were statistically not significant. Variances due to moisture stress for the *roti* quality attributes were insignificant and small. Genotypes × moisture stress variances were insignificant for all characters, except grain weight and endosperm texture.

In another experiment, a commercial hybrid, CSH-8, was grown in a split plot design under two fertilizer × three irrigation treatments. The experiment was conducted in the postrainy season on deep black soils that were left fallow during the rainy season. The fertilizer treatments in kg/ha were zero N + 20 P_2O_5 and 80 N + 20 P_2O_5, respectively. *Roti* quality of grain samples from the various treatments did not differ significantly (data not presented here).

Flour Particle Size Index (PSI)

Waniska (1976) found that the average flour particle size expressed as particle size index (PSI) is a useful indicator of food quality. At ICRISAT Center we studied the flour composition of grain samples from 72 cultivars of diverse origin. A domestic carborundum stone grinder was used to mill bulk samples of grain, and all samples were milled at a uniform grinding pressure. Three flour samples (25 g each) of each cultivar were dried in the oven at 70° C for 2 hr, followed by cooling in a desiccator. They were sieved for 15 min in a RoTap Sieve Shaker using U.S. standard sieves 30, 40, 50, 60 (250μ), 70 (210μ), and 80 (177μ). No bouncers were used during sieving. The weights of various flour fractions retained on the 30, 40, 50, 60, 70, and 80 mesh sieves were recorded and PSI was estimated using the following formula (Waniska 1976):

Table 7. Analysis of variance (mean sum of squares) of quality characteristics of sorghum from a split plot design experiment with two levels of moisture treatment.

		Quality parameters									
		Grain			Dough			*Roti*			
Source	df	Corneousness	Weight (g/100)	Breaking strength	Water absorption (%)	Water required (ml)	Rolling quality	Taste	Texture	Aroma	Keeping quality
Blocks	1	0.100	0.0001	0.694	1.66	1.77	1.949	0.188	0.0607	0.018	0.169
Moisture level	1	0.400	3.0200	7.120	17.50	16.18	2.376	0.010	0.0008	0.005	0.004
Error (a)	1	0.025	0.0630	4.136	6.33	0.16	0.073	0.012	0.0615	0.014	0.009
Genotypes	9	1.558**	0.2888**	16.020**	15.50*	4.55	0.644	0.115**	0.1182	0.101**	0.117*
Genotypes × moisture	9	0.122*	0.0518**	1.284	2.57	1.17	0.618	0.040	0.0495	0.023	0.018
Error (b)	18	0.0347	0.0131	0.683	4.64	1.56	0.357	0.020	0.0621	0.013	0.034
CV% (b)		9.7	4.9	9.3	6.9	4.0	2.6	8.2	12.2	8.3	7.6

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

$$PSI = (0.1)\ (\% > 250\mu) + (0.4)\ (\% > 210\mu) + (0.7)\ (\% > 177\mu) + (1.0)\ (\% < 177\mu).$$

Average PSI values of the 72 cultivars ranged from 25 to 80 with fair repeatability. A high PSI value indicates small particle size and a low PSI value indicates a large particle size. Flour from floury grains had a larger particle size (low PSI), while that of corneous grains had a small particle size (high PSI) (Murty et al. 1981).

Grain samples from four cultivars, E35-1, M35-1, IS-9985, and P721, with different endosperm texture were ground at three grinding pressures—high, moderate, and low—and the flour samples were evaluated for their PSI. The experiment was replicated three times. Analysis of variance of the flour particle size index data has shown (Table 8) that variances due to genotype as well as grinding pressures were significant. Variances due to the genotypes × grinding pressures were highly significant and larger than variances due to grinding pressures. When grinding pressure was increased, the flour PSI of E35-1 and M35-1 increased, whereas that of P721 decreased. The flour PSI of IS-9985 was higher at a moderate grinding pressure than at high or low grinding pressures. *Roti* quality of M35-1 grain samples was superior to that of E35-1 at the high and moderate grinding pressures, while the two cultivars were equally poor at the low grinding pressure. These results indicate that optimum grinding procedures should be established for evaluation of *roti* quality parameters of grain samples from diverse breeding stocks.

Grinding methods have a profound influence on flour properties. The nature and extent of damage to the starch grains caused by different milling equipment might be different (Murty and Subramanian 1981). The milling equipment and the grinding pressure applied have a unique and significant effect on the flour and consequently the dough and *roti* properties.

Table 8. Analysis of variance for flour particle size index obtained with different grinding methods.

Sources of variation	df	mss
Blocks	2	7.12
Grinding pressure	2	65.23*
Error (a)	4	5.18
Genotypes	3	1419.72**
Genotypes × grinding pressure	6	194.92**
Error (b)	18	5.52
CV% (b) = 3.8	CD5% = 4.03	

* Significant at 5% probability level.

** Significant at 1% probability level.

Mean Properties of Grains with Good *Roti* Quality

Correlation coefficients between grain, dough, and *roti* quality attributes were estimated using the data set from 167 pearly white grain types (c.f., Table 1). Several of them were statistically significant (Table 9.). However, none of the characters was correlated strongly enough with *roti* quality to be used for indirect assessment. Since extreme levels of any parameter did not appear to be associated with *roti* quality, observations on 72 cultivars with pearly white grains were grouped into three classes: good, moderate, and poor, based on the taste panel scores of their *rotis*. The mean physical properties of the grain, flour, and dough corresponding to these classes were examined. The analysis indicated (Table 10) that on an average, good *roti* producing grain types exhibited 60–70% corneous endosperm, flour PSI values around 65, and less than 24% water absorption. White grains with 100% corneous endosperm produced *rotis* with a relatively hard texture and less desirable keeping quality, while floury grain types produced a poor dough and *rotis* with poor flavor and keeping quality (Table 2).

Selection Criteria for *Roti* Quality

The results discussed here indicate that sorghum *roti* quality is influenced by several grain, flour, and dough properties. More detailed studies are required to develop suitable selection indices for *roti* quality. Efforts should be made to develop simple tests that require small quantities of grain to assess *roti* quality of early-generation segregating material. Genetic variation that exists among pearly white grain types for *roti* quality could be exploited.

Breeders can select in the early generations for white and light yellow (endosperm) grains free from subcoat and with a thin pericarp and 60–

Table 9. Correlation coefficients (r) between some grain, dough, and *roti* quality attributes.[a]

	Taste	Texture	Aroma	Keeping quality
Corneousness	0.35[b]	0.20	0.32	–
Breaking strength	0.46	0.27	0.38	–
Water absorption of grain (%)	−0.38	−0.47	−0.35	−0.26
Water for dough	0.35	0.42	0.31	0.27
Dough kneading quality	0.28	0.42	0.34	0.32

a. Based on replicated observations on 167 genotypes with pearly white grains.
b. All r values tabulated are significant at 1% probability level.

Table 10. Mean (±SE) properties associated with *roti* quality.

	Roti quality		
Parameter	Good (18)[a]	Moderate (34)	Poor (20)
Endosperm texture	2.2±0.15	2.4±0.10	2.9±0.16
Water absorption of grain (%)	24.5±0.84	26.7±0.60	30.1±1.02
Kneading quality of dough	1.0±0.02	1.1±0.03	1.3±0.10
Dough rolling (cm)	22.5±0.20	22.3±0.15	21.7±0.36
Flour PSI	65.8±2.36	65.8±2.04	58.7±0.40
Roti taste	1.7±0.06	2.1±0.05	2.6±0.09
Roti texture	1.8±0.05	2.1±0.04	2.7±0.08
Roti flavor	1.3±0.05	1.4±0.05	1.6±0.08
Roti keeping quality	2.3±0.05	2.6±0.05	3.2±0.12

a. Numbers in parentheses indicate the number of cultivars, based on which the group mean property was expressed.

70% corneous endosperm. Grain samples from F_3 and F_4 material can be evaluated for desirable physical properties of grain like low percent water absorption. Flour and dough tests are best undertaken from F_5 generation onwards and laboratory taste panel evaluation of *rotis* can be done on elite F_6 material under yield tests. Consumer tests are necessary for only a few cultivars recommended to the farmers. Wet weather is the most important factor that affects *roti* quality. It is recommended that for routine screening purposes, clean and normal grain samples from cultivars of comparable maturity grown in the same season and location should be used.

As mentioned earlier, the *roti* quality of rainy-season harvest is frequently poor due to grain deterioration problems. Rao et al. (1980) found that low water absorption and higher breaking strength of the grain showed a negative association with grain deterioration. In general, our experience at ICRISAT Center in breeding for improved *roti* quality of rainy-season sorghums has been similar. However, extremely hard endosperm types (80 to 100% corneous) selected from crosses involving pearly white and hard grain types produced *rotis* with a harder texture and poor keeping quality, particularly when the crop is not affected by grain deterioration. It might be necessary to develop an appropriate selection index for improved *roti* quality and reduced grain deterioration of early maturing rainy season sorghums.

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Screening and evaluation of *Tortilla* from Sorghum and Sorghum-Maize Mixtures

A. Iruegas, H. Cejudo, and V. Guiragossian*

Summary

Maize has been cultivated in Mexico and other Latin American countries for a long time and is one of the major crops for direct human consumption in the form of tortilla *and other products. Since there is a deficit of production in maize every year, crops such as sorghum could be a cropping option to increase the quantity of dough suitable for* tortilla, *which is a daily food, simply by mixing corn and sorghum in acceptable combinations.*

Maize is preferred for tortilla *production in Central American countries; sorghum, however, is being consumed alone, or in mixtures with maize, to produce* tortillas *when maize supplies are low. In addition, social and psychological factors limit its quality acceptance. Recently, however, ICRISAT identified and developed food-type sorghums with improved* tortilla-*making properties. Cooperative work between the National Institute of Agricultural Research (INIA) Mexico, and ICRISAT is in progress and the sorghum lines from this progress are being further improved. It is well recognized that sorghum frequently produces higher yield than maize and production is more reliable in harsh areas that are marginal for maize production.*

Genotypes M-62588 and M-62724 produced acceptable tortillas *from 100% sorghum because they have low tannin and phenol contents. In addition, their color difference values (ΔE) were among the highest of sorghum entries and were closer to ΔE values for white maize. Also, their organoleptic determinations indicated good acceptability, when compared with maize. However, M-62499, although it has low tannin and phenol contents, and acceptable color difference value, produced unacceptable* tortillas *for reasons unknown at this stage.*

One SEPON 78 selection and RTAM 428 produced unacceptable tortillas *because they have high phenols, and their color difference values were among the lowest of sorghum entries. In addition, their organoleptic qualities were poor.*

The objective of this study is to screen food-type sorghum genotypes, using different analyses, and to evaluate sorghums with different kernel characteristics for making tortillas *from different combinations of maize and sorghum. Results from this experiment indicated that it is possible that sorghums with improved properties for use in* tortilla *production can be found, using the screening methods applied by INIA (Mexico), and used in breeding programs to develop sorghum cultivars for use in making* tortillas.

In Mexico there is an increased interest in using sorghum for making *tortillas*. This is mainly due to low yields in maize production. Sorghum performs very similar to maize during lime cooking, both in the rheological properties of the dough and in the quality of the *tortilla*. But the darker color produced by the tannins and phenols is frequently present in sorghum *tortilla*. Because of the possible rejection of the pure sorghum *tortilla*, due to the greenish and light pinkish colors, *tortillas* made from mixtures of maize and sorghum are thought to be the most promising form in which sorghum will be accepted in the Mexican diet. Also, the mixtures of maize and sorghum are a partial solution to the low maize supply in Mexico. Mixing sorghum to the extent of 15% with the estimated 7 million metric tons of maize that is used in human consumption, would amount to more than 1 million metric tons of sorghum being incorporated into the Mexican diet.

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Selection Strategy

The selection of sorghum genotypes of acceptable *tortilla* quality involves two types of tests. The first, the prediction test, is designed as a simple routine method to evaluate large numbers of different genotypes from small samples. This test requires at least 10 g of sample. The sequence of analysis and selection is shown in Figure 1. The analyses undertaken in this test evaluate tannins, phenol contents, and kernel texture.

Visual Selection of Color

This selection is initiated by obtaining only sorghums with a white pericarp without a testa. The sorghums of darker grain or with conspicuous testa are put aside for feeding purposes.

Tannins

Kernels with a testa or a colored pericarp are tested for tannins (Maxson and Rooney 1972) and those with values lower than 0.05 equivalents of catechin/g of sorghum are selected, if they are high grain yielders. These genotypes are acceptable for *tortillas* made with mixtures of maize containing up to 10% sorghum. Also, this sorghum can be used as feed for poultry and monogastric mammals.

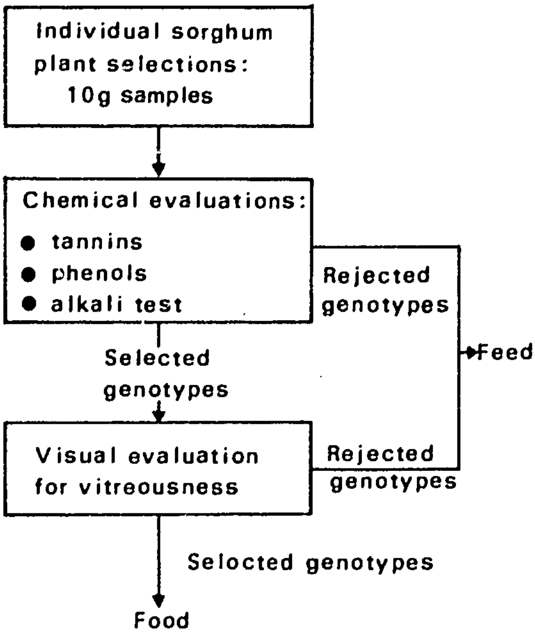

Figure 1. Flow chart for predicting the potential of sorghum for food and feed.

Phenols

The clean grain genotypes without testa are subjected to analysis of phenolic compounds (Price and Butler 1977) for the purpose of screening out those sorghums with phenolic contents higher than the equivalent of 0.40 mg of tannic acid/g because they will produce darker colored *tortillas.* The sorghums with a high phenol content and light color grain have the same type of utilization as the sorghums with low tannins and dark color. Some genotypes of low phenol content, as determined by these methods, will produce *tortillas* of unacceptable color, mainly greenish.

Alkali Test

The low phenol content samples are tested in an alkaline cooking procedure, with a solution of 12 N sodium hydroxide. The purpose of this test is to simulate the calcium hydroxide cooking conditions and to develop the color produced by phenols. The colors formed are a display of continuous variation that ranges from creamy white to purple. Five kernels are introduced in a test tube containing about 1 ml of 12 N sodium hydroxide. The test tube is allowed to stand for 120 min in a boiling water bath and cooled at room temperature. The kernels are placed over white paper towels for visual evaluation of color.

A scale of color corresponding coded selection values has been devised as follows:

Color	Score
Creamy white to creamy yellow	1
Yellow	2
Brown	3
Red brick	4
Purple	5

The selected genotypes are the light colored, scored as 3 or lower, with preference for the lower scored values.

Visual Selection of Kernel Vitreousness

It is important that the cooking requirements of sorghum and maize are similar in order to process them in the same batch. Through visual evaluation, the genotypes with medium and high degrees of vitreousness are selected because they will cook in about the same time as the commercial maize varieties. These genotypes are described by Maxson et al. (1971) as endosperm texture ratings 1, 2, and 3. The soft-textured kernels frequently require 10-15 min cooking time and most of the commercial maize genotypes need 25-30 min.

Final Evaluation

The second type of test was concerned with the final evaluation of the genotypes selected in the preliminary tests. In this phase, some physical aspects of the kernel, the milling performance, and the quality of the final product were evaluated (Figure 2).

Physical Evaluation of the Kernel

This evaluation involved determination of the kernel's hardness as described by Maxson et al. (1971) in an attempt to relate this trait to the cooking requirements. The only clear result of this comparison was that the soft endosperm sorghums, i.e., those with a hardness of 20 or lower, required cooking times in the range of 10-15 min. The medium and hard endosperm kernels with hardness ranging between 45 and 60 needed cooking times from 25 to 30 min and are more compatible with the cooking requirements of Mexican commercial maize. However, it has not been possible to determine more precisely the equivalent range of hardness and cooking requirements in order to establish groups of low, medium, and high cooking times. The main problem is our inability to determine the optimal cooking stage.

Milling Performance

Pilot Cooking Test

The milling evaluation was started with a pilot cooking test in order to determine the cooking time required for a sample to reach a moisture content of 50%. This information was obtained by cooking 2 g samples from 15 to 30 min in a 0.5% calcium oxide solution. The 50% moisture limit was established.

Lime Cooking and *Nixtamal* Preparation

Lime cooking was achieved in a crude fiber apparatus to avoid excessive evaporation. Grain samples of 150 g were required for subsequent tests. Cooking time was determined in the pilot cooking test. Three hundred ml of 0.5% calcium oxide solution were needed for the cooking liquids. The cooked kernels (*nixtamal*) and the cooking liquids (*nejayote*) that have some suspended particles of the kernel, some solubilized kernel constituents, and the nonabsorbed calcium oxide solution are allowed to rest overnight. The rest phase is a common practice in the production of commercial *tortilla* because it permits increased water absorption and thus higher dough yield. The cooking liquids (*nejayote*) are poured off, the kernels washed, and the wash water added to the cooking liquids.

Reducing Sugars

The reducing sugars present in the *nejayote* increase as the cooking time increases. But again, it has not been possible to determine the amount of reducing sugars that indicate that the optimum cooking time has been reached. We are studying these parameters now, relating the cooking time with water absorption performance.

Total Solids

The solids present in the *nejayote* are the remains of calcium hydroxide and kernel ingredients that have been solubilized or removed from it. The loss of these ingredients reduces the milling yield. The estimation of total solids (assuming that the amount of nonabsorbed calcium hydroxide is constant) can be regarded as a negative effect on milling yield. Dry matter was determined by heating the *nejayote* overnight in a convection oven at 100° C to achieve dryness. The values vary from 2 to 5%.

Milling

The lime cooked and washed kernels (*nixtamal*) were wet milled in a stone mill that was a laboratory model of the commercial mill. In order to obtain dough with the usual commercial texture (using 15 cm diameter stones) it was necessary to provide for an adjustable pressure between the

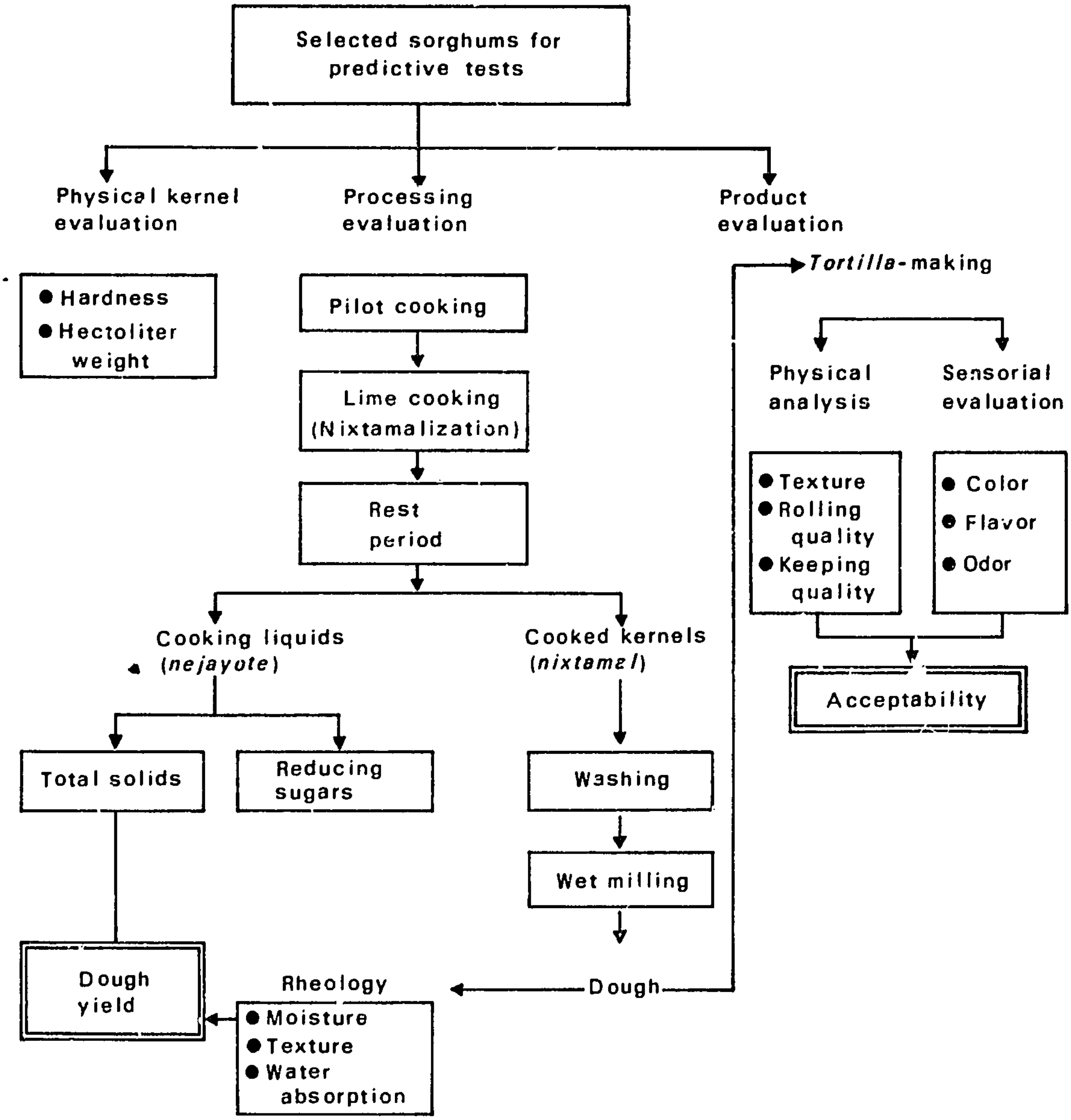

Figure 2. Flow chart for sorghum tortilla *evaluation.*

stones and a driving motor of 1 hp with 850 rpm.

Rheological Determinations

In estimating the milling yield, it was necessary to know the water absorption capacity of the dough when the dough had an optimum texture for making *tortilla* by hand or machine.

A sampling at the feeding point of the *tortilla*-making equipment at 20 maize *tortilla* factories was done to determine the optimum texture. A wide variation in dough viscosities was found. Hereafter, a standard texture is defined as the average of the viscosities of the sampled doughs. The dough moisture is estimated by wide band nuclear magnetic resonance, which permits a rapid determination of this variable. The texture of the dough is estimated as the extrusion time of a constant dough volume in the Simon extrusor that is usually used for wheat doughs (Price and Butler

1977). T' moisture determinations and extrusion times were made on sorghum genotypes with doughs containing water below, above, and close to the "standard texture". These data are plotted in Figure 3. By locating the intersection of the water absorption line of the genotype with the standard texture extrusion time, the water absorption of the sample is determined.

Product Evaluation

Pure sorghum *tortillas* and *tortillas* of mixtures of sorghum and maize were made. The proportions used in the mixtures were 3 : 1, 1 : 1, and 1 : 3. The *tortillas* were evaluated for attributes of color, flavor, taste, and flexibility to estimate overall acceptability.

Results and Discussion

The genetic material used was 150 lines selected from the nursery of ICRISAT and seeded in the spring-summer season of 1980 at the experimental station of CIMMYT in Poza Rica, Veracruz, Mexico. Lines with white, cream, or yellow kernel color, (mainly light colors) were selected. The samples were submitted to the food technology laboratory of INIA for evaluation of their processing and *tortilla* quality.

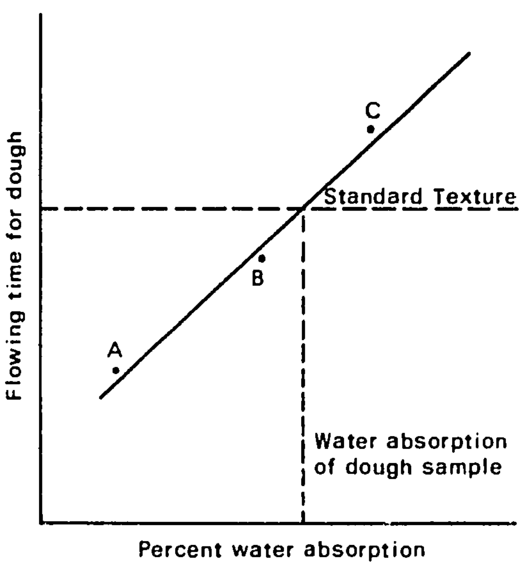

Figure 3. Water absorption determination in sorghum.

The analysis was started with the prediction test. The data showed variability in the phenol content from 0.0 to 0.8 mg of tannic acid/g of sorghum, and under alkali treatment all colors were developed except the purple, which was coded as 5. The correlation coefficient of phenol vs alkali response was 0.17, which did not permit prediction of estimates of either of them. This low association indicated that the selection criteria should be toward low levels of expression of both phenol content and color developed by alkali treatment.

Nineteen lines were selected to study the precision of prediction, based on prediction test data (Table 1), of the color and quality of pure sorghum *tortillas* and *tortillas* made from mixtures of sorghum with yellow and white maize. Correlation coefficients of *tortilla* color vs phenol and tannin content and color developed by alkali treatment, were not pursued, due to the low number of observations made on *tortillas*. In order to typify the results, six lines that show a wide variability among them in the organoleptic attributes of sorghum *tortillas* were chosen (Table 2). Lines M-62588 and M-62724 have low tannin and phenol contents and low alkali test readings. As a result of these values, the *tortillas* showed closer values of color difference (ΔE) to white and yellow maize and thus produced good organoleptic results. However, although M-62499 and the CS-3541 cross A showed low tannin and phenol contents, respectively, and low alkali test readings, the ΔE values were lower (darker *tortillas*) than values obtained from M-62588 and M-62724, but the organoleptic results were fair for reasons that we are not able to explain at this stage.

The SEPON 78 selection and RTAM 428 have higher tannin and phenol contents, respectively, and higher alkali test readings. As expected, ΔE values were much lower than white and yellow maize ΔE values. As a result the organoleptic test gave poor *tortilla* ratings.

Table 3 shows the organoleptic evaluations of four sorghum types selected with good, fair, and poor reactions in 100% sorghum *tortillas*, to show the type of response obtained when mixing them in different combinations with white and yellow maize. Line M-62588 produced good organoleptic results from 100% sorghum; likewise in the combination 75% S + 25% M, both for white and yellow maize. From 50% S + 50% M and 25% S + 75% M mixtures excellent *tortillas* were produced. However, CS-3541, with a fair organoleptic result at 100%, produced results similar to M-62588 in different combinations with maize.

Line M-62499, which had a fair rating in organoleptic tests at 100%, produced different results from the above mentioned genotypes in mixtures, and *tortillas* were less acceptable in the 75% S + 25% M combinations. Line RTAM-428, with a poor reaction from organoleptic evaluations

Table 1. Laboratory screening of sorghum for *tortilla* evaluation (INIA).

Genotype	Tannin C.E.	Phenol mg TA/g	Alkali treatment score	Laboratory selection
M-63594	0.66	0.25	1	+ + +
M-62650	0.02	0.21	1	+ + +
M-62637	0.05	0.10	2	+ + +
CS-3541 cross A	0.03	0.13	1	+ + +
M-62588	0.03	0.16	1	+ + +
M-62492	0.06	0.10	1	+ + +
M-62490	0.96	0.09	1	+ + +
M-62707	0.05	0.05	1	+ + +
M-62400	0.05	0.05	1	+ + +
M-62499	0.03	0.25	1	+ + +
M-62724	0.00	0.06	1	+ + +
CS-3541 cross B	0.12	0.24	3	+ +
M-62671	0.05	0.59	1	+ +
7607132 NAF	0.42	0.16	3	+ +
SEPON 78	0.00	0.31	1	+
SEPON 78	0.01	0.49	2	+
SEPON 78	0.06	0.34	5	0
RTAM 428	0.25	0.65	3	0
SEPON 78	0.00	0.53	4	0

+ + + Selected for low tannin, phenol, and alkali treatment score
+ + Selected in two of the three studied factors.
+ Selected in one of the three studied factors.
0 Not selected

C.E. = Catechin Equivalent.
TA = Tannic acid.

Table 2. Comparisons between kernel and *tortilla* characteristics for 100% maize and sorghum.

Genotype	Tannin C.E.	Phenol mg TA g	Alkali test score	ΔE[a]	Organoleptic test
White maize	0	0	-	68.6	Excellent
Yellow maize	0	0	-	73.0	Excellent
M-62588	0.03	0.16	2	59.6	Good
M-62724	0.00	0.06	2	56.1	Good
M-62499	0.03	0.25	1	49.7	Fair
CS-3541 cross	0.03	0.13	2	57.3	Fair
SEPON 78	0.06	0.34	6	45.1	Poor
RTAM 428	0.25	0.65	4	42.9	Poor

a $\Delta E = (a^2 + b^2 + L^2)^{1/2}$, where "a" is the color reading with Hunterlab equipment for red and green, "b" is the color reading for yellow and blue, and L is total brightness at 100% sorghum, produced unacceptable *tortillas* in all combinations. Table 4 shows the organoleptic evaluations of the 19 sorghum lines of pure sorghum *tortillas* and *tortillas* made from mixtures of sorghum with white and yellow maize.

Conclusions

The screening methods applied by INIA to evaluate sorghum genotypes for potential use in making *tortillas* are generally effective. Genotypes with very low tannin and phenol contents will generally produce acceptable *tortillas;* however, intermediate organoleptic results are expected from sorghum with low and intermediate tannin and phenol values. Unacceptable *tortillas* are almost always produced from genotypes with high tannin and phenol contents.

Table 3. Organoleptic evaluation of sorghum in mixtures with white and yellow maize.

		White maize and sorghum			Yellow maize and sorghum		
Genotype	100% sorghum	75% S +25% M	50% S +50% M	25% S +75% M	75% S +25% M	50% S +50% M	25% S +75% M
M-62588	Good	Good	Excellent	Excellent	Good	Excellent	Excellent
CS-3541	Fair	Good	Excellent	Excellent	Good	Excellent	Excellent
M-62499	Fair	Fair	Good	Excellent	Fair	Good	Excellent
RTAM 428	Poor	Poor	Fair	Fair	Poor	Poor	Fair

Table 4. Organoleptic evaluation of sorghum *tortillas* in different combinations with white and yellow maize.[a]

Genotype	S 100%	S 25% WM 75%	S 25% YM 75%	S 50% WM 50%	S 50% YM 50%	S 75% WM 25%	S 75% YM 25%	M 100%
M-63594	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62650	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62637	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
CS-3541 cross	Fair	Excellent	Excellent	Excellent	Excellent	Good	Good	
M-62588	Good	Excellent	Excellent	Excellent	Excellent	Good	Good	
M-62492	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62490	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62707	Fair	Excellent	Excellent	Good	Good	Good	Fair	
M-62400	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62499	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
M-62724	Good	Excellent	Excellent	Excellent	Excellent	Good	Good	
M-62671	Fair	Excellent	Excellent	Fair	Fair	Fair	Fair	
7607132NAF	Fair	Good	Good	Fair	Fair	Fair	Fair	
SEPON 78 sel. 1	Good	Excellent	Excellent	Good	Good	Good	Good	
SEPON 78 sel. 2	Poor	Good	Good	Fair	Fair	Fair	Fair	
SEPON 78 sel. 3	Poor	Good	Good	Fair	Fair	Poor	Poor	
RTAM 428	Poor	Fair	Fair	Fair	Poor	Poor	Poor	
SEPON 78 sel. 4	Fair	Excellent	Excellent	Good	Good	Fair	Fair	
White maize								Excellent
Yellow maize								Excellent

a. S = Sorghum; M = Maize; WM = White maize; YM = Yellow maize.

Tortilla Preparation

1. Lime Cooking

Mix 150 g of sorghum kernel with 300 cc of distilled water and add 1.5 g of $Ca(OH)_2$ (hydrated lime).

2. Boiling

Boil this mixture for 30 min in a 600-ml beaker on a crude fiber extraction apparatus in order to diminish excess evaporation and to obtain uniform boiling treatment for different samples.

3. Cooling and Rest Period

Allow the mixture to cool and rest for 17 hr. Make sure the beaker is covered with an aluminum foil in order to prevent evaporation and contamination.

4. Separation and Washing

Separate the kernels from the liquids with a sieve and wash the kernels with tap water accumulating the washed liquid into the original collected liquids. This washing will help remove the excess alkali and loose pericarp.

5. Wet Milling

Use a grinder (adjustable stone grinder). The wet kernels are ground very fine into a dough (*masa*).

6. *Tortilla* Making

Using a round press with a diameter of 15 cm, place about 30 g dough in a round ball shape in the middle of the press between two pieces of nylon plastic and press very gently to form the round *tortilla*.

7. Baking *Tortilla*

Place the *tortilla* on a heated metal plate and allow some time to cook on one side and then turn over the other side for complete cooking.

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Use of Sorghum as Food in Southern Honduras

Mary Futrell, Eunice McCulloch, and R. Jones*

Summary

A survey made in southern Honduras from May to August 1981 revealed that 29% of the families in Corpus, 80% in Guajinquil, and 37% in Pavana were making tortillas *from the traditional tall, white tropical varieties of sorghum. The sorghum* tortillas *observed were heavier, darker, and more grainy in texture than corn* tortillas; *sorghum was used more for* tortillas *during the last 2 months of the dry season and the beginning of the wet or planting season. New varieties of sorghum with more desirable characteristics for tortillas would be well received.*

The importance of grain sorghum in the diets of the people of southern Honduras has not received sufficient emphasis, and if it were not for this crop the problem of malnutrition and actual hunger would be greater than is found in this study. Because grain sorghum produces well in this environment and can be planted on a flexible time schedule, it appears to be suited to the life styles and the resources of the people of this area. In addition to human consumption, sorghum is used as an animal feed and is well suited to the small-scale type of animal husbandry that is practiced. It may be that because the people growing and consuming sorghum in this area practice subsistence farming and very little of the produce enters the market economy, the importance of this crop has been overlooked.

Information concerning the use of sorghum for food was obtained by interviewing a female member of the household, usually the wife during the months of May, June, July, and August in 1981. The villages of Corpus and Guajiniquil, in southern Honduras, were chosen because they were representative of a high-elevation area where sorghum is grown, and Pavana which was representative of a lowland area. All of the persons interviewed in Corpus, Guajiniquil, and Pavana customarily used sorghum for food during these months of planting corn and sorghum. These same areas will be visited again for interviews during January 1982 after the harvest of these grains to see if a difference of food intake exists.

Twenty-nine percent of the families in Corpus were making sorghum (*maicillo*) *tortillas*, while 80% in Guajinquil and 37% in Pavana were using sorghum for *tortillas*. Only those persons with wage incomes or donations of corn from outside agencies were using corn. Some *liga* (league) members in both Corpus and Pavana were able to have corn because of the government assistance given to them in the form of "food for work." Fifty percent of the families in Corpus were eating corn *tortillas* and 26% of the Pavana families used corn alone. These allotments did not last each family very long however, and 21% in Corpus and 37% of the families in Pavana used a mixture of half sorghum and half corn for *tortillas*. Some families, having run out of grain, were buying sorghum for their *tortillas* at a cost of 1.25 Lempiras (63¢) for 3.6 kg, which was the amount eaten by a large family in 1 day.

Sorghum was also consumed in other forms. *Atole*, a mixture of the *masa* mixed with milk and sugar, was eaten as a porridge by 43% of the families in Corpus, 40% in Guajiniquil, and 5% in Pavana. Forty-seven percent of the women in Pavana mixed sorghum *masa* with oil, sugar, cinnamon, and egg to make little round cakes 5 mm in diameter, which were baked and sold in the market. This was called a *rosquito*. Families in all villages reported that they popped sorghum. Balls were prepared by mixing the popped sorghum with honey or a brown sugar syrup by 29% of the families in Corpus, 60% in Guajiniquil, and 53% in Pavana. In Guajiniquil it was also reported

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to be cooked as a grain in soup.

We now come to the most important accomplishment of a woman in this society: the making of *tortillas*. This task is the one in which she takes the most pride. It is central to her homemaking activities and occupies a great deal of her time, more than any other job. In the mornings, after sweeping the hard-packed earthen floor and splashing a little water on it here and there to freshen it, she begins to prepare *tortillas*. She measures out the day's supply of grain, which varies from a quantity of about 1.8 kg for a small family to about 3.6 kg for a large family. This grain is winnowed by pouring it from one pan to another and sometimes it is washed before the next step, which is steeping with alkali. The grain is covered with water and alkali is added. This can be either *cal* (lime) or *ceniza* (ashes) or a mixture of both. All the *cal* used is purchased at the local *pulperia* (a small store) or the market, there apparently being no natural source of alkali in the area.

There was considerable local variation in the use of alkali. In Corpus and Guajiniquil, it was more common to use ashes being 46% and 90%, respectively, or a mixture of lime and ashes (45%) in Corpus. In Pavana, lime was more commonly used (86%); however, 14% used either ashes alone or a mixture of lime and ashes. Lime (calcium hydroxide) was added at the level of 1% of the weight of the sorghum to be used by 57% of the families and at the rate of 2% by 43% of the families in this study. The amount of ash varied from 18 g to 450 g for 1.8 kg of grain.

All of the women steeped the grain and alkali but there were considerable variations in time, some due to the practice of steeping corn and sorghum together and some due to whether ashes, lime, or both were used. Steeping times ranged from 2 hr to 15 min; however, 70% of the women steeped sorghum for 30 min and stated that if they used a mixture of corn and sorghum, the corn was cooked for approximately 30 min before sorghum was added and then cooked for an additional 10-30 min. Since sorghum required a much shorter steeping time, it required less firewood which was scarce and expensive in this area. Two types of cooking vessels were used to steep the grain and alkali, i.e., clay pots and aluminum pots. Fifty-four percent used the clay pots but some women commented that aluminum was better because it heated faster and required less firewood.

After the grain has been steeped and washed, the empty hulls that float to the top are removed to be fed to the chickens and the grain is then ground into *masa*. This is done either by a motor-driven small commercial *molino* in the village or by hand-cranked grinder in the home, or in a few cases entirely by hand on a grinding stone. In Corpus, the *molino* was powered by electricity and 64% of the women used this method for grinding. In Pavana, where the molino was gasoline powered, 52% used the *molino*. In Guajiniquil, where there was no *molino*, 80% of the women owned a hand-cranked grinder. As far as we could determine, all of the women had grinding stones in their houses and they were always used in the next stage of *tortilla* preparation. Taking the grain to a *molino* was preferred because it was easier and faster but there was no general agreement as to which method produced the best *masa*. The cost of the *molino* was 5 centavos for one batch, consequently many used the grinding stone because of economic necessity.

After the grain was ground, the *masa* was shaped into a circle with the hands. *Tortillas* in this area of Honduras were very large ranging from 14 to 18 cm in diameter with an average of 16.5 cm. They were made to a thickness of 0.5 cm. All of the women said that their *tortillas* puffed well and this was obviously a matter of pride. Exceptions were mentioned—if the *masa* were very coarse, the *tortillas* would not rise.

Tortillas were cooked one by one. As one *tortilla* was cooking on the clay comale, the next was being shaped to be ready just as the other finished cooking. During cooking, the *tortilla* was turned once to be lightly browned on both sides. After cooking, it was laid on the table or preparation area for a few moments to cool a little, and then placed in a bowl of some sort lined with a cloth. This bowl could be half of a large gourd, a clay bowl, a plastic bowl, or a basket. The *tortillas* were covered with a cloth and the major task for the day was done.

Although almost everyone prepared *tortillas* only once a day and made enough for the entire day's supply, a quarter of the women made *tortillas* two or three times a day. They did not keep either sorghum or corn *tortillas* for the next day and remarked that they would taste sour and get flat if kept for the next day.

There did not appear to be a very strong bias in favor of corn *tortillas* on the grounds of higher prestige, but rather on the basis of taste, texture, and appearance. The sorghum *tortillas* that were observed were heavier (denser), darker, and more grainy in texture than were those of corn. A mixture of half sorghum and half corn improved these qualities a great deal and the persons interviewed said that they liked them almost as well as corn *tortillas*.

Considerations other than preferences for certain types of *tortillas* are important however. At this point, it may be useful to point out that there are significant differences between the types of sorghum grown for food (*maicillo*) and those grown as feed for animals (*sorgo*) in this area. *Sorgo* was described as good tasting but made very dark tortillas. The *sorgos* are more similar to the grain sorghum grown in the USA, being short in stature and having a relatively short growing season, whereas the *maicillos* grow very tall and take 6 months from planting to harvest. New varieties that are to be introduced into the region, in addition to improved productivity and more desirable characteristics for *tortillas*, may need to be evaluated on the basis of yearly work schedules and seasonal dietary needs.

Boiled Sorghum Characteristics and their Relationship to Starch Properties

V. Subramanian, D. S. Murty, R. Jambunathan and L. R. House*

Summary

Traditional methods of boiled sorghum preparations are described. The cooking quality of boiled sorghum prepared from dehulled grain of 25 cultivars was evaluated using laboratory procedures. 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 the genotypes. Color, taste, texture, and keeping quality of boiled sorghum were evaluated using a taste panel. Swelling power, solubility, and inherent viscosity of starch were determined for 12 cultivars. The relationship between starch characteristics and cooking quality of boiled sorghum was studied. Cooking quality characteristics of boiled sorghum were significantly correlated with the swelling power and solubility of the starch.

Sorghum grains are an important source of food for several million people in Africa and India. The status of sorghum has long been underrated and is considered as a poor man's food. Subramanian and Jambunathan (1980a) carried out a survey of sorghum utilization methods in India and reported on the consumption pattern of boiled sorghum. In this paper, an attempt has been made to describe the traditional method of boiled sorghum preparation and laboratory evaluation of the boiled sorghum quality of 37 cultivars.

Rice is preferred over sorghum in certain regions, because it is comparatively easy to process and cook. The cooking and eating quality of rice have been studied in detail (Juliano 1979). The processing and cooking of sorghum take more time and fuel than rice (Desikachar 1975). Sorghum grains are used for food in several ways in India and African countries. In India, particularly in southern regions, boiled sorghum (rice-like) called *annam* or *soru* is one of the common products prepared and it accounts for about 10% of the total sorghum grain produced.

A similar product of sorghum is known as *khicuri* in Bangladesh, *lehata wagen* in Botswana, *kaoliang mi fan* in China, *nufro* in Ethiopia and *oka baba* in Nigeria (Subramanian and Jambunathan 1980 b).

A brief account of information obtained through a survey (Subramanian and Jambunathan 1980) is given in this paper. The boiled sorghum is mostly preferred by the village population rather than the urban or semiurban population. As a finished product, it is not usually sold in restaurants. Boiled sorghum is consumed mostly by adults and generally is not given to children below the age of 5 years. The freshly prepared product is consumed with dhal, sambar (a sauce prepared with tamarind, dhal and vegetables), buttermilk with pickles, or onion and green chillies for lunch or supper. Sometimes, it is stored overnight by adding water and consumed the next morning with buttermilk. The nutritive value may vary according to the cultivar used and the degree of dehulling, etc. The nutritional composition of boiled sorghum has been reported by Pushpamma and Geervani (1981).

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Traditional Methods of Preparation of Boiled Sorghum

Dehulling

Sorghum is traditionally used as boiled sorghum after dehulling the grains (Subramanian and Jambunathan 1980a). The color of the grains normally used varies, i.e., white, yellow, and red. The use of dehulled grain gives the product an appearance resembling polished rice. The grains are moistened and pounded in a stone mortar with a wooden pestle. The loosened bran is winnowed out and the dehulled product is used for food. The husk is used as cattle feed or is fermented in water, which is used in some food product. Generally, dehulling is done whenever needed and the grains are cooked the same day. Dehulled sorghum grain is not stored for more than 2 or 3 days.

Cooking

The dehulled grain is cooked in water in the proportion of 1 : 3. Sometimes the grains are also soaked overnight in water to soften the grain and cooked the next morning in water (Subramanian and Jambunathan 1980a). The cooking is preferably done in an earthen pot, which is heated using firewood. The grains are cooked to softness and the excess water is drained off. Depending upon the economic status of the consumer, cooking of sorghum is done with the addition of spices, mungbean, chickpea, groundnut, etc. The cooked product has to be fluffy, uniform yellow or creamy white in color, with a sweet taste. The cooked product should not be sticky with poorly defined kernels. It is also desirable that the solids dispersed into gruel be a minimum.

Standard Laboratory Procedure

Sorghum cultivars grown at ICRISAT Center during the postrainy season of 1979 were used. A quantity of 300 g samples was dehulled using a wooden mortar and pestle. The husk and brokens were removed by winnowing, and dehulled grains were used for cooking.

1. Dehulled grain samples were dried to a moisture content of about 10%. Grain characteristics such as corneousness, color and 100-grain weight were recorded.

2. The initial volume of 20 g of dehulled samples used for cooking was measured. The samples were transferred to a 500 ml beaker, to which 200 ml distilled water were added. The contents were allowed to boil on a hot plate maintained at 350° C. The completion of cooking was tested by pressing the grains between two glass slides and examining the loss of opaqueness in the center of the grain. The time required for completion of cooking was recorded. The excess water was decanted. The volume and weight of cooked samples were measured after cooling for 30 min at room temperature. The increases in volume and weight of the product were calculated as percent increase over initial volume and weight of the grain.

Evaluation of Organoleptic Qualities

The boiled sorghum (*soru*) quality of the grain was evaluated with the help of six selected farm women at Bhavanisagar (South India). Since boiled sorghum is a traditional product, persons who regularly consumed sorghum as a boiled product were selected as panelists. The panelists were requested to evaluate independently for color, taste, and texture on a scale of 1 to 3, where 1 was good and 3 was poor. The keeping quality was judged by the same panelists for acceptability, after storing the product overnight at room temperature. The keeping quality was judged for firmness of the product without off-flavor.

Evaluation of ISFQT Samples

Using the standard procedures mentioned, 25 genotypes of the International Sorghum Food Quality Trials (ISFQT) were evaluated in duplicate for cooking quality and organoleptic properties. The time required for cooking 20 g samples was highly variable, which ranged from 33 to 79 min. The increase in volume varied from 283 to 466% and increase in weight varied from 212 to 340%. The texture of the cooked grain which was subjectively scored, varied from 1 to 3.4 (Table 1).

The data on *soru* quality characters of the 25 cultivars are given in Table 2. The data indicate that *soru* from white or creamy colored grains was preferred. Although the grain with testa and colored pericarp had been dehulled before cooking, the final product was unacceptable. Boiling of

Table 1. Variability for grain and cooking quality attributes in traditionally dehulled sorghum grain.[a]

Attribute	Mean	± S.E.	Range	
			Minimum	Maximum
Corneousness[b]	2.5	0.17	1.0	5.0
Grain weight (g/100 grains)	2.9	0.16	2.1	6.4
Time required for cooking (min)	45	2.2	33	79
Percent increase in weight	274	6.2	212	340
Percent increase in volume	362	8.8	283	466
Cooked grain texture[c]	2.3	0.11	1.0	3.4

a. Based on observations from 25 cultivars of the International Sorghum Food Quality Trial. Mean of two independent determinations.
b. Corneousness of endosperm was evaluated on a scale of 1 to 5, where 1 = 80 to 100% corneous and 5 = 0 to 20% corneous.
c. Cooked grain texture was evaluated on a scale of 1 to 5, where 1 = soft and 5 = hard.

Table 2. *Soru* quality parameters of 25 sorghum cultivars.[a]

Cultivar	Grain color	*Soru*[b]			
		Color appeal	Taste	Texture	Keeping quality
M35-1	Pale yellow	1.7	1.2	1.1	1.6
CSH-5	Pale yellow	1.5	1.4	1.6	1.3
M5009	Pale yellow	1.5	1.5	1.8	1.7
M50013	Pale yellow	1.3	1.5	2.0	2.1
M35052	Pale yellow	1.2	1.7	1.5	1.7
M50297	Pale yellow	1.6	1.8	2.0	1.3
P-721	White	2.6	2.7	2.7	3.0
CO4	Red	1.9	1.6	1.6	1.1
Patcha Jonna	Yellow	2.4	2.3	2.4	2.3
Mothi	Pale yellow	1.2	1.5	1.7	1.6
E35-1	White	1.3	1.7	1.7	1.8
IS-158	White	2.0	2.0	3.0	2.7
WS-1297	Light grey (testa)	3.0	2.1	1.8	2.4
Swarna	Pale yellow	1.9	1.9	1.9	1.7
S-29	White	1.1	1.2	1.1	1.2
S-13	Pale yellow	1.0	1.0	1.3	1.7
IS-2317	Light grey (testa)	2.9	1.2	1.0	1.2
IS-7035	White (testa)	3.0	2.6	2.8	1.6
IS-7055	Reddish brown (testa)	3.0	1.8	1.1	2.0
IS-9985	Yellow	2.0	2.1	2.3	1.3
IS-8743	Dark yellowish brown	2.0	2.0	2.0	2.0
Dobbs	Brown (testa)	3.0	3.0	3.0	3.0
CS-3541	Pale yellow	1.1	1.7	1.3	1.9
Segaolane	Pale yellow	1.7	1.6	1.6	1.3
Market-1 (Ouagadougou)	White	1.5	2.0	2.0	1.8
Mean ± S.E.		1.9 ± 0.12	1.8 ± 0.09	1.9 ± 0.11	1.8 ± 0.10

a. All characters rated on a scale of 1-3 where 1 = good and 3 = poor.
b. Mean of two independent observations; each cultivar was evaluated two times by six panelists at Bhavanisagar.

grains caused leaching of pigments into the water and into the endosperm (Waniska 1976). However, the texture of the cooked product from soft endosperm types like IS-2317 and IS-7055 was very much preferred in addition to those of CO-4, M35-1 and S-29. The keeping quality of *soru* from the local variety CO-4 was the most desirable followed by that from IS-2317, S-29, M35-1 and Segaolane. The waxy grains (IS-158) yielded a sticky product.

Cooking Quality and Starch Properties of 12 Cultivars

The cooking process for boiled sorghum appears to be mostly a physical phenomenon. The chemical factors, i.e., amylose and amylopectin, were considered to be important criteria of grain quality of milled rice (Juliano 1979). Since boiled sorghum is similar to rice, analogous studies were undertaken on the cooking and starch characteristics of 12 sorghum cultivars including a waxy line, IS-158. The grain samples used in the study were obtained from the postrainy season harvest of 1979, except for two market samples.

The variation in cooking quality of boiled sorghum for the above 12 cultivars as evaluated by the standard laboratory procedures is given in Table 3. The hardness of the dehulled grain varied from 1.9 to 4.7 kg/cm^2 though the range in hardness of whole grain was 5.6 to 8.5 kg/cm^2. The cooking time ranged from 33 to 42 min. The volume expansion expressed as percent increase over initial volume of the grain was from 150 to 400. Swarna and Market-2 showed higher values, while waxy line IS-158 recorded the lowest value. Variation for increase in the weight of cooked grains ranged from 124 to 186%. There was wide variation between cultivars for gruel solids extracted into the cooking water (Table 3). Gruel solids is desired to be minimal coupled with soft cooking from a nutritional point of view. The quality of boiled sorghum was evaluated by three trained panelists using a scale of 1-5, where 1 is more acceptable. The product with pale yellow color without stickiness was rated good, which is similar to the conclusion obtained from the consumer panel. Genotypes M35-1, Market-2, Swarna, CSH-8, Local White and SPV-351 produced acceptable boiled sorghum. The waxy line (IS-158) and NK-300 produced an unacceptable product.

Starch was isolated from the whole grains

Table 3. Grain characteristics and cooking qualities of boiled sorghum.[a]

Cultivar	Grain color	Hardness (kg/cm^2) Whole grain	Hardness (kg/cm^2) Dehulled grain	Cooking time (min)	% volume increase	% weight increase	Gruel solids (g/100 ml)	Overall acceptability[b]
M35-1	Pale yellow	7.7	1.9	41	288	170	1.08	1.6
GPR-148	White	8.5	2.8	36	350	184	0.65	2.7
P-721	White with brown spots	6.1	3.5	37	388	164	1.04	3.0
Market-1 (Hyderabad)	Yellow	6.9	3.5	39	370	176	1.11	2.8
CSH-1	Pale yellow	6.6	3.4	42	225	132	0.49	2.7
Swarna	Pale yellow	6.4	2.4	39	400	186	1.3	2.3
Local white	Pale yellow	5.6	2.6	33	363	164	1.00	2.5
SPV-351	Pale yellow	8.1	3.9	37	338	170	0.61	2.5
NK-300	Brown	6.5	4.7	39	300	124	0.61	3.9
CSH-8	Pale yellow	5.8	2.5	40	300	148	1.21	2.3
Market-2 (Hyderabad)	Pale yellow	7.6	2.0	37	400	174	1.53	1.3
IS-158 (Waxy)	Pale yellow	6.0	4.0	35	150	150	0.37	3.5
Mean		6.8	3.1	38	328	162	0.92	2.6
S.E.[c]		±0.72	±0.32	±1.0	±13.2	±6.4	±0.068	±0.40

a. Five g dehulled grains were cooked with 100 ml water over a hot plate, maintained at 350° C.
b. Evaluated by three panelists for appearance, softness, and acceptability on a scale of 1-5, where 1 is more acceptable. All values are a mean of at least two independent determinations; hardness is a mean of values from 20 individual grains.
c. Standard error of estimation.

following the method of Adkins and Greenwood (1966). Swelling power and solubility of the starch at different temperatures were determined as per Schoch (1964). Gelatinization of starch was measured by the Congo red method (MacMasters 1964). Inherent viscosity of the starch solution in sodium hydroxide at 25° C was determined using the Cannon-Ubbelohde viscometer (Myers and Smith 1964). Starch granule size was measured using a microscope. The variation for starch content in grain was between 62 and 72% (Table 4). Swelling power and solubility of starches were measured at 25°, 50°, 60°, 70°, 80°, and 90° C. Swelling power of starch at 25° C showed little variation, while the variation was large at 60° C being 1.1 to 7.5. The waxy cultivar (IS-158) showed greater swelling power at 90° C than other cultivars. The variation for solubility of starch ranged from 0.3 to 1.1, 0.9 to 5.7, and 7.0 to 18.0% at 25°, 60° and 80° C respectively. The gelatinization temperature of starch from the 12 cultivars ranged between 66.0 and 70.5° C. The variation for inherent viscosity and granule size of starch among the cultivars was limited.

Correlations among Cooking and Starch Properties

The relationship between cooking quality of boiled sorghum and starch characteristics has been studied and a few of the important correlations are given in Table 5. The volume increase of cooked grain was positively associated with percent increase in weight and gruel solids (Table 5). A negative relationship was observed between cooking time and volume increase. Grains having lower hardness values produced an acceptable product (r = 0.89). Of the several starch characteristics tested, only swelling power and solubility have shown a significant relationship with cooking quality of boiled sorghum. Percent weight increase of the product showed a negative relationship with starch solubility at 60° C, the temperature at which most of the starch granules reach gelatinization. Gruel solids showed a positive relationship with starch content in the grain.

Table 4. Starch characteristics of 12 sorghum cultivars.

Cultivar	Starch in dehulled grain (%)	Swelling power[a] at 25° C	at 60° C	at 90° C	Starch solubility, (%)[a] at 25° C	at 60° C	at 90° C	BEPT[b] (° C)	Inherent viscosity (n)	Granule[a] size (μ)
M35-1	69.9	0.9	2.6	11.6	0.3	3.4	16.7	66.0	1.69	15.7
GPR-148	69.8	1.2	4.5	17.5	1.0	2.9	18.8	68.5	1.76	14.0
P-721	68.6	1.0	2.1	13.4	0.5	3.3	16.5	69.0	1.78	13.6
Market (yellow)	67.4	1.0	1.3	15.5	0.3	1.1	18.4	68.0	1.7	14.0
CSH-1	67.7	1.1	3.8	16.6	0.5	3.5	20.8	69.5	1.74	13.6
Swarna	71.8	1.1	3.8	16.6	0.5	2.9	20.9	70.5	1.76	12.3
Local white	69.5	1.1	3.0	15.1	0.8	2.5	21.6	70.0	1.71	12.6
SPV-351	66.6	1.0	4.9	18.8	1.0	2.1	22.5	68.5	1.76	12.9
NK-300	62.2	0.9	7.5	16.7	1.1	5.7	16.3	66.5	1.62	13.4
CSH-8	66.3	1.2	2.8	11.6	0.3	3.5	16.7	66.0	1.75	11.5
Market (white)	71.2	1.1	1.1	12.5	0.5	1.2	14.5	68.5	1.84	12.6
IS-158 (waxy line)	69.4	1.3	1.7	47.8	0.3	0.9	17.0	67.0	1.72	11.1
Mean	68.4	1.1	3.3	17.8	0.6	2.8	18.4	68.2	1.74	13.1
S.E. ±	2.36	0.03	0.47	0.62	0.02	0.21	0.60	0.63	0.037	2.08

a. Determined using isolated starch.
b. BEPT: Birefringence end point temperature (gelatinization temperature).

Table 5. Correlation coefficients (r) among the starch characteristics and cooking quality of boiled sorghum.[a]

Characteristics	(r)
% volume increase vs % weight increase	0.72*
vs gruel solids	0.62*
vs cooking time	−0.64*
% weight increase vs gruel solids	0.48
vs cooking time	−0.40
vs starch solubility at 60° C	−0.71*
Cooking time vs starch solubility at 60° C	0.32
Gruel solids vs starch content in grain	0.62*
vs grain hardness	−0.68*
vs swelling power of starch at 60° C	−0.72*
vs swelling power of starch at 90° C	−0.69*
vs solubility of starch at 25° C	−0.64*
vs solubility of starch at 50° C	−0.70*
Acceptability vs gruel solids	−0.65*
vs swelling power of starch at 60° C	0.67*
vs grain hardness	0.89*

a. based on 11 cultivars (waxy line IS-158 was not considered).
* Significant at 5% level; ** Significant at 1% level.

The swelling power of starch at 60° and 90° C and solubility at 25° C and 50° C showed a negative relationship with the gruel solids content. This may be due to the association of starch with factors like protein in the grain. Gelatinization temperature did not show a significant correlation with the cooking quality of boiled sorghum. But in rice, varieties with a high protein content and gelatinization temperature required longer time for cooking (Juliano 1972).

Our studies indicate that it is necessary to intensify research on the physical and chemical characteristics of starch to elucidate factors responsible for boiled sorghum quality.

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Sorghum *Couscous*: Quality Considerations

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Summary

Couscous *is the major sorghum food of the Sahclian zone of West Africa. With the exception of varieties with a thick testa or waxy endosperm, most sorghums can be prepared into acceptable* couscous. *In Mali, the most important* couscous *quality criterion is the yield of the final product compared with the original flour. There are large varietal differences for* couscous *yield that can be detected with the 20-g sample laboratory test described in this paper.*

Couscous is a steamed granulated product made from cereal flour. It is the principal cereal food of North Africa, the Sahara, and the Sahel. In North Africa and in the Niger inland delta, *couscous* is prepared from wheat, whereas in the Sahel it is prepared from pearl millet or sorghum. *Couscous* can be prepared directly into a steamed product that is eaten with a sauce. It can be steamed, sun dried, stored indefinitely, and reconstituted in milk, or again steamed and served with a sauce. The versatility of *couscous* preparation and storage serves well the migrant life style of Saharan and Sahelian pastoralists and seasonal farmers.

Preparation

Whole or dehulled grain is reduced to flour, which is sifted through a sieve with 1-mm mesh openings. Only the flour that passes through that sieve is used for *couscous* preparation.

The flour is wetted with cool water and agglomerated into small particles with the fingers. Those flour aggregates are forced through a sieve with 1.5-mm mesh openings. The wet aggregates are steamed in a covered perforated pot, which is placed directly over another pot containing boiling water. The juncture between the two pots is sealed with a damp cloth to force the steam through the perforations and into the flour aggregates. The wet cloth is wiped with okra (*Abelmoscus esculentus*) powder to assure a tight seal. In the absence of a cloth, a mixture of mud and okra powder is used to seal the two pots.

After about 15-min steaming, the aggregates form a large single chunk, which is taken out of the bowl, broken up into aggregates, and again steamed for an additional 15 min. The aggregates are again broken up into single units and sifted through a 2.5-mm sieve. At that point, the steamed aggregates can be dried and stored for future use. If *couscous* is to be consumed immediately, the aggregates are sprinkled with cool water and mixed thoroughly with the fingers. Baobab (*Adansonia digitata*) leaf powder is mixed with the particles. This powder serves as a lubricant, which prevents desiccation and stickiness, and improves palatability. Okra powder can be used as a substitute for baobab leaf powder. After mixing, the aggregates are again placed in the perforated bowl and steamed for about 15 min. The *couscous* is allowed to cool slowly and is then served with a sauce.

Couscous preparation is summarized in the diagram shown in Figure 1.

Quality Criteria

Couscous can be prepared from practically any cereal species and variety type within species. In Mali, a wide range of sorghum types is tolerated

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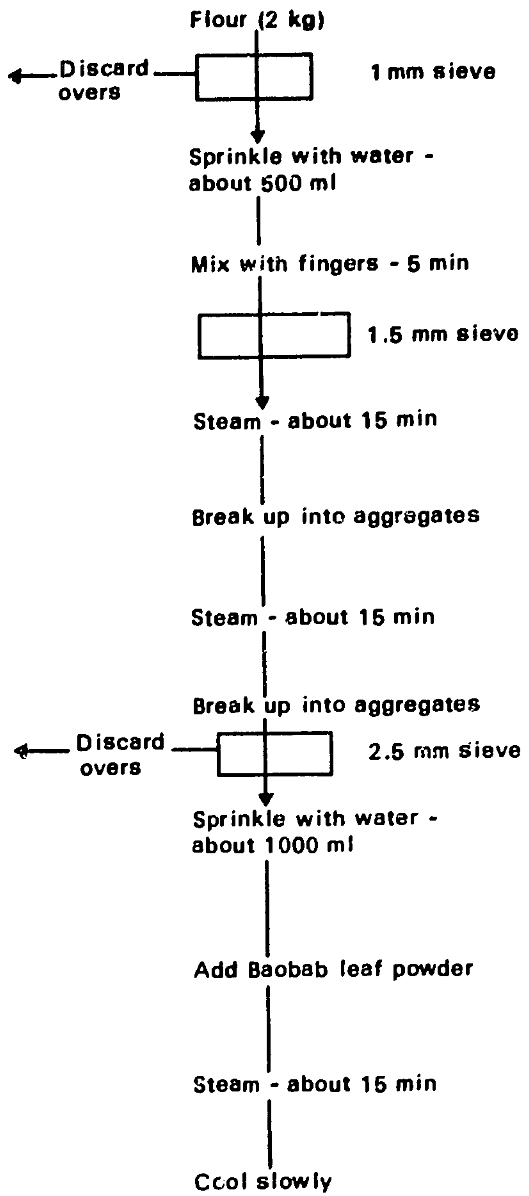

Figure 1. Summary of couscous preparation.

for *couscous* preparation. During the drought years of 1972–74, American aid sorghum made repulsive *tô*, but made acceptable *couscous*. The only sorghums that are clearly unacceptable for *couscous* are those varieties with a thick testa or a waxy endosperm. While most types are tolerated, some sorghums are clearly preferred over others for *couscous* preparation.

Given a choice, Malian women prefer to prepare *couscous* from Keninke (Snowden's *Guineense gambicum*) grain which is characteristically small and vitreous. There are three commonly cited reasons for that choice:

1. Keninke flour absorbs considerable amounts of water, which results in greater product yield than other sorghums and pearl millet.
2. In spite of considerable water uptake, the steamed granules of Keninke *couscous* remain firm and do not become mushy or sticky.
3. *Couscous* is easy to prepare from Keninke, flour and the product has consistent quality from batch to batch. Other sorghums are sensitive to the amount of water added; excess water causes stickiness and insufficient water causes dryness.

In northern Mali, sorghums with particularly good *couscous* qualities are given the name *Dagafara* which means pot breaker. That name implies that the *couscous* swells so much that it breaks the pot. It is significant that the five *Dagafara* sorghums in the Malian Sorghum Collection are all Keninke types.

We compared relative *couscous* yield of Keninke with two other local sorghums and a pearl millet. The two sorghums were Nio-Fionto (Snowden's *Nervosism* var *membranaccein*) and Gadiaba (Snowden's *Durra* var *cernuum*). Both of those sorghum types are common in northern Mali where *couscous* is the principal food preparation. The millet was Sanio, the common full season variety. The data for *couscous* preparation are summarized in Table 1.

The Keninke sorghum yielded about 35% more *couscous* product than the other two sorghums. The swelling of Keninke *couscous* granules is such that there are few oversized granules lost over the 2.5-mm sieve, yet the total yield is very high. The Keninke granules allow considerable water absorption without losing granule integrity. That characteristic is very similar to the quality sought in wheat semolina flour destined for pasta products: the ability of the semolina to take up considerable water, yet make a strong dough.

Quality Measurement

The senior author devised a rapid small-scale laboratory test that will enable breeders to detect *couscous* product yield differences between varieties that occurred in the large-scale preparations (Table 1). The test consists of the following steps:

1. Whole grain (20 g) is ground in a Salton Quick Mill for 1 min.
2. Water (12 ml) is mixed with the flour until it is uniformly wetted.
3. The flour is placed in a small piece of cotton cloth in a small perforated bowl over a small pot of boiling water.
4. The perforated bowl is covered and left over the boiling water for 3 min.
5. The steamed flour is broken up into small pieces with a spoon and again steamed for 2 min.
6. The steamed flour is again removed and broken up. The flour is sprinkled with 20 ml water and stirred to obtain uniform wetting.
7. The flour is again steamed for 2 min.
8. The steamed product is removed from the cloth and immediately weighed.

Using flour from the same grain lots as the varieties in Table 1, we obtained the mini-test data in Table 2. These results consistently reflected the varietal differences recorded in large-scale preparation. The Keninke and Sanio millet consistently yielded more than the Gadiaba and Nio-Fionto sorghums. The relative total water uptake was greater in the mini-test because the total steaming time is only 7 min compared with 45 min in large-scale preparation. Using Keninke sorghum as a check, we will be able in the future to differentiate between high and low *couscous* yielding varieties.

Conclusion

Our sorghum breeding program is generating many agronomically promising varieties and hybrids for the north of Mali. When yield considerations are the same, we would like to identify those varieties and hybrids that most closely approximate the *couscous* quality of Keninke sorghums. The use and perfection of the small-scale laboratory test described in this paper will enable us to predict the *couscous* yield and granule quality of promising new varieties being made available in our breeding program.

Table 1. Relative *couscous* yield of major Malian sorghum and millet types.

Variety	Flour weight (g)	Overs of 1-mm sieve (g)	Flour used for *couscous* (g)	Volume of first water addition (ml)	Overs of 2.5-mm sieve (g)	Volume of second water addition (ml)	Final weight of *couscous* (g)	Weight increase (%)[a]
Keninke	2390	225	2170	545	135	1000	3715	59
Gadiaba	3200	125	2875	600	420	800	3895	22
Nio-Fionto	1830	115	1715	500	150	950	2280	24
Sanio	1670	100	1570	200	0	1000	2450	46

a. Final weight above original flour weight used for *couscous*.

Table 2. Mini-test *couscous* yields.

Variety	Flour weight (g)	*Couscous* weight (g)	Weight increase (%)
Keninke	20	58.8a*	194
Gadiaba	20	52.0b	160
Nio-Fionto	20	51.8b	159
Sanio (millet)	20	57.0a	185

* Means followed by the same letter are not statistically different at $P = 0.05$.

Fermented Beverages

L. Novellie*

Summary

Fermented beverages, both alcoholic and nonalcoholic, of Africa are surveyed from a number of interlinked points of view, including low and high-level food technology, organoleptic qualities and their changing nature, problems involved in reconciling consumer preferences and processing qualities with agronomic needs and realities, types of cultivars available, the polyphenol and bird problems.

Fermented beverages may be classified in a number of ways, for example, according to the raw materials used and the types of fermentation involved.

In Africa, the great majority of nonalcoholic fermentations are sourings, mainly lactic fermentations. Lack of precise microbiological control under tribal conditions makes it difficult to conduct fermentations that are absolutely pure, i.e. only alcoholic or nonalcoholic. Nevertheless, some degree of control can be exerted in practice and many of the soured beverages produced have low, or negligible, amounts of alcohol in them.

The alcoholic beverages can be classified into beers and wines. Beers are commonly made from cereals and the steps involved in their preparation may be divided into two groups. The first group involves (a) steps to convert the cereal into a medium suitable for yeast growth and alcoholic fermentation; and (b) steps that give the beer some special characteristic, e.g., hop flavoring in the case of European beers, and souring in the case of some African beers.

In the first group, reactions are brought about by using the enzymes formed when a cereal is sprouted or malted, to degrade starch to sugars and proteins to peptides and amino acids. Raw starch and native protein are not easily degraded, so it is usual to cook, completely or partially, at least part of the cereal. Since malt is expensive and/or difficult to make, brewing formulae (technically called mash bills) often include unmalted cereals. These supply substrates such as starch and protein but little or no enzymes. Sorghum, for example, has no amylases (Novellie 1977) while barley grain has only a little β-amylase but no α-amylase. Malt is thus an essential ingredient of all beers.

The cooking of substrates for brewing purposes has, of course, close connections with porridge preparation, while the souring of porridges is closely related to souring in sorghum beer brewing.

The second group of steps comprises those needed to bring about an alcoholic fermentation without other undesirable microbial activities occurring. Alcoholic fermentation gives two major products, alcohol and carbon dioxide, and many minor products of fermentation such as higher alcohols, esters, etc. These minor products of fermentation are responsible for the characteristic flavor and aroma of the many varieties of beers and are thus of great organoleptic importance.

Beers may be further classified according to whether the yeast is a top fermenting or bottom fermenting yeast. Most African (indigenous) beers are top fermenting with a very mixed flora of yeasts. Johannsen (1972) has made a survey of cultured and wild yeasts in sorghum beers.

Beers, Brewing Processes, Recipes

Information on brewing in Africa is difficult to obtain and often of little use. For example, there are a number of often quoted old publications, e.g., Turner (1909), Juritz (1906), Bryant (1967—a reissue, hence the later date), that have

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their place in anthropological history but otherwise serve little purpose. It is of little practical value to the food technologist to have recipes for traditional foods and beverages that have all but vanished from the daily diet of the majority of the members of the tribe. Considerable emphasis has been placed on the supposedly unchanging, and unchangeable, nature of tribal customs and traditions. This is not correct. Africa is in a state of transition from old tribal traditions and customs to a peculiar mixture of the old and the new; the new being that of the Western World and modern technology (Malinowski 1965, p. 102; Latham 1965, p. 16; Jones 1963, p. 79). The particular mixture of old and new encountered in any area depends on many factors, especially the degree of urbanization. Up-to-date surveys of food habits and preferences are urgently needed since much of the older literature tends to be misleading.

Squires (1938) gives the method for brewing in Botswana (Bechuanaland) and Beemer (1939) describes the Swazi process. Kretschmer (1981) has described the preparation of *busaa* beer in Kenya, while Muller (1970) described *pito, burukutu, kunnu tzaki* as kaffir beers. Ogundiwin (1977) deals with *otika* ale as made from sorghum (guinea corn) in Nigeria. Ekundayo (1969) concentrated more on the microbiology of *pito* but gave a description of tribal and laboratory preparations of the beverage. Miracle (1965), in a chapter devoted to Food Technology in Africa, treats a wide range of African beers and wines from the point of view of raw materials, recipes and tribal preferences.

Typical Modern Sorghum Beer Brewing Procedure in South Africa

A typical modern formula and process used to make millions of hectoliters of sorghum beer is given below.

The first fermentation is a lactic acid fermentation called souring, with the medium being a 10% malt slurry, for example, 300 kg as is sorghum malt (270 kg dry mass) together with 2700 liters water, inoculated with *Lactobacillus leichmannii*, is held at 50° C for 12–16 hr, after which time pH is 3.3 with 0.8 to 1.0% lactic acid content. To this sour, 2750 kg as is (2420 kg dry mass) refined maize grits (degermed, less than 1% fat) are added, plus water to a volume of approximately 15000 liters. The slurry is cooked at 75 kPa for 10 min, then cooled to 60° C and mashing starts; at this temperature 800 kg sorghum malt as is (720 kg dry mass) are added. Volume is adjusted to 24200 liters, with total solids now about 14% and the pH 3.9 to 4.0. This mash is held for between 45 and 90 min until approximately 6% fermentable sugars (measured as glucose) is reached. This mash is centrifuged through Alfa Laval or Westfalia decanters to achieve a separation of coarse particles (sizes larger than 0.250 mm are unwanted). The liquid called wort consists of about 22000 liters. The wort has a pH of 3.9, 0.16% lactic acid, fermentable sugar as glucose 6.0%, a specific gravity of 1.037, and total solids 11.8%. The residue, called strainings, contains about 37% solids so that about 24% of the initial dry solids are discarded.

Second fermentation is based on a *Saccharomyces cerevisiae* sp which grows and ferments well at 25 to 30° C. After 48 hr the active fermentation beer is ready for consumption (note that yeast is not removed). The beer characteristics are pH 3.6, lactic acid 0.26%, total solids 6.20%, glucose 0.15%, ethanol 2.9 to 3.0%, and acetic acid 0.03%.

Wines

These are usually made by an alcoholic fermentation of plant saps or juices, e.g., grape or apple juices, palm tree sap (Okafor 1975a,b; Bassir 1968; Faparusi 1970; Miracle 1965, p. 132). The beers and wines of Europe are almost invariably clear beverages; those of Africa are often cloudy or heavily turbid, i.e., suspensions of noteworthy amounts of insoluble material—a difference of considerable significance nutritionally.

The term *wine* is sometimes used to describe the clear liquid obtained by clarifying a strong African-type beer (cereal beer) (Chevassus-Agnes et al. 1976), but this is rather misleading.

Fermented but Nonalcoholic Beverages

Because yeasts are so widely distributed and multiply and ferment sugars so rapidly and readily, alcoholic fermentation is extremely common and widespread. In spite of this, nonalcoholic beverages are also common. These are usually sour, lactic acid being the chief souring agent. This sourness seems to have a great appeal to the African palate. The generally very hot climate no doubt makes an easily prepared thirst quencher very popular. The high acidity of such beverages (low pH) keeps pathogens from proliferating, an important point in areas of contaminated water supplies. African babies are often weaned on soured paps or, where milk is available, on soured milks. This early conditioning to lactic acidity is perhaps another factor in the popularity of this type of beverage.

Maize, sorghum, and the millets in particular, are often good sources of lactobacilli. The process of malting naturally encourages the development of a variety of microorganisms on the grain. Under tribal conditions, grain storage, malting, brewing, and cooking, all take place within a very limited area, quickly resulting in the buildup of a very favorable microflora for inoculation.

Mahewu, amahewu, emahewu, amaheu, amarewu, marewu, magou, all refer to the same product—a sour, normally nonalcoholic drink made of maize meal, very popular amongst the Bantu-speaking tribes of Southern Africa (Quin 1959, 1964; Hesseltine 1979; Jones 1963). It is "used to satiate hunger and quench thirst" (Jones 1963, p. 83).

Sour Beverages as Opposed to Sour Porridges

Often the only difference is in the concentration of the cereal present. Golberg (1946) gives (his Table VIII) the concentration of solids in *marewu* as 9%, while that of *lambalaza* (soft sour porridge) was 14.7%, and *leting* (a fluid, not to be confused with *ting*) was 9.5%.

Muller (1970, p. 190) classifies beverages as low-viscosity liquids with a water content of more than 94%. This means that the content of non-volatile materials would be under 6% in the case of nonalcoholic beverages (and much less than 6% in the case of alcoholic beverages). These figures do not accord with those of Golberg (1946) or with those of the modern industrially made *mahewu* (8.8% solids).

Mahewu Formula Used on an Industrial Scale

An 8% suspension of maize meal is pressure-cooked for up to 1 hr at 1.3 atmosphere, after which the mixture is cooled to 45 °C; 0.8% of unrefined wheat flour and 5 to 10% of *mahewu* from a previous batch (as starter) is then added. The mixture is allowed to ferment for approximately 20 hr when the product will be ready for consumption. A thinner *mahewu* can be made by adding more wheat flour; a thicker product by using either less wheat flour or preferably more maize meal. Perhaps the difference in solids is tribal since Muller was dealing with Nigeria and Ghana, while the other results refer to Southern Africa.

Hesseltine (1979) reviews the traditional and modern processes of making *mahewu* (*magou*). Quin (1964) and Waldmann (1975) describe *metôgô* of the Pedi (Bapedi), a nonintoxicating beverage made with cereal meal and sorghum malt, which resembles *leting* (Golberg and Thorp 1946, p. 183). According to the latter authors, *leting* may be prepared from meal and malt, from maize, sorghum, finger millet, or bulrush millet; the recipe varies from one part of Africa to another. This souring of meal and malt resembles the first stage of sorghum beer brewing. The straining of the mixture to give *leting* removes much of the insoluble cereal solids, which include most of the substrates and some of the enzymes, e.g., maltase. This must limit microbial action. Table 1, adapted from Doidge (1910), is illuminating.

In view of the prevalence of alcoholic fermentation, how can the primitive technology direct a fermentation towards souring? The necessary lactobacilli are present, but so are the yeasts. One answer is temperature control. Many tribal brewing procedures involve a step where boiling water is poured onto a mixture of malted and unmalted cereal. This causes partial gelatinization of starch and some amylase destruction, but a surprising amount survives. Sugar is produced readily at the elevated temperature of the mixture. Thermophilic lactobacilli can flourish but not the yeasts. The gelatinous mass (sometimes it is worked up as a

Table 1. Souring of *leting* (sorghum malt sour). Source: Doidge (1910).

Analysis	Days of fermentation[a]					
	1	2	3	4	5	6
Alcohol by volume	0.2	0.9	0.4	2.0	2.6	3.1
Total acidity as lactic acid (g/100 cm^3)	0.5	1.0	1.3	1.6	1.8	2.0

a. Under normal circumstances the beverage would not be kept for such a long period.

dough) cools only slowly, thus further favoring souring. As the temperature drops towards the range suited to alcoholic fermentation, the mesophilic lactobacilli take over. Finally, the yeasts get a chance to multiply and ferment. A similar succession of lactobacilli to yeasts has been observed in sake although not provoked by temperatures (Kuriyama 1979, p. 298). By this time there is not a great amount of sugar left and only a little alcohol will be produced. It is because of this that it is usual, when making beer, to add more malt at this stage, thus causing a second conversion of starch to sugar and eventually giving more alcohol.

The quantity of sugar produced in the first conversion will depend on the quality and quantity of malt employed. A malt of low diastatic power (d.p.) will naturally produce less sugar than a malt of high d.p., weight for weight. Careful tests with a graded series of malts (gradually increasing d.p.) have shown that souring is not greatly influenced by d.p. Apparently, even in a short-malted malt there is more than sufficient nitrogenous breakdown products to promote healthy lactobacillus growth. According to Whiting (1975, p. 79), "as little as 0.03% hexose yields sufficient energy for the growth of 10^8 cells per ml," (dealing with lactic acid bacteria in ciders and wines). This explains the extreme case where souring is conducted with only unmalted cereal whose sugar content is low. From this, one sees that control of temperature and sugar can be used to favor production of lactic acid instead of alcohol. As carried out under tribal conditions, the control is not perfect and sour beverages and foods may sometimes be slightly alcoholic. The relative unimportance of d.p. takes us to an important conclusion, i.e., variety as it affects malt amylase quality is not important in the production of sour beverages. The exact opposite is true of brewing, i.e., variety very much affects d.p. and a good d.p. is vital to successful brewing. Although the influence of variety on amylase production is not important in souring, this process is influenced by the presence of polyphenols, which inhibit the lactobacilli used in sorghum beer souring (Watson 1975)

Factors Affecting Cereals Used in Brewing and for Food

In many cases, maize has come to be the dominant foodstuff and has displaced sorghum and millets (Murdock 1959, p. 387; Latham 1965, p. 16-17; Doughty 1979, p. 281). In some cases, rice is dominant over the other cereals; in others, cassava has replaced cereals. In general, some staple has displaced the coarser grains—sorghum and the millets. Two points are important here. First, foods and beverages made from maize can usually be made from sorghum provided certain disadvantages inherent in the use of sorghum are overcome. Second, the conservatism of the African consumer, together with a growing desire for whiter and more refined foods, makes it difficult to go back to the more distant past.

For instance, in Southern Afric , the general displacement of sorghum by maize in the making of the thin, sour drink *amahewu* is sufficiently far in the past for the use of maize to have become "traditional" or at least widely acceptable. To persuade the African to turn from maize meal, a standard product available everywhere from every tiny country shop, to sorghum, which is not available in a *comparable* form, would be a major undertaking and one not likely to succeed. It is important to realize that in promoting sorghum, one is going against a general trend in the food world. In considering the development of new and improved cultivars, this must be taken into account. There is some evidence of a reversal of this trend (Vogel and Graham 1979, p. 43) i.e., sorghum is gaining some ground over maize. In Nigeria, the improved sorghums seem less popular than the traditional (D'Silva and Raza 1980, p. 237). Recently in South Africa, sorghum, because of a favorable price difference compared with maize, has made a minor comeback in sorghum beer brewing (Novellie 1981).

Sorghum Malting Studies

The development of new varieties and hybrids in the world of cereals and other crops has undoubtedly produced notable improvements in yields, disease resistance, etc. Unfortunately, the new cultivars have not always possessed the same cooking and processing characteristics as the older types. The South African sorghum beer industry has been plagued with brewing troubles stemming directly from the introduction of unsuitable cultivars. These sorghums are weak producers of amylases when germinated. Lack of sufficient amylase activity in sorghum malts results in poor thinning and saccharification of cereal mashes—processes essential to the production of sorghum beer. Ten years of research has enabled us to classify sorghum cultivars according to their ability to produce diastatic activity (joint α- and β-amylase activity) during germination, and has revealed the extent to which this activity varies with season and locality. The best cultivars are those that consistently produce a high activity, whatever the season or locality.

Daiber in a series of reports deals with sorghum cultivar evaluation (Daiber and Achtig 1970a,b; Daiber 1971, 1975, 1978a, 1979, 1980) and of all the characteristics studied, the ability to produce amylases on germination has always been the most important. Many other grain and malt qualities have been studied, e.g., specific gravity, moldiness, malting loss, Brabender hardness (ease or otherwise of grinding), percentage germination, water sensitivity, water uptake, 1000-kernel weight, protein, magnesium, polyphenol, and free amino nitrogen content.

Although the list of cultivars examined has changed over the years, it has been possible to investigate a good number of varieties over a number of seasons and to build up a good picture of their qualities. It has also been possible to examine the effect of environment (farms in different districts). Cultivars were grown by the South African Department of Agriculture and Fisheries under carefully controlled conditions and thus constitute well authenticated materials. A survey has been made of commercially available grain (Daiber 1975). All results have been statistically analyzed including multivariate, stepwise regression analysis.

The screening of varieties is painstaking and time-consuming, and it is exasperating to see a good malting cultivar vanish from the market because of unforeseen agronomic weaknesses, only to be replaced by a succession of weak amylase producers. In spite of all this, the years of research have achieved notable successes. Our group now has a place on the cultivar selection committee, i.e., the processor and consumer have a voice and selection is not entirely in the hands of agriculture. South Africa is in the process of changing over to an entirely new sorghum-grading system based on malting and feed qualities, with premiums for malting grades. The new system makes a fundamental distinction between birdproof (bird-resistant) and non-birdproof sorghums, which means, at the present juncture, a distinction between high-tannin (polyphenol) and low-tannin types. This is a distinction of great importance, not only to brewers but also to those who make foodstuffs from sorghum.

All this points to the moral that there must be good communication between grain processors, breeders, and producers.

Varieties and Cultivars Suited for Fermented Food and Beverages

Beers

The most important characteristic of a sorghum for brewing is its ability to produce amylases when germinated. No other quality is of greater importance.

In the brewing of European type beer from malted barleys, the amount of extract obtainable is very important and varies with variety as well as many other factors. The solubilization of starch and other substrates in African beers is of much less importance since these beers are, according to tradition, usually rich in suspended material including unconverted starch. In those cases where the beers are filtered to give fairly clear liquids, greater solubilization of substrates would give a better yield of beer and less residue (beer waste, strainings, draff, spent grains). These residues are sometimes used to make "small beers" (second beer, third beer). Small beers, usually light in alcohol, can be nutritious (Golberg 1946). In many cases the spent grain or beer waste is fed to livestock.

Bird-resistant or High-tannin Grain

A high content of polyphenols in the grain or malt adversely affects beer making, souring, and the feeding of humans and livestock. Bird-resistant cultivars usually malt well to give high diastatic power malts. In the unground malt the enzymes are separated from the polyphenols that occur in the outer layers, specifically the testa (nucellar layer) of the grain. Milling and mashing brings enzymes and polyphenols together. Depending on the stoichiometry, there will be a greater or lesser degree of enzyme inhibition. Inhibition with high tannin varieties can be so severe as to completely wreck the brewing process. The polyphenols also directly inhibit the souring organisms employed in African beer brewing (Watson 1975). As long ago as 1910 a bitter, astringent variety of sorghum was known to the Zulus as being poor for brewing according to Doidge (1910), who complained of the vagueness of the varietal descriptions. This is still the case with much of the later literature.

There is little doubt that high polyphenol sorghums are unsuited for food and brewing purposes without treatment. Any pretreatment procedure should be as simple as possible while not damaging the nutritional and other qualities needed for the product to be made from the grain.

The simplest mechanical treatment is pearling (dehusking, debranning), but this removes not only the unwanted husk and tannins, but also valuable nutrients. Furthermore, pearled grain cannot be used for malting.

Chemical Treatments

Quite a number have been put forward but I propose to deal solely with that devised in our laboratories (Daiber 1978b) because it is relatively simple and effective, but not well known. Briefly described, the bird-resistant grain is treated with a calculated amount of very dilute formalin solution for 4 hr, washed and further soaked in water, then put to germinate. The amount of formaldehyde required depends on the quantity of grain and its polyphenol content. The latter is very much cultivar-dependent and little affected by season and environment. By suitable modifications this treatment can be applied to grain for purposes other than malting.

In circumstances where such treatment cannot be applied, for example, where no agricultural extension services or similar offices are available, then high tannin sorghums are not a suitable choice for planting. One must bear in mind that, where subsistence farming is not the rule, such grain can be sent from the farm to the city for treatment.

Recommendations

Very useful general recommendations are made by Vogel and Graham (1979, pp 63-64). The links between cereal breeders and food scientists are certainly most important. It is very important for food scientists, even senior scientists, to make the various foods themselves. I have never regretted the time spent in making porridges and brewing beers personally. Time spent in tasting is never wasted; it gives one a better appreciation of the organoleptic qualities even if one never becomes an expert. The setting up of African taste panels must rate a high priority. Expert advice is needed in the setting up of taste panels and test procedures, for whatever group, because the field of organoleptic assessment has become highly specialized.

Food scientists need to establish quality criteria and tests for each food and beverage with which they are concerned. One should realize that well-established tests and standards are not always available for European foods and with African foods one has a long way to go.

The most important quality tests may need modification before they can be applied to the small quantities of material available to breeders. Clearly, the earlier we can gain some idea as to whether a cultivar meets the food processor's requirements or not, the better it will be for progress.

Although low-level technology and cottage industries have an important role to play, it is also desirable to examine at the same time the possibilities for higher-level technology. I say "higher" but not "high" level, as very sophisticated technology is not appropriate to the lesser developed countries. In fact, very high-level technology is rapidly becoming too expensive even for wealthy, developed countries. Higher-level technology can provide more jobs and also more reliable products with better shelf-life. Attention should be given to the manufacture of semiprocessed products and intermediates. These can be cheaper than fully processed preparations and can be time-savers in the home. Successful low-level technology requires either great ingenuity or much scientific background and sometimes both.

I can assure you as someone who has spent 28 years on sorghum malting and brewing, that high level technology requires a tremendous and continued research input. The development and improvement of sorghum and millet based human foodstuffs will require similar inputs.

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Fermented Porridges

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Summary

This paper surveys African fermented porridges and notes the ways in which they resemble and differ from fermented beverages of alcoholic and nonalcoholic nature. Problems in the organoleptic assessment of African foods are discussed, together with those of linking process parameters with consumer likes and dislikes.

Fermented porridges are undoubtedly very important items of the African diet (Quin 1964; Waldmann 1975; Beyers et al. 1979; Manning et al. 1974). These porridges differ with regard to the cereal or root crop used and the fineness of grind, as well as the method of preparation and nature of the fermentation.

The raw materials, methods of preparation, and general quality characteristics of fermented porridges have much in common with those of fermented cereal beverages, such as sorghum beer, so the division between fermented porridges and fermented beverages is rather artificial.

Many publications, especially the older ones, mention the great variety of dishes consumed by the African in traditional tribal life (Quin 1964, 1959).

Many dishes are served with pot herbs or types of spinach (tender leaves of certain plants). The African consumer regards a porridge or stew served with two different herbs, etc., as distinctly different dishes. This may also be the view of the nutritional expert since different herbs may differ in nutrient content, but the basic component remains a cereal or root crop (Manning *et al.* 1974). From the point of view of the food technologist and cereal scientist, the different herbs and relishes served do not change the basic problem.

A number of publications have pointed out that food choices have diminished over the years (Waldmann 1975; Doughty 1979; Robson 1976; Omololu 1971). Waldmann (1975, p. 145) stated that most of the relishes quoted by Quin (1964, 1959) are no longer available. Doughty (1979) indicated the dangers of a reduced food choice and quoted a number of illuminating examples. Robson (1976) showed that the variety available has diminished, a multiple choice of cereals often giving way to one cereal or root crop, frequently maize. Annegers (1973) gave details of the geographical patterns of starchy staple consumption in West Africa and concluded that the use of staples has significantly changed in this century.

Many beliefs, habits, and traditions concerning food are dying or have died out (Omololu 1971). A new or modified food will only be regarded by the masses as a prestige product if consumed by well-off or well-placed people.

Manning et al. (1974) have studied dietary patterns of urbanized Blacks and found that soured and fermented foods were still popular, but in general, there was a move away from the traditional tribal porridge-bowl pattern.

Thus the diet has become increasingly monotonous and ill-balanced. This adverse state of affairs may be partly ascribed to the change from the production of three or four cereals, in relatively small amounts, to the massive production of one cereal, often maize. There is a tendency to favor whiter, blander products, e.g., those from white maize rather than yellow maize (Latham 1965), and those from maize rather than from sorghum. There is also a desire for less fiber and coarseness in food products. The small-grained millets are in a less favorable position because of higher bran to endosperm ratios, than the larger grain cereals, particularly maize.

Another influence tending towards nutritional imbalance is what might be termed the sophistication factor. The more sophisticated urban dweller, aided by the advertising media, is exerting an

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effect on his country cousin. The highly refined foods of Europe and the United States, bleached flour, super-white bread, etc., have become status symbols. There is consequently a move towards these and a move away from those regarded as "primitive", "old-fashioned", or "peasant type" foods.

All these factors must be borne in mind when considering the quality characteristics demanded of a new cultivar of sorghum.

Quality Characteristics Desired

These may be broadly divided into process characteristics and organoleptic qualities.

Process Characteristics

These are qualities essential to the process. For example, if starch is to be converted to sugar, then enzymes are essential. It would include the factors affecting processing properties and yields of desired product(s).

Organoleptic Qualities

These are the qualities demanded by the consumer. His demands may be pure and simply traditional *or* a mixture of traditional and sophisticated (as previously described).

Determining the African consumer's organoleptic demands is one of the most difficult and neglected fields in food science. It is so important as to deserve special consideration here. Assessing the qualities of foods and beverages is normally handled by taste panels which may be roughly of two types.

Expert Taste Panel

This consists of people very experienced in tasting the particular product and usually very knowledgeable about its raw materials, processing, quality control, etc. Their judgments are of great value to the food processor, factory manager, etc. Just occasionally they are out of touch with what is really required by the man in the street.

In the case of many African foods and beverages, such experts are not available (De Garine 1972, p. 147).

Layman's Panel

This is composed of housewives or the consumers. They may know what they like but are often inarticulate when it comes to describing likes and dislikes. They have no technical vocabulary such as the experts possess. The layman (or woman) is not always a consistent taster. Those who are inconsistent in their judgments must be discovered and eliminated from the panel. This is a precaution quite often neglected.

People who never consume African dishes or beverages are in general useless on taste panels. Taste panels have many problems, chief of which are linguistic, educational, and psychological. Many food terms in African languages either have no equivalents in European languages or the equivalents are unknown to the panel members (and also to the panel organizers and controllers). Similarly, many technical terms employed by the food technologist, e.g., viscosity, consistency, mouth feel, etc., are either difficult to translate or have no equivalent in African languages.

Psychological factors include a lack of trust between the panel members and the organizers of the tests. Panel members may feel they are being duped or led to approve something of poor quality. In many cases there is a desire on the part of the panel members to please the organizers and to avoid appearing rude by expressing disapproval of a product. The panel member may also feel that his image is on trial and may not want to appear unsophisticated. He will, therefore, express approval of what he believes to be a sophisticated product and disapproval of, or give a lower rating to, a traditional but unsophisticated product.

The net result of all these factors is a misleading judgment. Much patience and many discussions are needed to establish understanding, trust, and real communication.

The above statements apply to panel tests used to evaluate new varieties of grain as well as to the introduction of new products.

Types of Fermented Porridges

In surveying African foodstuffs and beverages, one is often confused by the multiplicity of recipes and the claims made for the superiority of the particular variety of cereal, tuber, etc., used and the associated process. This confusion cannot be resolved unless we realize the truth of the saying: "*Chacun a son goût*!" We must pay attention to the likes and dislikes of a particular tribe or a particular area. We must be wary, however, of translating these preferences into generalizations.

From the scientific point of view we must seek out the fundamentals of the raw materials and their processing so that we can have a basic understanding of the production of all fermented porridges. The next stage is to link process parameters to organoleptic qualities. This enables us to link the fundamental and general to the particular.

In the early years of our research we were often asked, mostly by laymen, to find the ideal recipe. We were never able to find such a recipe. Firstly, tribal recipes are almost always quantitatively vague; secondly, they sometimes include steps serving no known or discoverable purpose. The ideal recipe fallacy can be exposed by considering the question: how sour should a sour porridge be? The answer is simply, as sour as the consumer wants it to be! Since the consumer's tastes vary with his age, his tribal background, etc., there is no ideal degree of sourness but a range of acceptable sourness. The research worker must, therefore, study the souring process to determine the range of acidities achievable under a variety of conditions, using a variety of raw materials. Organoleptic testing can link the characteristic studies with tribal and other preferences.

The Preparation of Sour Porridges

The ways in which sour porridges can be made vary considerably. There are three operations to be considered: grinding (with or without sifting), souring (with or without inoculation), and boiling (in original medium or in fresh water). The order in which these three operations are carried out varies from region to region.

1. Whole Grain—Wet Process

The whole grain is soaked for several days. Microorganisms on the grain surface grow on materials leached from the grain. The microbial metabolic products influence the grain itself. At the same time, the prolonged soaking promotes autolysis within the grain. The soaked grain is ground and sifted using more water. This can be left to sediment and sour further (Akinrele and Bassir 1967). The sediment can be filtered through a cloth and pressed to remove water. This preparation can be dispersed in water and boiled to give porridges of various consistencies according to the concentration chosen (Oke 1967).

2. Whole Grain—Dry Process

The whole grain is ground dry and not sifted. It is then mixed with warm water, with or without an inoculum of previously soured porridge, and allowed to sour overnight or a little longer. When soured according to the consumers' desires, the mixture is boiled, with or without further dilution with water.

3. Fractionated Grain

There are three major variations:

(a) The dry grain is ground, winnowed and sifted to give a flour or grits (semolina type of product).

(b) The grain is dry pearled (dehusked, debranned), winnowed or sifted, ground, fermented, etc.

(c) The grain is moistened (or soaked) and pounded (mortar and pestle) to dehusk, winnowed, and/or sifted. It is sometimes dried and stored but is usually used immediately. The soaking given is not long enough to cause extraction of solubles to an appreciable extent.

All these preparations, (a), (b) and (c), have the cereal nutrients minus the fraction sifted out or pearled off. Such losses can be appreciable and are very much influenced by the desire for whiter and finer products.

Many of the processes can easily be carried out either with legumes or mixtures of cereals and legumes. Similarly, cereal malts can be admixed with unmalted grain. Malts can have an important effect on flavor, viscosity, and sugar content, and consequently affect the course of the fermentation. In Southern Africa, the processes outlined under (2) and (3) are most common.

4. Souring of an Unsoured Porridge

A porridge is first made in the normal way (or leftover porridge is taken) and then it is soured. Souring may easily be achieved with the thinner types of porridge by mixing in *mahewu* (Novellie 1981) or other soured products. Thicker porridges are not easy to inoculate (although they may be diluted); however, spontaneous souring may occur, especially if the porridge is not too dry and if it has not been well-cooked, i.e., unsterilized.

Milling and Extraction

A low extraction rate (high degree of refining) gives a product nutritionally inferior to the original cereal or legume. These products are richer in starch and whiter in color than those obtained with high extraction rates. Milling and sifting in the United States and Europe are characterized by a high degree of automation, control, and reproducibility, while the traditional and slightly modified and modernized methods used in Africa are often variable. In investigating particle size and its effect on cooking, nutritional quality, and organoleptic characteristics, one must be prepared to deal with a wide range of fine and coarse materials. Scattered throughout the literature are references to "fine" and "coarse," which have no precise meaning but serve merely as a starting point for any investigation of milling and organoleptic qualities. Beemer (1939), for example, points out that grinding for beer need not be "too fine" but for *incmbe* (food for suckling children) one goes to a "very fine powder."

Carr (1961), in a study of traditional grinding methods (mortar and pestle; grinding stones or quern) in Southern Rhodesia (Zimbabwe) found that they gave a low extraction rate and, consequently, nutritional impoverishment of the final product. The introduction of power-driven hammer-mills, giving a substantially straight-run product, gave nutritionally superior products. One wonders for how long this continued. The temptation on the part of miller and customer to have whiter and more refined products surely modified this happy state of affairs.

Golberg et al. (1946) studied a large number of milled fractions from a wide variety of South African cereals and legumes. [See also Golberg and Thorp (1946) and Golberg (1946) for related works.] Their data permit some comparisons between industrial and traditional milling and the effects on thiamine content. Pilon et al. (1977) followed the way in which lysine, ash, thiamin, and niacin were distributed between the fine, coarse, and bran fractions of milled sorghums. Ali and Wills (1980) showed that cooking times of sorghum were reduced by pearling. However, no mention was made of the concomitant nutritional losses.

The amount of damaged starch has been related to different milling procedures and fractions (Mustafa 1978). With amylases, damaged starch produces sugars without cooking being necessary. Pilon et al. (1977) and Abecassis et al. (1978) have studied milling from the point of view of flour and pasta production. These studies could usefully be integrated with investigations of porridges and beverages and the relation of fine and coarse, floury and corneous particles to viscosity, mouth-feel, etc. A number of useful observations on milling and food quality are given by Vogel and Graham (1979). A report on milling as an agroindustry for Botswana is available from the Sorghum and Millet Information Center (Anon. 1981).

The Effect of Sifting

Sifting of ground cereals has a considerable effect on the processing or food characteristics of the resultant products. Sifting changes the husk or bran content and the ratio of peripheral endosperm to interior endosperm.

Husk or Bran Content

The fiber content is usually decreased by sifting. Diminished fiber gives smoother, more bland products, less mouth irritation, and whiter or lighter color. The consumer experiences reduced bowel bulk and possibly, a smaller loss of nutrients such as trace elements, which are complexed and rendered insoluble by bran constituents, particularly phytic acid.

Although bran absorbs water and swells on cooking, its influence on viscosity is much less than that of starch. Hence higher bran content implies less starch, and produces less viscous porridges with a different mouth-feel.

Ratio of Peripheral to Interior Endosperm

It can be increased or decreased by sifting procedures depending upon circumstances. The amount of peripheral endosperm can be boosted to a level higher than that found in unsifted ground grain. Such a change gives more protein and less starch because the peripheral layers are higher in protein and lower in starch than the interior layers. It also decreases the ratio of free starch granules to bound starch granules (those wrapped up in protein). This, in turn, influences particle hydration, cooking time, and especially the course of gelatinization and viscosity development. Enzymes are less able to attack bound starch granules than free starch granules.

Greater amounts of peripheral or corneous endosperm particles have an effect on mouth-feel. Highly proteinaceous particles swell less than those less tightly bound. They have a diminished "jelly-envelope" about them; consequently they feel harder and grittier in the mouth. Of course, these effects, which are very much linked to particle size, and resistance to swelling, grittiness, etc., will diminish as particle size is decreased. Theoretically, most differences should vanish on ultra-fine grinding of cereal material. Ultra-fine grinding has, in practice, been shown to do just this in the case of enzymic solubilization.

The starch content increases and the protein content decreases when the relative proportion of floury endosperm is increased by sifting. The amount of free starch granules and weakly-bound starch granules are raised in relation to the bound starch granules, which are imprisoned within a corneous (horny) protein matrix. In general, the level of damaged starch granules, especially with severe mechanical milling, is increased, which has a great effect on cooking and enzymatic solubilization. On cooking, such a preparation gelatinizes more easily and the viscosity rises more sharply but has a tendency to be "beaten out" on long cooking especially with vigorous mechanical stirring.

Kernel texture or the ratio of corneous (horny, glassy, flinty) endosperm to floury endosperm is partly genetically determined and partly determined by environment. Within a sample of grain, the kernels vary greatly in relative amounts of corneous to floury endosperm. Using some standardized milling procedure, the texture of different batches can be compared by examining the yields of flour and of grits obtained. Much depends on the milling procedure adopted and on the definitions of flour and grits. Standards of operation and fineness, obtained in modern wheat milling plants, do not necessarily correspond to those of tribal milling procedures. The exact milling procedure used is thus of great importance. Sieve analyses should always be done on all milled fractions. Again, it is a matter of determining particle size ranges acceptable (or otherwise) to the particular class of consumer one is aiming at.

Acidity and Cooking Qualities

The acidity of the medium in which the starchy material is cooked has many important effects (Novellie and Schütte 1961; Novellie 1967). The actual gelatinization of free starch granules was not influenced by the presence of lactic acid (up to 1 %) (Novellie and Schütte 1961), but the final viscosity was reduced by increasing acid concentration.

Turning now to starch granules within a protein matrix: The acid softened the matrix during cooking and gave it a higher initial viscosity than was obtained in the presence of water alone. These initial peaks were higher as the acid concentration was increased, reached a maximum, and then declined at the highest lactic acid levels. The presence of lactic acid always produced a lower *final* viscosity compared with that obtained with water. The magnitude depended on the particle size, protein content and concentration of material in the mixture cooked, as well as the cooking time (Novellie and Schütte 1961). One should note here that African porridges are often undercooked by European standards. These studies were carried out with carefully graded sieve fractions, e.g., − 40 + 60, − 60 + 80, etc. In practice, one has a wide range of particle sizes from fine flour to coarse particles in the one sample. Any attempt at exact scientific description and prediction is liable to become hopelessly complex, and one is forced to a pragmatic approach. Nevertheless, it is important to have a good grasp of the basic factors and their effects; otherwise one is at a loss as to the general direction in which to move when modifying parameters. The exact degree to which one modifies a particular parameter, e.g., acidity or fineness, depends on trial and error.

Organoleptic Aspects of Sour Porridges and Beverages

Many comparisons of porridges cooked at their natural pHs (around 6.4) and soured by the addition of chemically pure lactic acid and porridges soured microbially, have shown distinct differences. Pure lactic acid gives a sharp, "clean" sourness devoid of any taste overtones, and rather characterless. The sourness induced by fermentation is subtly different and more agreeable in general to the African palate. Of course, even with homofermentative lactobacillus souring, some acetic and other acids are formed, although usually only in traces. These can, however, be readily detected by the consumer. In the southern parts of Africa, strong acetic acid values are not normally found to be acceptable and beers of such a nature are rejected as "sour." It is common to set a limit to the volatile acidity of a beer (lactic acid under normal conditions of steam distillation is nonvolatile) to 0.03 % in South Africa.

A different state of affairs apparently holds for *burukutu* beer of Nigeria according to Faparusi et al. (1973). With this beer, the acetic acid content may reach 0.4 to 0.5 % and the vinegary color and taste determine the quality. Banigo and Muller (1972) found the ratio of volatile and nonvolatile acids of *ogi* varied from 0.08 to 0.61. As a "standard", lactic acid was set at 0.65 % and the volatile acids—acetic acid, butyric acid, etc.,—were set at 0.11 %. Thus there must be a marked contrast in flavor compared with the soured porridges of Southern Africa.

Names of Fermented Foods and Beverages

These can be very confusing as there are many languages in Africa. The Bantu languages possess a complex grammar dominated by the prefixes. These prefixes may be abbreviated and are often left out by European writers. The Zulus, for example, do not refer to themselves as Zulus but as the amaZulu. The soured drinks known in Zulu as *amasi* and *amahewu* may be referred to as *maas* and *mahewu* which is very confusing to European compilers of glossaries who are not familiar with the languages. Since most African languages were not written languages, the orthography adopted depends on the Europeans who first wrote the language. Orthography may be based on English, Afrikaans, French, etc. The letters *c, q* and *x* in the Nguni languages which include Zulu (Murdock 1959) represent clicks and not their usual European equivalents.

The African often makes very fine distinctions in naming things. In the old days, special names were given to beers and to sour drinks for each day they aged (Doidge 1910, p. 6; Beemer 1939, p. 231). Thus a good description of the product and its exact method of production are very important since considerable variations can occur from tribe to tribe, although with related tribes the same word or a very closely related word may be used for the various products.

Useful vocabularies or glossaries may be found in the following publications:

Richards (1939) - Appendices Table A.
Jones (1963) p. 88, Annexures.
Hesseltine (1979, p. 368) Asian and African fermented foods.
Hesseltine (1965, p. 184) mostly of Eastern food and beverages.
Turner (1909); Beemer (1939); Deyoe and Robinson (1979).
Steinkraus (1979); Ramakrishnan (1979, p. 14) (Indian).
Ulloa and Ulloa (1973, p. 426, Table 1) Mexico and South America.
Muller (1970); Quin (1964 and 1959).
Miracle (1965); Bryant (1967).
Batra and Millner (1976, p. 123) (mostly Asian).

Fermented Porridges—Literature

A thin soured porridge which is really a beverage is widely consumed in Southern Africa and is variously called *amahewu, mahewu, maheu, amarewu, marewu, magou*. This beverage is often discussed in the literature together with the soured porridges of a thicker consistency to which it is closely related. The African distinguishes between:

(1) a soft or sloppy porridge [Xhosa—*isidudu* (unfermented); fermented—*imbila*]
(2) a thick porridge, stiff consistency (Xhosa—e.g., *umqo*)
(3) a crumbly porridge—a stiff porridge heated until much of the water has been driven off (Afrikaans—stywe pap; Xhosa—*umphokoqo*; Zulu—*phuthu*).

Beyers et al. (1979) make a useful distinction between *marewu* which is a thin fluid even when cold, and *isidudu*, a soft fermented porridge, which pours when hot but gels when cold. Porridges of types (2) and (3) cannot be poured. Golberg (1946, p. 213 and his Table VIII) gives the solid content of *lambalaza* (boiled soured maize meal similar to *imbila*) as 14.7 %, in contrast to 9 % of *marewu*.

Waldmann (1975, p. 145) describes how, amongst the Pedi (Bapedi), meal in lukewarm water is kept near the fire for 24 hr and then boiled to give a sour porridge. This product, called *ting*, is also described by Quin (1959, 1964) in his extensive studies of Pedi foods. Porridges made with soured milk are referred to as *mpshi* by the Bapedi.

Manning et al. (1974, p. 498) gave a recipe for *ting* pap as made in Northern Lesotho. Amongst the Tswana people, *ting* pap is still popular. Commercial preparations with lot of husk are not liked for this preparation. The porridge should be smooth, neither sticky nor gritty. A similar product made from maize instead of sorghum is called *motsweketlane* (William Marokane, personal communication, National Food Research Institute, CSIR, Pretoria). *Umvubo* is a crumbly porridge, type (3) *mphokoqo* mixed with soured milk (*amasi*).

Doggett (1970, p. 223) deals with the assessing of porridge quality and varietal characteristics. Johnson (1968) states that brown millets are preferred to white or red types in making porridge.

According to Muller (1970), grain is fermented as a slurry of ground meal or as a dough. The nutritional loss with a dough is less than with a suspension, e.g., Ghanaian *koko* prepared via a dough (*mbor*) compared with *ogi* prepared by a suspension process (Nigeria; parts of Ghana). The dough is dispersed in water before boiling to give a porridge. Miracle (1965, p. 147) mentions *ogi, agidi, eko,* and *kenkey*.

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Sorghum for Special Uses

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Summary

Sorghum is used for various special purposes such as popping, roasting, chewing, malting, and flavoring. Germplasm accessions known for these uses are presented with their geographical origin and taxonomic status. Germplasm accessions from India (3682) were screened at ICRISAT and 36 lines that exhibited superior popping quality were identified. Empirical selection for sweet stalks among 7000 accessions of the World Collection resulted in the identification of 253 lines for chewing purposes. Landraces preferred for malting, cooking like rice, and Basmati *sorghums for flavoring are indicated.*

Sorghum (*Sorghum bicolor* L. Moench) is used in the semi-arid tropics primarily for human consumption. It is used in the preparation of porridges and both leavened and unleavened bread (Vogel and Graham 1979). In addition, sorghum is used in the preparation of several snacks and for popping, chewing, and malting. Literature on the use of sorghum for special purposes is limited (Ayyangar 1939; Damon 1962; Rachie 1970). At ICRISAT, specific efforts were made to collect germplasm and information on the special uses of sorghum during the collection expeditions in India and African countries and through correspondence with various sorghum scientists. Traditionally, farmers have consciously selected landraces of sorghum for these special purposes. Our surveys have indicated that although these sorghums were still in use, with growing urbanization and changed market demands, the area cultivated with the special-purpose sorghums has dwindled and is restricted to the remote areas.

The objective of this paper is to document and describe the land-races known for various special uses and to present data on those that were investigated in detail.

Popping Sorghums

A broad survey of the geographical distribution of popping sorghums available in the World Collection showed that a majority of them originated in India. Popped sorghum grains are consumed in several states of India by the poor as well as rich as a snack food and as a delicacy. Popping is done by putting small quantities of grain in a hot pan kept over a steady fire. The popped grains are removed immediately after they are formed. Popped sorghum is considered to be superior to popped corn as they are tender, have less hull, do not clog the space between the teeth, and cause less noise when eaten. Besides, the popped sorghum grains have been found to have as much flavor and be as nutritious as popcorn (Subramanian 1956). Popped sorghum grains are used in the preparation of sweet snacks, which are commonly sold in the state of Maharashtra (India). It was reported that popping varieties of sorghum belong to the *Talavirchina* group (*S. roxburghii* var *hians*) characterized by small grain with a dense and corneous endosperm (Ayyangar and Ayyer 1936). *Pelalu jonna* belonging to the Snowden species *S. membranaceum* was considered to be good for popping (Reddy 1957). During our recent germplasm collection trips to the Karnataka and Andhra Pradesh states in India, landraces with names *Allinajola* and *Dholijaki* belonging to durra (*S. membranaceum*) and *Pelalu jonna* and *Allu jonna* belonging to guinea (*S. roxburghii*) were collected as superior popping cultivars. Damon (1962) reported that in Ethiopia, *Fendisha* sorghums were popped like popcorn besides being used for making *injera*.

Since most of the pop sorghums are identified in the Indian subcontinent with various colloquial

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names, it was felt desirable to screen the germplasm originating from India for popping quality. Grain samples chosen for popping studies were drawn from the ICRISAT cold store (regularly maintained at 4°C and 40% RH). They had a moisture content of 9 to 10%. A 10-g sample of the grain without pretreatment was placed on an open steel pan maintained at 300-324°C and stirred briskly. The number of completely puffed grains per sample were recorded after 1½ min and expressed as percent popping. Of 3682 accessions screened, 36 accessions showed 80% or more popping. The identity, physical grain quality characteristics, and taxonomic classification of the superior popping sorghums are presented in Table 1. Most of these exhibited small grain size, white color, medium thick pericarp, a breaking strength of about 7 kg, and a hard corneous endosperm. This conformed with the observations of Doggett (1970). Popping sorghums have a very low germ endosperm size ratio and the embryo is located at a corner in the hilar region. The germ remains unaffected during popping. The availability of sorghum cultivars whose grains exhibit superior popping quality without any pretreatment should be of significance to food technologists and breeders. Utiliz[illegible] of these popping sorghums in breeding programs aimed at improved popping quality might be rewarding (Murty et al. 1981b).

Roasting or Parching Sorghums

In several parts of Africa and India there is a practice of roasting sorghum heads at the dough stage and eating the threshed grain as a delicacy. The cultivars most suitable for roasting have a sweet endosperm that is dimpled at maturity. *Vani* sorghums (durra group) of India are especially popular in this respect. Rachie (1970) reported that roasting *Vani* type sorghums during the crop season was common in some areas of Gujarat. The whole earheads were harvested at the dough stage and brought to the roasting pits. They were buried in hot coals and ashes for several minutes to be cooked, following which the light green seeds were lightly beaten off the heads and hand winnowed. A similar practice exists in the state of Maharashtra where this snack is called *Hurda*.

The practice of eating sorghum at the dough stage either raw or roasted exists also in Ethiopia and Sudan. Dimpled red grain sorghums *Wotet beguncha* (IS-11758), *Red merchuke* (IS-11167) cultivated in the Wollo province of Ethiopia were stated to be specially suited for this purpose. The other varieties utilized for this purpose are *Bsenga* and *Muyera* (Damon 1962). The two landraces IS-11758 and IS-11167 are also known to be high lysine sources (Rameshwar Singh and Axtell 1973). *Maleek*, a half broomcorn type (IS-22383, durra caudatum), cultivated in the backyards in the Kassala province of Sudan, is used for roasting.

Sweet Stalk Sorghums/Chewing Sorghums

Sorghum landraces possessing sweet stalks are sparsely distributed in the sorghum-growing areas of Africa and India. The green stalks are often chewed in a manner similar to sugarcane, particularly in dryland areas. The grain yield of these sorghums is poor and hence they are grown only as special types in the backyards or in small patches.

A study of the sorghum World Collection maintained at ICRISAT and accessions collected in recent ICRISAT expeditions showed that sweet stalk sorghums exist in collections from Botswana, Cameroun, Chad, Ethiopia, India, Kenya, Malawi, Niger, Nigeria, Somalia, South Africa, Sudan, Thailand, Uganda, USA, Zambia, and Zimbabwe. In Ethiopia, sweet stalk sorghums were used for a confection besides chewing (Damon 1962). *Fendisha*, *Keyila* and *Eja Saa* cultivars possess sweet stalks. *Tinkish* is the common Ethiopian name for sweet stalk sorghums (Mengesha personal communication, 1981).

In Sudan, sweet stalk sorghums are cultivated in patches and are called *Ankolibs*. These belong to the intermediate race durra-bicolor with poor grain quality. *Ankolibs* could be the *Sorghum ankolin* Stapf. described by Snowden, the distribution of which is stated to be North East Africa including Sudan (Snowden 1935). Stems are very sweet and farmers chew them like sugarcane.

In Malawi, sweet stalk sorghums are grown in maize fields or in the backyards. These are locally called *Misale* in the southern region and *Njiho* in the northern region. These are mostly grown for domestic consumption but at times they are sold in the market (Appa Rao 1979). In Zambia, different landraces are grown for chewing purpose. These are known as *Kamutu halli* (Chama area) and *Misale* (Petanke area) (Appa Rao 1980). In

Table 1. Grain quality characters and taxonomic distribution of selected popping sorghums from India.

Genotype	Origin[a]	Classification[b]	Grain: Corneousness[c]	Grain: Weight (g/100 grain)	Grain: Breaking strength (kg)	Grain: Popping (%)
White grain types						
IS-1192	A.P.	G(R)	1	2.77	7.9	80
IS-1199	T.N.	G(R)	1	2.11	8.5	80
IS-2205	U.P.	D(M)	3	2.38	5.6	80
IS-4596	Mah.	G(R)	1	1.66	6.6	82
IS-4939	Mah.	D	2	3.02	7.4	82
IS-5111	A.P.	G(R)	1	1.87	8.2	91
IS-5112	A.P.	G(R)	1	1.80	5.2	87
IS-5113	A.P.	G(R)	1	1.75	6.4	87
IS-5115	A.P.	G(R)	2	1.49	5.5	87
IS-5116	A.P.	G(R)	2	1.98	7.4	87
IS-5285	A.P.	D(M)	2	2.25	6.1	91
IS-5418	T.N.	G(R)	1	1.89	6.9	85
IS-5484	Kar.	D	2	2.37	6.0	82
IS-5566	Kar.	D(M)	3	2.43	6.1	90
IS-5604	Kar	D(M)	2	2.46	5.6	98
IS-5638	Kar.	D(M)	2	2.19	6.9	97
IS-5648	Kar.	D	3	2.27	5.3	85
IS-5653	Kar.	D(M)	2	2.38	7.5	96
IS-5655	Kar.	D	2	2.40	5.8	96
IS-5665	Kar.	D	3	2.51	.0	90
IS-5726	Bihar	G(R)	1	1.36	7.1	85
IS-5732	Bihar	G(R)	1	1.71	7.5	82
IS-5741	Bihar	G(R)	1	1.72	8.7	90
IS-5849	M.P.	G(R)	1	1.74	7.9	86
IS-5910	M.P.	G(R)	1	1.99	8.2	82
IS-6243	W.B.	G(R)	1	1.80	6.3	80
IS-6248	W.B.	G(R)	2	2.63	8.6	92
IS-17903	A.P.	G(R)	1	2.01	6.1	80
IS-18363	Mah.	D	2	3.08	7.3	80
IS-18488	A.P.	D	2	3.31	8.5	82
Red grain types						
IS-2185	Mah.	D	3	2.63	7.6	92
IS-4803	Guj.	D	3	2.97	7.0	90
IS-5646	Kar.	D	3	2.27	4.2	94
IS-5651	Kar.	D	2	2.80	7.0	96
IS-8347	Mah.	G(R)	1	2.47	7.8	88
IS-17860	A.P.	G(R)	2	2.17	6.4	85

a. A.P. = Andhra Pradesh
T.N. = Tamil Nadu
U.P. = Uttar Pradesh
Mah. = Maharashtra
Kar. = Karnataka
M.P. = Madhya Pradesh
W.B. = West Bengal
Guj. = Gujarat

b. G(R) = Guinea (*S. roxburghii*)
D = Durra
D(M) = Durra (*S. membranaceum*)

c. 1 = Completely corneous
2 = Corneous
3 = Partly corneous

Zimbabwe, a variety known as *lowa* is grown for chewing and sweet stalks are commonly sold in the market.

In Nigeria, the *Takanda* group of sorghums is sweet stemmed and are chewed like sugarcane. They are quite distinct from the popular guinea race and can be distinguished by their persistent pedicelled spikelets. The grains are small, brown or grey, with a brown testa, and are less exposed. *Takanda* flowers before the main crop and is thus maintained as a distinct variety. The *Takanda* variety of sorghum is not confined to any particular zone (Curtis 1967).

Most of the sorghums grown in India are found to be dual-purpose varieties providing grain for human consumption and fodder for livestock. Sweet stalk sorghums are planted sparsely mixed with cultivated sorghums. In a recent collection expedition to the Karnataka state of India one cultivar, *Kareguni* (IS-22122), was collected that possessed sweet stems and desirable agronomic characteristics (Prasada Rao and Gopal Reddy 1980). Although the sweet stalk sorghums are used in the traditional sorghum-growing areas for chewing or for confectionary purposes, their importance is increasing because of their potential use in the production of sugar, syrup, and alcohol. In view of their growing importance in the developed and developing countries, a part of the sorghum germplasm (about 7000 accessions) was tested for stalk sweetness by chewing a stem sample. About 250 lines were identified as very sweet. The geographic and taxonomic distribution of these lines are presented in Table 2. It was observed that more than half of the lines belonged to the race caudatum followed by those of durra and are mainly from the Sudan, Cameroun, Ethiopia, USA, and India. Studies on the techniques of evaluating sweetness are under way in collaboration with physiologists and biochemists and it would be useful to rescreen the gemplasm through rapid objective tests.

Sorghums for Cooking Like Rice

The boiling of dried sorghum grain with water is practiced in several parts of the semi-arid world. There is a special type of sorghum variety called *Kyaram* in West Africa that is usually cooked like rice. This variety belongs to the race guinea and subrace margaritiferum (de Wet et al. 1972). *Kyaram* is distinguished from other guinea sorghums by its very small flinty grains. The grain is either freely exposed at maturity or it remains cupped in the lower glume. In both cases the seed is readily shed at harvest. de wet et al. (1972) opined that margaritiferum (IS-7818) with its small white flinty grain seemed to have originated in the West African forests as a selection for cooking in the same way as rice, a cereal commonly grown in the forest. There are some World Collection accessions belonging to margaritiferum from Japan (IS-8064) and Sri Lanka (IS-19467). In the Abobo area of Ethiopia, another special type of preparation was found to be made by boiling green sorghum grain with water and salt (Prasada Rao and Mengesha 1981).

Malting Sorghums for Nonalcoholic Drinks

It is widely known that most of the red and brown grained sorghums of Africa are used for the preparation of a variety of alcoholic drinks. Novellie (1981a,b) reviewed the information available on fermented sorghum porridges and beverages. Nonalcoholic porridges of sorghum are made by souring the grain overnight and cooking it in the morning. Such preparations are diluted and consumed as a thin gruel (Novellie 1976). In the highlands of southern Uganda extending into Rwanda, there is a practice of malting the dark brown sorghums for preparation of *Obushera*, a thin porridge, in addition to the usual practice of making *ugali*. The dark brown sorghum grain, which has a bitter taste due to tannins, is germinated in a mixture of wood ash and water. After sprouting, the grain is sun dried, pounded to remove the sprouted radicals, and then ground. The flour is mixed with water and kept overnight to obtain a delicious drink, which is not intoxicating (S. Z. Mukuru personal communication, 1981). By malting and treating with wood ash the grain is less bitter and forms a delicious drink fit to be consumed by children.

Scented Sorghums

The existence of sorghums with a special aroma or scent was reported as early as 1919 (Kottur 1919). *Ambemohor*, a rainy season variety of the Maharashtra state (India) ripening in 4.5 months was reported to contain a special flavor like

Table 2. Geographic and taxonomic distribution of sweet stalk sorghums (identified from 7000 accessions of the World Collection).

	Basic races[a]					Intermediate races[b]										
Country	B	G	C	K	D	BG	BC	BK	BD	GC	GK	GD	CK	CD	KD	Total
Cameroun	–	–	33	–	5	–	1	–	–	–	–	–	–	3	–	42
Chad	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1
Ethiopia	–	1	10	–	12	–	–	–	1	1	–	–	–	–	–	25
India	–	–	1	–	10	–	–	–	1	–	–	–	–	1	1	14
Kenya	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1
Nigeria	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	2
Niger	–	–	1	–	–	–	–	–	–	–	–		–	–	–	1
Somalia	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1
South Africa	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
Sudan	4	–	107	–	7	–	1	–	–	10	–	–	5	1	–	135
Thailand	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1
Uganda	–	–	3	–	–	–	1	–	1	1	–	–	1	–	–	7
USA	–	1	6	1	3	–	1	–	–	–	–	–	5	–	–	17
Zimbabwe	–	–	3	–	1	–	–	–	–	–	–	–	1	–	–	5
Total	4	2	167	1	39	–	6	–	3	12	–	–	13	5	1	253

a. B = Bicolor; G = Guinea; C = Caudatum; K = Kafir; D = Durra

b. BG = Bicolor-guinea; BC = Bicolor-caudatum; BK = Bicolor-kafir; BD = Bicolor-durra; GC = Guinea-caudatum

c. GK = Guinea-kafir; GD = Guinea-durra; CK = Caudatum-kafir; CD = Caudatum-durra; KD = Kafir-durra

Ambemohor rice (*Ambemohor* = mango inflorescence). This variety was specially cultivated by the farmers as a delicacy. A variety of sorghum from Tanzania named *Kinungapembo* belonging to *S. conspicuum var conspicuum* Snowden has been reported by Ayyangar (1939) to have scented grains. The scent was somewhat similar to scented rice. Seedlings were stated to emit scent and also the adult leaves when crumpled. Unfortunately, both of these scented sorghums are not available in the World Collection. Neither do they seem to exist in the place of their origin.

In a recent ICRISAT germplasm collection trip to the remote hilly areas of Central India, head and seed samples of three sorghum landraces, IS-19907 (KEP-472), IS-19910 (KEP-475), and IS-19912 (KEP-477), with the local name *Basmati* were collected in the Karri and Sarwa villages of Chattarpur District (25° N, 79° E, altitude 300 m). These samples belong to the race durra and had white seeds with a floury endosperm (Prasada Rao and Murty 1979). The grains and the crumpled leaves emitted a mild scent typical of *Basmati* rice. The stiff porridge (*sankati*) made from the *Basmati* grain was distinctly scented. The simple KOH technique devised originally for the scented rice was used on sorghum to detect the scent released (Prasada Rao and Murty 1979). A distinct and strong aroma was noticeable a few minutes after adding KOH to the *Basmati* samples. In crosses with nonscented varieties, the scented gra' character proved to be a monogenic recessive (Murty et al. 1981a).

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Discussant's Comments

Session 2: L. R. House*

The importance of documenting the processes used to make food from sorghum has been recognized in this session of the symposium. It is encouraging that this activity has begun, but it is recognized that more information is still required. There are several reasons for documentation: as a reference of traditional methods of preparing sorghum products; to provide information in establishing objectives in a crop improvement program; to provide a base for evaluating food preparation procedures as these affect nutritional traits; and to gain an insight into changes in food habits and how these affect crop improvement objectives and nutritional traits. The problem of language in properly documenting food habits has been noted. It has been recognized that although there is a multiplicity of food preparations from sorghum they can be grouped into several different broadly definable types.

Food quality is an important consideration in crop improvement. The priority of yield and stability compared with food quality has been acknowledged. However, high-yielding stable varieties can fail because of poor food traits or the rate of their acceptance can be prolonged. Important in evaluating food quality is the availability of people who can tell if the food prepared from the grains of a particular variety is good or bad; and the development of adequate, simple, and reproduceable methods for evaluating relevant food parameters. Many methods were mentioned in this session. Evaluation includes the identification of standards either against varieties recognized for their quality or by the development of methods that will discriminate between varieties recognizing that different methods of processing of grain from the same set of varieties can produce different results. The need is to establish traits relevant to quality and to develop scales and measures that will quantify differences. Ideally, these procedures should be simple and applicable to the screening of a large number of breeding stocks. Breeding lines in early stages of development can be visually selected, but as the crop improvement process continues more refined procedures are required. Important to final evaluation are people who can identify quality indicating the need to undertake evaluation in regions where different major food types are prepared. Emphasis is placed on evaluation of breeding stocks—evaluation of food quality at the time that a variety is being considered for release is descriptive but does not contribute to the development of varieties and parents of hybrids superior for food quality traits.

The cooperative work of the last 2 years on international evaluation of a standard set of samples of sorghum varieties has been very good; hopefully such cooperation will continue in the future.

An understanding of the effect of different methods of food preparation on nutritional properties is important. It is recognized that some modification of the food preparation process might improve nutritional properties. Such modifications could reflect back on crop improvement objectives and we, as a group of scientists, should be alert to such possibilities. The drudgery of hand pounding to mill sorghum has been frequently identified as well as the fact that this practice is generally abandoned in urban situations. There has been an increasing interest in the use of pearlers and mills, some reaching the pilot stage. Such changes as these also raise the question of what contribution can be made by breeding to develop grains that do not require pearling or that can be pearled better by machine than by traditional methods. Differences in the grain type required for the two processes have been identified.

Flour from sorghum is frequently blended with that of wheat and maize when these flours are in short supply. The opportunities for blending, possibly even with flour from legumes, in the future may be a route to improved nutritional value of foods. The opportunity to do this would be particularly good in urban areas.

The effect of insects and diseases on stored

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grain is well known; less well understood is the effect of these on nutrition; the quality of the food from damaged grain is reduced.

The bird problem can be severe, particularly the *Quelea* bird in Eastern and Southern Africa. Brown grain with a bitter taste and hard endosperm has not yet been found. More knowledge of tannins and the milling of softer grains can be of great value.

Session 2—Traditional Food Preparations and Their Quality Parameters

Discussion

Munck:
The falling number method is widely used for studying weathering of wheat and rye in relation to starch gelatinization. We have used it with success in sorghum Seven grams of flour are stirred with water and the viscosity is studied during heating. A low falling number indicates a high level of α-amylase. The analysis takes 3 min.

Miller:
Is there any indication that *tô* quality is either positively or negatively affected by crop succulence, nutrition (fertility) level, or other major agronomic characteristics?

Scheuring:
We are not sure of the effect on *tô* quality of crop succulence. Fertility has an effect on *tô* quality, by reduced hardness and increased chaffiness. Drought has an effect on kernel hardness. However, there are varietal interactions.

Reichert:
Is it necessary to take both texture and stickiness measurements on *tô*? What is the correlation between texture and stickiness?

San San Da.
Both are highly correlated.

Morris:
Are children fed with *tô*?

Sidibe:
Tô is fed to weaning children; *couscous* gruels and rice-like products are also given at this age.

Miche:
Tô is fed to young children soon after they are taken off breast feeding. It is important to know the pH of the water used in laboratories to make *tô*.

Chandrashekar:
Sankati is processed in parts of Karnataka, India, especially for older people, by further steaming and cooking. We have been working on the reduction of viscosity of sorghum by processing. Puffing/flaking reduces viscosity to acceptable levels for children's food. Malting is by far the best.

Busch:
What is the leavening agent used in the preparation of *injera*?

Gebrekidan:
Some of the previous day's batter is used as a starter.

Latif:
Unlike the other African countries, the flour for *kisra* is from whole grains and not dehulled grains. White color is preferred and soft grains generally give better *kisra*.

Reichert:
Why then is the FAO project in Sudan pushing the pilot plant for dehulling?

Gebisa Ejeta:
The objective is to make bread from dehulled sorghum flour mixed with 25% wheat. Dehulled grains produce a *kisra* with better color appeal.

Munck:
What is the microbe responsible for fermentation in *injera*? In the case of *kisra*, mostly *Lactobacillus* is responsible for decreasing the pH to 3.8.

GebreHiwot:
We assume that yeast is commonly associated.

Miche:

Mixing tef and barley improves storability of sorghum *injera*. Are pentosans involved here?

Gebrekidan:

I cannot give the chemical basis. The keeping quality of *injera* is improved when mixed with tef or barley.

Prasada Rao:

This comment refers to the comment of Dr. Gebisa Ejeta. In our collection missions in Africa, we have found that people prefer the dark brown sorghum and sorghum with a subcoat for the manufacturing of beer. In fact, they say that the bitterness gives taste to the beer.

Miller:

Is there a difference in the time of lime exposure (cooking time) between maize and sorghum for *tortilla*, because of seed size difference?

Guiragossian:

There is an advantage to sorghum because of its small seed. There is some difference of opinion based on the fact that more vitreous seeds of sorghum are selected and are matched to the cooking time of maize to fit the appropriate *tortilla* sorghum mixture.

Gebrekidan:

What are the differences in *tortilla* and *roti* preparation methods?

Guiragossian:

In the case of *tortillas*, sorghum grain is boiled in water mixed with alkali and stored overnight. The *nixtamal* is wet-ground with stone into a dough from which *tortillas* are prepared. *Rotis* are prepared from freshly ground whole sorghum flour.

Rooney:

Grain molds are a problem and affect the *tortilla* quality very badly.

Clara:

In El Salvador 93% of the total surface area used for growing sorghum is in association with maize. For this reason, CENTA has a strong sorghum breeding program to improve local varieties to produce more grain in this cropping system and to select genotypes for human consumption in the form of *tortilla*.

Among the different sources of sorghum introduced to El Salvador, ICRISAT SEPON materials were superior for grain quality for human consumption in the form of *tortilla*. Thus, crosses were made between SEPON and local varieties. Improved varieties were recently developed that are superior to local varieties by 50%.

Parallel with this work, ICRISAT and INIA in Mexico have evaluated the local and improved varieties from El Salvador and Honduras in chemical and organoleptic tests for *tortilla* making. Two of the improved varieties, ES-412 and San Miguel No. 1, had better dough yield as compared with other varieties and also maize. Organoleptic results indicated that *tortillas* prepared from 100% ES-412 were good and were also good in all combinations with yellow and white maize. The other improved variety, SM No. 1, produced excellent tortillas with 75% yellow maize and 25% sorghum mixture, and produced good *tortillas* in all other combinations with white and yellow maize.

von Oppen:

Are the taste panel evaluations replicated?

D. S. Murty:

Yes. Scores presented for *sankati* and *roti* are averages over replications and the standard errors are also given.

Morris:

In research with CNRA Bambey (Senegal) and IDRC, a Purdue researcher (Edna Loose, M. S. student) studied the economics of mechanical pearling and grinding of sorghum and millet at the household level. Adoption of mechanical grinding took place very rapidly, although the use declined subsequently when the shortage of money became felt in the dry season. Non-availability of money in the hands of women was clearly a constraint on use.

The pearler was used very little. The financial constraint was certainly important. However, the women reported that the pearling quality was not satisfactory and that if they were constrained to use only one mechanical process (pearling or grinding) they preferred mechanical grinding.

Deosthale:

I comment on the question raised by Dr. Gebrekidan on the differences and similarities of *tortilla* and *roti*. In *tortilla* preparation, the steeping of the maize with lime water is a treatment which as an alkaline condition brings about significant changes in the nutritional properties of the grain. Nutrients such as niacin, which are practically unavailable in raw maize, become available due to the lime treatment. Similarly, some of the amino acids also become more available. This is an important nutritional advantage of *tortilla* due to the calcium hydroxide (lime water) treatment.

Munck:

Are there any comments on malted products of sorghum?

Rooney:

For babies, 15 g of flour per 100 ml water must be obtained to get a reasonable caloric density. Cooking sorghum flour at this concentration makes a too viscous product to be conveniently fed. Twenty percent sorghum malt mixed in the flour drastically reduces the viscosity. Additionally, a protein supplement such as milk should be fed to compensate for the low lysine content. The habit of feeding sorghum malt to small children is well known in Tanzania.

Session 3

Grain Structure and Deterioration

Chairman: S. Z. Mukuru

Discussant: R. V. Vidyabhushanam
Rapporteur: N. Seetharama

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Variation in the Structure and Kernel Characteristics of Sorghum

L. W. Rooney and F. R. Miller*

Summary

The structure of the sorghum kernel plays a major role in determining the processing properties of the grain. Structure is affected by genotype and environmental conditions. Knowledge of kernel structure and its relation to grain quality can be utilized on a practical basis in field selection for sorghum quality. Considerable progress can be made by scraping, cutting, and evaluating processing quality in the field by making a close examination of the kernels. The basic structure of sorghum kernels is described in sufficient detail using light, fluorescence, and electron microscopy to provide general information of use in crop improvement programs.

This paper is an attempt by using photomicrographs to present some of the essential facts of sorghum kernel structure of direct use to scientists involved in sorghum breeding programs, especially those concerned with sorghum food quality. The variation in processing properties of sorghum can be directly related to variation in kernel structure some of which can be estimated and selected for in the field using a pocket knife. These kernel characteristics include size, shape, pericarp color, testa, endosperm texture, and other properties.

In our laboratory, we have for the past 12 years conducted numerous studies relating structure to processing properties and food and feed quality of sorghum genotypes from the breeding program. This work has been done cooperatively with numerous colleagues over the years. We have selected some photos to represent key differences in structure. Unfortunately, space does not permit a complete presentation of all aspects of kernel structure that relate to processing properties.

Kernel Structure

The sorghum kernel or caryopsis is composed of three main parts: the outer covering (pericarp), the storage tissue (endosperm), and the embryo (germ) (Figs. 1 and 2). The sorghum kernel is a caryopsis in which the ovary wall dries and adheres strongly to the mature ovule. The pericarp, originating from the ovary wall, can usually be divided into four parts: the epicarp, the mesocarp, the cross-cell layer, and the tube cell layer. The epicarp is the outermost portion of the kernel and is often divided into the epidermis and hypodermis. The first cell layer is the epidermis consisting of thick-walled rectangular cells coated by a cutin layer (Fig. 3) and often contains pigments. The hypodermis layer can be one to three cell layers thick but the cells are smaller than those in the epidermis.

The middle portion is the mesocarp, which may vary in thickness from a few remnant cells without starch with a thin, translucent appearance to several layers of cells containing starch granules, which gives a thick, chalky appearance (Fig. 4). Mesocarp thickness is controlled by the Z-gene where thin is dominant over thick, but a wide range in mesocarp thickness can be observed (Fig. 5). Mesocarp thickness is involved in mold resistance; sorghums with a thin mesocarp, in general, appear to be more resistant to molds. For hand milling, a thick starchy mesocarp associated with a hard endosperm is preferred.

The innermost layer of the pericarp is the endocarp consisting of the cross and tube cell layers (Fig. 4A). The cross cells are long and narrow with

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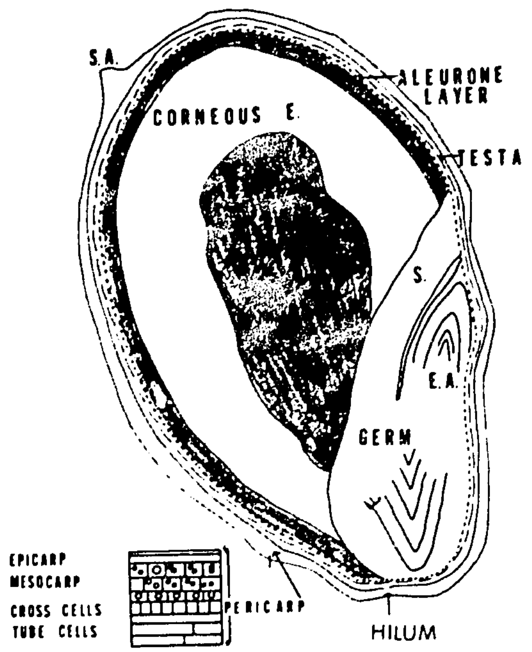

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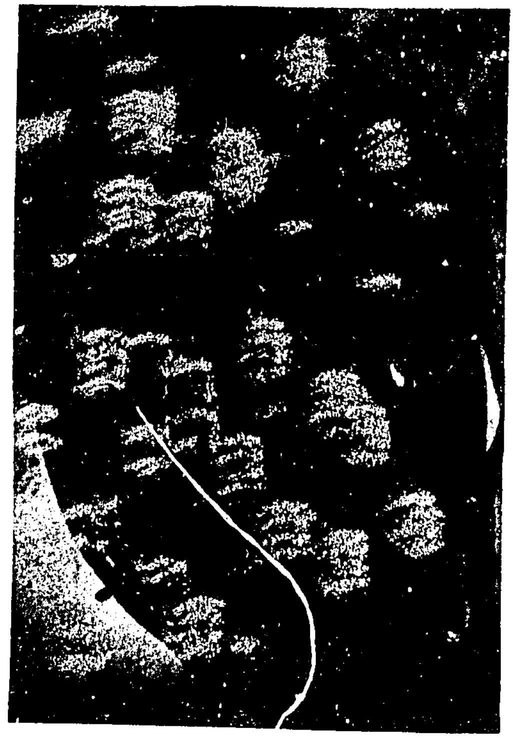


Figures 1. and 2. The sorghum kernel is diagrammed and labeled on the left (Fig. 1) and an actual light photomicrograph (35x) is presented on the right (Fig. 2).

their long axis perpendicular to the long axis of the kernel. The tube cells are 5μ wide and up to 200μ long with their long axis parallel to the long axis of the kernel. The cross and tube cells function to transport moisture throughout the kernel. The cross and tube cells appear to be a major point of breakage when the pericarp is removed during dry milling of the grain.

Two other anatomical portions of the sorghum kernel are the stylar area and the hilum (Figs. 1,2; 3B,3D). The stylar area is the point at which the style was attached during pollination of the seed. The hilum is the scar tissue resulting from detachment of the seed from the funiculus (Fig. 3). The stylar area has pigments that sometimes cause staining of the kernels. It is an entry point for moisture and microorganisms to move inside the pericarp. The hilum is sometimes referred to as the black layer, which forms when the kernel reaches physiological maturity. Black layer formation has been used as an index of maturity.

The embryo or germ is composed of two major parts: the embryonic axis and the scutellum (Figs. 1,2,3C). The germ cells are modified into transfer cells, which function in the movement of moisture, microorganisms, and solubilized endosperm components. Glueck and Rooney (1980) showed that the embryo plays a major role in water uptake and mold susceptibility of sorghum kernels. The scutellum cells contain oil globules, protein bodies, and only a few starch granules.

The relative proportions of the pericarp, germ, and endosperm in kernels vary among varieties of sorghum. For medium-sized sorghum kernels, the bran, germ, and endosperm were found by hand dissection to be 6, 10, and 84% of the kernel dry weight (Hubbard et al. 1950). The data were obtained for kernels that had a relatively thick, starchy mesocarp with a prominent germ. Many sorghums with very small germs and t. pericarp exist that would probably have up to 90% endosperm with 3-5% bran and 5-7% germ. These figures are approximations based on milling yields obtained from some kernels with a thin pericarp, small germ, and very hard corneous endosperm (Rooney, unpublished data). The germ of some sorghum cultivars is more deeply embedded inside the endosperm and is extremely difficult to remove while others protrude from the kernel. Kernel size, shape, and details of germ placement inside the

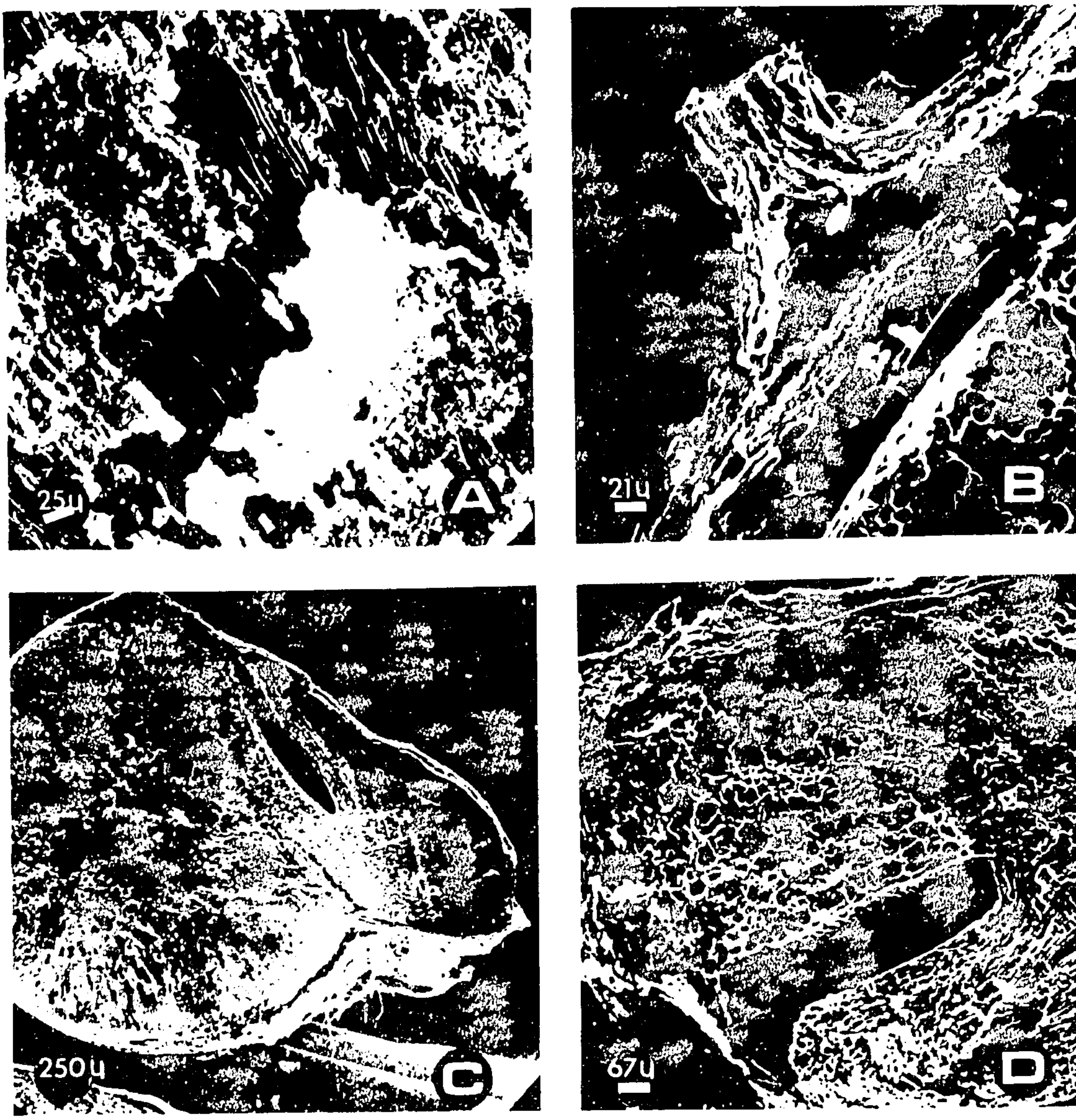


Figure 3. Scanning electron photomicrographs of: (A) partial wax coverage on the epicarp of a sorghum kernel, (B) stylar area, (C) overview of the germ, (D) hilum.

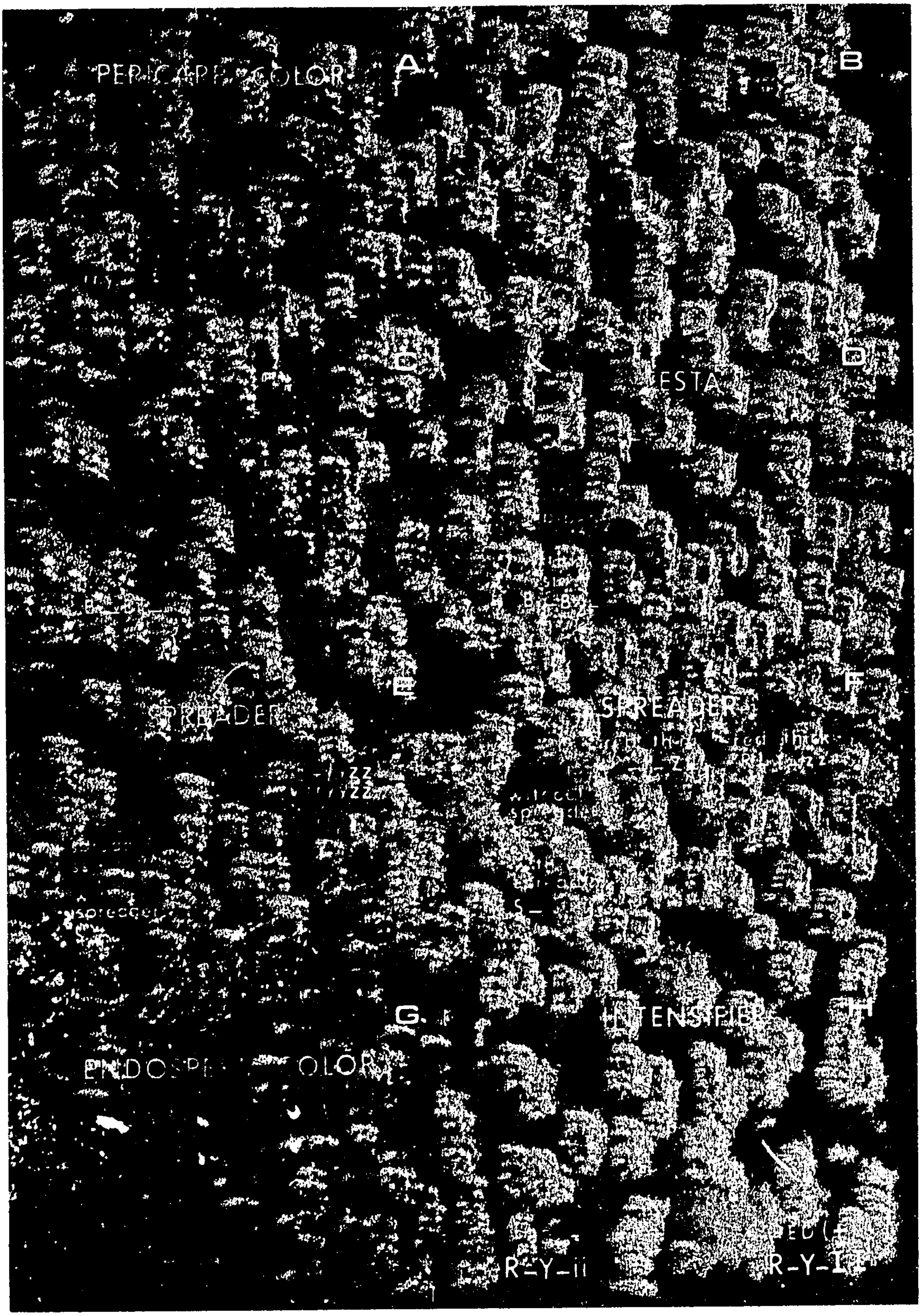
kernel affect milling properties, water uptake, and mold susceptibility as well.

The Appearance of Sorghum

Several interacting factors influence the color of the sorghum kernel as viewed by the eye: the genetics of pericarp color, pericarp thickness, the presence of testa, color and thickness of the testa, and the endosperm color (Rooney et al. 1980). Glumes and plant color also affect grain color and the color of food, especially foods made with alkali such as *tortilla* and alkaline *tô*. The many terms used to describe grain color are very confusing unless the genetics affecting these factors are understood. The various terms of reddish brown, gray, yellow, salmon pink, and other terms mean very little and color should be described in terms of the genetics of the factors affecting it.

Colorplates 1 and 2 show the major genetic factors affecting kernel visual appearance. The

C. Plate 1. A. Three genetic pericarp colors: white, lemon yellow, and red.
B. Pericarp thickness of a segregating cross showing thin, intermediate, and thick mesocarp.
C. Absence and presence of a testa in thin and thick kernels with a colorless white pericarp. (Absence can result from $b_1b_1b_2b_2$, $b_1b_1B_2$-, or B_1-b_2b_2.)
D. Absence and presence of a testa in kernels with a thin and a thick red pericarp. (Absence can result from $b_1b_1b_2b_2$, $b_1b_1B_2$-, or B_1-b_2b_2.)
E. Absence and presence of spreader gene in kernels with thin and thick pericarp that have pigmented testas. The pericarp color is white.
F. Absence and presence of spreader gene in kernels with thin and thick pericarp that have pigmented testas. The pericarp color is red.
G. White and yellow endosperm colors. The pericarp color is white.
H. Presence and absence of the intensifier gene in a kernel with red pericarp color without a testa.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B
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SPREADER
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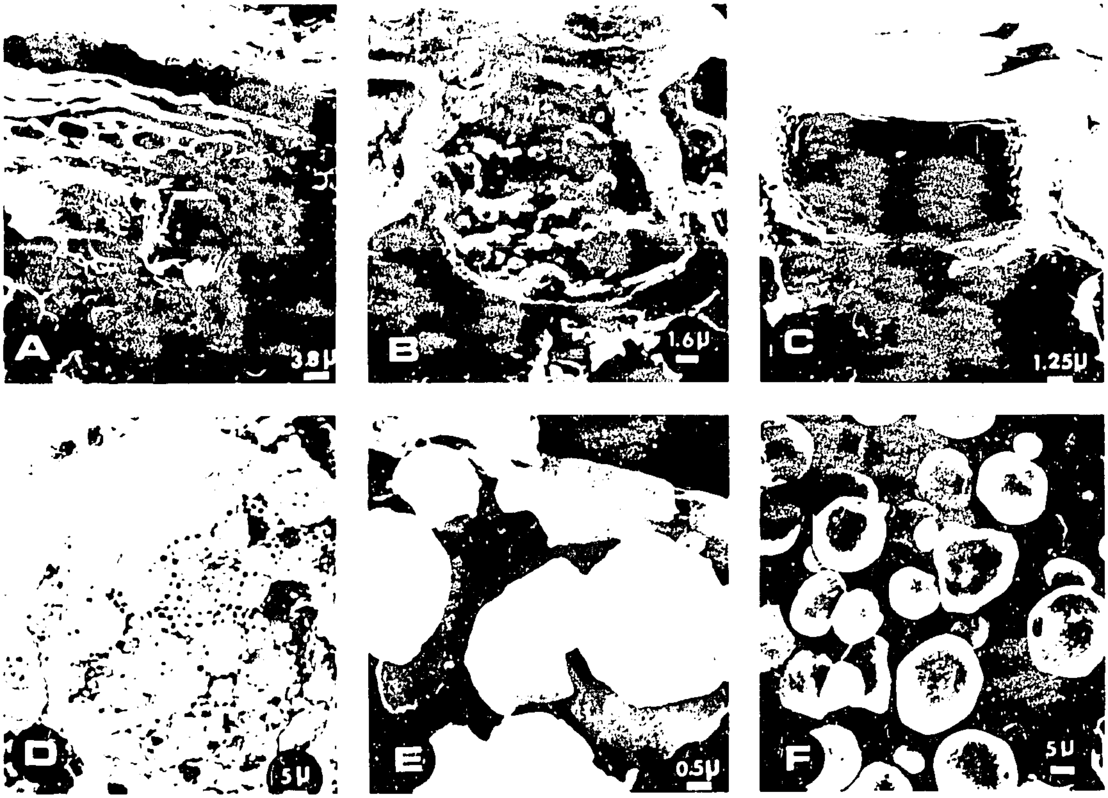


Figure 4. Scanning electron photomicrographs of:
A. The cross and tube cell layers that comprise the endocarp.
B. Aleurone cell with cell wall covering intact.
C. Aleurone cell showing differences in cell wall density. The area closest to the pericarp is the thickest.
D. Peripheral endosperm cell wall torn open showing the starch granules, protein bodies, and matrix protein.
E. Starch granules in the mesocarp with a cell wall.
F. Isolated nonwaxy sorghum starch. Indentations are from protein bodies.

photos were taken of sorghum kernels in which the genetics are known; the kernels were mature, sound, and free of mold and insect damage. The genetics of kernel characteristics that affect color are not understood and will change as new information is obtained. However, the photos in color plate 1 were designed to summarize the [illegible] information available.

Pericarp Color

The R Y genes determine whether the pericarp is [illegible] red (R Y), colorless or white (R yy [illegible]), or lemon yellow (rr Y). The lemon yellow color is usually bleached by the sun turning a dull brownish yellow color upon drying. The lemon yellow color is often retained in the pericarp underneath the glumes. Yellow pericarp color is not associated with yellow endosperm and should not be confused with it.

The intensifier gene (I) affects the intensity of the pericarp color (Colorplate 1) when R Y genes are present. For example, a kernel with dominant R Y and I genes will appear bright red when compared with the genotype R Y ii. The intensifier functions with the lemon yellow pericarp (rr Y I). Kambal and Bate-Smith (1976) have proposed a mechanism to show how synthesis of the red pigments in the pericarp are controlled.

C. Plate 2. A. Glume color: red, purple, and tan (PPQQ = purple; PPq'q' = red, and ppqq = tan.)
B. Plant color: tan, red, and purple (genetics same as above.)
C. Glume covering: from relatively little glume covering to a glume longer than the kernel.
D and E. Kernels with purple and brown testa, respectively; the pericarp has been partially scraped away to reveal the testa.

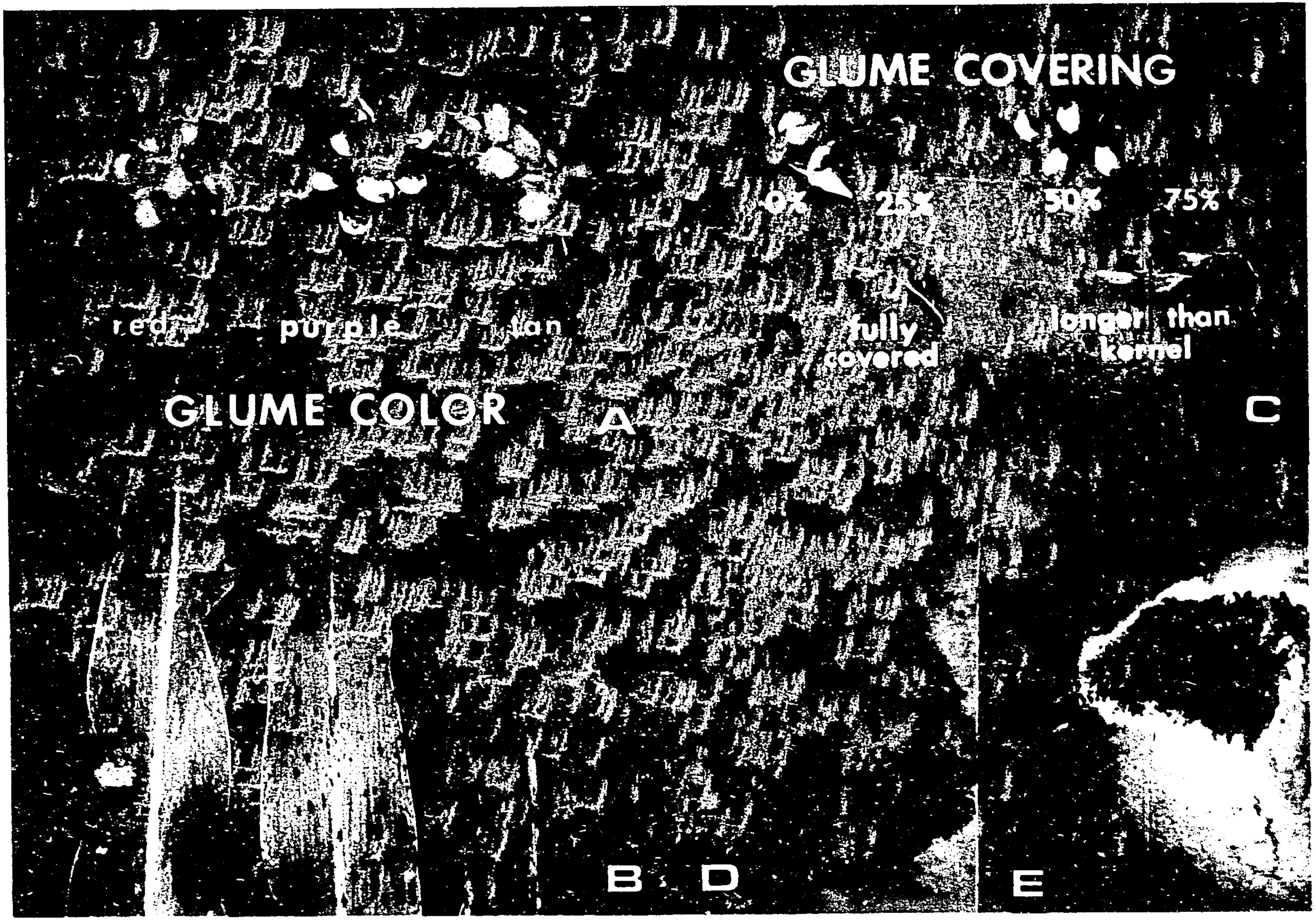

GLUME COVERING
0%
25%
50%
75%
red
purple
tan
fully covered
longer than kernel
GLUME COLOR
A
C
B
D
E

Figure 5. Scanning electron micrographs (600x) of sorghums with varying pericarp thickness:
A. Thin pericarp, variety CS3541.
B. Intermediate pericarp, variety BTx623 × CS3541.
C. Thick pericarp, variety BTx623.
Pictures indicate thickness along side of kernel and not at the crown or base of the kernel, where pericarp thicknesses may vary.

Other Genes Affecting Pericarp Color

Other genes have been reported that affect pericarp color and many more probably exist in the world sorghum collection. A gene (Pb-) causes purple spots in the pericarp in some commercial sorghums. Brown wash genes (Bw_1-Bw_2-) affect pericarp color when B_1-B_2- genes are present with a homozygous recessive (ss) spreader. The brown color washes through the pericarp in some places but apparently the color is different from that due to the dominant spreader gene. Another gene, sun red (Rs.-), causes the color of the pericarp to become red when it is exposed to the sun during maturation. The color then disappears with the pericarp color determined by the R-Y-I- genes. These genes can affect products such as *tortillas* when the sorghums used have these additional pigments in the pericarp. Some sorghums with a colorless pericarp without a testa apparently contain color precursors which produce off-colors when cooked in alkali.

Glume and Plant Color

Plant and glume color can affect the polyphenol content of the grain. Three main plant colors are red (P-q'q'), tan (ppqq), and purple (P-Q- or Pqq) (Colorplate 3). Glume color is associated with plant color. The best way to determine glume color is to examine the color of the inside of the glume after the kernel is removed. The colors are again red, tan, and purple. Glumes with intense red and purple color have a tendency to stain the sorghum kernel because the polyphenolic pigments leach into the pericarp. This leaching occurs under humid conditions or when rainfall occurs during kernel maturation. The extent of the kernel covered by the glumes can vary from a completely open glume to a glume that is longer than the kernel (Colorplate 2).

Pericarp Thickness

The Z-gene controls the thickness of the pericarp with the dominant gene giving a thin pericarp and the recessive (zz) a thick pericarp. The thickness refers to the number of layers in the mesocarp and the presence of starch granules. A thick, starchy mesocarp masks the color of pigments present in the testa and endosperm while a thin, translucent pericarp permits the color of the testa and/or endosperm to affect the visual color of the kernel. The thickness of the pericarp (mesocarp) varies when the genes are recessive (zz) which suggests that there may be additional modifiers influencing pericarp thickness (Fig. 6). The genetics of pericarp thickness should be studied in more detail especially in view of their effect on milling properties of the grain and mold susceptibility.

Testa

Just beneath the cross and tube cell layers, some sorghum kernels have a highly pigmented layer called the testa or subcoat (Fig. 4). The presence or absence of the testa is controlled by the complementary B_1 and B_2 genes with the testa present when both the B_1 and B_2 genes are dominant (B_1-B_2-). Some sorghum lines contain a partial testa that is found at certain places around the kernel (Blakely et al. 1979). Testa thickness varies among sorghum genotypes and within the individual kernels with the thickest part at the crown and the thinnest area over the embryo (Fig. 6). The color of the testa can also vary among sorghum lines (Colorplate 2 D and E). The testa color is purple for tptp and brown for the genes Tp-. Hegari and Feterita have the purple testa. The testa develops from the inner integument which has a definite cellular structure. However, as the kernel matures and the endosperm expands, the cellular configuration usually gives way to a continuous layer.

Spreader

The B_1-B_2- genes affect pericarp color when they are dominant in combination with the dominant spreader gene (S-) causing intense pigmentation in the epicarp and imparting a brown color to the pericarp. The name "spreader" was derived from the belief that this gene caused the color to "spread" from the testa into the epicarp of the grain. At the present time, the mechanism by which this pigmentation occurs is not known. It is likely that the presence of the S- gene causes formation of different kinds of pigments in the epicarp as well as possibly in the testa. The shade of brown in the epicarp is determined by the R-Y-I genes with a large variation existing between the sorghums with genetically white, red, or lemon yellow pericarps (Colorplate 1).

Phenotypic Appearance of the Kernel

After having discussed the genetics of pericarp color (R-Y-), color intensification (I), presence or absence of a mesocarp (z), presence or absence of a pigmental testa (B_1, B_2 and T_p) and spreader (S), color modification is still induced. These color changes are the result of differences in endosperm color (yellow, white), texture (corneous, floury), and type (normal, waxy, or sugary). Factors affecting endosperm characteristics are not included in most market classifications. Therefore, if we had a white sorghum (RRyy) with a thick mesocarp (zz) covering a yellow endosperm it would appear quite white. However, if we were to substitute Z- (no starchy mesocarp), the kernel would appear light yellow because the colorless pericarp and absence of starchy mesocarp would allow the yellow endosperm color to show through. Differences in intensity of red color over a yellow endosperm can also give a range of bronze colors.

Corneous textured endosperms result in more brilliant colors, and floury textures give dull or opaque colors. Waxy endosperm type causes a change in degree of brightness of the seed. Normal types are more brilliant for all colors than the waxy

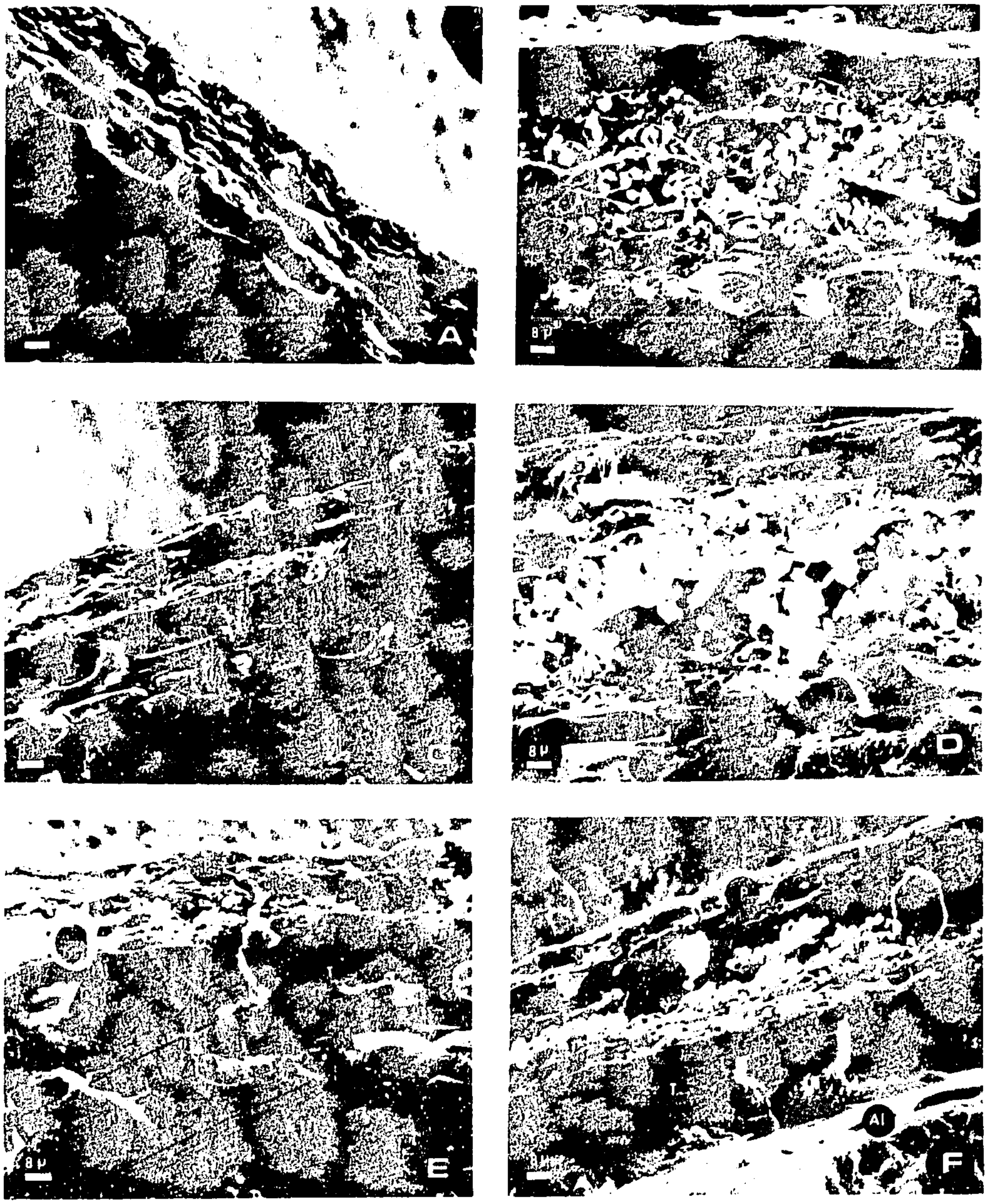


Figure 6. Scanning photomicrographs (600x) depicting pericarp and testa thickness of several sorghum kernels:

A. Thin pericarp without testa (IS9985).

B. Thick pericarp without testa (Mali sorghum—thick keninke). Starch granules in the mesocarp.

C. Thin pericarp with thin testa.

D. Thick pericarp with thin testa (Mali sorghum—CSM184).

E. Thin pericarp with thick testa (GA615).

F. Thick pericarp with thick testa (623 × SC103). Starch granules in the mesocarp.

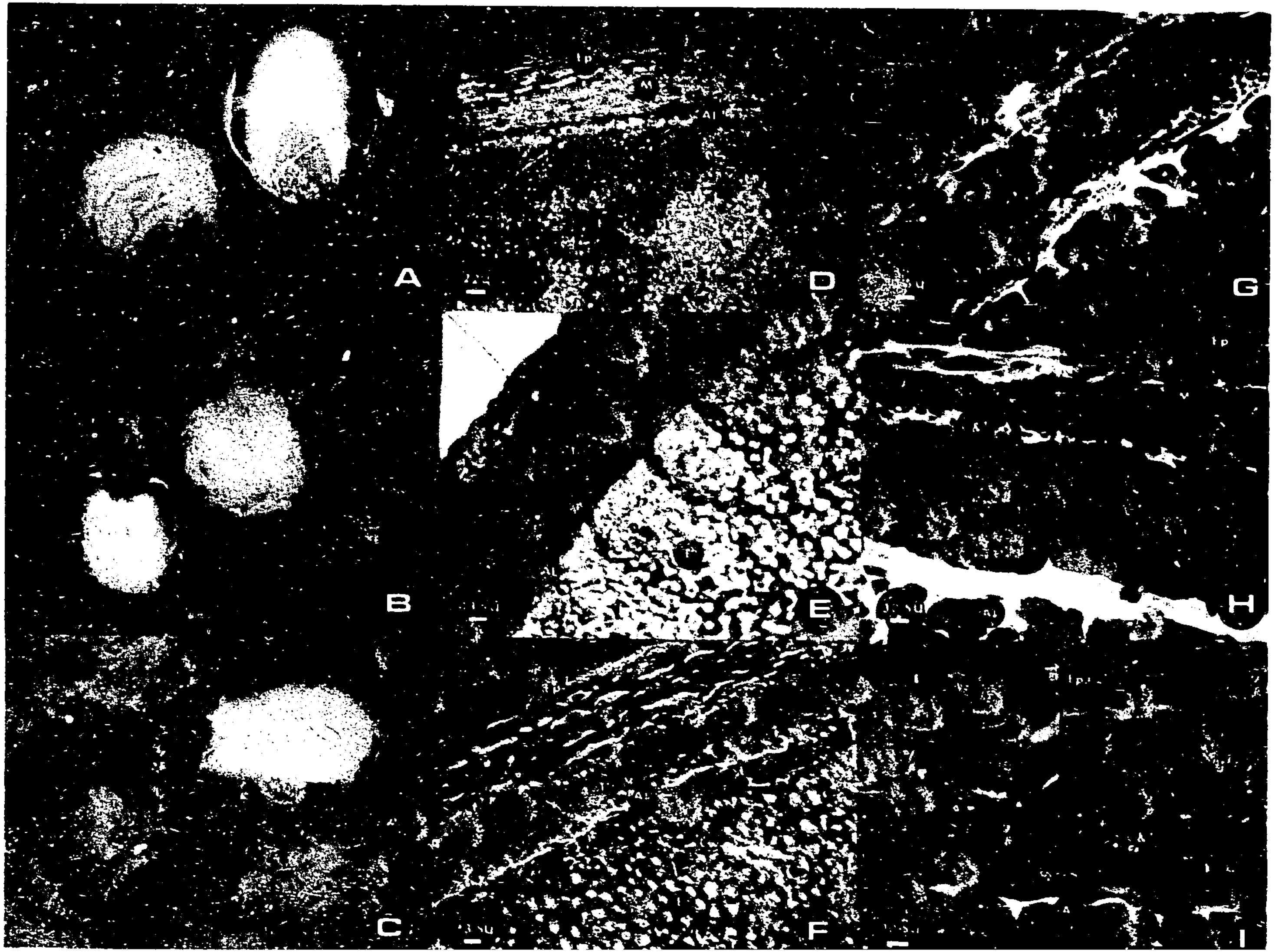
P = pericarp; Al = aleurone layer; T = testa. The sorghum kernels were longitudinally cut approximately the same place on each kernel so that differences in pericarp and testa thickness represent true variation among the sorghum genotypes.

C. Plate 3. A, B, C. White sorghum without a testa, white sorghum with a testa (B_1B_2-ss), and sorghum with a testa and spreader (B_1B_2-S-), respectively. All of the sorghum kernels have a thick pericarp.

D, E, F. Light micrographs of sorghums A, B, and C, respectively. The micrographs were taken using Nomarski differential interference contrast techniques. In E, the epicarp of the pericarp has been lost during sectioning.

G, H, I. Fluorescent photomicrographs of sorghums A, B, and C. Autofluorescence occurs in all three samples, indicating the presence of small phenolic compounds—in particular ferulic acid. Other pigments can be detected as orange color in the epicarp of the brown sorghum.

Labels are: AL = aleurone layer; T = testa, C and T = cross and tube cells; EP = epicarp; M = mesocarp; E = endosperm; and CW = cell walls.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endosperm mutant. Sugary endosperm is hard and crystalline as well as dimpled, but gives a color reaction similar to the corneous endosperm textures.

Plant color that affects glume color also affects the expression of the red and lemon yellow pericarp colors. When tan plant color (ppqq) exists, the colors generally appear washed out or slightly bleached. When white pericarp color is present and glume color is tan, the seed appears much whiter than the same seed on a red or purple plant. These express to different degrees when endosperm type and texture are changed and can result in misclassification if unsuspected.

Brown sorghum, i.e., those with a pigmented testa, appear visually to range from white to dark black browns. This variation is easily explainable with an understanding of pericarp color, color intensity, spreader, and endosperm characteristics. The variety Hegari from Sudan, which was widely grown in the USA, appears white with a slight blue hue but it is a brown sorghum. TAM 2566 with a red pericarp, intensified color and pigmented testa appears a very bright reddish purple; whereas "ATX378x combine shallu" has a red pericarp, recessive with a dominant spreader and appears brown. The literature is filled with incorrect references to red or white sorghums that are in fact brown sorghums. Characteristics of the grain that under optimum environmental conditions appear bright may appear quite different when the grain is molded, injured by insects or cold temperatures. It is important to evaluate materials in a condition of optimum kernel quality. More progress could be made in understanding the role of grain quality traits if an effort were made to understand pericarp color and those factors affecting it.

Other Factors Affecting Kernel Appearance

Several conditions related to environment can affect the appearance of sorghum. Upon insect attack, the kernel often produces phenolic compounds which surround the area. This can cause pigmentation in isolated areas and can even cause leaching of pigments into the aleurone and sometimes the endosperm areas. Mold damage can occur in several ways. Mold at low levels can produce spots on the kernel and in larger amounts can completely cover the sorghum kernel. Mold attack on a kernel can lead to a decrease in kernel weight upon maturation while extensive mold action can lead to a floury, highly degraded kernel. Sprouting or preharvest germination can occur when the sorghum heads receive excessive moisture prior to harvest.

Terminology

Numerous mistakes have been made in the literature regarding many of the terms used to refer to the various anatomical parts of the kernel. Until 1974, the U.S. grain standards for sorghum erroneously used the term seed coat to refer to the pericarp of sorghum. The term seed coat should be used to refer to the layer that is the mature ovule wall in sorghum. Several terms including testa, subcoat, undercoat, inner integument, outer integument, nucellar layer, and probably others have been used to refer to the seed coat. Current United States standards for sorghum use the subcoat; the authors prefer the use of subcoat or testa to avoid confusion. Another item is the use of the term pigmented testa vs testa. By common use, authors who refer to a testa are nearly always referring to a pigmented testa. Conversely, sorghums without a testa means that a sorghum kernel does not have a pigmented testa. Technically, all sorghum kernels have a few cell remnants between the pericarp and the aleurone layer that can be referred to as a testa. However, for practical purposes, the terms as used are appropriate and they are used in this manuscript.

Brown Bird-Resistant Sorghums

The presence of a testa in the sorghum kernel automatically places the sorghum in the brown class according to United States Grain Standards, which recognize brown, yellow, white, and mixed sorghum classes.

Therefore, sorghums with B_1-B_2-ss and B_1-B_2-S- genes are classified together even though a great deal of variation in tannin content exists. The white class is restricted to kernels with rryy or R-yy with b_1b_1—or—b_2b_2 genotypes. The yellow class can have any combination of pericarp colors as long as a testa is not present. This classification scheme has been effective in discriminating against the high-tannin lower nutritional value of the brown sorghums. The bird-resistant high-tannin sorghums are those that have B_1B_2S- genes while those sorghums without the spreader (B_1-B_2-), in general, do not have acceptable bird resistance.

The level of tannins and their effect on nutritional value as related to the presence or absence of the testa and spreader in sorghums have been described by Maxson et al. (1972, 1973).

For practical purposes, sorghums with testa were grouped together since they had some effect on nutritional value. These data were considered when the United States Grain Standards for sorghum were revised in 1974. A scheme to classify sorghums in groups I, II, and III based on chemical analyses was proposed by Cummings and Axtell (1973) and redefined by Price and Butler (1977). It is now clear that, in general, group I does not have a testa, group II has a testa (B_1-B_2-ss), and group III has a testa and spreader (B_1-B_2-S-). Light, fluorescence and low power photomicrographs of the three types of sorghum are presented in Colorplate 3. The pigments in the epicarp of the sorghum with dominant testa and spreader (B_1-B_2-S-) show up clearly with fluorescence microscopy (photo 1 of Colorplate 3). In photos G, H, and I, the blue color is due to autofluorescence primarily of ferulic acid derivatives located in the cell walls. In plate G and I, the epicarp and endocarp (cross and tube cells) are shown quite clearly. The slight orange-brown tinge in the endocarp and hypodermis may be due to the carrying of pigments during sectioning from the epidermis and testa into adjacent layers.

Endosperm Structure

The sorghum endosperm consists of the aleurone layer, peripheral, corneous, and floury portions. The aleurone cell layer is a single layer of blocklike rectangular cells located directly beneath the pericarp or below the testa, if it is present (Figs. 4A,B,C). The aleurone cells contain large amounts of minerals, water soluble vitamins, autolytic enzymes, and oil. The aleurone cells also contain spherical bodies high in protein, phytin, and minerals. The aleurone cell layer plays an important role in autolysis and mobilization of kernel constituents during germination.

The peripheral endosperm is a rather ill-defined area directly beneath the aleurone layer. The peripheral area consists of small, blocky cells containing small starch granules and may be anywhere from the first two to six endosperm cells thick. The starch granules are embedded in a dense proteinaceous matrix composed mainly of glutelins or alkali soluble proteins and prolamins (Figs. 7A,B). The prolamins, alcohol soluble protein, are located predominantly in the form of protein bodies surrounded and sometimes embedded in the protein matrix. When kernel sections have been treated with α-amylase, these protein bodies can be observed (Fig. 7C).

The endosperm contains both free protein bodies, those embedded in the protein matrix, and those glued together by the glutelin proteins. The protein bodies of the peripheral and corneous endosperm range from 0.3 to 3.0μ in diameter and decrease in size and number toward the center of the kernel as the amount of starch increases. The protein bodies in the floury endosperm area range from 0.3 to 1.5μ in diameter.

In the peripheral endosperm, the starch granules are embedded in a dense mixture of protein bodies and matrix and are difficult to remove. Enzyme hydrolysis of the starch granules is greatly retarded by the protein bodies and matrix, rendering much of the starch in the peripheral endosperm unavailable for utilization. The kernel must be processed in some manner to disrupt the protein matrix and release the starch granules.

The corneous endosperm (often called hard, flinty, vitreous, or horny) is located beneath the peripheral endosperm and has a continuous interface between the starch and protein (Fig. 8). The starch granules are very angular or polyhedral in shape with depressions where protein bodies were trapped between expanding starch granules (Fig. 4). The starch-protein bond is strong and starch granules often break rather than pull from the protein matrix.

The floury endosperm area has loosely packed endosperm cells (Fig. 8). Small voids occur between the spherical starch granules with little or no matrix protein seen. These voids permit the passage of light through the floury endosperm area causing it to look opaque or chalky in appearance. Protein bodies are present in the floury endosperm but in much smaller amounts than seen in the corneous or peripheral endosperm areas. The matrix protein that does exist is spread in thin discontinuous sheets over the surface of the starch granules. The protein content of the floury endosperm within a kernel is lower than the corneous endosperm, thus the availability of the starch is improved. At some place in the en-

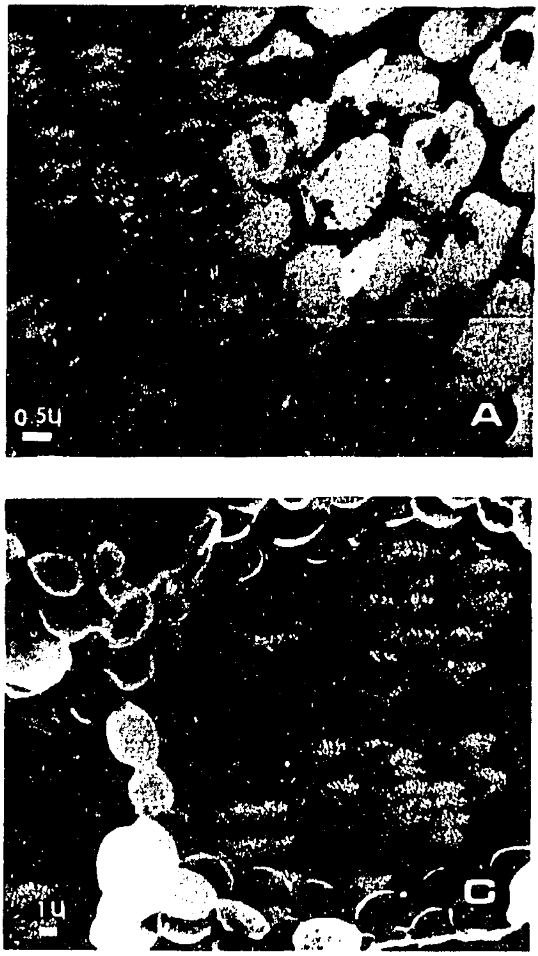

Figure 7. A. Transmission electron micrograph of sorghum matrix protein that has been extracted with 60% tert-butanol and stained with uranyl acetate. The protein bodies have dissolved, leaving the darkly stained protein matrix and cores of the protein bodies.
B. Transmission electron micrograph of sorghum endosperm showing the variation in protein body size and shape.
C. Scanning electron micrograph of sorghum protein bodies and matrix after removal of starch with alpha-amylase.

dosperm, there is a transition from corneous to floury endosperm. Figure 8 is a photomicrograph of this transition area. Some cells in the floury portion contain starch granules that appear well meshed together, while other cells are loosely packed with voids more closely resembling the floury endosperm.

Sorghum starch granules are polyhedral with large variation in size from 2 to 30µ in diameter. An isolated starch sample from the endosperm of a nonwaxy sorghum is presented in Figure 4. No difference can be visually observed between waxy and nonwaxy sorghum starch. The smallest starch granules are located in the mesocarp of sorghums with a recessive z gene (zz). These are shown in Figure 4E.

Endosperm Color

Some sorghums have a yellow endosperm containing high levels of carotenoid pigments. In true yellow endosperm varieties those genes affecting carotenoid content are homozygous. If the pericarp is thin or colorless (R-yy or rryy) and the testa is absent, the color of the kernel appears yellow. If the kernel has a thick mesocarp (zz) the kernel will appear white because the yellow endosperm color has been masked by the thick pericarp. Some sorghums are called bronze in color, which is a combination of a thin red pericarp with the yellow endosperm color showing through and modifying the kernel color. If a thick red pericarp is present, the yellow endosperm is at least partially masked by the thick pericarp. The presence of a pigmental testa, red color, and spreader can completely mask the color of the endosperm. Generally, the presence of a thick mesocarp is the most effective in masking the color or texture of the endosperm regardless of the pericarp color. When yellow endosperm varieties

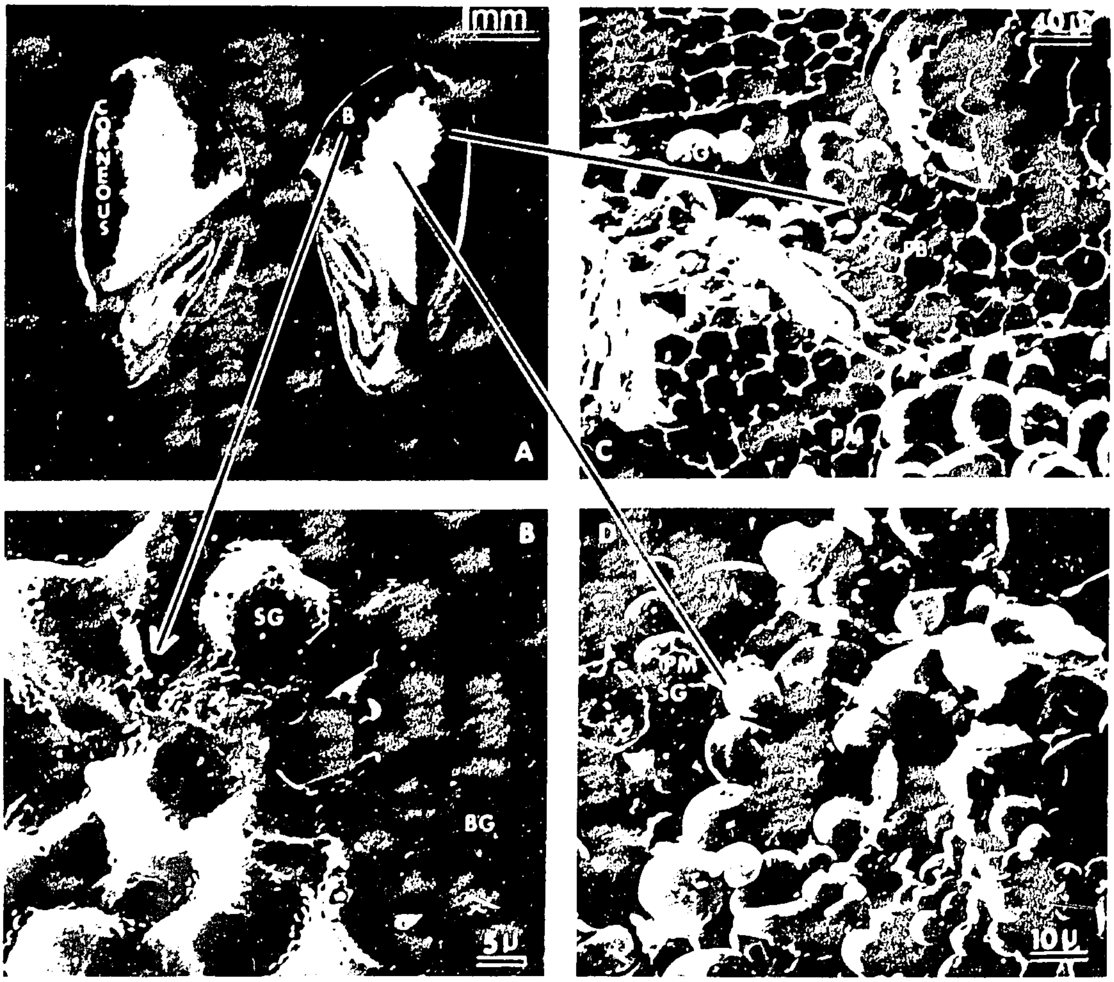

Figure [illegible]. Scanning electron photomicrographs illustrating sorghum endosperm structure. (A) longitudinal section of kernel, (B) corneous endosperm area, (C) transition zone between corneous and floury endosperm, (D) floury endosperm area.

are pearled to remove the pericarp, the true yellow endosperm is easily observed. In the United States, very few yellow endosperm sorghum varieties are grown, but it is not uncommon to see heteroyellow endosperm hybrids. In other parts of the world, yellow endosperm varieties are grown and are an important source of vitamin A in some areas where sorghum is a major part of the diet. The carotenoid pigments are most easily seen in the corneous portions of the endosperm. These pigments are also present in softer portions of the endosperm even though they are less evident. The carotenoid content is reduced by oxidation resulting from exposure to sunlight.

The aleurone of sorghum is usually colorless, although under certain circumstances of insect or disease attack, pigment has been observed in the aleurone layer (Blakely et al. 1979). A colored aleurone exists in barley (*Hordeum vulgare*) and maize (*Zea mays*), but none has been reported for sorghum, although a Sudanese variety with a black or purple pericarp may have one. Confirmation of this must still occur.

Endosperm Texture

The relative proportion of the corneous to floury rating meaning that the kernel contains very little floury endosperm (almost completely corneous) and a 5 rating meaning essentially all floury. These ratings are determined by comparing the unknown kernels with a photo of samples that have been previously rated (Fig. 9). All of the samples in Figure 9 were grown under comparable conditions indicating that a range in genetic diversity of endosperm textures exists. Environment can also affect the texture, often making it difficult to assess one rating to a variety. Texture affects the processing properties of the grain. In sorghums with a higher percentage of corneous endosperm, the pericarp (bran) is more readily separated from the intact starchy endosperm thus giving a higher yield during dry milling. Norris (1971) found that the floury sorghums gave the best starch yields when subjected to a laboratory wet milling procedure. Texture has also been related to storage potential. Insects more readily attack a soft, floury endosperm sorghum than a corneous sorghum. The particle size, amount of damaged sorghum, and other important factors relating to food quality of sorghum are related to endosperm texture and the way the endosperm breaks down during milling. For example, the grittiness of some sorghum flours is due to the peripheral and corneous endosperm intact cells. Some processing methods eliminate these particles by fermentation, beating during cooking, etc.

Endosperm Type

Waxy sorghum was first used in the United States in World War II as a substitute for tapioca starch. Normal or nonwaxy sorghum starch has approximately 75% amylopectin and 25% amylose, while waxy starch contains nearly 100% amylopectin. Nonwaxy starch stains deep purple with iodine, while the waxy starch stains a reddish-brown. Waxy starch has unique cooking and gelation properties of industrial importance. The waxy gene is recessive with the term waxy referring to the glossy "waxed floor like" appearance of the endosperm surface. Waxy sorghum does not contain larger amounts of wax than normal sorghum. The gross composition of waxy sorghum is nearly identical to that of nonwaxy sorghum. The alleles were subjected to α-amylase digestion and were examined with the scanning electron microscope to determine the effect on endosperm hydrolysis. The starch in waxy sorghums is hydrolyzed more rapidly than that of the nonwaxy counterparts, which is shown clearly in Figure 10. This explains why waxy sorghums do not generally have acceptable food quality. However, waxy sorghum food products may be desired in some areas of China. More information is required to determine what the real situation is.

Normal sorghum has a plump or full endosperm with a dense concentration of protein bodies in the peripheral endosperm area. Two different sources of genes for high-lysine sorghums have been found (Singh and Axtell 1973; Mohan 1975; Sullins and Rooney 1974). The Ethiopian high-lysine sorghums have a dented kernel and are soft and floury. The shrunken or dented characteristic is a result of less starch being synthesized, and as water is lost at maturity, the kernel shrivels or dents. The induced high-lysine mutant P-721 has a more plump floury kernel. The Ethiopian mutants have a markedly reduced number of protein bodies in the endosperm compared with the normal counterpart (Fig. 11). The basic difference in protein bodies was used by Rooney and Sullins (1977) to attempt to find a corneous sorghum with high lysine content. That goal was not achieved, but it was not because of a failure in the SEM technique.

We have considerable information on the structure of processed products from sorghum. However, we will not present the information here since space is limited. We are convinced that an understanding of sorghum kernel structure and its variation due to genetics and environment is extremely useful in sorghum improvement programs as well as in milling studies. Such information helps to explain why it is possible to use a pocket knife to evaluate kernels in the field for texture. In the near future the combination of light, scanning and transmission electron microscopy as well as fluorescence microscopy will provide new information of great importance in determining mold and insect resistance as well as processing properties. This will only be accomplished by the wise application of microscopy as part of an integrated study of the physical, chemical, proces-

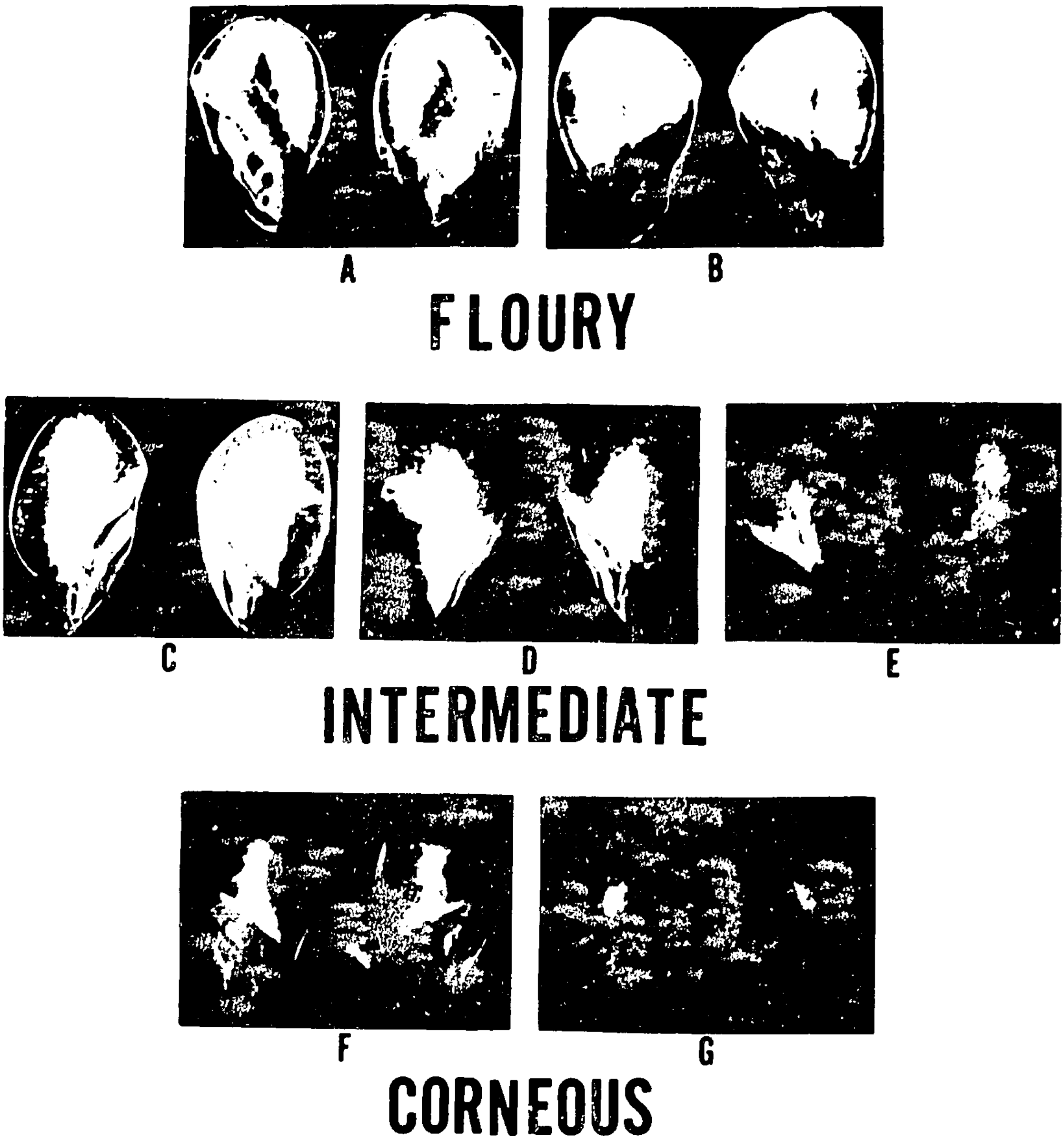

Figure 9. Endosperm texture of sorghum: median longitudinal half kernels of sorghum showing the range from almost entirely corneous endosperm samples to entirely floury kernels. The ratings for the kernels are A and B-5, C-4, D-3, E and F-2, and G-1. Cross section.

sing, and structural properties of sorghum. We have only begun to use these techniques.

In Figure 12, we have a picture of starch granules that look like Mickey Mouse, the Walt Disney character. Actually "Mickey Mouse" is composed of four starch granules from sorghum. The right ear is a small starch granule from the floury endosperm or perhaps the starchy mesocarp. The left ear is a small starch granule from the peripheral endosperm, and the head is from the corneous endosperm. The body is a large starch granule from the floury endosperm. The pock

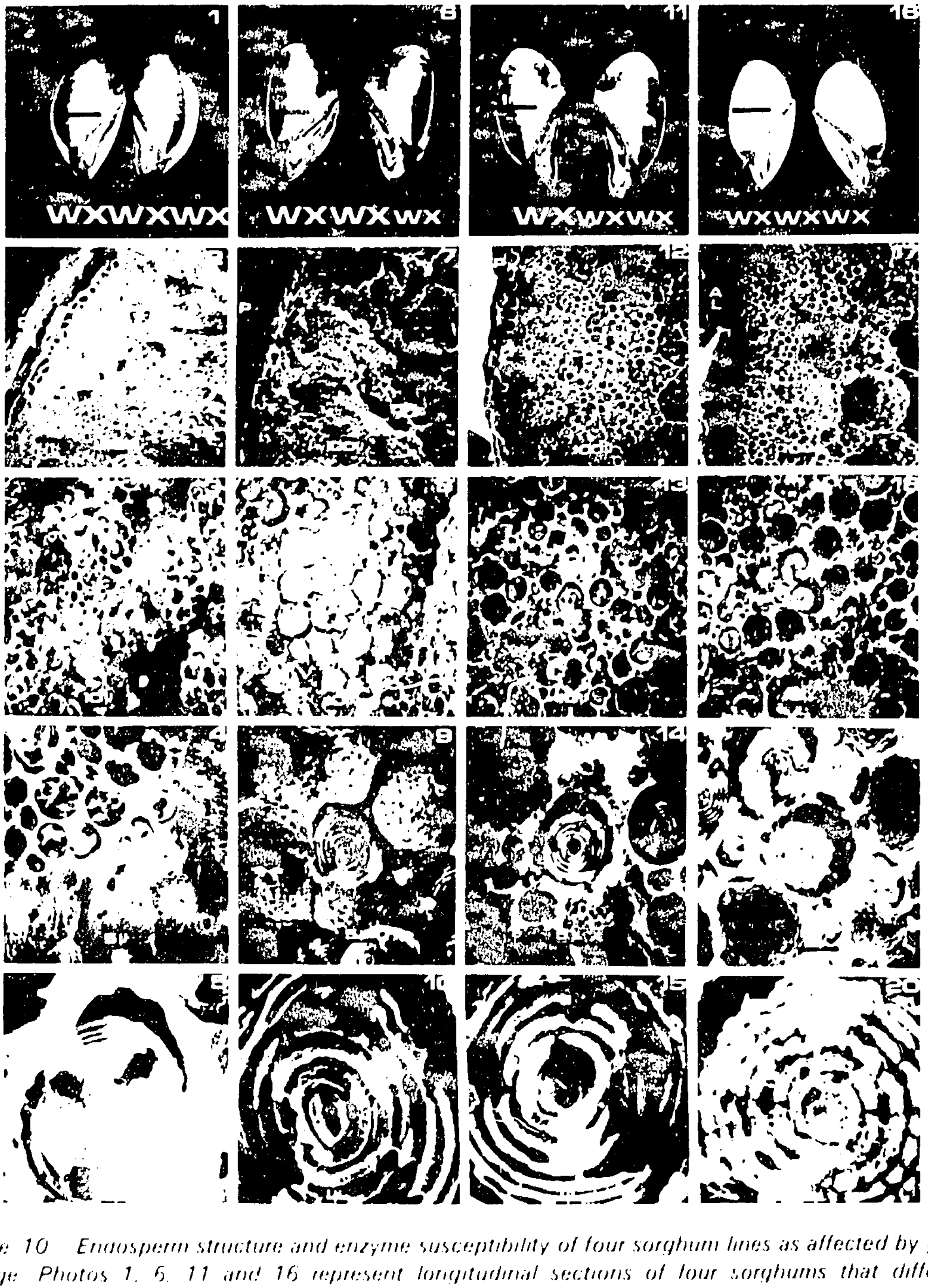

Figure 10 Endosperm structure and enzyme susceptibility of four sorghum lines as affected by gene dosage. Photos 1, 6, 11 and 16 represent longitudinal sections of four sorghums that differ in concentration of the recessive waxy allele in the endosperm. Photo 1 is normal or homozygous nonwaxy Kafir. Photo 6 is hetorozygous Kafir with one dose of the recessive waxy allele, photo 11 is a heterozygous Kafir with two recessive waxy alleles, and Photo 16 is homozygous waxy Kafir (Tx615). Photos 2, 3, 4, and 5 are scanning electron photomicrooraphs of half kernels of the homozygous nonwaxy line after treatment with hog pancreas alpha amylase for 2 hr at 39° C. Kernels from the four grains were treated simultaneously with the enzyme. In general, the number of recessive waxy alleles in the endosperm is associated with more extensive hydrolysis.

teristics that is encountered in a breeding program. Once the variability is understood, a pocket knife can sometimes be used effectively to select for sorghums with certain desirable properties.

Acknowledgment

The information in this paper has been obtained over the past 12 years. Author Rooney acknowledges the contributions of many former students and staff members of the Texas Agricultural Experiment Station (TAES) who interacted with him during the past 15 years. Drs. R. D. Sullins, J. A. Glueck, Ms. Lisa Blakely, Ms. B Johnson, Ms. Wanda Stuart, and currently Ms. C. F. Earp, research associate, deserve special thanks for their assistance. Drs. L. E. Clark, D. T. Rosenow, and J. W. Johnson of the TAES have made significant contributions in terms of advice, samples, and encouragement. This research was supported in part during the past 2 years by Grant AID DSAN XII G-0149 from the Agency for International Development, Washington D.C., USA.

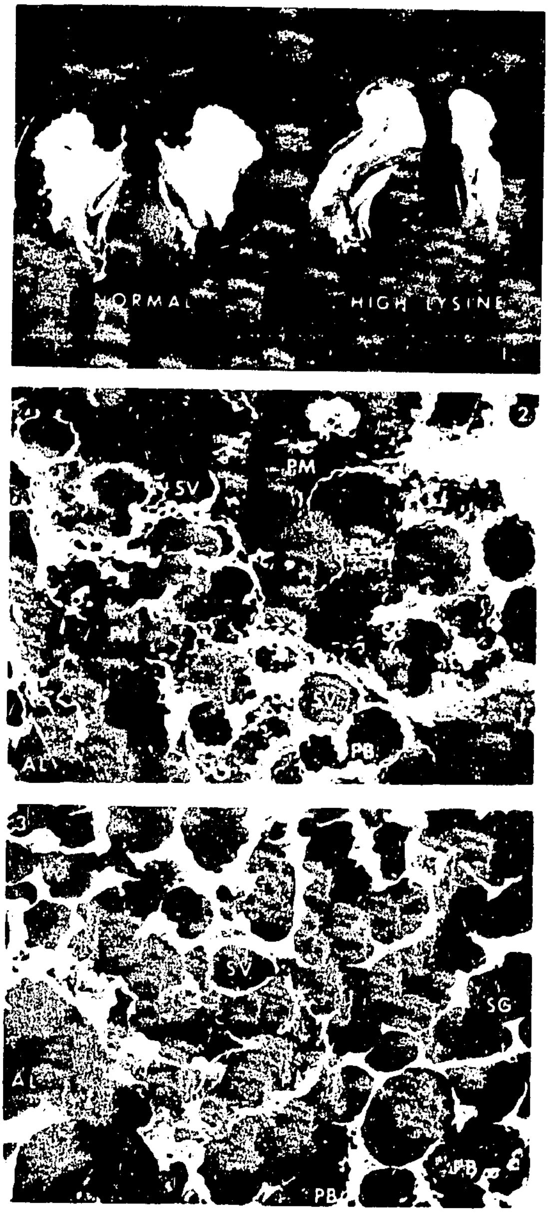

Figure 11. Normal sorghum versus a partially dented Ethiopian high lysine sorghum. Scanning electron photomicrographs show that the normal sorghum has larger and a greater number of protein bodies (2) in the peripheral endosperm than does the high lysine variety (3).

marks on Mickey Mouse's stomach is starch that was pitted by amylase attack.

Knowledge of sorghum kernel structure can aid in understanding the variation in kernel charac-

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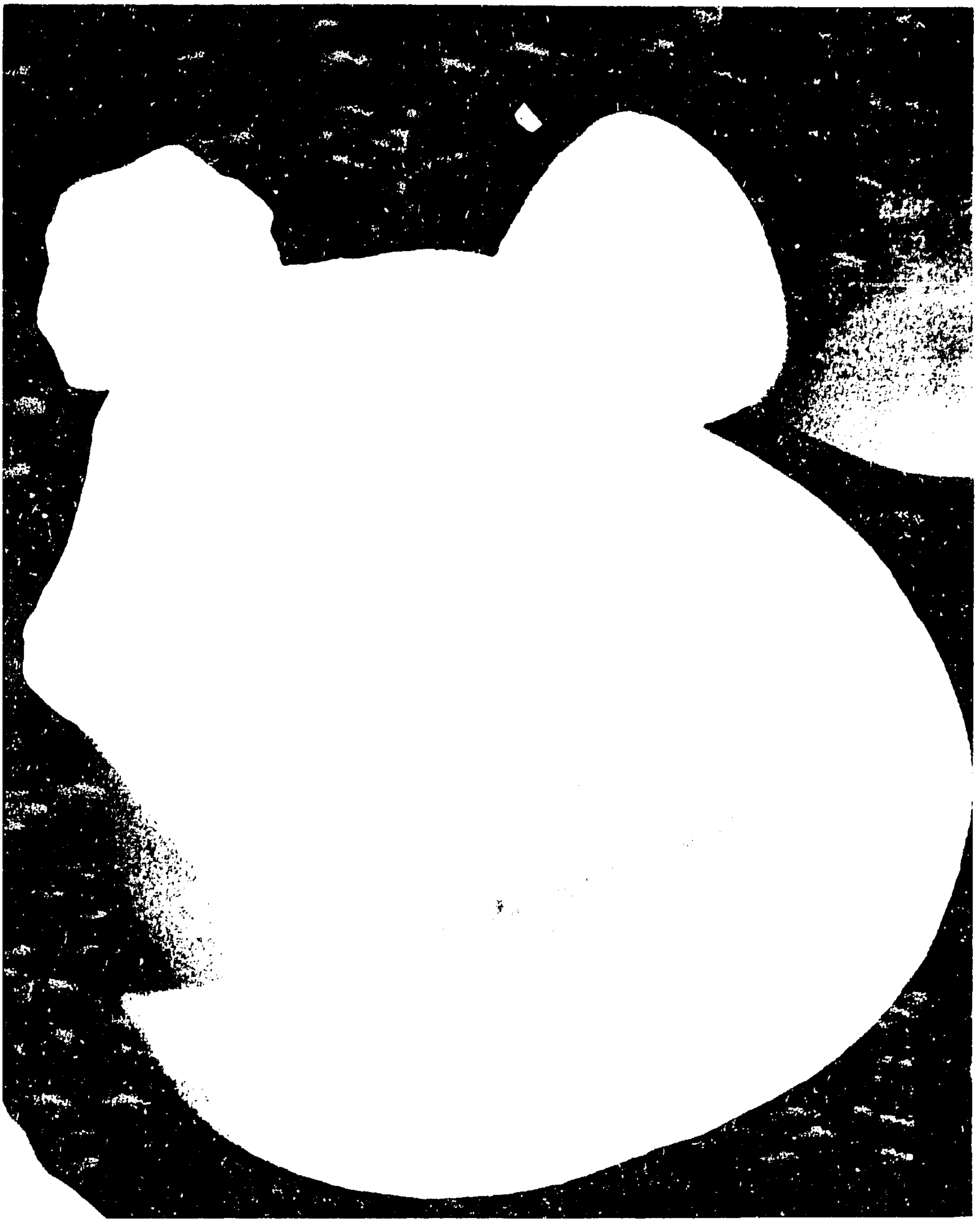

Figure 12. Mickey Mouse: a sorghum starch character.

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Grain Deterioration in Sorghum

L. L. Castor and R. A. Frederiksen*

Summary

Fungi affect sorghum seed quality in many ways. Based on behavior, there are two types: field and storage fungi. Field fungi may be further divided into pathogens causing grain mold, and saprophytes responsible for postmaturity deterioration or weathering. These are all capable of causing substantial losses in food quality and quantity of grain and they represent one of the most significant production hazards when attempting to introduce higher-yielding sorghum in the tropics (Williams and Rao 1981). Some of these fungi produce toxic metabolites known as mycotoxins. Considerable progress has been made in the development of sorghums resistant to grain mold and weathering. There is also evidence suggesting that some sorghums are more resistant to storage fungi.

The quality of any cereal grain, including sorghum, is dependent on many factors. These include the *uses* of the grain, as a feed or food product, and the *methods* of preparation of the product, which may vary between cultures or within a culture over time. In this paper, we will discuss the role of fungi in reducing the nutritional quality of sorghum grain during the preharvest and postharvest periods.

Grain Fungi

Fungi in dozens of genera occur in sorghum grain (Swarup et al. 1962; Williams and Rao 1980). These fungi can be divided into two groups based on their behavior: the field fungi, and the storage fungi (Christensen and Kaufmann 1969). Field fungi invade kernels prior to harvest and grow only in kernels with a moisture content (20 to 22% net weight basis) in equilibrium with a relative humidity of 90% or more. Damage by field fungi is caused before harvest and usually does not increase in storage, as opposed to damage by the storage fungi. Storage fungi can invade kernels prior to harvest, but the greatest invasion of kernels occurs after harvest. Storage fungi can grow in kernels whose moisture contents (13 to 20% net weight basis) are in equilibrium with relative humidities of 70–90%. Storage fungi are species of *Aspergillus* and *Penicillium*. Generally, sorghum grain samples with a high incidence of storage fungi have a very low incidence of field fungi and vice versa (Doupnick 1974; Niles 1976; Pettit and Taber 1978; Seitz et al. 1975). This is to be expected in view of the differences in moisture requirements of the two groups of fungi and the possible antagonism between them (Wicklow et al. 1980). Castor (1981) found that the most common species of field fungi in sorghum grain belong to the genera *Alternaria, Fusarium, Helminthosporium, Curvularia, Phoma,* and *Colletotrichum,* based on published reports.

Preharvest Degradation of Sorghum Grain

The period prior to harvest can be divided into two periods in the development of the sorghum kernel: prematurity and postmaturity. The species of fungi contributing to kernel degradation vary depending on the period. Grain molds result from infection of the spikelets on developing kernels as early as anthesis by parasitic fungi such as *Fusarium moniliforme* Sheldon and *Curvularia lunata* (Wakker) Boed. (Castor 1981). Other fungi, such as species of *Alternaria, Cladosporium, Phoma,*

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and possibly, *Fusarium semitectum* Berk. and Rav., invade mature kernels as saprophytes, whenever moisture conditions are favorable. This type of molding has been referred to as grain weathering in the United States (Anon. 1978; Seitz et al. 1975). Grain molding fungi colonize from the base of the kernel toward the tip. Sporulation follows this pattern and mold frequently appears on the kernel surface beneath the glumes and progresses toward the tip. The internal structure of the kernel is disrupted and degraded from the base toward the tip. Grain weathering fungi colonize the tip of the kernel and the portion of the kernel not covered by the glumes. Indeed, in the early stages of weathering, the kernel is clean and normal in appearance beneath the glumes. Sporulation occurs first on the exposed portion of the kernel. The internal structure of the kernel is degraded from the outside in, and from the tip to the base. We speculate that the grain weathering fungi may infect before kernel maturity; however, the infections remain latent until maturity or after, when rains or dews favor colonization.

The types of damage caused by grain molding and/or grain weathering fungi are: (a) pericarp discoloration, (b) reduction in kernel filling, (c) reduction in germination, (d) increased sprouting, (e) degradation and molding of the kernel, and (f) production of mycotoxins (Table 1).

The discoloration of sorghum grain may be caused by infection of grain molding fungi. The cells of the developing kernel produce compounds (pigments) in response to fungal colonization. The pigments may be found in several areas of the kernel, but occur most frequently in the pericarp. A pigmented pericarp may not reduce the nutritional value of the kernel, but it does make the kernel look bad. Similarly, *Alternaria* and *Phoma* spp often colonize the pericarp and sporulate on the kernel surface leading to an unsightly appearance of the grain. The nutritional value may or may not be affected, depending on the severity of fungal colonization. A study in Texas, USA concluded that weathered grain was equal in nutrition to normal grain (Anon. 1978). However, the weathered grain weighed only 50-70% of the weight of normal grain. Scheuring et al. (1981) reported that *tô*, a thick porridge in West Africa, was discolored

Table 1. Mean values[a] for 11 variables measured on 11[b] sorghum lines from the International Sorghum Grain Mold Nursery, ISGMN, grown at ICRISAT Center, Andhra Pradesh, India in 1978.

	Control treatments[c]			Fungal treatments[d]				
Variables	NAT	NW	N	FM	FS	CL	F	FC
Field mold (%)	7.1AB	7.4AB	5.7AB	12.2AC	4.9B	20.3D	7.4AB	14.5CD
Moisture content (%)[e]	16.0AB	14.9ABC	15.6AB	12.4D	16.4A	12.3D	14.2BCD	13.3CD
100 Kernel weight (g)	2.73A	2.76A	2.75A	2.53B	2.76A	2.51B	2.64AB	2.61A
Small kernels (%)	5.6A	4.1A	5.5AB	27.2D	6.5A	35.3D	13.2BC	18.7C
Kernel rating[f]	2.2B	2.1B	2.1B	2.9C	1.6A	3.3D	2.3B	2.8C
Molded kernels (%)	9.8AB	9.3AB	9.2AB	18.8CD	6.8A	22.9D	14.2BC	18.2CD
Preharvest sprouting (%)	3.4A	2.9A	3.2A	6.9B	3.0A	3.1A	5.0AB	4.3A
Germination (%)	86.7A	82.2AB	82.2AB	70.6D	81.8ABC	76.5BCD	74.0CD	78.6BCD
Curvularia lunata (%)	23.5AB	26.0A	28.8A	12.0B	23.8AB	86.3D	13.8B	74.5C
Fusarium spp (%)[g]	65.0A	83.3A	87.5A	100.0A	79.2A	75.0A	100.0A	72.5A
Phoma spp (%)[h]	12.8A	11.8A	11.5AB	3.8C	6.5BC	4.0C	3.7C	3.4C

a. Mean separation using Duncan's Multiple Range Test; means followed by the same letter are not significantly different at 0.05 significance level.
b. M36333, M35052, M4337-2, M36113, M36348, M36049, M36285, CS3541, E35-1, CSH-6, and M36423.
c. NAT = not treated, not bagged; NW = water sprayed, bagged; N = not treated, bagged.
d. FM = *Fusarium moniliforme*, FS = *Fusarium semitectum*; CL = *Curvularia lunata*; F = a mixture of *Fusarium* spp isolates; FC = a mixture of *Fusarium* spp isolates and *Curvularia* spp isolates.
e. Based on net weight.
f. Ratings on a 1-5 scale: 1 = clean seed; 5 = severely molded.
g. Frequency of *Fusarium* spp isolated from treated grains.
h. Frequency of *Phoma* spp isolated from treated grains.

when moldy grain was used to prepare it.

Early infection by grain molding fungi can affect kernel development. In some cases, kernel development is stopped at such an early point that the kernel does not form (Castor 1981). In other cases, the kernel forms, but is smaller and lighter than it would be in the absence of the fungus. The reduction in size and weight of kernels can occur without molded kernels being present. The nutritional quality of this grain should not be affected.

Grain molding fungi can also reduce the germination of sorghum kernels, without obvious external mold. This would be important where farmers plant varieties rather than hybrids and save their seed for planting. This probably would not reduce the nutritional quality of the grain. However, as with reduced kernel filling, the quantity of grain from subsequent plantings could be affected. The quantity of grain available is as important as the quality of the grain in many areas of the world.

Castor (1981) has presented evidence that certain sorghum lines exhibit increased preharvest sprouting in the presence of certain fungi. A small amount of sprouting and enzyme release may actually improve the availability of nutrients in sorghum grain (Anon. 1978). However, once the process of germination starts, it may continue long enough to significantly reduce the amount of carbohydrates and proteins available.

Similarly, grain molding and grain weathering fungi can completely degrade the germ and endosperm of sorghum kernels. In these cases, the kernels are extremely light, soft, and covered by mold. Nutrients may be available in grain of this kind, but the grain may be unacceptable as a human food and barely acceptable as an animal feed.

Grain molding and grain weathering fungi may produce mycotoxins in sorghum grain. *F. moniliforme* and *F. semitectum* are known to produce zearalenone and T-2 mycotoxins in a variety of cereal grains. There are a few reports indicating that these mycotoxins may occur naturally in sorghum grain (Rukmini and Bhat 1978; Schroeder and Hein 1975; Stipanovic and Schroeder 1975). The effects of these mycotoxins on animals is well documented. However, the danger they pose to humans may be less, because (a) moldy grain might not be purchased, (b) moldy kernels might be discarded when the food is prepared, and (c) moldy grain might be fed to animals rather than humans.

Postharvest Degradation of Sorghum Grain

Sorghum grain is stored in many different ways and for varying periods of time around the world (Sorenson and Person 1970). Six factors determine how well sorghum grain will store: (1) moisture content of the grain, (2) temperature of the grain, (3) amount of inoculum of storage fungi in or on the grain, (4) amount of foreign material in the grain, (5) presence of insects and mites, and (6) length of storage (Christensen and Kaufmann 1969). Each of these is closely related to the others. In general, the lower the temperature and humidity, the longer the grain quality remains high. Low winter temperatures in temperate regions help to maintain grain quality in storage. However, the temperature of large masses of grain often remains close to harvest temperature, unless some artificial means of reducing the temperature is employed. Grain is a poor conductor of heat. Grain temperature in storage can remain well within the range (Table 2) favorable for growth of storage fungi in tropical and temperate regions. Even when the grain moisture content is low enough to prevent fungal growth, troubles can occur. If temperature differences exist in a single mass of grain, moisture may migrate and raise the moisture content enough for fungal growth to start. For example, Christensen (1970) stored sorghum seeds of 14.3% moisture in glass containers and maintained the temperature of the grain 10–15°C higher on one side than on the other. After 3 days, the moisture content of the grain on the cool side was 1.4% higher than on the warm side; after 6 days the difference was 7%.

The types of damage caused by storage fungi are: (a) discoloration of the kernel, (b) reduction in kernel germination, (c) heating, (d) mustiness, and (e) production of mycotoxins (Christensen and Kaufmann 1969).

Storage fungi may cause discoloration and molding of whole kernels or the germ, which is the preferred site of invasion. Germs often darken before fungal sporulation occurs. "Blue eye" of corn, caused by growth and sporulation of *A. glaucus* on the surface of the germ, is an example of discoloration (Christensen and Kaufmann 1974). This type of damage in sorghum might not be obvious, because of the thicker,

Table 2. Cardinal temperatures and minimum moisture contents for the growth of selected storage fungi on sorghum.

Fungus	Temperature (°C)[a] Minimum	Optimum	Maximum	Minimum moisture content[b]	Relative humidity
Aspergillus restrictus	5–10	30–35	40–45	14.0–14.5	(70)
Aspergillus glaucus[c]	0–5	30–35	40–45	14.5–15.0	(73)
Aspergillus candidus	10–15	45–50	50–55	16.0–16.5	(80)
Aspergillus flavus	10–15	40–45	45–50	19.0–19.5	(85)
Penicillium spp	-5–0	20–25	35–40	17.0–19.5	(80–90)

a. Christensen and Kaufmann 1974.
b. Wet weight basis; relative humidity in parenthesis corresponding to minimum moisture content.
c. *A. glaucus* group.

pigmented pericarps of many sorghum cultivars. However, the mold development would greatly reduce the quality of the food product.

Germination decreases as colonization by storage fungi increases. This can occur quite rapidly and with little outward appearance of damage, because storage fungi colonize the germ and embryo tissues.

Heating of grain can result from the growth of storage fungi. Once storage fungi start to develop, their respiration will help raise the moisture content of the grain still further. *A. flavus* can increase the temperature of grain to 55° C and hold it there if the heat cannot escape. Christensen and Kaufmann (1974) state that thermophilic bacteria and fungi may raise the temperature from 55 to 75° C, at which time purely chemical processes may raise the temperature to the point of combustion. However, the quality of the stored grain has been reduced long before the grain catches fire.

Mustiness and caking of stored grain occur in the final stages of spoilage and makes the grain unacceptable in a food product.

Many of the storage fungi produce mycotoxins that may be toxic or debilitating to livestock as well as to man (Christensen and Kaufmann 1974). Sorghum grain may have these mycotoxins present in it (Alpert et al. 1971; Coady 1965; Martin 1974; Shotwell et al. 1969). High concentrations of aflatoxin can be deadly in grain. Grain quality is reduced to such an extent that it cannot be safely used as food or as an animal feed.

Measuring Damage Caused by Fungi

The damage to sorghum grain caused by field and storage fungi may take many forms. Some of these, e.g., reduced kernel filling and germination, are less important than others. Regardless of the relative importance of the damage, the measurement is difficult. *All* types of damage by field and storage fungi can be measured, but the time and expense involved are prohibitive. Mold is easy to see with the naked eye, mycotoxins are not. With both grain molding and storage fungi, molded kernels indicate the final stages of the kernel degradation process. Other types of damage can occur prior to molding (Castor 1981). Observing the external and internal appearance of the grain is the simplest test for quality, but one cannot see mycotoxins. The simplest way to avoid mycotoxins is to avoid the fungi that produce them. The least expensive measure of avoiding the fungi is to incorporate genetic resistance into sorghum cultivars.

Ergot

Sorghum ergot or sugar disease is caused by the fungus *Sphacelia sorghi*, which is reported to be a conidial stage of *Claviceps* (Sundaram 1980). Ergot needs to be mentioned for two reasons. First, it directly and indirectly affects grain quality and quantity by replacing kernels with fungus sclerotia through early infection and covering others with a sticky conidial ooze that contaminates the otherwise healthy grain. Second, ergot sclerotia contain alkaloid mycotoxins.

Improving the Quality of Sorghum Grain

Sorghum cultivars exist that have good resistance to grain molding and grain weathering fungi (Tables 3 and 4) (Castor 1981; Glueck 1979). There is evidence that cereal cultivars including sorghum (Table 5) can have resistance to storage fungi as well (Christensen 1970). The utilization of genetic resistance to field and storage fungi will depend on our ability to detect the resistance and then incorporate it into lines with suitable agronomic traits. The use of genetic resistance can reduce losses caused by sorghum grain fungi.

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Table 3. Relative resistance of 24 sorghum lines to *Curvularia* spp and *Fusarium* spp based on their response at three locations in Texas in 1977.

Sorghum line	Mean acceptability ratio	Acceptability ratio[a] at: Berclair	Corpus Christi	Lubbock
SC279-*14*	0.296	0.304	0.186	0.398
SC630-*11E*	0.317	0.317	ND	ND
CS3541	0.321	ND	0.460	0.182
SC103-*12*	0.369	0.366	0.360	0.381
SC748-5	0.374	0.393	0.354	0.375
SC566-*14*	0.381	0.330	0.267	0.545
TP1	0.418	0.420	0.416	ND
BTx398	0.427	0.411	0.466	0.403
B2219	0.448	ND	0.441	0.454
SC719-*IIE*	0.468	0.509	ND	0.426
SC283-*14*	0.469	ND	0.534	0.403
SC269-*14*	0.473	0.625	0.261	0.534
SC546-*14*	0.496	ND	0.634	0.538
TP2	0.524	ND	0.497	0.551
TP5	0.525	0.598	0.516	0.460
SC97-*14*	0.533	0.804	0.335	0.460
SC599-*14*	0.559	0.491	0.528	0.659
TAM428	0.583	ND	0.621	0.545
74PR759	0.629	ND	0.814	0.443
BTx378	0.653	0.536	0.640	0.784
75PR1639	0.662	0.634	0.665	0.686
SC108 × Tx7078	0.685	ND	0.733	0.636
SC110 × (Tx414 × 1490)	0.689	ND	0.696	0.682
Tx2536	0.884	0.875	0.969	0.807

a. Calculated by: Individual line acceptability value maximum possible acceptability value at each location.

b. ND = no data.

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Table 4. Relative resistance of 17 International Sorghum Grain Mold Nursery lines grown at ICRISAT Center, Andhra Pradesh, India in 1978 to *Curvularia lunata* and *Fusarium moniliforme* based on rankings of eight variables.

Sorghum line	Acceptability value[a]	Ranks[b]							
		FR	TKRC	TKRF	KWC	KWF	GC	GF	PSF
IS2327	27	2	4	1	5	3	7	4	1
M35052	36	6	4	1	10	4	9	1	1
CSH-6	40	3	7	1	7	11	3	2	6
IS14332	43	1	2	6	6	6	12	5	3
M36049	53	8	11	6	2	2	11	7	6
M36113	54	6	7	6	4	5	8	9	11
IS472	63	3	1	1	15	15	10	12	6
M36423	67	8	2	16	3	16	5	8	9
M36348	69	11	7	6	11	6	1	13	14
M36533	69	8	11	6	13	1	15	3	12
M36284	70	11	13	1	8	7	4	14	12
CS3541	70	15	7	6	9	12	6	10	5
M36285	88	11	13	6	12	9	17	11	9
M36471	90	5	4	13	1	17	16	17	17
M4337-2	100	17	17	13	16	14	14	6	3
M36333	104	16	13	16	14	13	2	15	15
E35-1	108	11	13	13	17	10	13	16	15

a. Minimum value 17; maximum value 136. The smaller the value the greater the resistance (overall acceptability).

b. Lines are ranked from least to most damaged for each variable. FR = field rating for mold; TKRC = threshed kernel ratings with *C. lunata*; TKRF = threshed kernel rating with *F. moniliforme*; KWC = kernel weight with *C. lunata*; KWF = kernel weight with *F. moniliforme*; GC = germination with *C. lunata*; GF = germination with *F. moniliforme*; PSF = preharvest sprouting with *F. moniliforme*.

Table 5. Ranking of sorghum lines from least to most damaged by *Aspergillus* spp based on visual appearance and germination.

Line	Visual appearance		Germination		Total
	Aspergillus	Control	*Aspergillus*	Control	
BTx398	2	2	1	1	6
Tx2536	1	1	2	2	6
SC748	3	3	5	4	15
SC630	7	5	3	3	18
CS3541	5	5	4	5	19
SC719	4	7	6	7	24
SC566	6	8	7	6	27
A399 x Tx430	7	4	10	11	32
SC103	11	9	8	8	36
SC170	10	10	9	9	38
SC279	9	10	11	10	40

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Discussant's Comments

Session 3: R. V. Vidyabhushanam*

The three speakers, Drs. Rooney, Miller, and Frederiksen have adequately summarized and updated our knowledge on sorghum grain structure, genetics, and deterioration. As Dr. Frederiksen pointed out, the change in the cropping pattern and breeding of improved cultivars, which flower earlier than locals and exploit the limited moisture better, has led to grain mold and weathering problems. This is particularly true in India. In the Indian program, the first released hybrid, CSH-1, was early and so was frequently caught in late rains. Therefore, considerable search for grain mold resistance was made in the germplasm which led to the release of better hybrids like CSH-5 and CSH-6.

The characteristics of grain mold susceptibility and grain weathering were clearly defined by Dr. Frederiksen. Although a certain degree of grain mold resistance has been identified, more work needs to be done to identify resistance to grain weathering. Characters like glume color, stylar tip color, glume thickness and structure have an important bearing on grain mold and weathering resistance. In India we have tried to use the tan plant character against these problems.

Another aspect of interest is seed germination. It was rightly pointed out by Dr. Frederiksen that the organisms causing grain mold enter the floret at the stage of anthesis itself. We have observed that although some grain mold affected seeds germinated, apparently clean grains did not germinate.

Dr. Miller stated that thick mesocarp types are susceptible to grain mold. This is not always true. Although pearly grains have better mold resistance, some thick mesocarp types also show resistance. I want to make a comment on the genetics of grain structure. Ayyangar and his coworkers opined that thick mesocarp is associated with floury endosperm and that it is simply inherited. However, it does not seem to me to be so simple and I agree with Dr. Miller's findings. There is some range in the thickness of the mesocarp and we need to do more work on the number of genes and modifiers involved.

An important point brought out by Drs. Rooney and Miller was about the location of the embryo and that water absorption by the embryo leads to sprouting. Therefore we need to look for grains with an embryo seated deeply in the endosperm rather than to a side of the endosperm.

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Session 3—Grain Structure and Deterioration

Discussion

Jambunathan:

Have you looked into the variability of the germ/endosperm ratio in sorghum? What is the role of the aleurone layer and its influence on the nutritional quality of sorghum?

Rooney:

The germ/endosperm ratio varies considerably among sorghums in the World Collection. No one has measured actual germ/endosperm ratios. Sorghums with a higher oil content often have higher germ to endosperm ratios as determined by visual estimates. The aleurone layer and peripheral endosperm have a major effect on the nutritional value and processing properties of sorghum. It is involved in the breakdown of the kernel during germination (malting process). It contains phytin, proteins, and other nutrients.

Obilana:

What is a gray sorghum?

Rooney:

I do not know, unless you are referring to a sorghum with a pigmented testa beneath the pericarp, which might give a bluish-gray appearance.

B. S. Rana:

Dr. Miller, you mentioned that two genes control plant pigment in sorghum. In this case, 9TQ (purple); 3Tq (red): 3tQ (?): 1tq (tan) F_2 segregation frequencies are expected. We did not observe this type of segregation in purple x tan crosses and found tan plant pigment to be monogenic recessive to purple pigment.

R. K. Maiti:

During the rainy season, grain deterioration is caused by grain mold infestation and preharvest sprouting. Our work at ICRISAT has shown that there is a range of variability for both traits.

Session 4

Milling and Processing

Chairman: J. C. Miche

Discussant: L. Munck
Rapporteur: N. Seetharama

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Assaying for Sorghum Milling Quality with a Laboratory Decorticating Mill

A. D. Shepherd* .

Summary

A laboratory decorticating mill produced by modifying a UD cyclone sample mill has been tried as a test instrument for assaying the milling quality of sorghum. A fixed set of mill variables and milling conditions for decortication were selected experimentally and maintained throughout the testing. Milling quality is related to the weight removed from the grain in the standard test. Lower weight removal indicates better milling quality. An average of 99% of the sample was recovered as the two mill fractions over the 2-year test period. Coefficient of variation of unadjusted weight removed was less than 8%. A definite year effect was found. Milling quality (1.523% removed) was better in 1980 than in 1979 (1.845% removed). It is projected that the standard milling can be done repetitively every 90 sec. On this basis, 40 assays per hr are possible. Refined determination of milling quality is possible but at a substantially slower rate. Several other possible uses for the mill are pointed out.

The laboratory decorticating mill used was developed to remove surface layers from small amounts of granular materials, as might be done by hand dissection. Although precision of separation is not as great as by hand, the tedium is eliminated. The mill has general utility as a decorticating device for samples of 5–30 g, more or less. It was tried as a test mill for sorghum milling quality, and the results have been very satisfying. Using the most abbreviated procedure, assays for milling quality can be accomplished quite rapidly and repetitively.

Description of the Mill

The mill has been described previously (Shepherd 1979, 1980 and 1981a). The laboratory decorticating mill uses as the basic unit the grinding chamber and cyclone collector of a UDY Cyclone Sample Mill. The modification and an array of interchangeable parts are shown in Figure 1. The conformation of parts is ideal for the purpose. There is a centrally located shaft within the chamber for an impeller which when rotated generates a current of air to convey a charge of grain around an abrasive lining the side surface of the chamber causing decortication. The number and size of the blades on the impeller may be varied.

Abrasive rings of several different grits are also available over the range of 36 to 240. The abrasive surface is interrupted at one point by a perforated plate, and to the outside of this is the entrance to a cyclone separator. Through the perforated plate, the material abraded from the grain surface passes into the cyclone to be collected in the receiver. Different hole sizes may be used in the plate. The cover for the chamber is transparent to allow viewing and photographing of the action inside.

The drive (Fig. 2) is a reversible variable speed motor, 30–2400 rpm, of constant torque with a speed control unit. Because of the reduced speed over the UDY drive, a vacuum cleaner must be used on the air discharge of the cyclone for it to operate properly.

For decortication, the impeller is driven in the forward position (counter clockwise) of a three-position switch (forward, brake, reverse) on the motor control box. The vacuum cleaner is turned on and a charge of grain is introduced quickly through a funnel in the center of the chamber above the impeller shaft. After a selected period of

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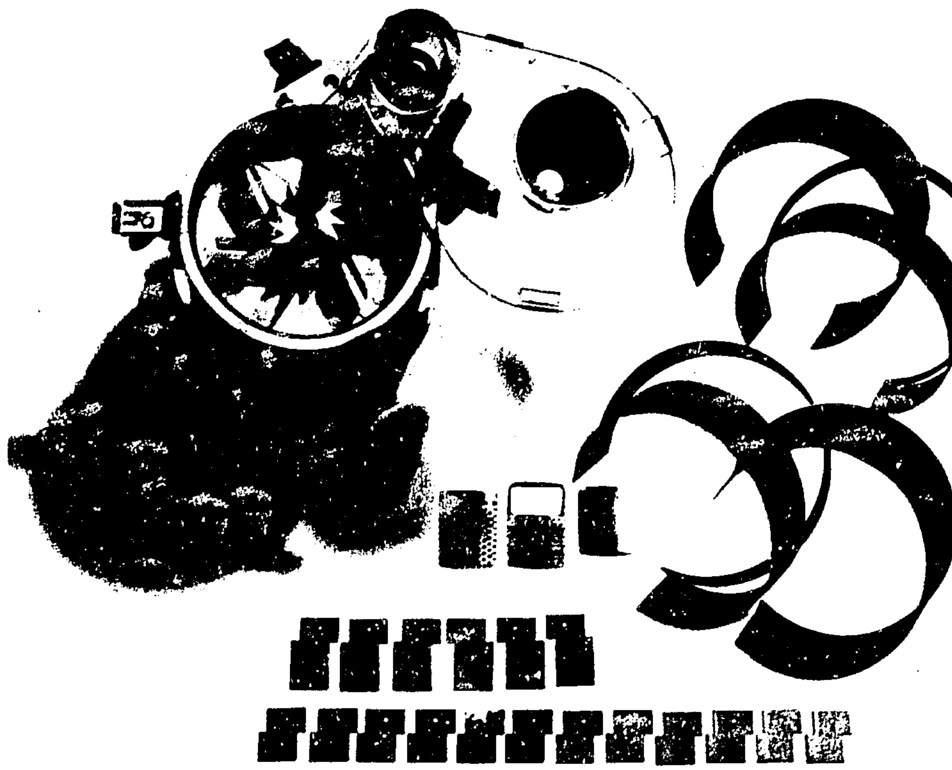

Figure 1. Partially assembled mill and alternate parts.

time, the action is stopped by turning the three-position switch on the motor control to the brake position. The vacuum cleaner is turned off and the receiver, now containing the material abraded off the surface, is removed (Container A) and replaced. The decorticated grain is collected in the second receiver (Container B) by removing the perforated plate, turning on the vacuum and moving the motor control to reverse for a few seconds. Weighing the tared receivers for contents provides a measure of the percent of removal and the recovery, which is usually around 99% at 10% removal. All of this is accomplished within a few minutes, usually one to two.

Basis for Milling Test

It is assumed that sorghum is milled by decorticating first, then followed by particle size reduction of the decorticated grain. The intent of the abrasive milling of sorghum is to remove the pericarp and germ from the grain while preserving the interior of the grain from the aleurone inward. This process is decortication and the material removed is decorticate. However, when grain is placed in an abrasive mill intending only to decorticate, other things invariably happen and tissues other than germ and pericarp are separated and collected with the decorticate. Therefore, the term "removed" is preferred over decorticate; hence, percent "removed" rather than percent decorticate.

The efficiency of the decortication process is reflected by the extent to which the decorticate in the "removed" is admixed with other tissues—that is, the aleurone and the endosperm—or by the extent to which residual pericarp remains adhering to the grain. From this mill both fractions

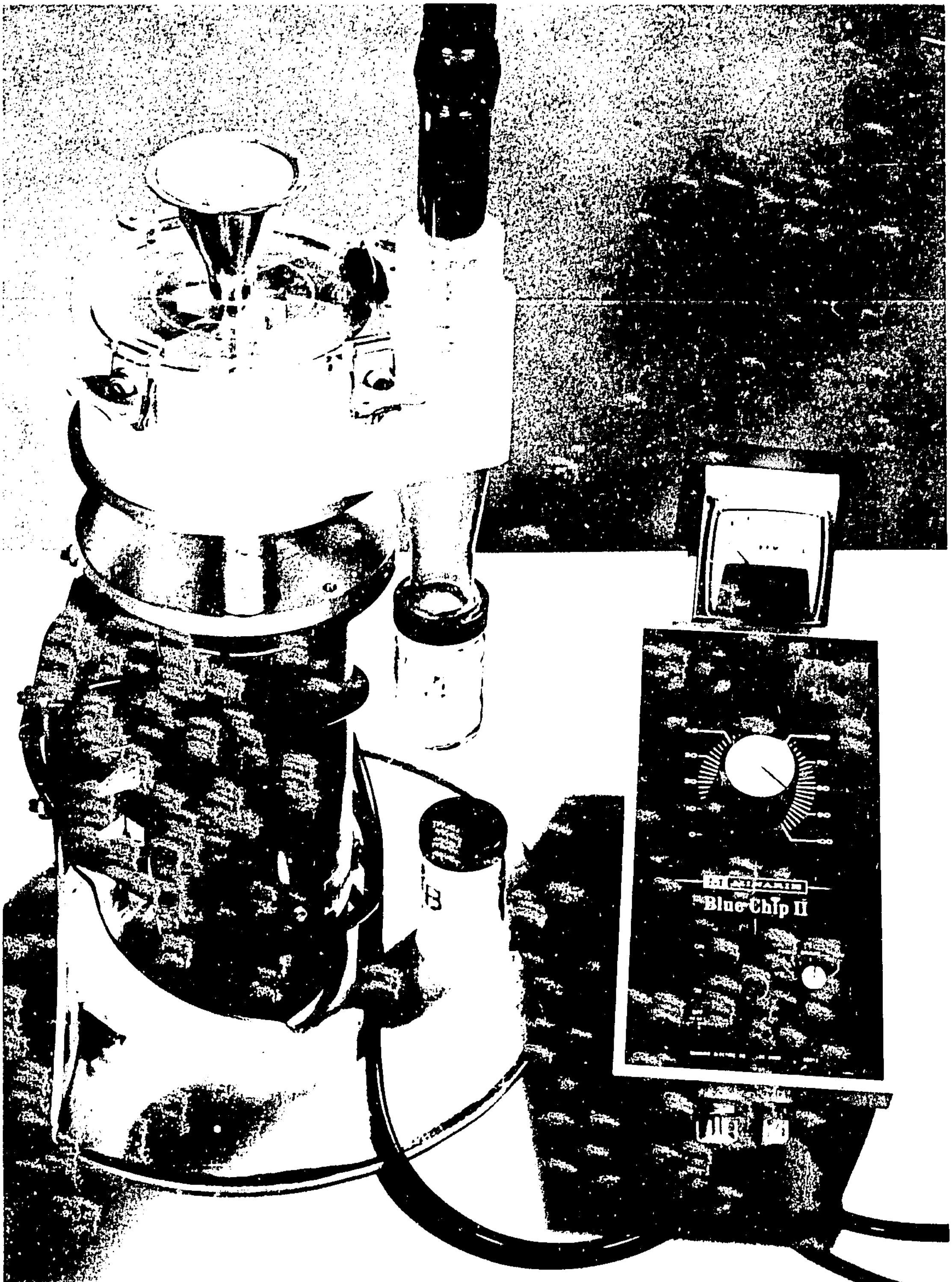

Figure 2. Mill with drive and speed controller.

are quantitatively recovered, so it is possible to work with the "removed" to correct it to more nearly represent the decorticate. This has been done but I shall defer this subject until after completing the discussion of the simple rapid determination.

The efficiency of decortication is influenced by the physical characteristics of the sorghum being milled; probably the most important one being its hardness or its ability to remain whole while its pericarp is removed. Grains lacking in hardness tend to break more readily and endosperm and aleurone will enter the "removed" to dilute the decorticate.

So the slower the rate of "removal," the better the milling quality. It is on this basis that we may test for milling quality and I believe other workers make similar assumptions.

Proposed Test Method

The selection of machine and operating parameters for the sorghum milling quality assay are as follows:

Sample size	10 g
Impeller	4-1/4" diameter, 12 blades
Abrasive	60 mesh grit
Perforated plate	3/32" rd perforations
Speed	1500 rpm
Time	60 sec.

When the milling is completed, there are two bottles containing fractions. The material "removed" is in bottle A and the grain in bottle B. The weighing of receiver A completes the determination of milling quality for rapid screening. However, the mill must be emptied of the residual grain before proceeding with the next determination, but weighing the second receiver is not required.

We estimate the turn around time on the mill to be about 90 sec, just 30 sec more than the milling time. The start-up consisting of inserting the screen, turning on the impeller and vacuum, placing receiver A in position, and introducing the sample may be accomplished in no more than 15 sec. The wrap-up requires removing receiver A, replacing it with B, removing the screen, turning on the vacuum, reversing the mill for 2-3 sec and emptying B. Again, no more than 15 sec work. A time of 90 sec per sample is equal to a rate of 40 samples per hr.

Assay of IFQT Samples

The method just described was used for three replicates of the 25 samples of International Food Quality Trials (IFQT) from ICRISAT grown in 1979 and 1980. The summary for the unadjusted weights of the "removed," X_0 are shown in Table 1. The average value of X_0 for 1979 is 1.845 compared with 1.523 for 1980. The standard deviation and coefficient of variation are also lower for the 2nd year. The grand mean for CV is between 7 and 8.

Figure 3 graphically shows the year-to-year variability for each of the 25 samples. Only four samples are higher in 1980 than in 1979. It also shows the range covered by the 25 samples.

Table 2 provides the means for the triplicate determination for all 25 samples for the 2 years, listed by sample number. Sample No. 16, S-13 first ranked overall, was second in 1979 and fourth in 1980. Sample No. 11, E-35-1, second overall was first in 1980 and third in 1979. Sample No. 3, M-50009, third overall, was first in 1979 and seventh in 1980. These provide an indication of the reproducibility. Sample No. 13, WS-1297, stands out as the poorest of the lot, being in twenty-fifth place each year. Number 7, i.e., P-721 had the biggest difference in its order for the 2 years, 18th to 5th with values of 2.18 and 1.14, almost two-fold. For the most part, the results seem to be believable.

Conclusions on Assaying Sorghum Milling Quality

The laboratory decorticating mill developed by modification of a UD Cyclone Sample Mill has been successfully used to assay sorghum milling

Table 1. Means and variance of unadjusted net weight of "removed", X_0; triplicate 10g IFQT sorghum samples.

	1979	1980	1979-1980
Mean	1.845	1.523	1.683
S^2	0.153	0.100	0.129
CV(%)	8.3	6.5	7.7

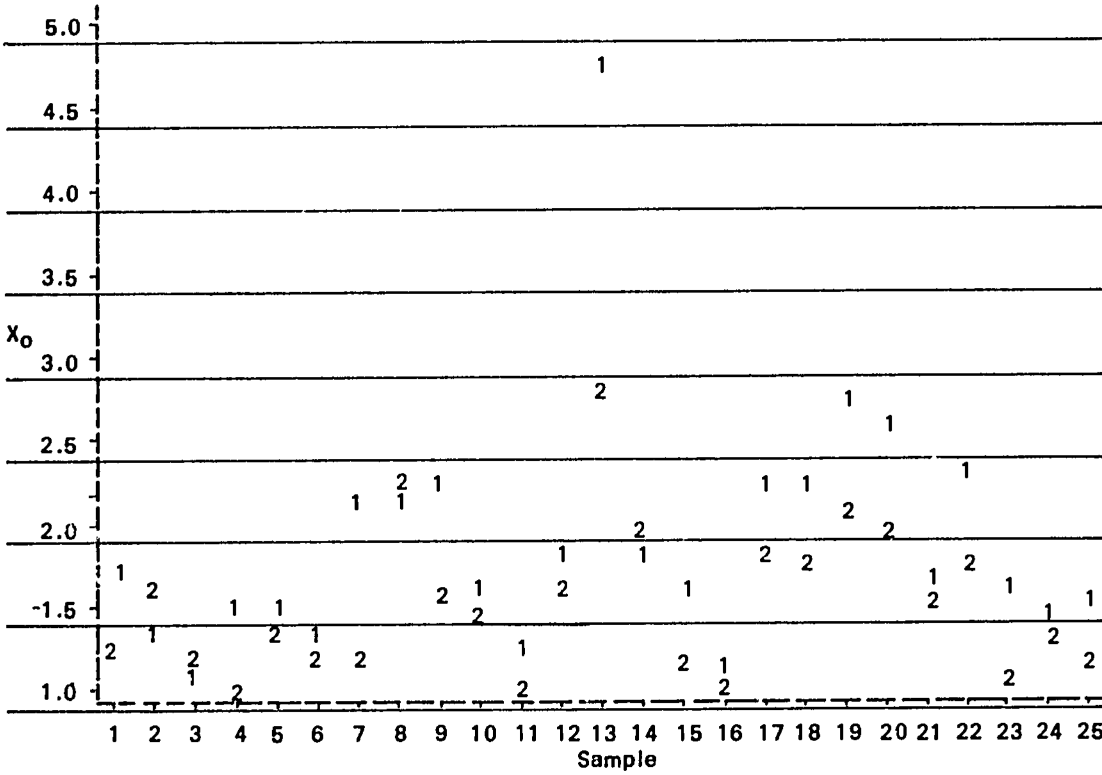

Figure 3. Unadjusted net weight removed (Xo); two-year plot. Symbol (1, 2) is value of year.

quality. Repetitive standardized millings using 10-g samples require about 90 sec each. Therefore, the mill has a capability of 40 determinations an hour. The mill appears to be useful for rapidly assaying milling quality.

Possible Improvements

The rapid-screening method above is adequate for its intended purpose. However, refined but more time-consuming measurements are possible and might be considered by breeders for later selections. The techniques are generally useful and will be briefly described. The milling procedure is unchanged but the handling of the fractions is changed.

When milling is completed, there are two bottles containing fractions—the material "removed" in A, and the grain in B. Invariably, bottle B has some material in it that obviously belongs in A. To adjust, first the grain is screened on 40 mesh and the fines transferred. Then the grain is blown in a seed blower to separate the flake and it is transferred. The total weight transferred is a few hundredths of a gram, and never as much as 0.1 g. The net weights of A and B at this point have been summarized in Table 3 to show recoveries and variance. Total recoveries were 98.6% and 99.4% for the individual years, and 99% overall. Coefficient of variation was less than 2% for the grain and about 8% for the "removed."

Next, the same technique as used above was applied to the adjusted contents of container A, the "removed." Shown in Figure 4A is a schematic representation of the fractionation of the "removed." Material through 40-mesh is separated and called fine. The over is put in a seed blower; the light is called flake, and the heavy is called broken.

We also used a slotted screen to separate broken from whole kernel as shown in Figure 4B. Ordinarily, we make this separation by inspection, but that would be even more time consuming. Therefore, a screening was substituted.

Now there are five fractions. Three are derived

Table 2. X_0 values and orders for 25 IFQT sorghum samples, 1979 and 1980.

Number	Designation	1979 Value	1979 Order	Overall order	1980 Order	1980 Value
1	M-35-1	1.74	14	13	10	1.25
2	CSH-5	1.35	5	11	16	1.60
3	M-50009	1.05	1	3	7	1.18
4	M-50013	1.49	8	5	2	1.03
5	M-35052	1.54	10	10	12	1.35
6	M-50297	1.29	4	4	9	1.20
7	P-721	2.18	18	15	5	1.14
8	CO4	2.14	17	22	24	2.19
9	Patcha Jonna	2.21	19	18	17	1.82
10	Mothi	1.50	9	12	13	1.48
11	E-35-1	1.21	3	2	1	0.98
12	IS-158	1.82	15	16	14	1.58
13	WS-1297	4.78	25	25	25	2.86
14	Swarna	1.86	16	17	22	1.95
15	S-29	1.60	12	9	6	1.16
16	S-13	1.11	2	1	4	1.07
17	IS-2317	2.23	20	20	20	1.82
18	IS-7035	2.28	21	19	18	1.72
19	IS-7055	2.76	24	24	23	2.11
20	IS-9985	2.55	23	23	21	1.90
21	IS-8743	1.61	13	14	15	1.59
22	Dobbs	2.37	22	21	19	1.73
23	CS-3541	1.56	11	6	3	1.05
24	Segaolane	1.40	6	8	11	1.34
25	Market-1	1.48	7	7	8	1.18
	Mean	1.845				1.523
	Range	1.05 – 4.78				0.98 – 2.86

Table 3. Recoveries and variance, 10 g IFQT sorghum samples.

	Removed		Decorticated grain		Total	
	1979	1980	1979	1980	1979	1980
Grand mean	1.88	1.54	7.98	8.40	9.86	9.94
CV (%)	9.26	6.91	2.29	1.29	0.39	0.15

from the "removed" and two from the grain. Figure 5 shows the results of the five-way fractionation. In A is sample No. 13, WS-1279, a Feterita, the poorest milling sorghum among the 25 samples. All of the fractions from it are large enough to be easily seen. The positions of the fractions are consistent for each picture; and the quantities, except for the unmilled grain, represent amounts from a 10-g sample. Centrally located is the largest fraction, the whole kernel. The unmilled grain is to the left. Between these two are flake, above, and fine, below. Brokens are at the right. The larger sized, those obtained from the screening of the grain, are in the upper position, and below are those separated from "removed."

The next sorghum (A in Figure 5) is M-50009, the best milling variety from the 1979 trials. It is a small-grained, pearly variety. The amount of broken from both sources is very small. The amount of flake is moderate.

The next sorghum (Figure 5C) is S-29, barely in the top ten. It is a chalkier grain and this shows up in the quantity of flake. The quantity here is much like the first sample, the poor milling Feterita. It

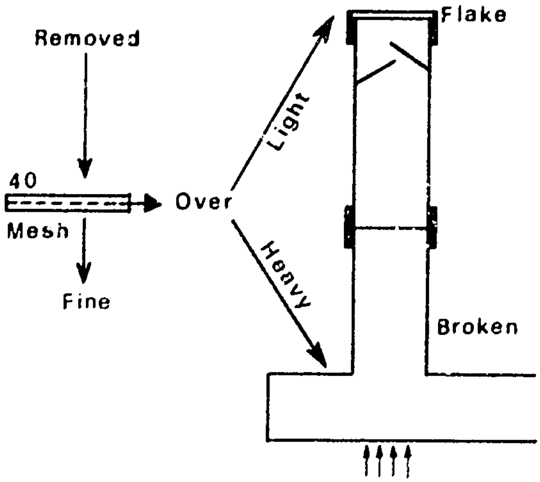

Figure 4A. Schematic fractionation of removed weight.

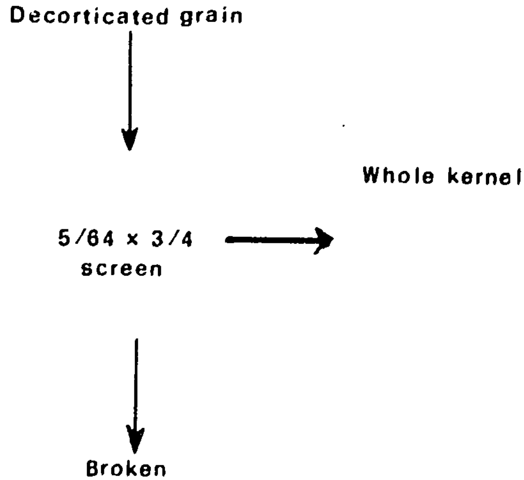

Figure 4B. Schematic fractionation of decorticated grain.

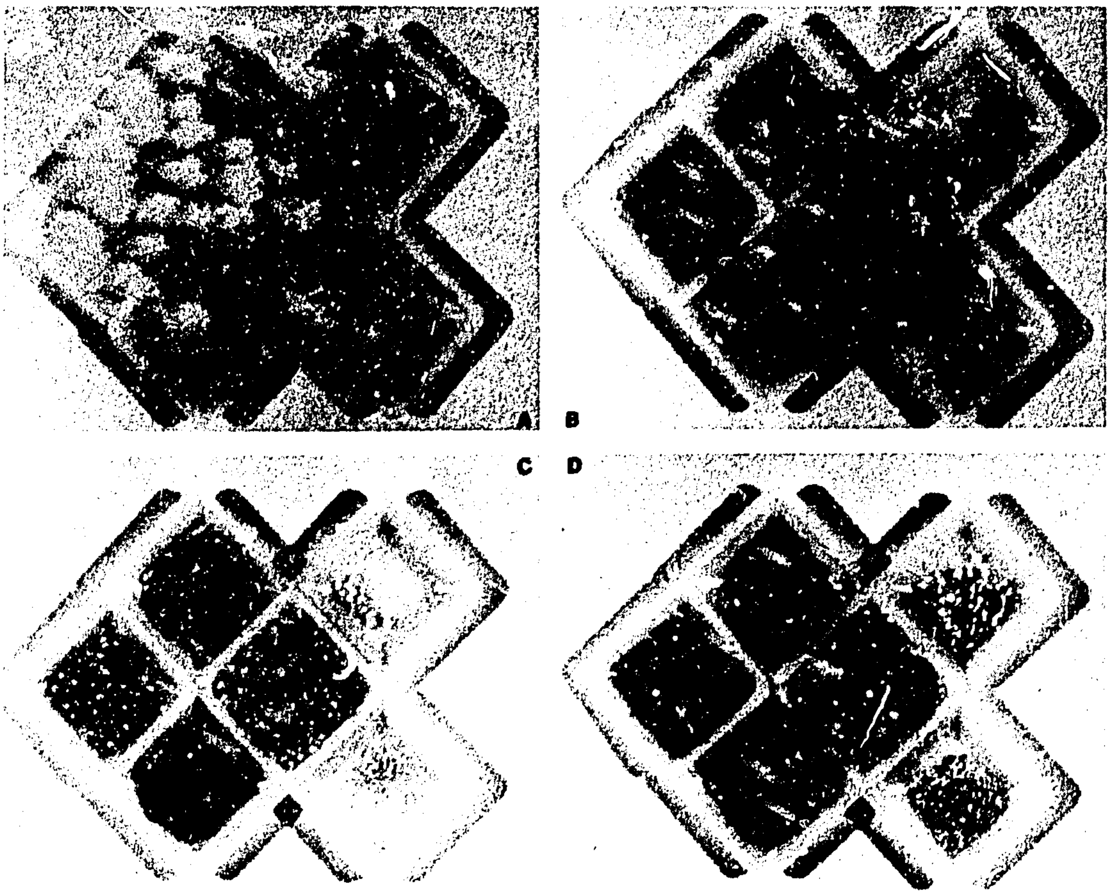

Figure 5. Photos of fractions according to scheme.

shows more broken from both sources than the last sample but not excessive.

The last sorghum picture (Figure 5D) is CO4, a mediocre milling sorghum. It has a pearly grain and substantial pigmentation in the pericarp. There is only a moderate amount of flake. There are considerable amounts of broken from both sources.

It is very interesting and illuminating to look at these samples. They reveal to a considerable extent what is happening with different sorghum types during decortication. To summarize the information from the fractionation, there are eight bits of raw data referred by X with subscripts. X_1 was the sample weight, always 10g; X_2, the adjusted weight of "removed"; X_3, the adjusted weight of grain; and X_4–X_8 were assigned to the five fractions, X_4 fine; X_5, small broken; X_6, flake; X_7, large broken; and X_8, whole kernel.

These raw data were treated in various ways to generate numerous derived bits of data, some 14 in number, which were designated by Y with a subscript. Only a limited number of these will be discussed here, however.

One useful measure from the fractionated samples is the whole kernel (X_8). This represents resistance to breakage under standardized conditions. It might be considered to be an indicator of hardness.

It is suggested that the fine and flake *only* would better represent decorticate and that the three largely endosperm fractions, one whole and two broken, become the grain. These become two of the derived bits of data, Y_4 ($X_4 + X_6$) refers to the decorticate and Y_7 ($X_5 + X_7 + X_8$) the endosperm. Another derived bit is the breakage index (Y_{12}). It is derived by summing the broken from both receivers ($X_5 + X_7$) and dividing by the decorticate (just fine, X_4, and flake, X_6). This becomes breakage at 10% decortication. This adjustment makes some sense because breakage accompanies decortication as any sample is milled, but rates for each will differ between samples. Therefore, comparison of breakage is only meaningful when compared at the same degree of decortication. We have chosen 10%.

The original net weight of the A receiver was an afterthought so it has been designated X_0.

One other measure, flake (X_6), is not used to evaluate milling, other than as a part of the "removed" or decorticate, but it is interesting and may be useful in estimating pericarp thickness, of interest to those working with the Z gene. These measures of interest are summarized in Table 4.

Certainly the information derived from the fractionation allows refinements of the raw data by establishing corrections that may be applied. No doubt this allows a more accurate representation of decortication. But when one looks at the correlation coefficients in Table 5 between the more precise, derived data, and the simplest measure, X_0, the quick-to-measure X_0 is clearly the measure of choice.

Table 4. Useful measures.

X_0	Unadjusted "Removed"
X_2	Adjusted "Removed"
X_3	Adjusted Grain
X_6	Flake
X_8	Whole Grain
Y_4	% Decorticate or % Decortication
Y_7	Decorticated Grain (Endosperm)
Y_{12}	Breakage Index (at 10% Decortication)

Table 5. Correlation coefficients of useful measures.

	X_0	X_2	X_3	X_6	X_8	Y_4	Y_7	Y_{12}
X_0		.999	−.999	.309	−.976	.924	−.946	.810
X_2	.999		−.999	.311	−.976	.924	−.946	.810
X_3	−.999	−.999		−.284	.978	−.916	.942	−.802
X_6	.309	.311	−.284		−.212	.585	−.512	−.103
X_8	−.976	−.976	.978	−.212		.847	.881	−.908
Y_4	.924	.924	−.916	.585	.847		.993	−.572
Y_7	−.946	−.946	.942	−.512	.881	.993		−.630
Y_{12}	.810	.810	−.802	−.103	−.908	−.572	−.630	

Other Uses for the Mill

The laboratory abrasive decorticating mill has been found to have great versatility beyond its use as a routine device for assaying milling quality; some of these other capabilities are now discussed.

A case in point has already been mentioned: that is, in providing samples of the "removed" that may be readily fractionated to provide a flake fraction. Table 6 shows the values and orders for flake (X_6) for 1979 and 1980 IFQT samples and the overall order. Higher values are obtained on the chalkier grains. Dobbs is a clear winner in both years. It is also interesting to note the greater consistency in order between the years for flakes than for the "removed." However, there is a year effect but not as great as observed for the other measures. It has already been suggested that it may be useful in Z-gene studies.

Shepherd (1981b) reported that fractionation of the "removed" was followed for successive small cuts from a single 20-g sample of Funk G 766W. The incremental amounts of broken, fine, flake, and their sum are plotted in Figure 6 for samples obtained every 15 sec up to 150 sec.

A comparison of the curves shows that total, fine, and flake have a short induction period. Curves for total and fine move through a straight line period of increase and then level off. The curve for flake reaches a maximum and forms a Gaussian curve. In the last 15-sec period, almost no flakes were produced. The curve for brokens shows a much longer induction period but during the last third, it greatly accelerates.

The Gaussian curve exhibited by the flakes is in

Table 6. Flake (X_6) values and orders for 25 IFQT sorghum samples, 1979 and 1980.

		1979			1980	
Number	Designation	Value	Order	Overall order	Order	Value
1	M-35-1	.17	24	25	25	.13
2	CSH-5	17	24	24	20	.25
3	M-50009	.33	15	15	13	.35
4	M-50013	.38	13	14	18	.31
5	M-35052	.48	10	10	6	.45
6	M-50297	.29	17	17	16	.32
7	P-721	.36	14	13	15	.33
8	CO4	.21	23	22	21	.25
9	Patcha Jonna	.22	22	23	24	.21
10	Mothi	.62	4	4	4	.61
11	E-35-1	.25	20	21	23	.22
12	IS-158	.60	5	5	7	.45
13	WS-1297	.59	6	9	10	.40
14	Swarna	.29	17	18	17	.31
15	S-29	.57	7	8	10	.40
16	S-13	.27	19	20	21	.25
17	IS-2317	.74	3	3	2	.64
18	IS-7035	.46	11	11	9	.41
19	IS-7055	.76	2	2	3	.62
20	IS-9985	.31	16	16	18	.31
21	IS-8743	.50	9	6	5	.49
22	Dobbs	.95	1	1	1	.75
23	CS-3541	.46	11	12	12	.36
24	Segaolane	.25	24	19	14	.35
25	Market-1	.55	8	7	8	.44
	Mean	.428				.385
	Range	.17-.95				.13-.75

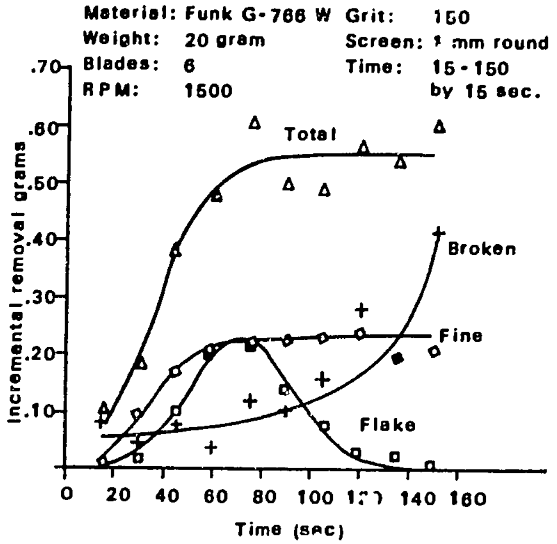

Figure 6. Incremental removal of fine, broken, and flake fractions, and their sum.

keeping with the concept of flaking, in which a fragile layer of tissue exterior to the endosperm breaks preferentially, producing units consistent in thickness. Flake thickness uniformity was checked using a machinists' micrometer and found to be about 50 and 55 microns. Flakes are produced only once from a surface and, therefore, the amount is more limited than for the other fractions.

Flaking could be likened to the extremely easy removal of the rind of a tangerine compared to the more difficult removal of an orange rind, for example, by grating or a skinning process.

In the above experiment, we collected successive small cuts of "removed" from the same batch of sorghum. But equally well, the mill can provide sequences of grain samples that represent any range of decortication desired. Such a sequence for Funk G-766W was produced. Dyed samples were used to elucidate the peeling mechanism (Shepherd 1981b).

In colored prints of the stained samples, tissues are readily identified by their color and location. The degree of decortication of a particular surface is more easily observed in the stained samples. Using this technique, one can follow decortication, beginning with removal of pericarp wax, then through several pericarp tissues, to removal of aleurone and exposure of endosperm. The tissue where the breakage occurs that gives rise to the commonly observed flakes during sorghum milling has been identified as the mesocarp.

Sequences of grain samples may also be analyzed for any component of interest and its distribution through the pericarp determined. This was done for proximate analyses on Funk G-766W shown in Figure 7. Less than 300 g of grain was required for the entire experiment, and one-half of that amount would have been required had 10-g samples been used which would have provided adequate quantities for the analyses.

The above examples show only some of the capabilities of the laboratory decorticating mill.

The UD corporation is now offering a mill with the same basic features as the modification described but using modified UD mill parts almost exclusively. At first glance, it is hardly distinguishable from the UD Cyclone Sample Mill. However, it has the 30-2400 rpm constant torque motor, removable and interchangeable perforated discharge plates, and the impeller has been machined to a smaller diameter. Abrasive liners of grits other than 60 mesh may be available.

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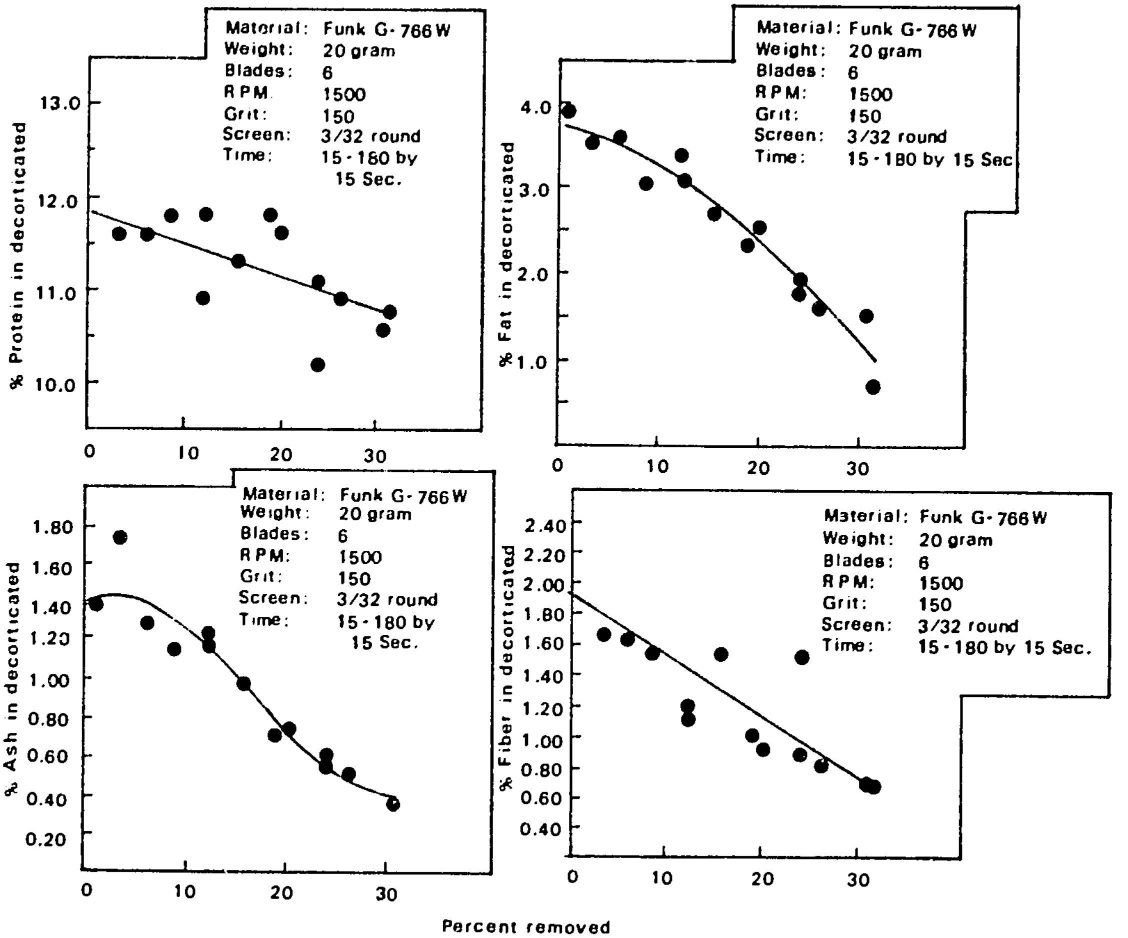

Figure 7. Proximate analysis of sequentially decorticated sorghum to 30%.

Measurement of Grain Hardness and Dehulling Quality with a Multisample, Tangential Abrasive Dehulling Device (TADD)

R. D. Reichert, C. G. Youngs, and B. D. Oomah*

Summary

Ease of dehulling, by either the traditional mortar and pestle or mechanical means, and grain hardness are quality criteria that directly influence the acceptability of new and established cultivars of sorghum. Mechanical dehulling on an industrial- or village-scale is usually accomplished by the action of vertically- or horizontally-mounted abrasive disks. A tangential abrasive dehulling device (TADD) was constructed to simulate the action of these large-scale dehullers. A carborundum stone or resinoid disk, mounted horizontally beneath 5 to 12 sample cups, provides the abrasive action. Advantages of this unit include its multisample capability, high reproducibility, minimal maintenance requirements, and convenience. Two parameters are determined with the aid of the TADD. The abrasive hardness index (AHI) is defined as the time in seconds required to abrade 1% by weight of the kernel. Secondly, the extraction rate is a measure of the percent by weight of the kernel that can be recovered as acceptable flour. Flour color was used to determine the extraction rate. These parameters showed wide variation for 31 nontesta sorghum varieties. The AHI was significantly correlated with other measures of grain hardness. The application of the TADD to predict traditional dehulling properties needs to be investigated.

Ease of dehulling and grain hardness are quality criteria that relate to processing characteristics of sorghum grain. Sorghum is dehulled by either mechanical means or in the traditional mortar-and-pestle fashion. Since sorghum grains vary enormously in dehulling quality, it is desirable to develop small-scale equipment and methodology for the selection of this quality characteristic.

There are numerous precedents in the use of small-scale or laboratory devices to predict the milling quality of grains, for example, wheat, barley, and rice. Canadian wheat breeders now rely on the Allis-Chalmers mill and Bühler laboratory mill (AACC official method 26-20) to predict flour yields. In effect, small rolls are used to predict the performance of large rolls used in wheat mills. Similarly, laboratory barley pearlers have been used to predict the relative quality of varieties for commercial pearling. Rice breeders and commercial millers evaluate small samples of grain with a variety of laboratory instruments (Webb 1974) such as the McGill sample sheller and McGill miller.

Some attempts have been made to evaluate sorghum dehulling quality. Rooney and Sullins (1969) and Maxson et al. (1971) used a Strong-Scott barley pearler fitted with a wire brush to dehull 100-200 g samples of grain. Rooney et al. (1972) used a Satake grain testing mill (similar in principle to a Strong-Scott barley pearler) to dehull 150-g sorghum samples. The disadvantages of the barley pearler are that it is relatively cumbersome to use, requires a relatively large sample size, and it processes only one sample at a time. Shepherd (1979) modified the grinding chamber of a Udy cyclone sample mill to provide a gentle, abrasive action. Hogan et al. (1964) and Normand et al. (1965) employed tangential abrasion to remove successive layers from sorghum and other cereal grains.

This paper describes the application of the

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tangential dehulling principle to the development of a rapid, highly reproducible, multisample dehulling device. The machine has been used to predict dry abrasive-type dehulling characteristics (mechanical dehulling). However, it may also have application in the prediction of traditional (semimoist) dehulling properties. Two parameters, the abrasive hardness index (AHI) and the extraction rate based on flour color were developed to evaluate dehulling quality with the tangential abrasive dehulling device (TADD). Details of this work are being published (Oomah et al., 1981).

Traditional and Mechanical Processing of Sorghum

Different methodologies may be required for the prediction of traditional and mechanical dehulling properties, since these processes differ markedly. Traditional methods of dehulling sorghum in Africa vary from area to area but are often aided by the addition of water (Carr 1961; John and Muller 1973; Reichert and Youngs 1977). Typically, 20–25% of water by weight is added to the grain in a mortar. The grain is allowed to stand for a few minutes and then pounded with a pestle for 10–20 min. During the tempering process, the bran layers swell and become partially detached from the endosperm. Pounding provides the abrasive action necessary to remove the bran layers from the endosperm. Relatively hard sorghum varieties with a thick, chalky mesocarp appear well suited to this processing.

Most industrial-scale mechanical methods of dehulling sorghum process the dry sorghum seed, although some attempts have been made at tempering followed by wire-brush peeling (Weinecke and Montgomery 1965; Shoup et al. 1970). Abrasive-type dehullers equipped with carborundum stones or emery-coated abrasive disks appear to be most commonly used. Some vertical-type dehullers in this category, all of which are very similar in principle, include the Decomatic (Bernhard Keller AG, Zürich, Switzerland), Bühler-Miag types DSRD and MHV (Bühler Bros., Uzwil, Switzerland) and the Vertical shelling machine type 270 (F. H. Schule GMBH, Hamburg, W. Germany). Figure 1 shows a schematic diagram of the latter with its seven emery discs mounted on a vertical shaft. Dehullers which have their abrasive disks or stones mounted horizontally include the Ce Co Co (Ce Co Co, Ibaraki City, Osaka, Japan), Wondergrain Jaybee (Jaybee Engineering Pty, Ltd., Dandenong, Australia), Bavaria Record (Etablissements Rohr, Sarcelles, France), Palyi Hansen BR 001-2 (United Milling Systems, Copenhagen, Denmark), PRL, PRL/RIIC and PRL mini dehullers (Nutana Machine Co., Saskatoon, Canada), and Bühler-Miag types DNRH and DSRH. A schematic diagram of the PRL dehuller showing horizontally mounted resinoid discs is illustrated in Figure 2.

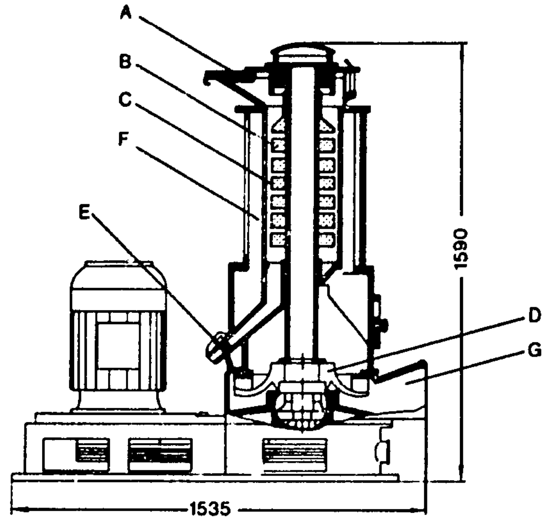

Figure 1. Schematic diagram of vertical shelling machine type 270, illustrating vertically-mounted emery discs (B), feed gate (A), perforated metal screen (C), fan (D), discharge gate (E), fines collection chamber (F), and fines discharge pipe (G). Dimensions are in millimeters. (F. H. Schule GMBH literature.)

The ease of dehulling by the mechanical method is a function of the degree of adhesion between the endosperm and bran layers as well as the hardness of the grain. Soft grains tend to crack easily under the pressure of the abrasive surface resulting in removal of fine material from all parts of the seed rather than from the peripheral layers only. Therefore seeds with vitreous (harder) properties are desirable.

The Multisample Tangential Abrasive Dehulling Device (TADD)

The TADD was designed and built to simulate as

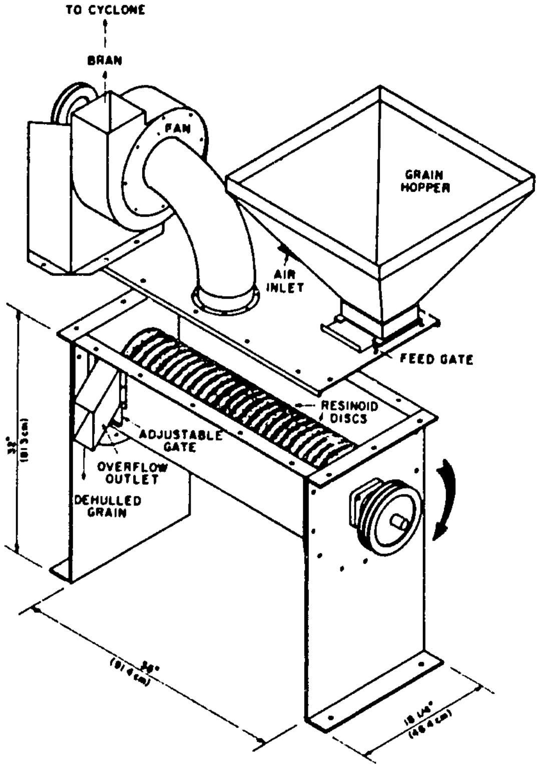

Figure 2. Schematic diagram of the PRL dehuller, illustrating horizontally-mounted resinoid disks.

closely as possible the abrasive action produced in commercial sorghum dehullers. Figure 3 compares photographs of the first prototype (TADD I) which we built and recently described (Oomah et al., 1981) and the second prototype (TADD II). The component parts of TADD II are illustrated in Figure 4. The latter is presently being field tested in Upper Volta. TADD II is fitted with a 254 mm (diameter) × 6.35 mm (thickness) carborundum stone (a) mounted horizontally, on the shaft of a 1/4 hp, 1725 rpm electric motor. A dehulling headplate (b) holds six stainless steel sample cups (c) [57.2 mm (diameter) × 28.6 mm (depth)] above the stone. A rubber-faced cover plate (d) closes the tops of the cups when the machine is in operation. An electric brake on the motor instantly stops the stone when current to the motor is discontinued. The height of the stone is adjusted by means of shims so that there is minimum clearance between the lower edges of the cups and the stone.

In operation, 5–10 g samples of grain are placed in the cups, the cover plate is fastened in position, and the carborundum stone is rotated under the cups at 1725 rpm for the time specified on the timer (e). Pearling times are normally 1, 2, and 4 min. Some fines generated during dehulling exit underneath the cups and are swept out of the machine and into a fines collection bag (f) by means of a built-in fan (g). The dehulled samples

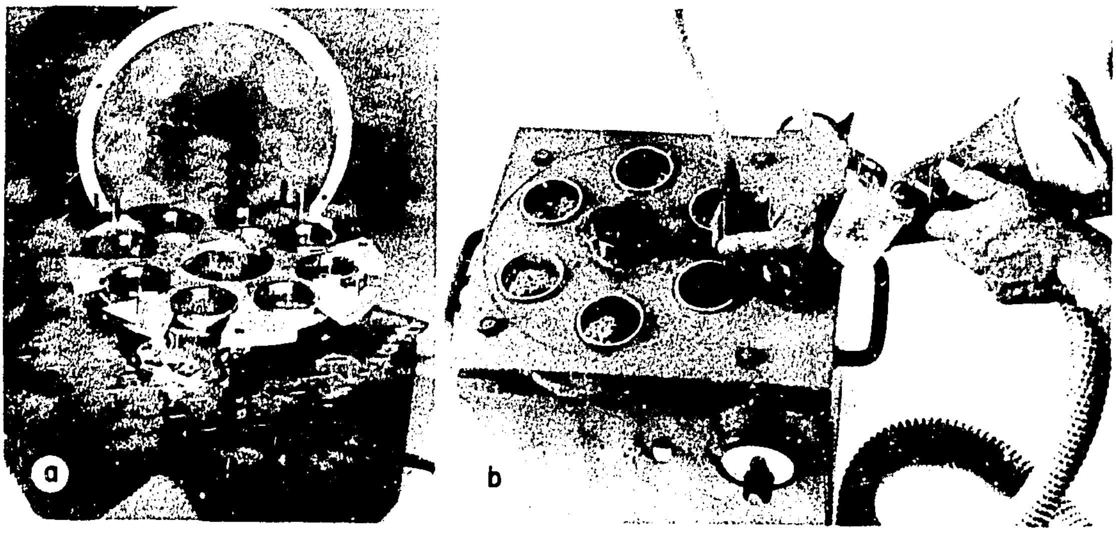

Figure 3. Comparison of the first (a) and second (b) prototypes of the multi-sample, tangential abrasive dehulling device (TADD I and II, respectively).

are then removed from the sample cups with a vacuum sample collector (Fig. 3b). Any residual fines are separated by means of a 20-mesh screen built into this device.

The abrasive surface used in the TADD affects the dehulling rate, efficiency, and reproducibility. Figure 5 illustrates that a coarse carborundum stone removes fines from barley at a much higher rate than two types of resinoid disks. Results for sorghum are similar. To eliminate variability between machines, it is essential that the abrasive surface characteristics of the stone or resinoid disks used in each be identical. Fortunately, the composition and characteristics of grindstones are strictly defined and regulated by the American National Standards Institute. Each stone is identified by a code, e.g., 23A30-M5VBE, which specifies the abrasive material, grit size, grade, structure, and bond.

To determine the reproducibility of TADD using the Simonds resinoid disk, eight replicates (10 g each) of a commercial sorghum were pearled for 2 min. The mean percent kernel removed was 17.4, with a standard deviation of 0.65. We anticipate that the reproducibility will be even better with carborundum stones in future models, since the stones are more uniform and the surface is more true than that of the resinoid disk.

Dehulling properties using TADD I (Simonds resinoid disk) and two large-scale sorghum dehullers were compared (Fig. 6) by progressively pearling a red-pericarp sorghum variety with each dehuller. Color measurements of the ground flour made into a paste (2 g flour + 3 ml water) plotted versus the percent kernel removed gave a relative indication of the rate of pericarp removal. The shapes of the curves are very similar, the TADD I being slightly more efficient in color removal than the PRL, RIIC and PRL dehullers. By changing the grit size and structure of the abrasive surface used

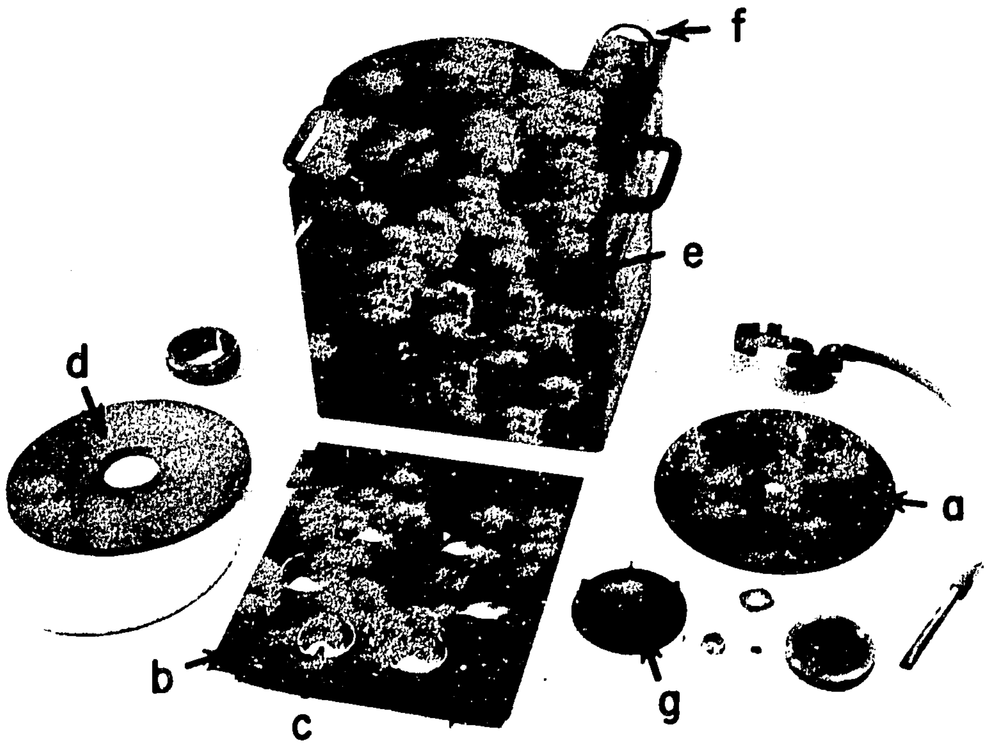

Figure 4. Component parts of TADD II, illustrating the carborundum stone (a), dehulling headplate (b), sample cups (c), cover plate (d), timer (e), fines collection bag (f), and fan (g).

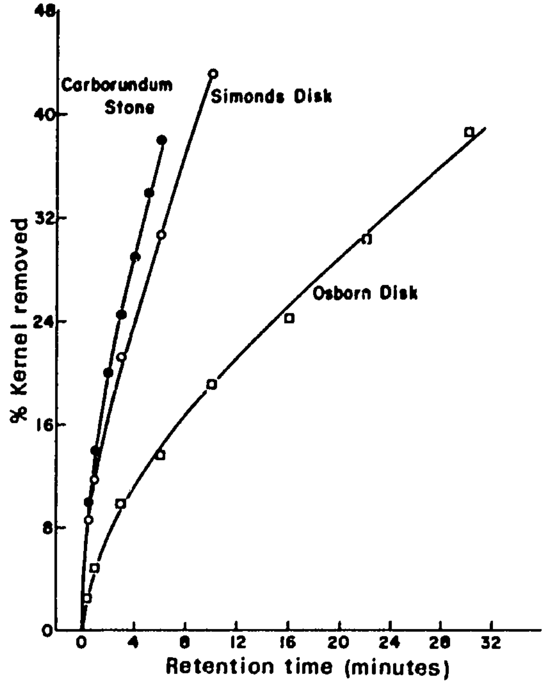

Figure 5. Comparison of the rate of dehulling barley in the TADD I with an Osborn and Simonds resinoid disk and a coarse carborundum stone.

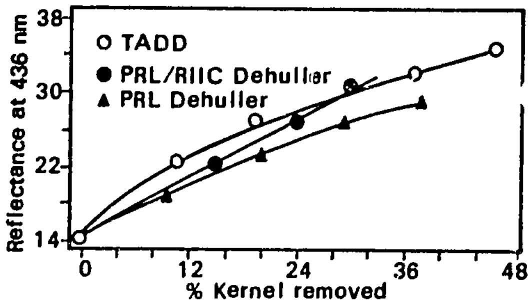

Figure 6. Comparison of flour color (flour reflectance at 436 nm) as a function of progressive dehulling with the TADD I (Simonds disk) and the PRL/RIIC and PRL dehuller at 1300 rpm.

in the TADD, it should be possible to mimic closely the dehulling properties of any large-scale dehuller (abrasive-type).

The Abrasive Hardness Index (AHI) and Extraction Rate

Barley pearlers or similar equipment have frequently been used to assess hardness characteristics of grains (Chung et al. 1975; Kuhlman et al. 1979). The TADD uses the same principle as the pearler, but has the advantage of being a multisample device. Figure 7 shows the calculation of the abrasive hardness index (AHI). The percent kernel removed at each of 3 pearling times is based on the weight of pearled sample recovered by the vacuum sample collector. The percent kernel removed equals $100 - \left[\frac{\text{final weight}}{\text{initial weight}} \times 100\right]$. Linear relationships with high correlation coefficients ($r = 0.998$) were obtained for 31 nontesta sorghum varieties when the retention times in TADD I were plotted against the percent kernel

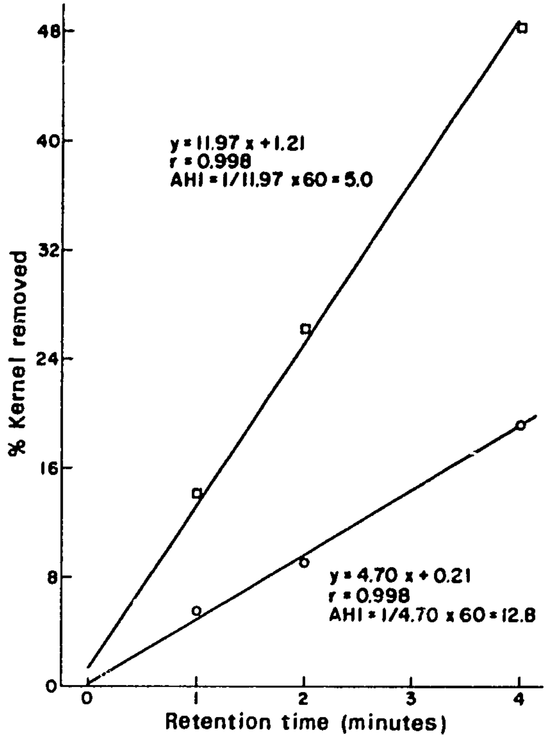

Figure 7. Regression of retention time in TADD I on % kernel removed for hard (o) and soft (□) sorghum samples (extremes of 31 nontesta samples). AHI = abrasive hardness index.

removed for individual samples. The hardest and softest grains are shown in the figure. The inverse of the slope of each lines was multiplied by 60 to give a convenient AHI, defined as the time in seconds required to remove 1 % of the kernel as fines.

Flour color was selected as the quality criterion to determine the extraction rate, which was defined as the percent of the kernel that can be recovered as acceptable flour. Figure 8 illustrates the derivation of the extraction rate for the extremes of the 31 sorghum samples tested. For each variety, the progressively pearled samples (from the AHI determination) were ground to flour, made into a paste and measured in the blue mode (436 mm) of an Agtron spectrophotometer. Acceptable flour (traditionally dehulled) had a reflectance value designated by the horizontal line in the figure. The intersection of the horizontal line and the line obtained by plotting reflectance versus percent kernel removed determined the extraction rate (extraction rate = 100 - percent kernel removed). The extremes of the 31 nontesta sorghums had extraction rates of 98 and 69%.

Application of the Methodology to Sorghum

Thirty-one samples of sorghum varieties without a testa obtained from the Andhra Pradesh Agricultural University, India; Kamboinse, Upper Volta; and Nazareth, Ethiopia were tested. Nineteen samples were distinct cultivars; two additional cultivars were grown in two locations each; one additional cultivar was grown in eight locations. TADD I equipped with a Simonds resinoid disk was used to determine the AHI and extraction rate.

Table 1 shows that the AHI ranged from 5.0 to 12.8 for the 31 samples. Similarly, the extraction rate ranged from 69 to 98%. The white pericarp sorghum varieties showed the largest range for both parameters. This indicates that even though a sorghum has a white pericarp it does not necessarily mean that it will produce an acceptable flour at a high extraction rate. For testa-containing samples we have observed extraction rate values as low as 41%.

The CSH-5 samples showed, however, that the range in the AHI for the same white variety grown in eight different locations was nearly as large as the range for all 31 samples. The range of the extraction rate for these 8 samples was smaller than the overall range of 31 samples. This large

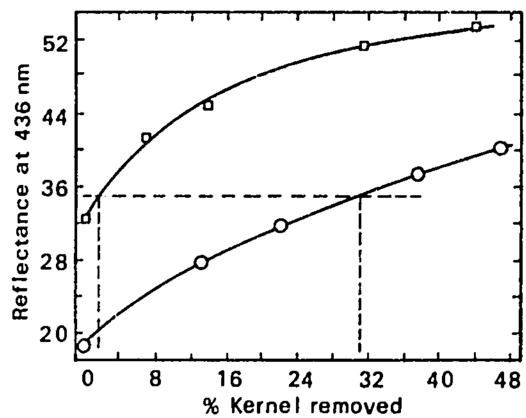

Figure 8. Determination of extraction rates for two samples of sorghum (extremes of 31 nontesta samples). Extraction rates are 98% (□) and 69% (o), based on a reflectance value of 35 for a traditionally acceptable flour.

Table 1. Abrasive hardness index (AHI) and extraction rate of 31 nontesta sorghum varieties and CSH-5 sorghum.

Pericarp color	Number of entries	AHI Range	AHI Mean	AHI SD[a]	Extraction rate Range	Extraction rate Mean	Extraction rate SD
White	23	5.4 - 12.8	8.3	1.8	71.3 - 98.0	89.6	6.6
Yellow	7	5.0 - 9.8	7.7	1.6	71.2 - 93.2	80.0	9.0
Red[b]	1		6.5			69.0	
All samples	31	5.0 - 12.8	8.1	1.8	71.2 - 98.0	86.5	8.7
CSH-5	8[c]	5.4 - 11.8	7.8	2.1	82.9 - 97.8	90.2	4.5

a. Standard deviation.
b. Low tannin variety.
c. Samples were grown at eight different locations.

Table 2. Abrasive hardness index (AHI) and extraction rate of eight samples of CSH-5 sorghum.

Pericarp color	AHI			Extraction rate		
	Range	Mean	SD	Range	Mean	SD
White	5.4 – 11.8	7.8	2.1	82.9 – 97.8	90.2	4.5

effect of environment on AHI particularly, and extraction rate to a lesser degree, may pose a problem in selecting cultivars with particular desired characteristics. However, this was very limited data on which to draw conclusions and a much larger study is needed to determine the influences of environment and genotype on sorghum quality.

Significant correlations were obtained between the AHI and two other measures of kernel hardness for the 31 varieties. The Brabender hardness index (BHI) was determined by grinding 6 g of whole sorghum in a Brabender micro-hardness-tester. The time in seconds required to obtain 4 g of flour on the weighing pan is the BHI. Flour yield, another measure of grain hardness, was the percentage of flour (sorghum ground in a KT-30 Falling Number ZB plate mill) passing through an 80-mesh screen. The AHI was significantly correlated with the BHI ($r = -0.521$, $p < 0.01$) and the flour yield ($r = -0.745$, $p < 0.001$). However, the correlation is not perfect suggesting that abrasive hardness also measures properties which are quite different from those properties measured by grain grinding techniques (BHI flour yield). The AHI was more highly correlated ($r = 0.940$, $p < 0.05$) to flour yield when only the one cultivar grown in eight locations was considered.

Future Work

A new model of the TADD is presently being constructed which will have the capability of dehulling 5, 8, or 12 samples at one time (Fig. 9). This will be accomplished by simply interchanging the dehulling headplate, which has the sample cups mounted into it. Cup diameters in the 5, 8, and 12 sample systems are 7.3, 5.7, and 3.8 cm, respectively. For large-seeded cereal grains or grain legumes such as faba beans or kidney beans, a larger sample size is required for dehulling and the five-hole dehulling headplate would probably be most appropriate. For grains such as millet or sorghum, it is anticipated that dehulling of 12 samples simultaneously will be possible, since sample size will only be in the 5 to 10 g range. The entire machine (automatic, digital timer; vacuum cleaner; dehulling unit) will be integrated into a compact, free-standing unit.

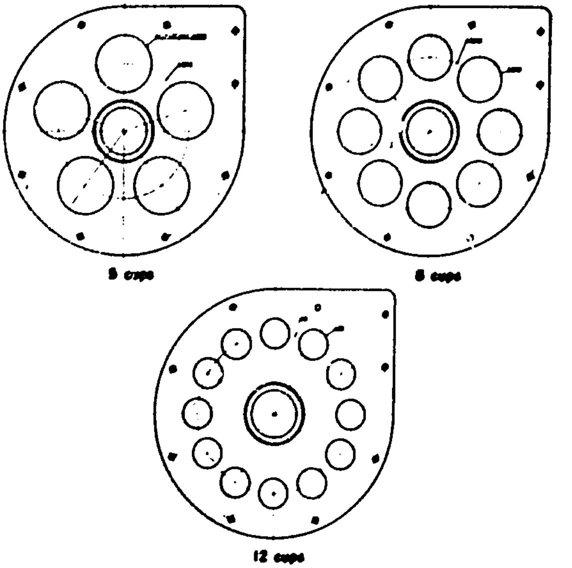

Figure 9. Technical drawings of the 5, 8, and 12 cup dehulling headplates for the TADD.

For hardness measurements, the AHI (three pearling times) appears to be satisfactory. It may be possible to shorten the procedure, however, by using the results of only one or two pearling times. For the measurement of extraction rate, however, a simpler method of evaluating flour color must be developed. The Agtron spectrophotometer may be too sophisticated and too costly to be used routinely in plant breeding laboratories. Visual techniques for the determination of the degree of dehulling, perhaps with the aid of staining techniques, may be developed.

It is necessary to investigate whether methodologies useful in predicting traditional dehulling properties (semimoist) can be developed with the TADD. Work is presently under way in Upper Volta to answer this question. It is conceivable that specific methodologies may differ from region to region, depending on the quality attributes required.

Acknowledgments

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Pearling and Milling Studies on Sorghum

H. S. R. Desikachar*

Summary

Removal of bran from sorghum is highly desirable to increase its palatability and versatility for culinary use. It was found that short-period moist conditioning of grain with 2–3% moisture enables removal of the bran by an abrasive machine similar to that used in rice milling. For soft-endosperm sorghums, the moist conditioned grain can be ground in a plate grinder and the major proportion of bran can be eliminated by sieving. Illustrative data are provided to relate the effect of polishing to the nutritive value of sorghum. Overmilling is to be avoided as this results in depletion of nutrients from the grain.

Because it is difficult to cook sorghum like rice as a whole grain, the practice has evolved over the centuries to grind the grain into flour or grits and use it for preparing porridge, pancake, etc. A whole-meal flour or a high extraction flour obtained after sieving out about 3–5% of the coarse bran is normally used for such purposes.

However, it became apparent in recent years that there was a need to develop methods for obtaining a semirefined sorghum flour from which a large proportion of the bran has been eliminated with minimum loss of nutritional constituents. The bran is a major cause of the coarse texture of sorghum products. Attempts have been made to develop such processes and machinery for removal of the bran constituents from sorghum in the USA, Africa, Canada, and India (Anderson et al. 1969; Hahn 1969; Miche et al. 1976; Perten 1976; Raghavendra Rao and Desikachar 1964; Rasper 1976; and Viraktamath et al. 1971). Both dry and wet processes have been used. Each method may have a certain edge over the other with regard to certain aspects. The main lines of research carried out at the Central Food Technological Research Institute (CFTRI) are indicated here.

Incipient moist conditioning of the grain with a small amount of moisture, just sufficient to wet the bran, allows it to be loosened and easily pearled from the grain. The bran, being moist, also resists fine grinding, unlike the endosperm which is relatively drier and more friable. Based on this observation, a pearling technique for obtaining polished sorghum grains and a process for obtaining a refined flour or semolina (soji) has been developed.

In the pearling technique, the grain is mixed with 2 to 3% moisture, just sufficient to wet the bran, and after conditioning for a period of 5–10 min it is polished in an abrasive-type polishing machine used for polishing rice with slight modifications. For studies on small samples, a laboratory McGill type rice polisher was used. For large-scale trials, commercially used rice polishers were tried. Although both the vertical cone polisher and the horizontal emery cylinder type polishers could be used, the latter was found to give less breakage than the vertical cone (Table 1). The water conditioning and horizontal polisher units are shown in Figures 1 and 2. Apart from the type of polisher used, the breakage during pearling depends also on the variety of sorghum. The hard varieties give less breakage and more whole grain yield than the soft varieties. Typical data on some varieties are presented in Table 2.

Tables 3 and 4 present data on the effect of pearling on the chemical composition of the pearled grain or the polishings removed during pearling as obtained in a laboratory mill or a commercial cone polisher. It can be seen that the nutritional value is adversely affected by overpolishing. However, at a stage of 10–12% degree of polish, maximum grain recovery with minimum

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Table 1. Comparative breakage during pearling of sorghum (commercial hybrid) with different types of rice polishers.

	Total milling yield (%)	Whole grain (%)	Brokens (%)	Brokens in bran (%)	Total brokens (%)	Bran (%)	Total (%)
Satake polisher (horizontal)	82.5	81.7	0.8	5.6	6.4	11.4	99.5
Cone polisher (vertical)	82.3	54.9	27.4	0.8	28.2	16.2	99.3
Laboratory (McGill polisher)	82.1	71.6	10.5	16.6	27.1	14.3	98.7

Source: Narayana and Desikachar (unpublished data).

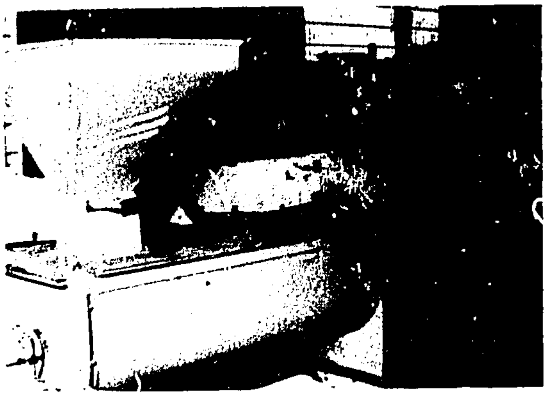

Figure 1. Mixer for wet conditioning of sorghum.

loss of nutritive value can be secured.

Pearling considerably improved the visual appearance and consumer acceptability of the grain by removing the colored, bitter, rough bran and glumes from the sorghum. The pearled grain could be ground to flour or semolina as desired. Also, pearled grain could be used for making sorghum flakes and several snack foods.

This pearling technique is not suitable for sorghum varieties with soft endosperms as they undergo excessive breakage during the pearling process. Such varieties can be milled with machinery used for milling wheat. Both the laboratory Buhler mill and the commercial roller mill have been used successfully to obtain fractions that would be highly refined. The chemical composition of shorts, and the break and reduction roll fractions have been determined (Table 5).

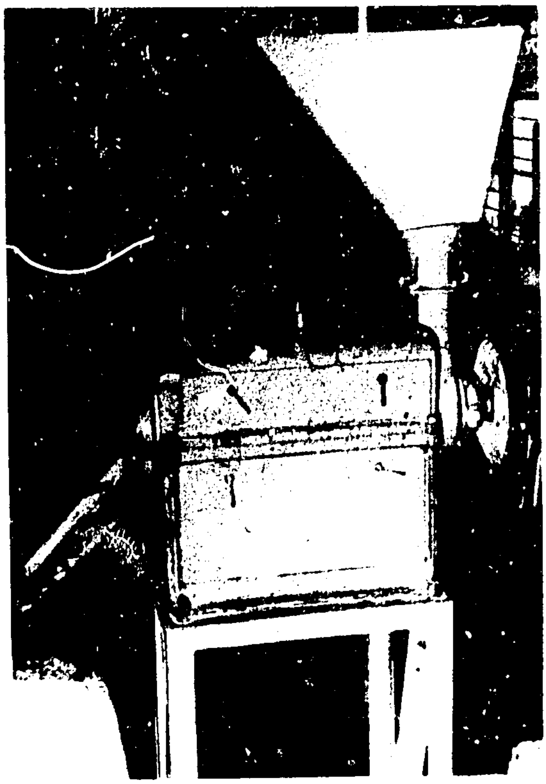

Figure 2. Horizontal emery pearler for sorghum.

As the roller flour mill is a sophisticated, high-capacity, commercial machine and may not serve

Table 2. Varietal 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 (%)
BP53	6.54	2.08	82.5	67.5	15.0
H2259	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
GPR148	5.82	2.30	86.0	80.5	5.5
M7777	6.20	4.00	88.0	82.2	6.0
P721	5.88	1.86	82.0	68.5	13.5
CSH	6.56	1.90	82.5	68.5	14.0
M-64 77	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
A2283	3.00	0.90	87.2	64.7	22.5

Source: CFTRI Annual Report 1979–80.

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

Table 3. Effect of pearling on the chemical composition[a] of sorghum using the laboratory McGill mill.

Degree of polish[b] (%)	Crude protein[c] (%)	Ether extract (%)	Crude fiber (%)	Ash (%)	Calcium mg %	Phosphorus mg %	Thiamine µg %
Sorghum							
0 (11.3)	12.0	2.6	3.1	2.0	40	254	421
4.5 (12.4)	12.0	2.2	2.0	1.5	35	219	410
7.8 (13.0)	11.5	1.9	1.7	1.4	31	218	391
12.0 (13.0)	11.4	1.3	1.1	1.3	26	160	358
15.0 (13.1)	11.4	1.1	0.9	1.1	22	135	344
18.4 (13.0)	11.2	1.0	0.6	1.0	19	134	311

Source: Raghavendra Rao and Desikachar, 1964.

a. All values are expressed on a moisture-free basis.

b. Figures in parentheses represent percent moisture in the milled grains immediately after polishing. All values are expressed on a moisture-free basis.

c. N × 6.25 in the case of sorghum.

the needs of consumers and farmers who would like to have their grains processed and dehusked for personal consumption, the development of a simpler low-capacity sorghum mill was attempted. After several trials the following adaptations of the plate grinding mill have been found to give satisfactory results.

The modified mill consists essentially of a plate mill to which a set of sieves has been fitted. The motion for the sieves has been obtained by means

Table 4. Chemical composition of products from milling of sorghum (CSH-1) using a commercial vertical rice polisher.[a]

Sample	Crude protein (%)	Ether extract (%)	Crude fiber (%)	Ash (%)	Calcium (mg/100g)	Phosphorus (mg/100g)
Control (unpolished sorghum)	11.3	4.2	1.8	1.7	49	303
Polished sorghum (I cone)	11.0	3.8	1.0	1.5	45	270
Polished sorghum (II cone)	10.7	3.2	0.8	1.3	39	210
Polished sorghum (III cone)	10.5	2.2	0.7	1.1	39	210
Large brokens	10.5	1.8	0.8	1.2		231
Small brokens	10.4	4.7	0.8	1.2		190
First cone bran	11.6	8.4	11.9	5.7		517
Second cone bran	13.0	9.8	6.4	5.2		931
Third cone bran	13.7	2.8	4.8	4.8		718
Bran	13.0	8.0	8.6	7.2		1383

Source: Virktamath et al. 1971.
a. The degree of polish of the sorghum from cone I was 3.7%; cone II, 7.0%; and cone III, 9.5%.

Table 5. Composition of sorghum fractions milled in a roller mill.

Products	Recovery (%)	Protein[a] (%)	Fat[a] (%)
Fine semolina	33.5	10.9	2.1
Maida (white flour)	33.7	6.9	2.5
Atta (shorts)	26.5	10.3	8.8
Bran	4.1	11.9	1.4
Sweepings	0.8		
Losses	1.4		

Source: Viraktamath et al. 1971.
a. On dry-weight basis.

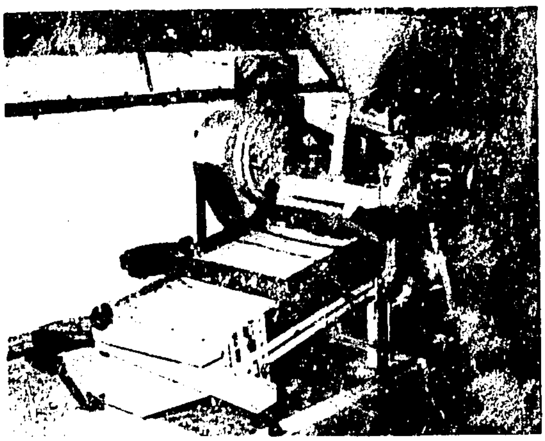

Figure 3. Chakki sieve unit (grinder with sieve attachment).

of an eccentric drive from the main motor. Suction for aspirating small traces of bran is provided by means of a fan fitted to the main shaft (Fig. 3). The grain is given a short conditioning by adding about 3% water, 5 min prior to grinding. The ground material is sieved immediately and the bran is held on a 16 B.S. mesh sieve. The −16 +30 B.S. fraction comes out as an attractive semolina, the −30 +60 fraction is a fine grade semolina, while the −60 fraction is a white flour with only small amounts of bran. The small amount of bran obtained in the semolina fraction is removed by aspiration. The yields of different fractions are presented in Tables 6 and 7. The same mill is also suitable for grinding other grains like wheat, maize, millet, and ragi.

Our results on sorghum milling have shown that the idle capacity of existing commercial rice milling machinery could be utilized, with minor modifications, for the pearling or polishing of sorghum. Most of the hard grain commercial varieties, irrespective of bran color, could be pearled to obtain

85–90% yields of attractive polished or pearled grain that could find versatile culinary uses. Similarly, the existing grinding mills (Chakkis) when fitted with a sieving device either as an integral part of or as an adjunct to the grinding unit, can be used for removing a major portion of bran and obtaining a fairly refined semolina or flour of high nutritive value for traditional uses. Although our work is oriented to its suitability and utilization potential in the Indian context, we believe that the technologies could also find use in other countries where sorghum is a major staple grain.

Table 6. Yield of different sorghum fractions when ground in a 'Chakki' unit.

	Mesh size ISI	Pearly white (Indian medium-hard)	Red soft variety (E 1291 of Kenyan origin)
Fraction I (bran)	+30	6.2	11.6
Fraction II	−30+44	23.0	16.2
Fraction III	−44+60	25.6	30.5
Fraction IV	−60	45.2	42.3

Source: Desikachar (unpublished data).

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Table 7. Yield and chemical analysis of fractions of sorghum ground in an improved plate grinder.

	Fractions				Whole meal flour
	+16 B.S.[a]	−16+30 B.S.	−30+60 B.S.	−60 B.S.	
Yield (%)	11.4	21.0	32.5	35.1	
Protein % (N × 6.25)	16.8	8.5	8.6	7.9	9.6
Ether extract (%)	5.0	2.4	2.5	1.7	2.5
Crude fiber (%)	9.8	1.42	1.18	1.12	1.8
Bran residue[b] (%)	48.5	3.6	4.1	1.9	9.6
Total ash (%)	4.1	1.67	1.5	1.55	2.1
Calcium (mg/100 g)	136	24	27	14	32
Phosphorus (mg/100 g)	438	192	180	155	215
Thiamine (mg/100 g)	770	560	440	450	530

Source: Malleshi, Ananda, and Desikachar (unpublished data).

a. B.S. = British standard mesh

b. Material was soaked in five parts water and macerated in a waring blender and passed through B.S. 200 mesh. Residue was washed several times with water until washings gave negative test for starch. Residue was dried at 110° C to constant weight.

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Milling Processes and Products as Related to Kernel Morphology

L. Munck, K. E. Bach Knudsen, and J. D. Axtell*

Summary

A new industrial-milling process was devised on the basis of experience gained from traditional hand-decortication studies on sorghum. This system yields 80% flour at the same or higher level of whiteness as the traditional system. Grain structure of sorghum was studied in relation to decortication performance, using an abrasive dehuller. The problem of relating laboratory-milling data to large-scale milling is discussed. It is concluded that the hardness of sorghum grain determines the flour color and yield of the traditional-decortication products as well as the products from the abrasive dehullers. In the new industrial-milling system, moderately hard and semisoft varieties like Lulu-D can be used with good results, whereas hand pounding and abrasive milling require hard seed. Implementation of this new milling technique will render the soft endosperm, high-yielding types of sorghum useful for industrial milling.

Sorghum is today the cereal which is expanding most in acreage due to its excellent adaptability to semi-arid climates. Unfortunately, most of the increased sorghum production is used for feed, even in countries where sorghum has been used for food since prehistoric times. While sorghum is highly regarded as a food grain in rural areas in Africa, it has not withstood competition from maize and wheat in towns and cities. With the introduction of maize and wheat, appropriate milling processes on an industrial scale were introduced to feed the rapidly growing population in urban areas. The milling technology for sorghum is still inadequate for the production of flour with an acceptable, light color. Where sorghum yields more than maize and wheat, it should be grown not only for feed but also for food, as an adjunct to breweries, and possibly for the industrial production of products such as starch. To assure a suitable quality in the milling of sorghum, breeding programs should be directed to at least three distinctly different target groups:

1. The rural subsistence farmer who still mills, cooks, and eats sorghum mainly from local varieties, but who is exposed to high-yielding and softer-endosperm types of sorghums along with improved growing practices.
2. The village miller who operates small mills with decortication machines and hammer mills. Such mills are mostly used for milling batches of maize and occasionally of sorghum for customers supplying their own grain.
3. The industrial miller or food dealers in urban areas. These people mill and sell sorghum products and or food from other cereals.

It is important that milling studies of traditional and new varieties be made in cooperation with local people from groups 1 and 2, as the demands on the varieties could differ significantly from one area to another. With regard to industrial milling, plant breeders in most countries still have very few millers with whom to cooperate due to the low state of technology. In fact, plant breeding should be combined with the development of new mills so that varieties and processes could be "bred" together. This is a unique opportunity to combine biology and milling technology. At the Carlsberg Research Laboratory, traditional biological research has been combined with a new pilot plant displaying the principles of laboratory milling

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as well as those of milling on a semi-industrial/industrial scale. The process of milling aims at separating the various botanically definable parts such as pericarp, testa, aleurone, embryo, and endosperm ending with pulverization of the endosperm. The physical structure of the kernel plays a major role in the efficiency of milling in terms of flour yield, color, chemical composition, and acceptability.

In this paper we will first consider sorghum hand milling in Africa (Eggum et al. 1981). The information from the local milling processes is used for developing a new sorghum-milling process at the Carlsberg Research Laboratory. This process as well as the experience from milling by hand will be compared with the current abrasive-decortication techniques (Perten 1977; Perten et al. 1978; Eastman 1980), especially with regard to structural differences between sorghum varieties which are of importance in milling.

Material and Methods

Sorghum raw material was obtained from Purdue University, West Lafayette, Indiana, USA, and from the Ilonga Agricultural Institute, Ilonga, Tanzania.

Seed Structure Analyses

We have found the UNIVAR microscope (Reichert AG, Vienna, Austria) to be useful for studying endosperm hardness in polarized light as well as for following the migration of pigments into the endosperm in fluorescent light. Unfixed seeds are cast in black epoxy plastic and are then polished with a diamond polisher (Ultrafräser, Jung AG, Germany BRD) to obtain a median cross-section. The plane surface can then be studied in a natural state under incident light in the microscope.

A special incident light objective can be attached to the microscope, making it possible to measure Vickers' hardness units in single endosperm cells. Vickers' hardness units is a generally accepted measurement in the field of metallurgy. This objective has a small diamond pyramid on its front lens. The pyramid and the front lens can be pressed against the seed cross-section by a controlled force of compressed air passing through a pair of bellows. Thus an incision is made on the surface which can be measured in interference contrast in the microscope micrometer. The size of the incision is related to Vickers' hardness units in a table.

When cutting a sorghum kernel, the peripheral translucent hard parts, as well as the central soft part which reflects light, are apparent. These areas can be quantified in the microscope through an image analyzer (Quantimet 720, Cambridge Instruments, Cambridge, England). This apparatus consists of a TV camera attached to the microscope, a TV display, electronic hardware and a computer, which can calculate the digitized information on the areas from the microscope TV picture. The soft area measured also contains germ. These measurements can also be combined with Vickers' hardness measurements from the hard and soft areas to calculate hardness units per total seed area. The seeds most susceptible to cracking during the decortication process are the softest ones. Thus we have calculated the percentage of seeds that have a softness of more than 40% in order to determine whether there is a limit of softness where seeds break. The *form of the seed* can also be determined from the image analysis according to the formula

$$\frac{\text{Area}}{(\text{Perimeter})^2} \cdot 4\pi \cdot 100.$$

Thus a cross-section giving a perfect circle has a form factor equal to 100.

Hand Decortication by Pounding

It is essential that plant breeders study local hand milling practices and develop high-yielding varieties that give optimum milling yields from hand milling. Details of the hand milling practices presented here are reported elsewhere in these Proceedings (Eggum et al. 1981).

Local Machine Milling in Batch Scale

Hand pounding is hard and tedious work requiring about 1 hr for processing 2-3 kg of sorghum. Therefore small diesel-driven mills in the villages have a ready market for the milling of batches of sorghum for individual customers. Processing the same Lulu D sample by hand milling (Table 1:1) produced superior flour compared with a local decortication mill (Table 1:2). In fact, the Tanzanian housewife made such a fine product of

Table 1. Comparison between three different milling techniques with sorghum variety Lulu D.

	% soft endosperm in raw material	% milling yield	Blue Agtron reflectance	% d.m. Fiber	Fat	Ash	Protein
1. Lulu D hand decorticated	30.7 ±5.7	60[a] 50[b]	44[c]	0.6[c]	0.5[c]	0.31[c]	12.2[c]
2. Lulu D decorticated in a village machine mill	30.7 ±5.7	50[d]	40[e]	1.0[e]		0.68[e]	12.3[e]
3. Lulu D decorticated in the UMS DVA dehuller	35.0 ±3.2	78[f] 80[g]	51[f]	0.6[f]	1.1[f]	0.69[f]	12.1[f]

a. Approximate yield after 3 decortications.
b. Approximate yield after 4 decortications.
c. Chemical composition after 4 decortications.
d. Approximate yield after 2 decortications.
e. Chemical composition after 2 decortications.
f. Kernels' yield and chemical composition after 1 decortication (see C1, Plate 1b).
g. Total yield C1 + endosperm fragments (B3, Plate 1b).

Lulu D, that it was comparable in chemical composition to hand-dissected endosperm (Hubbard et al. 1950), but its yield was low. We concluded (Munck et al. 1981) that the diesel-driven village mills had to be supplied with hard types of sorghum in order to give higher yields of more acceptable products. Consequently, the development of a hard endosperm in sorghum should be given high priority in Tanzania.

Abrasive Milling

As a first attempt to mill sorghum on a larger scale, wheat roller mills were used. As pointed out by Perten (1977), the pericarp of sorghum and millet is less tough than that of wheat and therefore pulverizes during roller milling and mixes with the fine flour. In the USA, industrial sorghum milling started during the Second World War. These mills were essentially based on roller mill systems but were supplemented with barley pearlers with carborundum stones (Hahn 1969, 1970). The principle of such a pearler is illustrated in Figure 1. The sorghum flows by gravity from above (A) into the vertical rotor, surrounded by a cylindrical screen (B), and equipped with segments of abrasive grinding stones (C). While the motor runs with a peripheral speed of 18–25 m/sec, the kernels are abraded against the rough surface of the carborundum stones, against the peripheral screen and each other. Bran and endosperm particles are removed with a pneumatic system (D) and collected in a cyclone. The degree of polishing can only be regulated by controlling the flow of the outlet at the bottom of the machine (F). Thus the time during which the kernels stay in the polisher can be regulated. Cracking of seeds should be avoided in order not to lose endosperm to the bran fraction. The yield and the quality of the polished product depend on the following kernel characters:

1. Shape: Round kernels give smaller losses of endosperm than oval ones. The abrasive principle produces spherical polished kernels.
2. Size: Large kernels tend to crack if they are not hard enough.
3. Adhesiveness of the hull: The pericarp testa should easily break from the endosperm during mechanical treatment.
4. Hardness: A hard endosperm will normally break less easily than a soft one. Fortunately, the hard part of the sorghum endosperm is often

situated peripherally with the soft endosperm in the center near the germ.

Two extensive projects to introduce milling technology based on the abrasive principle for sorghum and millet into developing countries were started in the late 60s and early 70s. The Canadian IDRC project (Eastman 1980) started in 1972, and is directed to produce small horizontal abraders for villages. They are intended for milling small batches (about 10 kg) of grain taken to the mill by local customers. The FAO/UNDP project started in 1967 in several African countries to produce composite flours of sorghum and millet mixed with wheat on an industrial scale. A pilot plant mill with a vertical "Decomatic" grain polisher was erected in the Food Research Institute in Khartoum, Sudan (Perten et al. 1978).

Developing a New Milling Process for Sorghum

Mechanisms of hand pounding are very different from those of abrasive milling. In hand pounding, the pestle causes a mechanical shock which generates strong interactive forces between grains as well as between grains and equipment. When water is added, large flakes of hull material are formed. On the other hand, in abrasive milling (Perten 1977), the polishing effect is mainly obtained between the grinding stones and the seeds and as action of seed against seeds (Fig. 1), producing fine bran particles. Abrasive milling through kernel breakage causes losses of endosperm flour in the bran fraction. Hand pounding, however, initially produces coarse endosperm particles which dwindle during the successive cycles of decortication. At the Carlsberg Research Laboratory we have developed an industrial decortication process aiming at avoiding the disadvantages of abrasive milling and incorporating the advantages of the age-old hand pounding principle.

In the new decortication machine (Fig. 2) the UMS DVA machine (United Milling Systems A/S, DK-2500 Copenhagen-Valby, Denmark) the sorghum kernels are conveyed by a screw (C) into the decortication chamber (D), where a steel rotor rotates the grain mass towards the cylindrical screen (F). The pressure between the seeds during decortication can be controlled by the counterweight (G) in the outlet (H). The hulls and the endosperm fragments from the cracked kernels are

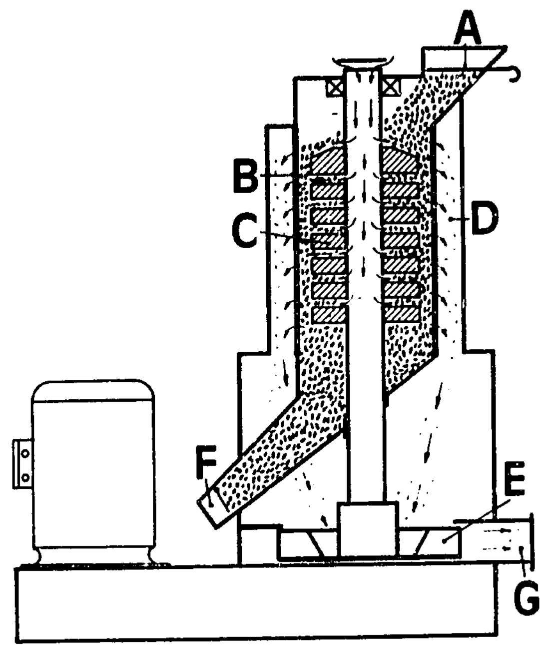


Figure 1. Principle of a vertical abrasive polishing machine.

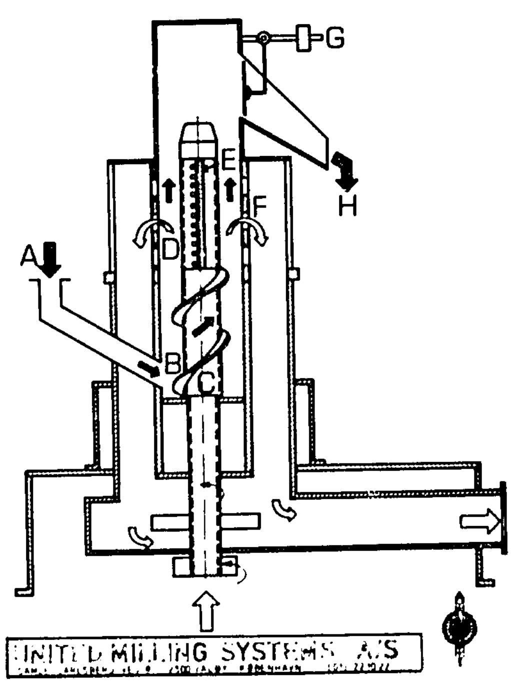


Figure 2. Principle of the UMS DVA sorghum decorticator (United Milling Systems A/S, DK-2500 Copenhagen, Denmark).

discharged through the screen by an air current at high pressure. This fraction—the screen flour—is sucked out from the bottom of the machinery into a cyclone. The first crucial point in the new dehulling process is described in Figure 3 where the UMS DVA decorticator is integrated into a milling system with a capacity of 2 t/hr. This milling system is devised in order to recover endosperm particles from the screen flour. After separating the fine bran fractions from the coarse ones through sifting (A2), the coarse fractions are separated by aspiration into an air sifter (B1) producing coarse hulls (B2) and cleaned endosperm fragments (B3) which then could be milled together with the decorticated kernels (C1) in a milling and sifting section. Thus grits and flours of a high yield are produced. Products from the various stages in this process are displayed in Plate 1b.

The new UMS DVA dehuller can, depending on the processing conditions, remove whole embryos, which produce sharp-edged decorticated, degermed kernels resembling children's milk teeth (Plate 1a:3). This indicates that the UMS DVA dehuller produces a small amount of fine endosperm flour compared with abrasion mills, which tend to produce round seeds (Plate 1a:2). Seeds decorticated with abrasive stone mills are more rugged on the surface and thus appear whiter than seeds from the UMS DVA decortication, which still have intact natural endosperm surfaces. Obviously, the rugged surface indicates losses of fine particles of endosperm. Breakage of kernels does not affect yield in the new milling process so much as when the abrasive polishing technique is used. The reason is that in the new process, losses can always be regained (B3) from the screen flour (A2), as long as the endosperm particles are kept sufficiently coarse. For example, grains of Lulu D milled in the new process (Table

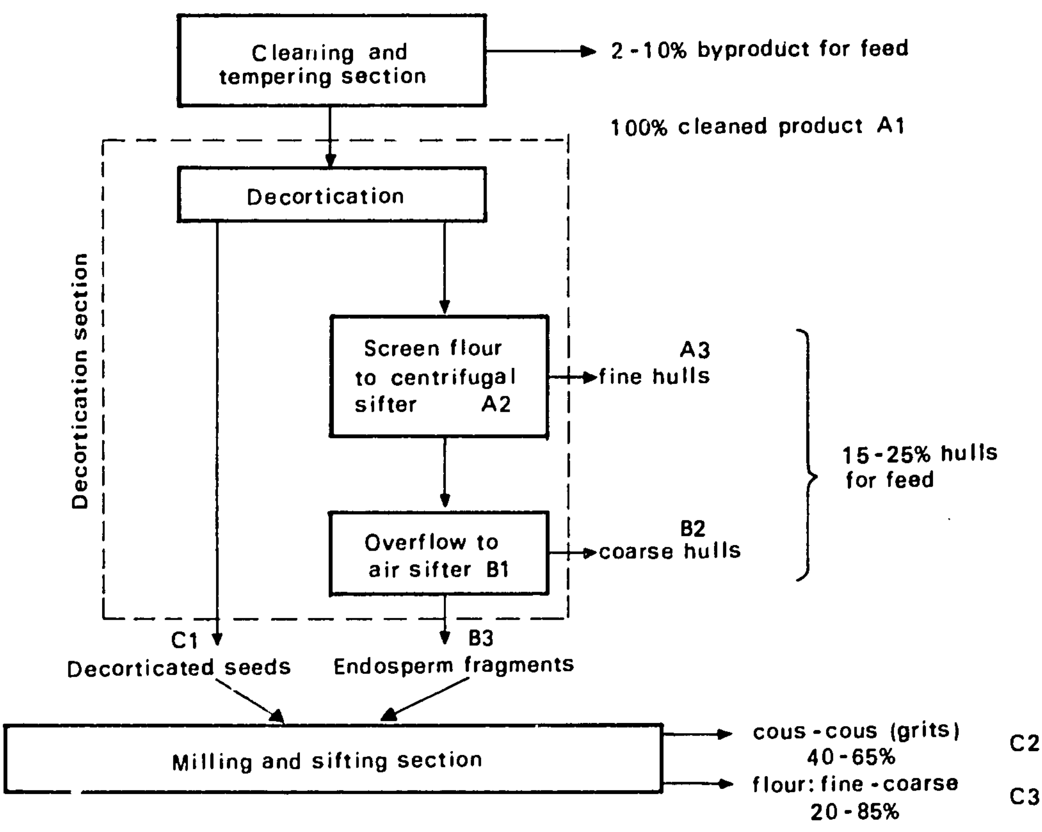
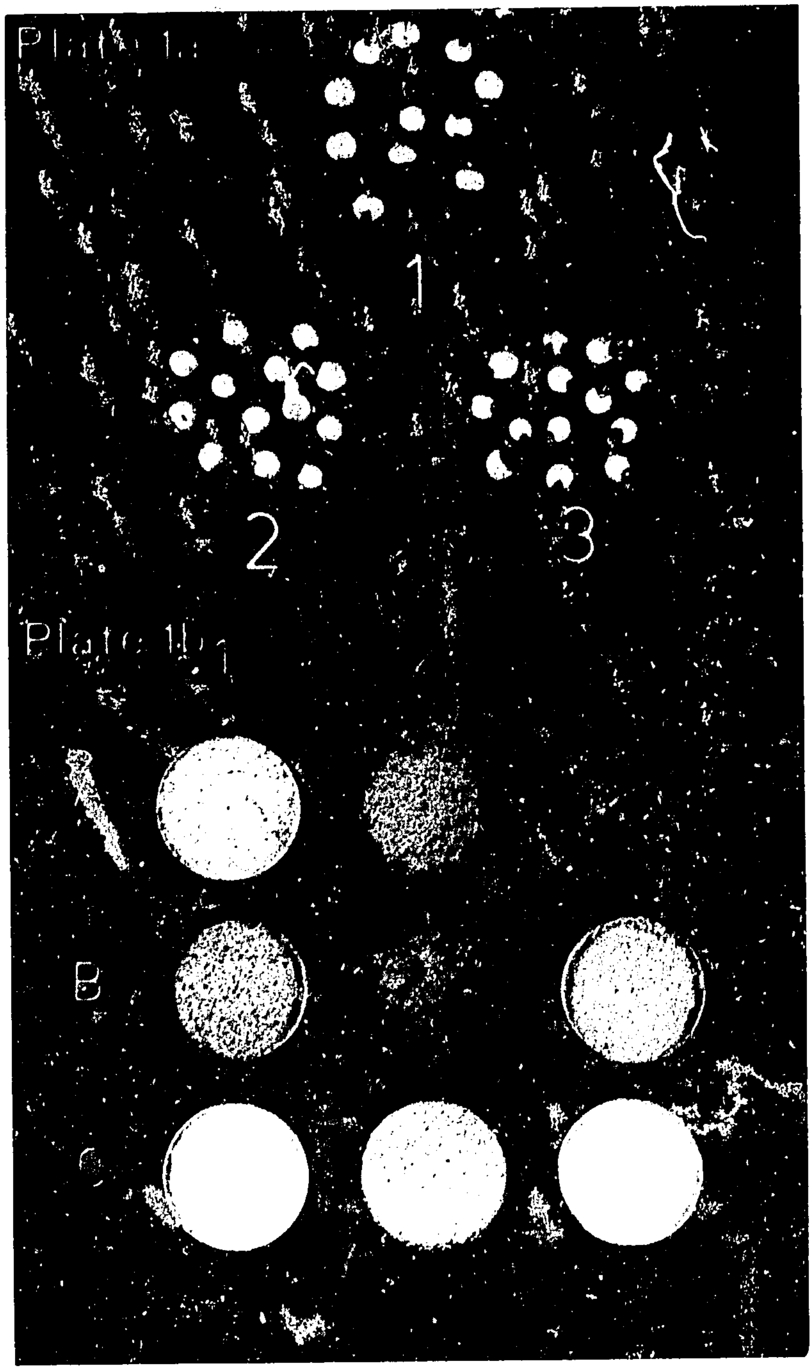


Figure 3. Principle of a compact industrial mill for sorghum with a capacity of 2 tons/hr (United Milling Systems A/S, DK-2500 Copenhagen, Denmark). For products A1, B1, C1 etc., see Color Plate 1b.



C. Plate 1. a. Dabar sorghum (1), treated in an abrasive polisher (2), and in the UMS DVA decorticator (3).
b. Sorghum raw materials and products from Dabar sorghum milled in the UMS sorghum milling process. Letters and figures refer to positions in Figure 3.

1:3), yield 78% of decorticated grains and 2% of endosperm fragments, rendering a total yield of 80% with lighter color than flour of the same variety milled locally in Tanzania.

Two different Lulu D samples were used in the comparative milling experiments. Table 1 displays comparable levels of soft endosperm as well as comparable chemical composition of raw material. The high efficiency of the new process is indicated by the low content of fiber and ash in the product at a high extraction rate.

Two high-tannin, red sorghums with soft endosperm IS4225 and Argentine were milled in the UMS DVA dehuller (Plate 2F, G). The difficulty of decorticating the Argentine variety (Plate 2F left) is clearly seen in the color pictures. These problems are even more clearly revealed when we look at the color of finely milled flour from the raw material and the decorticated products (Plate 2G left). Yield data from these experiments are presented in Table 2:2. In spite of the low extraction of product from the Argentine cultivar (52.5%), the Agtron reflectance shows extremely low values with the blue and red filters. Ash is, however, surprisingly low (0.53%), indicating that ash should not be used as a criterion of quality in sorghum milling as it is in wheat milling. Moreover, it is possible to obtain acceptable flour from IS4225 at a yield of 71.4% (Plate 2F center, 2G center). The soft endosperm character (Table 3) of this variety produces a large fraction of endosperm fragments, in fact nine times larger than that obtained for milling of Lulu D grain (Table 1). The content of fiber, fat, and ash in the product from IS4225 (Table 2:3) is less than half of that from the same variety milled with the abrasion technique (which will be discussed later) at a yield of 75% (Table 3). The samples of IS4225 and Argentine grain were not grown at comparable sites, so it is not possible to relate the large differences in their milling quality to either varietal or environmental effects.

The normal U.S. hybrids are low-tannin types with a strongly colored pericarp (Plate 2F, right). We have been successful in milling such a variety (Plate 2F, right; 2G, right). Data for a typical milling experiment with a U.S. hybrid (Dekalb 3P3 866VS) are presented in Table 2:1, displaying a total yield of 74.7% with no significant losses in broken endosperm. The milled decorticated product is much brighter than that of IS4225. Fiber, fat, and ash are as low as 0.5, 0.6, and 0.53%. The new technique could be used for profitable milling of

Table 2. Decortication of three sorghum varieties according to the process described in Figure 3, involving decortication in the UMS DVA dehuller (C1) and recovery of endosperm from the screen flour (B3).

Variety	% soft endosperm	% yield Total	C1	B3	Agtron reflectance raw material blue filter	C1 + B3 blue filter	red filter	% d.m. Starch	Fiber	Fat	Ash	Protein
1. Dekalb	34.7	74.7	74.7		25.0	56.4	75.5	86.5	0.5	0.6	0.53	12.1
2. Argentine[a]	43.4	52.5	36.0	16.5	13.5	27.0	34.5	83.4	1.5	1.1	0.53	11.7
3. IS4225[a]	38.7	71.4	51.0	20.0	17.4	46.8	64.0	81.6	0.9	1.1	0.69	11.5

a. Same samples as in the carborundum polishing experiment in Table 3.

Table 3. Milling characteristics of 16 sorghum cultivars; polished grain composition (% d.m. and Agtron reflectance) at 75% yield.

Variety	No. dehull to 75%	Soft end%	% kernels over 40% soft	Vickers hardness units/area	>2.5-mm kernel size	Form factor	Blue Agtron reflectance
1. 850637	1.5	68.9	94	1142	90	74.3	44.5
2. IS4225[a]	1.5	38.7	33	1236	87	73.6	43.8
3. Safra	1.9	45.9	77	1333	95	76.8	46.3
4. P721 opaque	2.0	75.7	94	1540	21	82.0	37.1
5. Argentine[a]	2.0	43.4	56	1596	50	55.0	27.5
6. 954063	2.4	27.0	0	1738	59	72.1	47.8
7. 954062	2.6	27.6	6	1441	25	73.0	48.1
8. 121089	2.6	25.4	13	1946	71	69.7	48.8
9. 954130	2.8	43.8	53	1805	48	66.9	45.9
10. 954100	2.8	28.8	13	2097	73	74.0	49.8
11. Dabar	2.9	29.9	23	1300	79	82.0	48.2
12. P721N	3.6	22.8	3	1972	50	80.7	44.4
13. 954114	3.7	14.1	0	2031	58	73.8	48.4
14. IS0452	4.4	32.9	16	1807	78	78.4	52.0
15. IS0469	7.9	29.2	3	1992	50	82.4	49.3
16. IS3681	8.6	15.1	6	1774	8.6	74.0	34.3

a. High-tannin varieties with a testa layer.

typical U.S. sorghum grains. The present roller mill systems yield about 50% grits of the raw material.

The Importance of Seed Structure in Milling

In order to study the importance of seed structure (percent soft endosperm, percent kernel over 40% soft, Vickers' hardness, kernel size, form factor) in milling, 16 sorghum varieties were milled on a laboratory abrasive mill (Schule LVSM, F.H. Schule GMBH, D-2000 Germany BRD). The laboratory mill is based on the same principle (Fig. 1) as the pneumatic polisher that is in use in Sudan (Perten et al. 1978). The outlet (F in Fig. 1) of the decorticator was opened so that a gentle decortication of 2-9 steps was obtained at a decortication percentage of 75%. No water was added. The bran and the endosperm fractions were analyzed and the values were interpolated to a 75% yield of polished grains (Table 3). The decortication treatment was thus much more gentle, producing less broken kernels as compared with industrial abrasive milling with decortication in one or two steps.

Correlation between Kernel Parameters

The form factor shows low correlation coefficients with all other kernel structure parameters (Table 4). This is also true for kernel size, but there is a tendency ($P < 0.10$) to a negative correlation with the number of dehullings to 75% yield. The parameters, percent soft endosperm and percent soft kernels of more than 40% softness are negatively correlated with Vickers' hardness. However, Vickers' hardness is positively correlated with the resistance to the abrasive forces, as expressed in the number of decortications to 75% yield.

Correlation between Kernel Parameter and Chemical Composition of Polished Endosperm

The overall picture of this correlation matrix turns out as expected (Table 5). The hard kernel parameters, Vickers' hardness and number of dehullings to 75% yield, are positively correlated with

C. Plate 2. a.-d. Micrographs displaying sections of kernels from the variety IS3681 (Table 3). FITC (a, b, d) and UV (c) exitation.
e. Cross section of high tannin Serena variety in normal light (above) and FITC fluorescence (below). Arrows point towards the testa layer.
f. Sorghum raw materials (above) and decorticated seeds (below) from the UMS DVA decorticator. Argentine (Table 3) left. IS4225 (Table 3) middle, and US hybrid (Dekalb 3P3 866VS) right.
g. Finely ground flours from the samples in Plate 2f in corresponding positions.

Table 4. Partial correlation matrix for the principal kernel parameters.

	No. dehull 75% yield	% soft endosperm	% soft kernels over 40%	Vickers hardness units/area	Kernel size	Form factor
No. dehull 75% yield	x	−0.51*	−0.51*	0.48	−0.48	0.29
% soft endosperm		x	0.94***	−0.58*	0.14	0 02
% soft kernels over 40%			x	−0.62*	0.20	−0.11
Vickers' hardness				x	−0.30	0.01
Kernel size					x	0.05
Form factor						x

* $P < 0.05$; *** $P < 0.0001$

Table 5. Partial correlation matrix for the principal kernel parameters and chemical components of polished endosperm at 75% yield.

	Starch	Fiber	Fat	Ash	Color reduction
No. dehull 75% yield	0.41	−0.65**	−0.52*	−0.64**	0.36
% soft endosperm	−0.73**	0.70**	0.86***	0.73**	−0.56*
% soft kernels over 40%	−0.72**	0.75***	0.75***	0.72**	−0.63**
Vickers' hardness	0.56*	−0.75***	−0.62*	−0.69**	0.33
Kernel size	−0.20	0.42	0.13	0.25	0.30
Form factor	0.15	−0.23	0.02	−0.30	0.27

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

starch content and negatively correlated with fiber, fat, and ash, indicating a greater precision in the separation of the botanical parts when the seed is harder. The soft endosperm percent and percent soft seeds with more than 40% softness follow the same pattern, but with opposite signs. In a multiple linear regression analysis (Table 6), there is no significant influence of seed structure parameters on starch yield in this experiment. (The yield parameters in this table are expressed as recovered material from the polished grain in percent of the raw material. The individual figures are not presented here.) The yields of fiber, fat, and ash (which should be low in order to obtain a good separation) are, however, significantly correlated with one to three of the seed quality parameters. Fiber yield is thus negatively dependent on Vickers' hardness. The yield of fat is positively correlated with soft endosperm, while the yield of ash depends on percent soft seeds, Vickers' hardness, and the form factor.

Correlation of Kernel Parameters with Color Reduction

The limiting factor for the acceptability of sorghum is the color of the product. The Agtron reflectance meter can measure color at four fixed wavelengths. The higher the reflectance, the lighter the color of the material. In Table 5 it is seen that percent soft endosperm and percent soft kernels with more than 40% softness are negatively correlated with the reduction in blue color, indicating a higher content of bran in products from soft varieties. In the multiple linear regression analysis in Table 6, the reduction of color is significantly dependent on both percent soft kernel and kernel size.

Varieties with Different Milling Characteristics

We shall now concentrate on differences with regard to milling characteristics. Just as plant

Table 6. Yield and color parameters (1-5) of polished endosperm as correlated with physical seed structure parameters in a multiple linear regression analysis.

Physical kernel quality parameters	Yield and color parameters	Significant seed structure parameters[a]	R[b]
A. Vickers' hardness	1. Color reduction	C. % soft kernels E. kernel size	+0.76
B. % soft endosperm	2. Yield of starch		
C. % soft kernels	3. Yield of fiber	A. Vickers' hardness	−0.52
D. Form factor	4. Yield of fat	B. % soft endosperm	+0.85
E. Kernel size	5. Yield of ash	C. % soft kernels	
		A. Vickers' hardness	+0.76
		D. Form factor	

a. $P < 0.05$.
b. Multiple linear correlation coefficient.

breeders obtain information by studying different breeding lines, we can obtain valuable information with regard to interactions between varieties and milling. The color of products from three varieties, P721 Opaque (No 4), Argentine (No 5), and IS3681 (No 16), differs from products of the other 13 varieties (Table 3). The Argentine cultivar is high in tannins, has a soft endosperm and a flat seed as seen in the low form factor. It is difficult to mill it to an acceptable color. However, IS4225, which is also a high tannin variety, gives a much lighter product in spite of the high content of fiber, fat, and ash in its decorticated grain compared with that of Argentine. The difficulties with eliminating the reddish brown pigments in the Argentine variety compared with that of IS4225 cannot be explained by available data on physical characteristics of the grain. The answer might lie in a closer look at the structure of pericarp and testa. While it is natural that the very soft, high-lysine line, P721 Opaque, gives an unsatisfactory milling result, the dark color of No. 16, IS3681, the hardest of all, cannot be explained by the available data. Variety IS3681 does not have a testa. Fluorescence microscope investigations of No 16, IS3681, reveals the existence of colored pigments in the outer coverings of the seed which migrate into the endosperm (Plate 2a-d). While it is possible that such pigments diffuse inward from the glumes, in the microscope it looks as if the pigments are produced in the seed itself, probably in the aleurone layer (Plate 2c, d). It is obviously difficult to obtain a white product from an endosperm polluted by pigments. Thus the genetically controlled ability of the sorghum kernel to produce pigments in the various botanically defined parts is of great importance when breeding for food quality. So are the weathering characteristics, which define the resistance of varieties to high humidity during maturation. In Plate 2e the high-tannin variety Serena from Tanzania is displayed to demonstrate pigment migration into the endosperm from the testa due to weathering. The combination of mold growth and insect attacks will be able to stimulate the production of pigments, and moisture causes diffusion of pigments into the endosperm.

The Relevance of Laboratory Milling Studies

The general trend in our experiments with the abrasive decortication technique has been in complete accordance with the literature on the subject, as reviewed by Hulse et al. (1980). Cereal scientists have been extremely innovative in the field of laboratory milling. Rooney and Sullins (1969) described a method for milling small samples of sorghum grain. This method gave a very good separation of the various botanical components. When considering the use of such techniques as a service for the plant breeders, two questions arise. How representative are they for current milling techniques such as abrasive milling? And, what is more important, how are they related to future milling techniques?

Our results show that laboratory-evaluation methods may be partially relevant to industrial milling. Argentine and IS4225 were both used in identical samples for milling in the laboratory abrasive decorticator and in the industrial new sorghum-milling system. Both milling systems show that it is much more difficult to remove the colored pericarp and testa from the Argentine variety than from IS4225. On the other hand, it is clear that breakage of kernels is much more serious in an abrasive decorticator than in the UMS DVA machine. The abrasive machine produces smaller kernel fragments which are difficult to recover, and thus it is not feasible to add a recycling unit to the system. This can be done with the new system which, because of the recycling of the endosperm particles, produces a higher yield at the same level of whiteness.

Conclusions

Because of variations in local utilization habits, it is important that sorghum breeders pay attention to seed quality parameters such as percent soft endosperm, genetically controlled pigment production, and weathering resistance.

Each region has to be considered separately. Whenever sorghum is hand decorticated or milled in small local village mills with present techniques, hard endosperm as well as good weathering resistance are preferred. In developing sorghum for industrial mills, however, the present high-yielding types, such as Lulu D, are sufficiently hard if an appropriate milling technology is introduced.

The breeder can thus concentrate on obtaining varieties which are free from pigments in the endosperm. If industrially-milled sorghum products are going to be competitive with wheat and maize products in urban areas, the white color of the product is the limiting parameter for acceptability. Thus the nutritional quality of sorghum products must be studied in relation to the color of the product. In finding solutions to these problems, breeders play an important part. Problems with weathering resistance and birds might favor the production of pigmented, high-tannin varieties. We have shown that it may be possible to mill some high-tannin varieties with a good extraction rate and a relatively high quality of product. However, an adequate control of tannin content in products from such varieties as well as a good cooking quality must be secured. An optimal extraction rate is of major importance, both when milled on a small scale and on an industrial scale. In Denmark, for example, a 1 % increase in extraction rate of a wheat flour mill will pay all running costs for a mill. It is our experience that in several developing countries there exists such a high degree of profitability as regards extraction rate. We therefore conclude that it will be possible to introduce improved methods of milling technology developed in cooperation with plant breeder. This will make sorghum competitive with other cereals. The future of sorghum for human consumption is thus quite promising, although there is still a long way to go before the implementation of these possibilities has been completed.

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Milling and Nutritional Value of Sorghum in Tanzania

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Summary

Sorghum milling was studied in Tanzania with regard to flour yield and quality. Three consecutive hand decortications of the hard local low-tannin varieties produced 73–83% flour of light color that was acceptable to Tanzanian villagers. To obtain the same color the new agronomically improved, but softer low-tannin varieties (e.g., Lulu) required four decortications, and even so flour yield was reduced to about 50%. The digestibility of protein and energy of whole unprocessed sorghum flour was in the same range as that of other food cereals, whereas the biological value was lower in sorghum grain due to a low lysine content. Decortication of the whole kernel had a positive effect on protein and energy digestibility, whereas the biological value was reduced due to a 40% reduction in lysine. The cooking procedure used had a moderately negative effect (5–8%) on digestibility, while the lysine content and the biological value were unaffected. It is concluded from the present work that food prepared from low-tannin sorghum is digested to the same extent as food from other cereal grains. However, because of the low lysine content, sorghum products should preferably be mixed with other food items that are rich in lysine. It is recommended that the milling processes remove only the pericarp and testa but retain the embryo. This will give the best compromise between a white, acceptable color and minimal losses of nutrients in the bran fraction.

In the arid parts of Africa and Asia, sorghum and millet are important food crops. In these countries up to 70% of the dietary protein and energy intake is supplied by locally milled sorghum and millet products (Hulse et al. 1980). Traditionally in Tanzania, hard, white, low-tannin varieties are primarily used for food. Sorghum and millet are decorticated by pounding and winnowing, followed by milling, into an attractive white flour suitable for cooking *ugali*, a stiff porridge (Vogel and Graham 1979).

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A recent review by the United Nations Economic Commission for Africa (1980) summarizes the present trends in the economies of African countries due to the adoption problems of cereals such as maize, barley, and wheat. Currently, importation of these cereals is increasing by approximately 10% per year. In 1979, 7 million tons of wheat were imported by African countries at a cost of US$ 1 billion, causing a severe drain in their foreign exchange reserves and serious problems with their food production. The increased dependence on maize makes the country more sensitive to crop failures because of drought. Sorghum and millet are more drought-resistant than maize. If sorghum flour is to be competitive with flours from wheat and maize, the white color must be taken into account as an important parameter for acceptability.

The aim of this paper is to determine the efficiency and effect of traditional Tanzanian milling and cooking procedures in relation to the nutritional value of sorghum. The experience obtained can be useful in optimizing an industrial process for sorghum milling (Munck et al. 1981) and thus make sorghum products more acceptable and nutritive.

Materials and Methods

Sorghum Material

The major sorghum-producing area of Tanzania, the Dodoma region, was visited in connection with a visit to the Ilonga Agricultural Research Institute, a coordinating center for sorghum improvement in Tanzania. The new sorghum crop was ready for harvest. The local varieties matured later than the introduced varieties. In Plate 1:1, seeds from nine typical sorghum cultivars are displayed. Two of these are commercial high-yielding, short-strawed varieties with compact panicles—Lulu D (low tannin) and Serena (high tannin). Two improved varieties are 2Kx89 and 2Kx18/B/1, which were grown at the Ilonga Agricultural Research Institute. These are semi-compact sorghum types with a low tannin content. Five local varieties collected in the field and displayed in Plate 1:1 were all very tall (up to 5 m) and had loose panicles. The local varieties aimed for milling were hard to very hard seeded and contained minimal amounts of pigment. The selection from Gairo (local 1) exemplifies a large-seeded type (T300 in Fig. 1) and that from Bihawana (local 5), a small-seeded grain (as T236 and T295 in Fig. 1). Chalky types such as the selection from Msanga (local 2), were also abundant (as T261 in Fig. 1). Local soft, high-tannin brewing types are represented by two samples from the village Machali (Plate 1:1, local 3 and 4).

Humid weather during ripening leads to severe mold and weathering problems among the improved sorghum varieties which matured early and had a semicompact head. Grains of 2Kx17/B/1 were badly weathered with gray seeds (Plate 1:1).

Handmilling Experiments

The experiments were performed by a local housewife from the Musalabani village close to the Ilonga Agricultural Research Institute. Experiments 1 and 2 with the high-yielding varieties were performed in the beginning of May 1980 and Experiment 3 with the local selections was carried out in October of the same year.

Equipment for Handmilling

For decortication, a mortar and pestle (Plate 1:2, 1:3) of hard wood was used. Bran was separated by winnowing the grain in a basket made of straw and leaves, and finally the decorticated grains were ground on a stone handmill. Drawings of the equipment are shown in Figure 2.

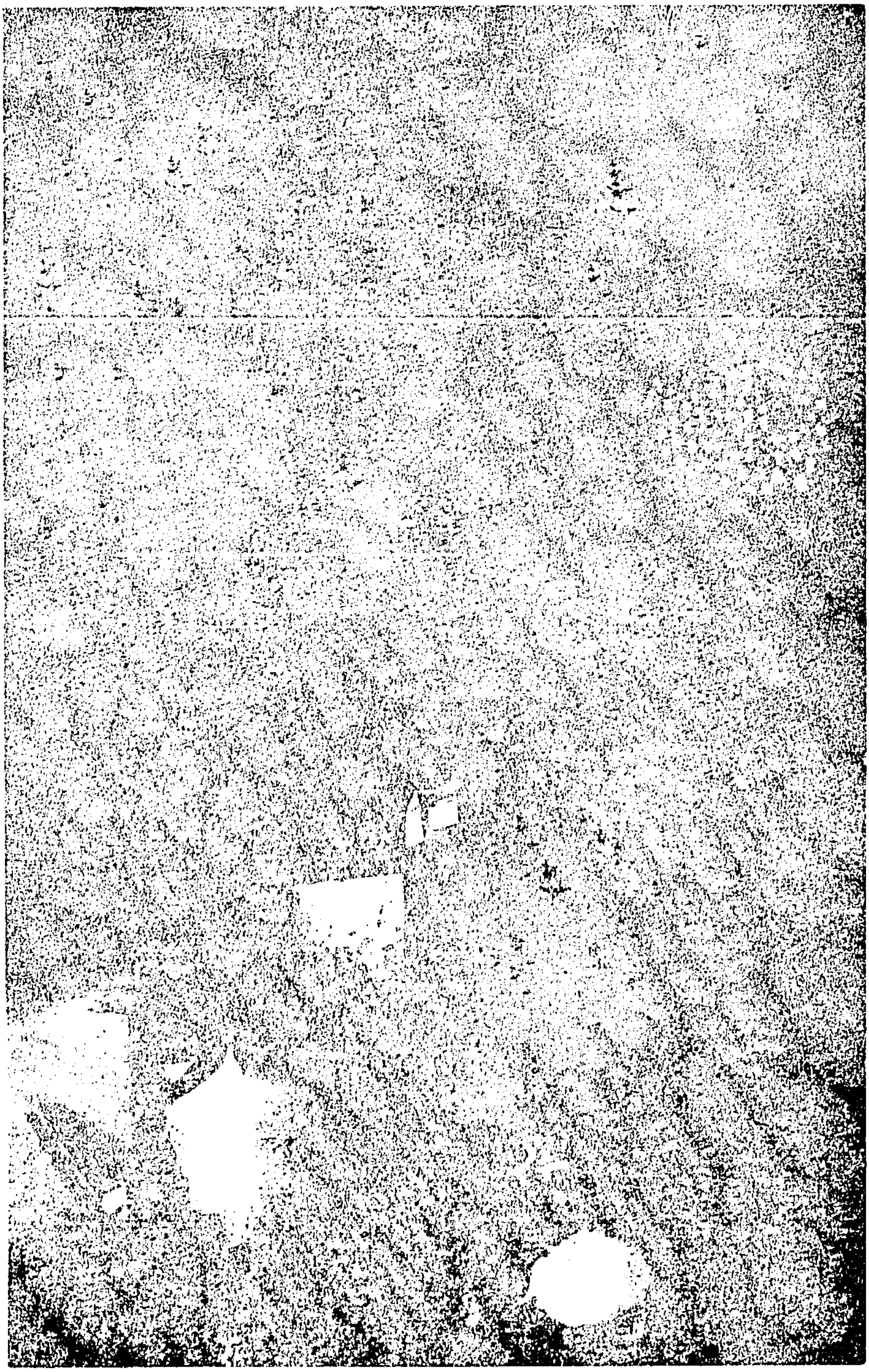
Decortication Procedure

The decortication of the variety 2Kx89 was studied in Experiment 2. The temperature during the trial was about 40° C with a high relative humidity. One kilogram of grain was poured into the mortar to form a 10-cm deep layer. Water was then added and the grains were pounded for 5 min. Every blow directed the pestle towards the center of the mortar. The grains were then skillfully winnowed to remove the bran. Following addition of more water, the decortication was repeated. After the first decortication cycle, the outer parts of the grains and the hull fractions were quite moist. The total water addition was estimated to be 20% of the original grain weight. A small bran sample from the first decortication was collected as well as the seeds after the second decortication. These seeds represent only a partly decorticated product. The experiment was terminated at this stage due to the high ambient temperature. Normally there would have been one or two more decortications to obtain an acceptable product. In October 1980, under the supervision of Mr. Saadan, five local varieties (T300, T236, T261, T295, and T275) were milled as earlier described. The ambient temperature varied from 21.0 to 28.0° C. The sorghum material (1000 g) was decorticated three times and small samples (10 g) of bran and decorticated seeds were collected following each cycle. The final recovery rate of dried decorticated seed was followed by weighing and ranged from 73 to 83% of the raw material.

Commercial Small-Scale, Diesel-driven Sorghum Milling

A small commercial mill located at the village of Ilonga was visited in May 1980.

The mill units were a rice polisher (W. McKinno, Aberdeen, Scotland) and a hammer mill and cyclone. The rice polisher contained a horizontal steel rotor surrounded by a screen. In spite of obvious wear on the machine, a good product was



C. Plate 1.1 Local and yield-improved sorghum varieties grown in Tanzania (above).
1.2 Decortication of sorghum (below left).
1.3 Decortication and milling equipment (below right): (a) mortar and pestle (also shown in plate 1.2), (b) winnowing basket, (c) stonemill.

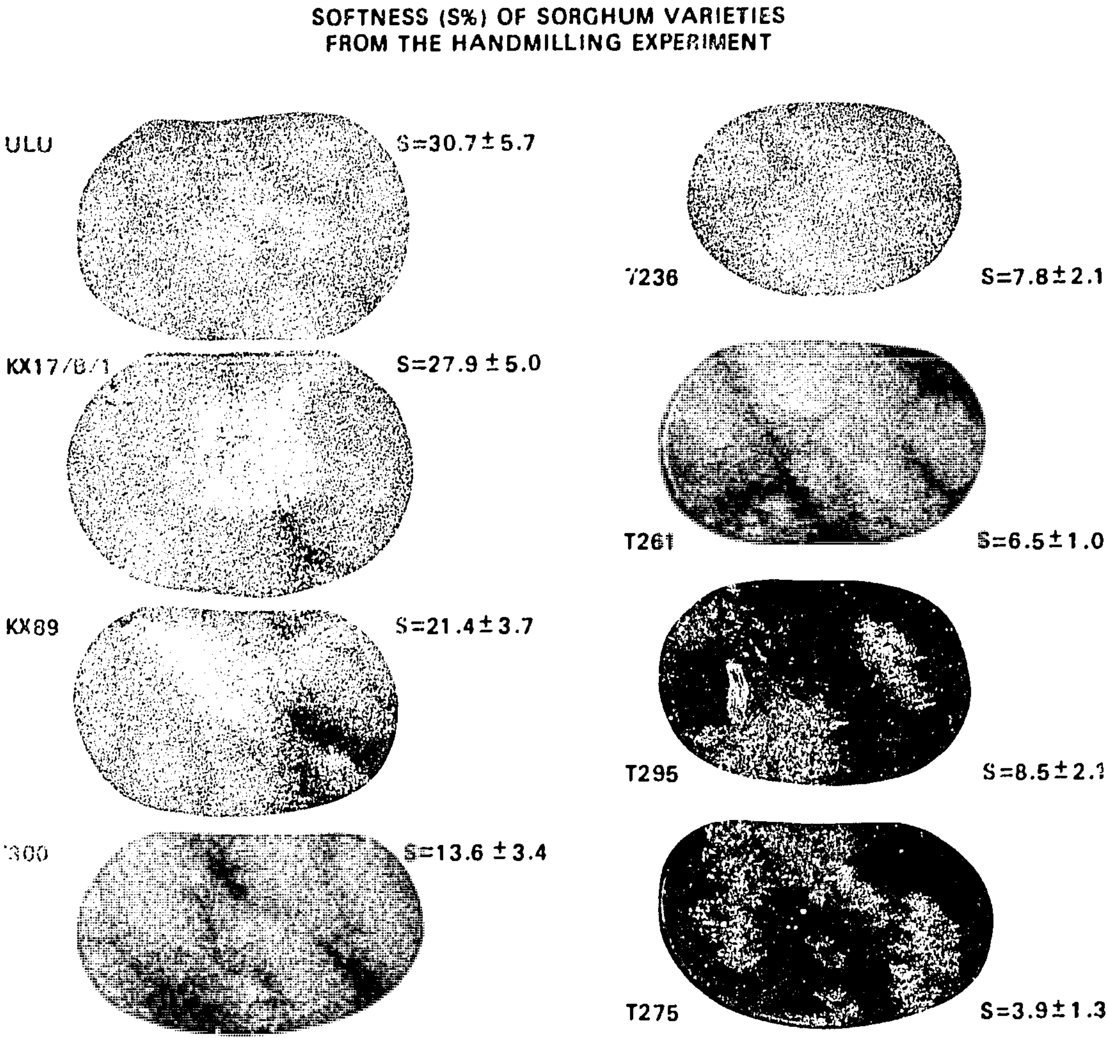


Figure 1. Transverse sections and % softness (± 95% confidence limits) of sorghum varieties used in the handmilling experiments shown in Plate 1.1. T300 is comparable with Local 1; T236, T295, and T275 with Local 5; and the chalky type T261 is comparable with Local 2 in Plate 1.1.

obtained from rice and maize, as judged when inspected by hand. The mill operated with individual lots of grains—5–10 kg per customer. The miller charged 5 shillings (US$ 0.61) for milling, and kept bran and other losses for his animals. Sorghum (Lulu D, 5 kg) was decorticated twice and winnowed by hand. There were high losses both in the decorticator and in the cyclone of the hammer mill. The yield of product was estimated at 50%.

Commercial Samples of Sorghum and Maize Products

Industrially milled maize and sorghum flour were collected in the community of Dodoma.

Microscopic Analyses

These techniques are described by Munck et al. (1981).

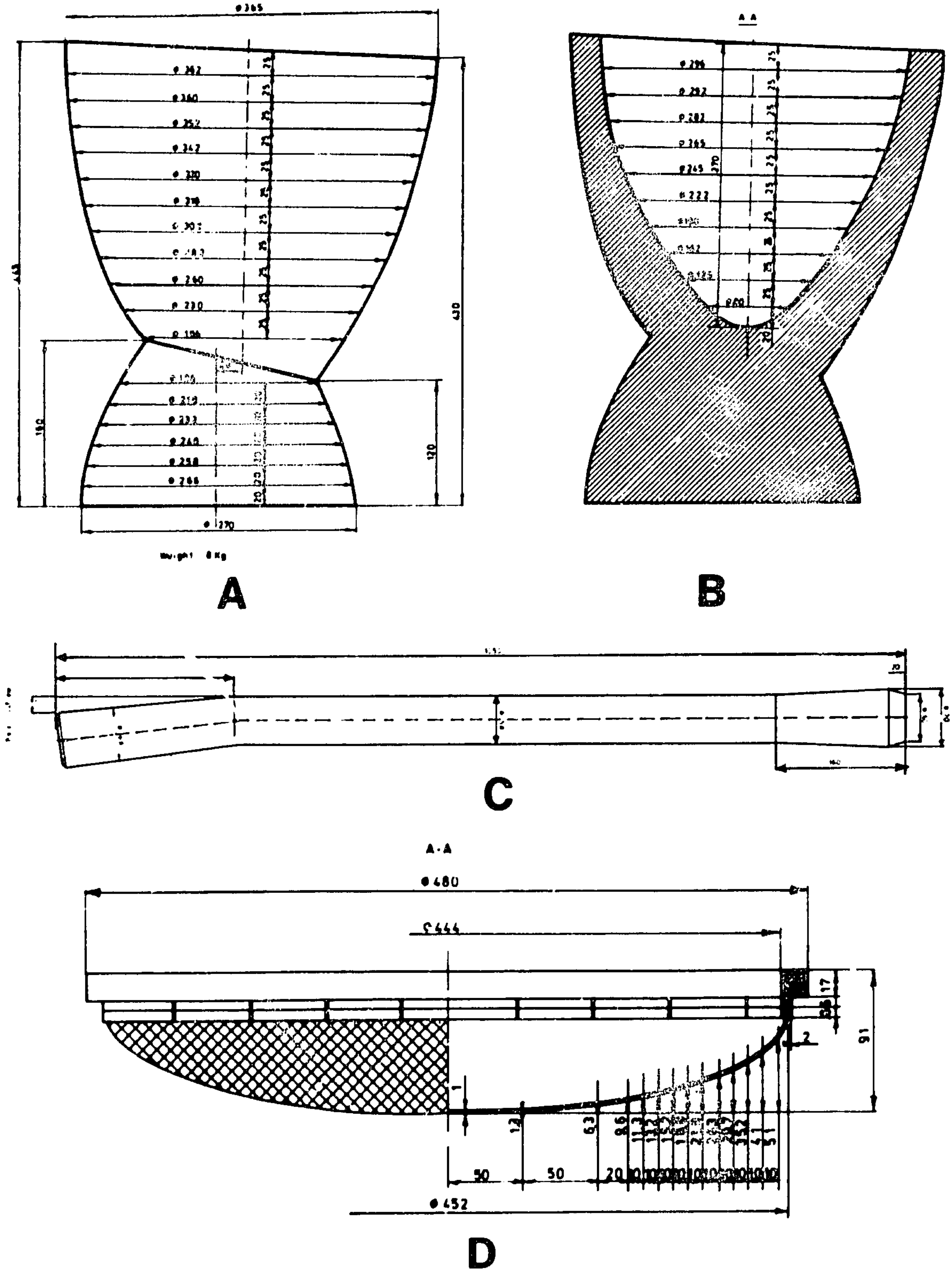


Figure 2. Technical documentation of mortar (A, B), pestle (C), and winnowing basket (D).

Ugali Cooking for Rat-Feeding Tests

The breeding line 2Kx17/B/1 was used in the feeding tests as whole milled grain, as decorticated white flour, and as *ugali* porridge. *Ugali* was prepared at Ilonga and the preserved *ugali* samples were used for rat trials conducted at the National Institute of Animal Science, Copenhagen. To prepare *ugali*, water and flour were mixed in an aluminum basket over a charcoal fire in the kitchen-house. The material became very viscous and was stirred vigorously for 20 min. Now and then small amounts of flour were added to the porridge to obtain a viscous product which became very difficult to stir after some time. After cooling, the dish was eaten by hand together with a sauce and with other foods. It was therefore important that the porridge had the right consistency to avoid sticking to the hand. In order to preserve the *ugali* for rat trials, the material was spread in small pieces on linen and sun-dried for 3 hr. As a comparison with Tanzanian *ugali*, whole milled flour of 2Kx17/B/1 was cooked in a water bath for 45 min in the Copenhagen laboratory and then freeze dried. A total of 2900 ml water were used per kg flour.

Analytical Methods

Samples were milled in a Udy-Tech mill (Udy Analyser, Comp. Boulder, Colorado, USA). The analyses (Tables 1-5, 8) of crude fiber, fat and protein were made according to standard AACC (1980) methods, and ash according to ICC (1977). Crude protein was measured as Kjeldal nitrogen × 6.25. Starch content was measured from the amount of glucose after complete enzymatic degradation by amyloglucosidase (Merck, Darmstadt, GmbH). Liberated glucose was estimated with a glucose oxidase-peroxidase reagent according to the method of Boehringer (Boehringer, Mannheim, GmbH). Amino acids were analyzed as described by Jonassen (1980). The color of raw materials and milled products were analyzed using an Agtron color reflectance meter (Magnuson Engineers Comp., San Jose, USA). Reflectance at blue (436 mm), and red (585 mm) wavelengths were measured with the following calibration discs: 24 and 44, respectively. Gain was set to 1.6 and 2.5 for the different wavelengths when disc 97 was set to 100% of scale. Flours were analyzed for particle size on a Jeel laboratory sifter (J. Engelsmann AG, Ludwigshagen, GmbH).

Rat Experiment

Fiber, fat, ash, protein, and tannin contents in the diets were determined according to the AOAC methods (1970), starch and sugar according to MacRae and Armstrong (1968) while the amino acid analyses were performed according to Mason et al. (1980) (Tables 6, 7, 9). Energy in feed and faeces was determined as described by Weidner and Jacobsen (1962).

The experimental procedure of the rat trials has been described by Eggum (1973). Groups of five Wistar specific pathogen-free animals weighing approximately 70 g were used. The preliminary feeding period was 4 days, and the balance period was 5 days. The feed consisted of 10 g dry matter and 150 mg N/rat per day. The rats were weighed at the beginning of the experiments and divided into groups of five so that the average weight of the groups differed by no more than 0.5 g. Weighing was repeated at the end of the preliminary period and after the balance period. Access to feed and water was stopped 3 hr before weighing. Faeces were collected dry each day and stored in a freezer at −20° C.

At the end of the experiment, samples of faeces were freeze-dried and homogenized for N and energy determination.

The parameters measured were true protein digestibility (TD):—

$$TD = \frac{(N_{intake} - (\text{faecal N-metabolic}) N)}{N_{intake}} \times 100$$

biological value (BV):— BV =

$$\frac{N_{intake} - (\text{faecal N-metabolic N}) - (\text{urinary-endogeneous N})}{N_{intake} - (\text{faecal N-metabolic N})} \times 100$$

net protein utilization:—

$$NPU = \frac{TD \times BV}{100}$$

and digestible energy:—

$$DE = \frac{E_{intake - faecal\ E}}{E_{intake}} \times 100$$

Results and Discussion

Characterization of the Sorghum Raw Materials

Color of Milled Flour from Whole Grains

The greatest differences in quality between the three improved varieties (Experiments 1 and 2), and the five local varieties (Experiment 3) were in the flour color (Table 1). A high reflectance value indicated a white appearance of flour. The local varieties from Milling Experiment 3 gave notably whiter flours than the improved varieties. Flour from two varieties in the different experiments, T295 and Lulu D, exhibited approximately the same level of whiteness. Weathering problems and mold growth in the compact modern varieties were especially prevalent in 1980 at Ilonga. Mold growth is probably the major reason for the dark flour color obtained with these varieties (Table 1). It is essential to avoid varieties exhibiting discoloration of endosperm. As discussed by Rooney et al. (1980), the kind and content of pigments are under genetic control. It should thus be possible to select varieties with a minimal content of pigments. The varieties in Milling Experiments 1, 2 and 3 (Table 1) did not show significant diffusion of pigments into the endosperm when examined under the fluorescence microscope. The improved varieties including Lulu D studied here in milling experiments have no testa.

Physical Characteristics of the Grain

The softness/hardness of the endosperm is an important component in the concept of milling (Fig. 1). A sorghum variety with soft endosperm is difficult to decorticate as such seeds tend to break, resulting in losses of fine endosperm particles to the hull fraction. The soft part of the endosperm is clearly seen in cross sections of seeds as a light area caused by the reflectance of loosely embedded starch particles. The improved varieties, Lulu D, 2Kx89 and 2Kx17/B/1 are intermediate in endosperm softness (30.7%, 21.4%, and 27.9%) between the soft high-tannin brewing varieties such as Serena, and the hard local cultivars. In the image analysis, the embryo is measured as a part of the soft area (Munck et al. 1981). The endosperm of variety T275 with 3.9% softness is therefore almost completely hard. Size and shape of the kernel also influence the milling characteristics. Variety T300 (Figure 1 and Table 1) has a large flat type of seed while T236 is small and round. The thickness of the pericarp also varies considerably. Variety T261 has a thick starchy mesocarp which is seen as a light peripheral strand in the micrograph, while T275 has an extremely thin pericarp without starch in the mesocarp.

Chemical Composition of the Sorghum Seeds

No systematic differences were found between the improved (Experiments 1 and 2) and the local

Table 1. Chemical composition, 1000 kernel weight and Agtron reflectance measurements of raw materials used in Milling Experiments 1, 2, and 3.

Sample	% dry matter					1000 kernel wt	Agtron reflectance	
	Starch	Fiber	Fat	Ash	Protein		Blue	Red
Milling Experiments 1 and 2						(g)		
Lulu D	69.7	2.0	3.2	1.90	13.8	24.6	26	42
2Kx89	70.5	2.6	4.0	1.87	11.4	23.1	23	34
2Kx17/B/1	71.6	2.6	3.2	1.65	11.7	27.4	24	37
Mean	*70.6*	*2.4*	*3.5*	*1.81*	*12.3*	*25.0*	*24*	*38*
CV (%)	1.4	14.6	13.2	7.5	10.6	8.7	6.3	10.6
Milling Experiment 3								
T300	78.8	2.3	3.3	1.81	11.4	30.0	36	60
T236	71.6	2.3	3.6	2.02	12.0	20.0	35	55
T261	72.1	2.3	3.2	2.10	11.4	20.1	39	60
T295	67.5	2.7	3.2	1.94	13.3	23.3	29	46
T275	72.0	2.2	3.1	1.70	10.4	23.0	36	60
Mean	*72.4*	*2.4*	*3.2*	*1.91*	*11.7*	*23.3*	*35*	*56*
CV (%)	5.7	8.1	6.0	8.4	9.1	17.5	10.5	10.9

varieties (Experiment 3) with regard to starch, fiber, fat, ash, protein, and lysine. The large-seeded T300 had a high content of starch (78.8%) compared with the other small-seeded varieties (67.5–72.4%).

Milling Experiments

Evaluation of Hand Decortication Experiment

The products from milling Experiment 1 (Table 2) showed a high degree of whiteness when compared with whole grain flour (Table 1). The blue and red reflectance of the flour from the local varieties T300, T261, and T275 from Experiment 3 was approximately equal to the varieties in Experiment 1, while T236 and T295 were significantly darker in the red region of the spectrum. Flour from the 2Kx89 variety in milling Experiment 2 (two decortication cycles) was darker than the products from Experiments 1 (4 cycles) and 3 (3 cycles). Hubbard et al. (1950) found that the fat and ash content in hand-dissected sorghum endosperm was 0.4–0.8% and 0.30–0.44%, respectively. In Experiment 1 with the improved varieties, the hand miller obtained a fat content of 0.3–0.5% and an ash content of 0.31–0.48% in the finished product which indicated that she had isolated almost pure endosperm. The fiber content varied from 0.5 to 0.6% in the milled products from these varieties compared with 2.0–2.6% in the whole grain, also indicating a high purification. The products lost 1–2 percentage points in protein content compared with the original grain. The low fat content of the decorticated seeds indicated an efficient removal of embryo.

Flour of 2Kx89 sorghum from two decortications (Experiment 2, Table 2) had higher fat, ash and fiber content than flour obtained after the three decortications in Experiment 1. The high fat value of 2.6% compared with 0.3% in Experiment 1 suggests that it is possible to retain most of the nutritious germ while improving the whiteness of the product. Apparently most germ removal occurs at the third and fourth cycle of dehulling.

Milled products obtained from local cultivars (Experiment 3, Table 2) show much higher levels of fiber (+30%), fat (+275%), and ash (+113%) than the products from the improved varieties.

Table 2. Chemical composition of decorticated grain and Agtron reflectance measurements from Milling Experiments 1, 2, and 3.

	% dry matter					Agtron reflectance	
Sample	Starch	Fiber	Fat	Ash	Protein	Blue	Red
Milling Experiment 1							
Lulu D	85.4	0.6	0.5	0.31	12.2	44	70
2Kx89	85.2	0.6	0.3	0.48	11.9	48	70
2Kx17/B/1	85.6	0.5	0.3	0.37	9.8	52	72
Mean	*85.4*	*0.6*	*0.4*	*0.39*	*11.3*	*48*	*71*
CV (%)	0.2	9.6	28.9	22.1	11.6	8.3	1.6
Milling Experiment 2							
2Kx89 2nd decort.	80.1	1.2	2.6	1.12	11.9	40	63
Milling Experiment 3							
T300	84.5	0.9	1.8	0.78	10.5	54	72
T236	85.0	0.9	1.3	0.80	11.8	55	60
T261	86.2	0.8	1.3	0.80	11.5	53	70
T295	86.0	0.8	1.6	0.88	12.8	50	66
T275	86.0	0.8	1.5	0.81	9.2	55	72
Mean	*85.5*	*0.8*	*1.5*	*0.81*	*11.2*	*53*	*68*
CV (%)	0.9	6.8	14.1	4.8	12.2	3.9	7.5

Chemical Composition of Hand-milled Products

In Experiment 3 (Table 3) the milling of local varieties was studied more closely. A variation in endosperm yield was found from 73% for the softest variety T300 to 83% for the hardest variety T275. Water addition varied from 10 to 20%. The lowest water addition was for the chalky type T261 which had a thick starch-rich mesocarp. Rooney and Kirleis (1979) reported that such varieties are known to be easier to hand-decorticate due to a rapid uptake of water by the starchy mesocarp. This facilitates separation of the seed coat from the endosperm. Analysis of starch and fat in the bran can be used as an indicator of endosperm and germ losses. Starch analysis of bran from the first, second, and third decortication in Experiment 3 (Table 3) was well related to flour yield after 3 decortications. Variety T261, however, deviated with a high starch value in the bran fraction after the first decortication due to its starchy mesocarp. Starch content in the bran increased from 23.1% to 30% in the decortication cycles 1 and 3, respectively, for the hard variety T275. With the softer T300, corresponding values were 32.2–40.3%. This explains the 10 absolute percent yield differences between these varieties. The fat content of the bran fractions increased steadily with an increasing degree of decortication. Fiber and ash were remarkably variable after the second decortication and the differences between varieties were almost negated by the final decortication cycle. It is probable that the hand miller adjusted her work during the last dehulling cycle in order to obtain an acceptable, even quality of final products from the differing sorghum varieties.

Grading and Composition of Flour from Milling Experiment

The grading of stone-milled flour from decorticated grains (Table 4) was compared with an industrially-milled sorghum flour from the community of Dodoma. The latter flour was significantly coarser with 62.7% over 250μ compared with 34.4–39.9% for the hand-milled flours. Chemical composition of the flours was similar to the corresponding decorticated grains except with regard to ash content which was increased by 2–15% for the stone-milled flours.

Comparative Qualities of Sorghum and Maize Flours

Hand decortication and milling of sorghum is a demanding task in a hot climate—it takes almost 1 hr to decorticate 2–3 kg of sorghum. Therefore, small diesel-driven mills are commonly used for milling separate batches of grain for each customer. However, decorticated sorghum flour from the diesel mill was much darker than the hand-milled flours (Table 5), even though the milling yield was only about 50%. The rice mill produced relatively good rice and maize products compared with sorghum. These observations are similar to those of Rooney and Kirleis (1979) of commercial mills in Upper Volta and Mali.

Samples of maize and sorghum flour (Lulu D)

Table 3. Chemical composition (% dry matter) of grain and bran at three stages of decortication (I, II, and III), in Milling Experiment 3.

Variety	Water per 1000 g (ml)	Decortication yield (%)	Decorticated grain: Fiber I	Fiber II	Fiber III	Ash I	Ash II	Ash III	Bran: Starch I	Starch II	Starch III	Fat I	Fat II	Fat III
T300	150	73	1.7	1.2	0.9	1.55	0.93	0.78	32.2	39.3	40.3	9.5		10.8
T236	200	76	1.6	1.3	0.9	1.79	1.45	0.80	29.2	36.7	37.0	11.6	12.0	13.0
T261	100	79	1.6	1.0	0.8	1.56	0.98	0.80	35.5	30.4	33.3	10.5	13.3	14.1
T295	200	80	1.8	1.5	0.8	1.55	1.01	0.88	21.5	25.1	27.1	10.6	12.4	13.7
T275	150	83	1.5	1.2	0.8	1.51	1.04	0.81	23.1	31.5	30.0	11.3	11.8	13.3
Mean			*1.6*	*1.2*	*0.8*	*1.59*	*1.08*	*0.81*	*28.3*	*32.6*	*33.5*	*10.7*	*12.4*	*13.0*
CV (%)			7.1	15.1	6.9	7.1	19.4	4.8	21.0	17.1	15.8	7.6	5.4	9.9

from an industrial mill in the community of Dodoma were acquired for comparison with hand-decorticated samples (Table 5). The sorghum flour had a grayish appearance with a low reflectance value both in blue and red. Fiber, fat, and ash levels indicated essentially a whole milled product (compare Table 5 with Table 1). The maize flour sample was much lighter in color than the sorghum flour in the red region of the spectrum. Chemical analysis of the maize sample, however, indicated poor fractionating in milling with fiber and fat values as high as 2.4% and 4.7%, respectively. However, because of its lighter appearance, the maize flour would be more readily accepted over the darker sorghum flour.

Effect of Milling and Cooking on Nutritive Value

Chemical Analysis including Amino Acids

The crude composition of 2Kx17/B/1 raw material and products are shown in Table 6. Crude fiber, protein, fat, and ash were all reduced by hand decortication as described earlier (Tables 1 and 2). The fat values (Table 6) are higher due to the use of the AOAC method. Tannin was reduced from 0.41 to 0.25% due to decortication. Proximate analyses did not indicate significant changes after cooking the flour.

The sorghum endosperm contains storage proteins of the prolamine type, which are poor in lysine (Wall and Blessin 1969), the essential limiting amino acid. The aleurone layer and the germ contain more proteins that are rich in lysine. As seen in Table 7 for the improved variety 2Kx17/B/1, the removal of bran and germ during decortication significantly decreases the lysine content from 2.0 to 1.2%. Changes in other essential amino acids due to milling are, however, very limited. Furthermore, the amino acid composition of the hand-decorticated variety 2Kx17/B/1 (Table 7) is almost identical with that of hand-dissected sorghum endosperm (Table 8).

Table 4. Flour grading of hand- and machine-decorticated sorghum samples.

Sorghum samples		<63μ	63–125μ	125–250μ	>250μ
Experiment 1					
Lulu D	hand decorticated	30.2	17.0	13.1	39.9
2Kx89	" "	30.6	16.5	13.7	39.3
2Kx17/B/1	" "	37.9	13.7	14.1	34.4
Flour from Dodoma	machine decorticated	11.0	12.4	13.9	62.7

Table 5. Chemical composition (% dry matter) and Agtron reflectance value of products from the Ilonga machine mill and from Dodoma City.

Place/product	Fiber	Fat	Ash	Protein	Agtron reflectance	
					Blue	Red
Ilonga machine mill						
Lulu D bran from 2nd decortication	2.8	4.6	2.8	12.8		
Lulu D decorticated grain	1.0		0.68	12.3	40	60
Commerical samples from Dodoma						
Sorghum flour (Lulu D)	2.3	2.1	1.85	9.8	27	39
Maize flour	2.4	4.7	1.47	10.9	22	60
Decorticated grain from Experiment 3						
Mean of 5 varieties	*0.8*	*1.5*	*0.81*	*11.2*	*54*	*68*

Table 6. Chemical composition (% dry matter base) of 2Kx17/B/1 whole grain, decorticated grain, and *ugali* prepared in Tanzania and in Denmark fed in the rat experiments (Table 9).

Sample	Crude fiber	Fat	Ash	Protein (N × 6.25)	Starch + sugar	Tannin
Whole grain	2.27	4.52	1.52	12.4	74.1	0.41
Decorticated grain	0.34	1.15	0.20	10.8	86.1	0.23
Tanzanian *ugali* (decorticated grain)	0.57	1.08	0.47	10.1	83.7	0.12
Laboratory *ugali* (whole grain)	2.45	4.22	1.66	12.1	70.2	0.34

Table 7. Amino acid composition (g/16gN) of 2Kx17/B/1 whole grain, decorticated grain, and *ugali* prepared in Tanzania and in Denmark fed in the rat experiments (Table 9).

			Cooked products	
Composition	Whole grain	Decorticated grain	Tanzanian *ugali* (decorticated grain)	Laboratory *ugali* (whole grain)
Lysine	2.0	1.2	1.2	1.9
Threonine	2.9	2.8	2.8	2.7
Cystine	1.4	1.4	1.3	1.3
Methionine	1.4	1.4	1.3	1.3
Histidine	1.5	1.6	1.5	1.4
Leucine	12.8	15.4	15.3	12.8
Isoleucine	3.9	4.3	4.3	3.9
Valine	4.6	4.7	4.7	4.6
Phenylalanine	4.6	5.2	5.2	4.7
Aspartic acid	6.3	6.2	6.1	6.1
Glutamic acid	20.7	24.2	24.1	20.8
Proline	7.6	8.9	8.9	7.6
Alanine	8.5	9.7	9.7	8.5
Arginine	3.3	2.4	2.4	3.2
Glycine	2.9	2.3	2.2	2.7
Serine	4.4	4.5	4.5	4.3
Tyrosine	3.6	3.9	3.8	3.5

Fat content with the AACC method (an indication for germ removal) was decreased from 3.2 to 0.3% in the variety 2Kx17/B/1, while the reduction in fat for the five local varieties (Tables 1 and 2) was from 3.2 to 1.5%. The reduction in lysine here was somewhat less pronounced (2.1 to 1.4%). In the milled products from the improved and local varieties as well as from the endosperm of the hand-dissected sorghum, the essential amino acid pattern is remarkably stable except for lysine. It can be seen that lysine in sorghum endosperm is reduced to 59% compared to 74% in wheat endosperm in percent of the whole grain (Table 8). The essential amino acids in the wheat endosperm are more reduced by milling than those of sorghum. Cooking of sorghum flour (Table 7) produced insignificant changes in the amino acid composition of the *ugali* product.

Rat Balance Experiments

The nutritional evaluation of whole, white, low-tannin sorghum grain (Table 9) shows that the protein (94.7%) and energy (89.6%) availability is as high as in other cereals used for human foods. From rat experiments, Eggum (1977) concluded

Table 8. Amino acid composition (g/16gN) of whole grain, decorticated grain, and hand-dissected endosperm of sorghum and wheat.

	Sorghum Means of 5 local Tanzanian Varieties (Tables 1, 2, and 3)			Sorghum U.S. Hybrid			Winter wheat		
Composition	Whole grain	Decorticated grain	%	Whole grain	Hand dissected endosperm	%	Whole grain	Hand dissected endosperm	%
Protein	10.3	9.9	96	13.5	13.1	97	13.0	8.7	67
Lysine	2.1*	1.4**	67	2.1	1.2	59	3.4	2.5	74
Threonine	2.9	2.8	97	2.7	2.6	96	3.1	2.5	81
Histidine	2.3	2.1	91	2.1	2.0	96	-	-	-
Leucine	13.9	14.9	107	14.7	16.1	109	8.9	8.5	96
Isoleucine	4.4	4.4	100	4.5	4.6	102	4.9	4.6	94
Valine	5.3	5.1	96	5.7	5.3	93	5.3	4.9	92
Phenylalanine	5.8	6.0	103	5.4	5.9	109	6.2	6.0	97
Aspartic acid	7.1	6.5	92	7.1	6.5	92	6.3	4.9	78
Glutamic acid	22.7	23.5	104	22.2	24.8	112	37.8	42.1	111
Proline	7.3	7.5	103	8.7	9.6	110	12.6	15.0	119
Alanine	9.0	9.4	104	9.5	10.1	106	4.4	3.5	80
Arginine	3.5	2.4	69	3.2	1.9	60	5.6	4.2	75
Glycine	3.1	2.5	81	2.9	2.2	77	5.1	4.2	82
Serine	3.5	3.3	94	3.3	3.2	98	3.6	3.2	89
Tyrosine	4.6	4.6	100	4.2	4.8	115	3.9	3.9	100

* Variation from 2.2–1.9
** Variation from 1.5–1.4

that true protein digestibility of wheat, maize, and rice are at 89.6, 87.6, and 90.8%, respectively, while energy digestibility in wheat and maize are at 86.4 and 87.2%. However, MacLean and Graham (1980) concluded from experiments in which cooked whole sorghum flour was fed to small children as a gruel that protein and energy digestibility was much lower for sorghum than for wheat, maize, and rice.

The biological value of sorghum was only 55.9% (Table 9) due to its low lysine content (Table 7). In wheat, maize, and rice the corresponding values are 62.6, 59.8, and 70.8%, respectively (Eggum 1977, Eggum and Duggal 1977; Eggum et al. 1977). Thus the present work indicates that digestibility of sorghum protein as well as of energy are in the upper range of values for cereals, but that the protein quality (biological value) is low, due to the low lysine content.

As an effect of decortication, true protein digestibility increased from 94.7% to 100.3% and energy digestibility from 89.6 to 96.4% (Table 9).

For flour of barley, wheat, and rice endosperm, the corresponding figures for protein digestiblity are 99.6, 97.0, and 99.7%, respectively (Bach Knudsen 1980, Eggum and Duggal 1977; Eggum et al. 1977).

The biological value was reduced from 55.9% in the raw material to 47.4% in the decorticated grain and the daily weight gain from 1.26 to 0.55g (Table 9). This reduction is due to the pronounced decrease of lysine from 2.1 to 1.2% through milling. In wheat, rice, and barley endosperm a similar decrease in biological value and lysine has been found when compared to whole seed flour (Bach Knudsen 1980; Eggum and Duggal 1977; Eggum et al. 1977). In Figure 3, lysine consumption (mg/animal per day) is plotted against weight gain (g/animal per day) for the sorghum products presented in Table 9 together with 4 barley milling

Table 9. Feed consumption in rat trials and nutritional quality of whole sorghum grain, decorticated grain, and *ugali* prepared in Tanzania and in Denmark.

	Diet	n	Feed consumption (g/day)	Weight gain (g/day)	TD[a] (%)	BV[a] (%)	NPU[a] (%)	DE[a] (%)
	Whole grain	4	9.7	1.26	94.7	55.9	53.1	89.6
	Decorticated grain	3	6.3	0.55	100.3	47.4	47.5	96.4
	Tanzanian cooked *ugali*	4	6.1	0.04	91.8	49.4	45.3	94.0
	Laboratory whole grain *ugali*	4	9.8	1.40	90.0	55.7	50.2	88.8
Pooled S			0.48	0.35	1.03	1.25	1.14	1.01
F value			67.7^{***}	12.6^{***}	64.5^{***}	43.4^{***}	32.2^{***}	49.4^{***}
Effect of:								
decortication	diet II − I		-9.3^{***}	-2.6^{*}	7.1^{***}	-8.9^{***}	-6.4^{***}	8.8^{***}
cooking	diet III − II		-0.6^{ns}	-1.9^{ns}	-10.2^{***}	-2.1^{ns}	-2.5^{*}	-3.1^{**}
lab. cooking	diet IV − I		0.3^{ns}	0.6^{ns}	-6.5^{***}	-0.2^{ns}	-5.8^{***}	-1.6^{ns}

ns $p > 0.05$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

a TD = True digestibility
BV = Biological value
NPU = Net protein utilization
DE = Digestible energy

fractions described by Bach Knudsen (1980). It is seen that the values for sorghum and barley fall on the same regression line. This strongly indicates that the poor weight gain in the present work can be fully explained by the low lysine content alone.

Protein digestibility was reduced by cooking from 100.3 to 91.8% in decorticated grain and in whole grain from 94.7 to 90.0% (Table 9). In in vitro experiments, Axtell et al. (1981) found a negative effect on digestibility of cooking of sorghum flour, while in experiments with small children, MacLean and Graham (1980) found a very low value of apparent retention of nitrogen. For cooked whole grain flour of sorghum, Eggum et al. (1977) found a significant reduction in protein digestibility of rice after cooking, like we did in our present experiments with sorghum. In rice, however, there was a concomitant increase in the biological value, because low lysine proteins (protein bodies) were rendered unavailable through cooking. In our experiments, cooking had no effect on the biological value of sorghum (Table 9).

In sorghum, gelatinization of starch takes longer and needs higher temperatures than do other cereals (Ali and Wills 1980). The cooked product is extremely viscous and has a low energy digestibility. In the present work the decorticated flour,

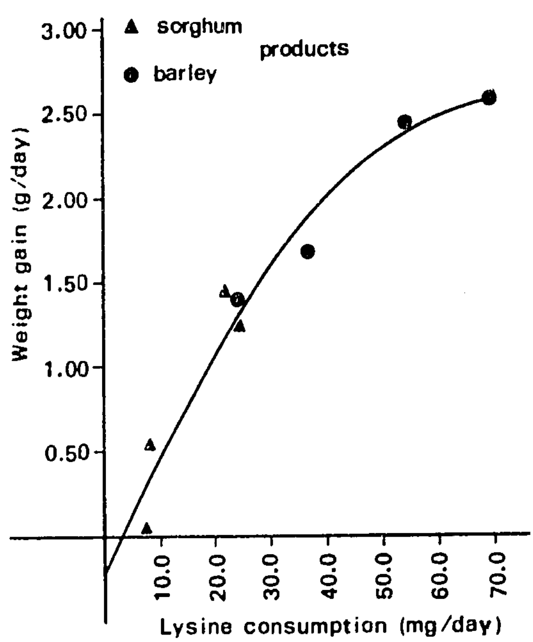


Figure 3. Relationship between lysine consumption (mg/rat per day) and weight gain (g/rat per day) of rats fed on sorghum and barley products Weight gain = 0.231 + 0.076, lysine consumption = 0.001 (lysine consumption)², $R^2 = 96.6\%$

diet III, was cooked for 20 min, which is the normal procedure in Africa (Vogel and Graham 1979), whereas diet IV, the milled flour, was cooked for 45 min. As seen in Table 9, the negative effect of cooking on protein and energy digestibility, feed consumption, and weight gain was lowest for the whole milled flour cooked for 45 min. Although the digestibility of energy as well as protein was reduced through cooking, the values are comparable with values from other cooked cereal products (Eggum 1973).

Conclusions

Quality of Sorghum for Hand Decortication

It is reasonable to conclude that the hand miller presented the most refined products during her demonstration, the quality of which would be comparable with the best sorghum flours for festive occasions in Tanzania. During our travels in the Dodoma region, however, we saw hand-milled sorghum flours of lower quality. These products were nevertheless whiter than the samples of industrially-processed sorghum (Table 5).

The hand miller showed that she could make a high quality white flour from Lulu D at the sacrifice of yield (to about 50%). With the present food situation in Tanzania, such flour would only be produced on special occasions. In practice, Lulu D is milled to about 80% yield, as are the local varieties, resulting in a considerably darker and less acceptable product, when compared with flour from local varieties at the same yield. Thus, it is clear that Lulu D is not a preferred sorghum variety. In the rural villages where hand milling is still practiced, millet was the most popular cereal, followed by sorghum and maize. However, maize was the cereal preferred in the towns and cities. To encourage the use of sorghum, which is more drought resistant than maize, it is of great importance to stimulate the use of hand milling in the villages. This can be achieved by introduction of acceptable sorghum varieties for hand milling with the following characteristics:

High yield per hectare. The present improved sorghum varieties have high yield potential but their grain quality is inferior to that of the local varieties. An optimal compromise between the high-yielding dwarf varieties and the local low-yielding, tall, high-quality varieties should be found.

Resistance to weathering and insect damage. The lax rice-like panicles of the local varieties are less damaged by insects and molds than the compact heads of Lulu D and Serena. The latter varieties are also impaired by their early maturation in the middle of the rainy season. The local varieties with their longer growing period, mature in a dry period. Planting time and photoperiodic sensitivity are thus important for avoiding molds and weathering.

High yield of a white flour. A round, hard kernel gives the best overall result in hand decortication. Sorghum genotypes should be selected to avoid formation of pigments which, under normal conditions and or under bad weathering, will diffuse into the endosperm.

Sorghum as a Raw Material for Machine Decortication and Milling

Hand milling of the variety 2Kx17/B/1 (comparable in milling quality with Lulu D) produces a highly acceptable flour, which is superior to Lulu D milled at a local village mill (Table 5). However, both procedures give completely unacceptable milling yields of about 50%. The commercial sorghum product from the community of Dodoma is a dark flour which is comparable to whole seed flour from Lulu D. It is apparent that this flour cannot compete with maize products. There are no suitable industrial facilities for sorghum milling either for the local varieties or for the improved cultivars of Lulu D type. Sorghum products therefore have a very low prestige in the larger cities such as Dar es Salam. For obvious reasons, hand decortication is not common in cities.

The stimulation of sorghum cultivation is heavily counteracted by a price subvention system in favor of maize sold by the government.

A high milling yield (75-80%) of acceptable flour is very important in industrial milling, where generally the entire capital and running costs can be paid for with a 2-3% higher yield. When milling soft varieties, such as Lulu D, the yield is also low in machine decortication due to losses of fine endosperm particles to the bran fraction. Thus there is a need for a new milling process where milling yield and flour whiteness can be optimized for all kinds of sorghum raw materials. Such a process is being developed on an industrial scale at the Carlsberg Research Laboratory (Munck et al. 1981).

Nutritional Quality

A calculation based on the 1975 joint FAO WHO Committee reports (Hulse et al. 1980) demonstrates that children and lactating women have problems satisfying their protein requirements with sorghum as the only protein source. It was found in the present work that rats had a low feed consumption and consequently low weight gain (Table 9, Fig. 3) when fed such diets. According to our results, it seems likely that the poor performance of the presently studied low-tannin sorghum raw material and products is caused by an unbalanced amino acid pattern and not by a low digestibility of protein and energy These conclusions are supported by data from feeding rats and preschool children. When sorghum was fed in a balanced ration with legumes to preschool children (Pushpamma and Devi 1979 and Pushpamma et al. 1979) protein digestibility as well as nitrogen retention of a sorghum/legume mixture was almost as high as for a rice/legume mixture. We conclude from our work that a diet consisting of only sorghum is poorly utilized as a food source due to the lack of lysine. In combination with other foods which are rich in lysine, the protein and energy from the sorghum source will be effectively utilized to an extent comparable with other cereal products, when properly processed. In milling sorghum, a high extraction rate of about 80% should be obtained to avoid losses of the nutritious embryo and endosperm while removing the pericarp and testa which is poor in nutrients.

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Discussant's Comments

Session 4: L. Munck*

I regret that Mr. Perten is not here. I have taken his place as a discussant. We remember that Mr. Perten was a pioneer in starting up sorghum milling with FAO—the composite flour program started in the 1960s in cooperation with the Food Research Institute, Khartoum, Sudan. A decortication technique used an abrasive barley pearler.

The Canadian IDRC development program, represented here by Dr. Reichert, was also among the first to design and implement for sorghum a decortication system on a small-batch scale, as well as on an industrial scale. Dr. Desikachar and his group at the Central Food Technological Research Institute, Mysore, India realized as early as the mid-1960s, the positive effect on sorghum of tempering in separating the bran from the endosperm either through decortication in a decorticator or in a plate mill.

It is interesting to note that in the first two papers both Dr. Shepherd's and Dr. Reichert's work dealt with abrasive laboratory milling to evaluate plant breeders' material. These results are significant for those who use abrasive decorticators but they are not optimized for hand decortication and other machine decortication principles. I would thus recommend finding a laboratory milling technique which is well correlated with hand pounding for screening plant breeders' material. I do not exclude that there may be factors in common for two or more different milling principles, but we cannot assume that "pearling index" would constitute such a universal principle.

Dr. Desikachar's milling methods seem well suited to process cereals and legumes to a quality standard to which the people in India are accustomed. The plate mill principle for decortication is quite interesting. I recall a newly issued American patent which advises a plate mill for removing the germ from maize, which seems very effective. Dr. Desikachar also rightly emphasized the importance of a high milling yield (85–90%), avoiding losses of important nutrients.

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Session 4—Milling and Processing

Discussion

Reichert:
Dr. Munck, could you use tempering and still retain the embryo? Could you specify milling yield and tempering condition?

Munk:
We are just at the beginning of understanding how the germ could be retained or separated. There are great differences between varieties in this respect. In the Dabar variety, we are able to retain the germ and still obtain an 80% yield without tempering. Other varieties, especially those with a colored pericarp and testa, need 3-5% water addition to be efficiently decorticated.

Shepherd:
My abrasive method of laboratory decortication compares well with that of Dr. Reichert. I need to know what we are working with in hand decortication, in relation to my method.

Scheuring:
In hand decortication those varieties that have a thick mesocarp and a hard endosperm are by far the easiest to process.

Shepherd:
Sorghum with a thick mesocarp produces much flakes in my mill. The breakage of the bran takes place in the mesocarp; tempering is disadvantageous in my system.

Reichert:
Dr. Munck, what inadequacy do you think goes with the laboratory decortication methods developed so far?

Munck:
We have to be far more specific regarding what we want to achieve with these laboratory milling methods. High product yield, about 80%, and a white flour color are the most important attributes in real life. Our philosophy has been—and I think Dr. Desikachar agrees with me in this—to take out the hull in big flakes as is done in hand decortication. In addition, we recover broken endosperm pieces from the screen flour in our decorticator by sieving and aspirating. This keeps our yield high even if we decorticate soft sorghums such as Dabar, and U.S. hybrids. I would not say that abrasive milling could not achieve the above mentioned goals. But I do think that the abrasive stones are likely to produce losses in fine flour which cannot be recovered from the screen flour. Thus the question about laboratory milling techniques is for what process do you want to select. Dr. Reichert's and Shepherd's methods are suitable for abrasive milling, but we do not know if they can be used for other decortication principles.

Rana:
It is important to decorticate high-tannin, bird-resistant sorghums to improve digestibility. I have sent a few samples to Dr. Desikachar. Could you tell us about the important problems?

Desikachar:
The soft Kenyan high-tannin variety is not suited for decortication but can be milled with good results with a flour-milling technique. The hard and semihard varieties could be decorticated, and they give light colored products. There are two separate aspects: (a) the development of laboratory milling techniques for plant breeders' samples, and (b) development of small, medium, and large machinery which can be used in developing countries for milling sorghum for food. Here the emphasis should be the utilization of existing machinery with minor modifications. We should have milling yields between 80 and 90% removing only the inedible parts such as pericarp and testa.

Reichert:
About 40 different milling devices have been proposed for sorghum during the last decade. They all differ in efficiency and milling quality. I

think one of the most important areas for future research will be to compare and evaluate these systems. At the Food Research Institute, Khartoum, Sudan, five different dehullers are now in a comparative test.

Munck:
Who is going to do this evaluation? I do not think it is possible for us as scientists to judge—it is the market which is going to be the testing place.

Reichert:
We should not introduce sorghum decortication where this is not done traditionally, e.g., in Sudan where they use white varieties. If we do so, there will be a loss of nutrients.

Munck:
I agree when it comes to rural areas. In the urban areas, there is a place for sorghum decortication and milling if sorghum is going to withstand competition from wheat, maize, and rice products.

MacLean:
We should not be so hesitant to introduce sorghum milling and processing into areas where they have not been used traditionally. The availability of nutrients from the bran is low. Seventy percent extraction wheat flour contains as much available protein as whole wheat flour in spite of a lower protein content. Anything that could improve the utilization of sorghum should be done in these areas.

Session 5

Laboratory Methods to Evaluate Food Quality

Chairman: J. C. Miche

Discussant: L. Munck
Rapporteur: N. Seetharama

Sorghum Hardness: Comparison of Methods for its Evaluation

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Summary

Sorghum grain hardness measurements were made with six different procedures (percent vitreousness, kernel density, particle size index, pearling index, percent floaters, and percent kafirin of total protein) on a set of 15 cultivars covering a range of grain hardness. A comparison of the methods showed that the particle size index and pearling index procedures provide a rapid and sensitive measure of the physicomechanical properties of sorghum, related to grain hardness. Several other methods (i.e., percent vitreousness, kernel density, and percent floaters) ranked the sorghum cultivars in an order similar to particle size index or pearling index, but these indices were either less sensitive or more time consuming. A chemical method for measuring hardness (percent kafirin of protein) was poorly correlated with the other hardness methods investigated.

A multiple linear regression analysis revealed that the abrasive-milling performance of sorghum is related to all the hardness parameters investigated. In addition, the analysis indicated that kernel size had an effect on the milling performance. Cultivars with vitreous or hard endosperm texture yielded better pearling results than those with a floury or soft endosperm. Sorghum grain with large kernel size appears to have better pearling properties than grain with small kernels, given the same endosperm hardness.

Plant breeders and cereal technologists have used the terms hardness or vitreousness to describe the endosperm textural characteristics of sorghum grain. Biting or cutting grain has provided a qualitative evaluation of endosperm texture. A number of attempts have been made to find a quantitative measurement of the hardness of individual kernels or of the average hardness of a bulk sample of grain.

Several studies have been conducted to evaluate sorghum grain hardness in relation to the grain's processing properties. Stringfellow and Peplinski (1966) reported on the air-classification characteristics of sorghum flours from varieties representing different hardnesses. Maxson et al. (1971) described a simple hardness test for sorghum using a Strong Scott laboratory barley pearler. In this work it was shown that hardness and density correlated inversely with milling yield, and that endosperm texture (relative proportion of hard to soft scored on a 1 to 5 scale where 1 represented completely hard) was negatively correlated with hardness, test weight, and kernel density.

Sullins et al. (1971) reported a procedure for determining the particle size index of hammer milled (screen aperture of 0.635 cm) sorghum grain which had undergone various reconstitution treatments. Their particle size index was determined by placing 300 g of ground material over a nest of six sieves, sieving for 5 min, and multiplying the percent overs of a sieve by a factor assigned to that sieve. The sum of the products for all the sieves and pan fraction total was called the particle size index. They found that reconstituted grain with larger particle size indices (smaller average particle size) had increased feed efficiency. However, these workers made no attempt to use their particle size index test to differentiate grain hardness between sorghum varieties.

More recently Shepherd (1979) modified a Udy Cyclo-Tec grinding mill to provide a means of evaluating the abrasive decorticating (or dehul-

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ling) milling properties for small samples of grain. Oomah et al. (1981) developed a laboratory tangential abrasive dehulling device (TADD) that can be used to process eight 10-g samples at a time to provide a measurement of grain hardness and extraction rate based on flour color. The TADD system is designed to provide plant breeders with a convenient means for evaluating the dehulling characteristics of sorghum.

Munck (1981) has used a Vickers' hardness tester, a hardness tester used in metallurgy, to determine the hardness of individual sorghum kernels. Determination of percent of soft (or 'floury') portion in kernels of sorghum is another reported (Munck 1981) measure of hardness.

Some of the above mentioned methods measure different properties of the grain. Particularly great differences could be expected, for instance, between methods based on pearling the grain, which probably are influenced by bran properties, and methods based on grinding properties, which likely depend on endosperm characteristics.

Interlaboratory comparison of published sorghum hardness results is difficult because very few workers have used more than one method on similar samples. In an attempt to alleviate this shortcoming, this paper reports hardness measurements made with a number of methods on a series of samples covering a range of grain hardness.

Materials and Methods

Grain from 15 sorghum cultivars varying in endosperm texture were used in this study. Twelve of the cultivars were grown at West Lafayette, Indiana during the 1980 crop year and the remaining three were grown at Halfway, Texas during the 1979 or 1980 crop year (Table 1). The chemical composition and description of the samples is listed in Table 1.

Prior to testing, all the sorghum samples were cleaned on a Carter dockage tester (Carter-Day Company, Minneapolis, Minnesota) and then hand picked to remove the remaining broken and shriveled kernels. After cleaning, 1 kg of each cultivar was equilibrated to a moisture content of $10.5 \pm 0.5\%$ by exposing the grain to ambient conditions in our laboratory for 3 weeks.

Vitreousness

Thirty kernels of a cultivar were placed in 2.54-cm diameter plastic cups with the germ tip to panicle axis in a horizontal position. A firm-setting, low-viscosity epoxy resin (Spurr 1969) was slowly added to a depth of 1 cm and allowed to polymerize overnight at 65° C. Cross sections of the embedded kernel were prepared by sanding with 60- and 100-grit sandpapers until the largest area of the floury endosperm was brought to the surface and a small part of the germ was exposed. This point was determined to be the approximate center of the kernel and can be seen by holding the cup close to a light. Kernels with no germ exposed or kernels that were out of position were not measured.

The images of the total and vitreous endosperms were traced while viewed under a light microscope (Wild M20-35207) with an external light source using the following: a 15X eyepiece, a 2.5X/0.08 objective, and a 1.25X camera lucida. The traced areas of the total and vitreous endosperms were then measured using a planimeter (1000 units = 64.52 cm^2). Percent vitreousness was calculated by dividing the measured area of the vitreous endosperm by the area of total endosperm.

Density

Density measurements were taken on a 1-m density gradient column (Shelef and Mohsenin 1968) at 23° C. Six solutions of toluene (0.87 g/cc) and carbon-tetrachloride (1.59 g/cc) were used to establish a linear density gradient in the column which was calibrated by using nine beads of known density ranging from 1.000 to 1.500 g/cc. Thirty kernels (10.5% moisture) were placed in the column at once and allowed 1 min to equilibrate to their resting positions. By using the calibration information, a computer program was used to calculate the density of each kernel from its resting position.

Kernel Volume

The mean kernel volume (cc) was determined by taking the weight of the same 30 kernels used in the density column and dividing the average kernel weight by the mean density (g/cc).

Percent Floaters

Three 50 kernel samples from each sorghum cultivar were equilibrated in a temperature and

Table 1. Chemical composition and description of sorghum (whole grain) cultivars used in grain hardness study.[a]

Cultivar[b]	% Protein (N × 6.25)	% Ash	% Fat	TKW (g)	Pericarp	
					Color	Thickness
SC-283-14[c]	13.0	1.68	4.0	21.0	White	Thin
954062	12.6	1.73	3.2	26.2	White	Int.[d]
954114[c]	13.2	1.74	4.2	25.3	White	Int.
CS-3541[c]	11.1	1.10	3.5	22.2	White	Thin
IS0469	12.9	1.73	4.3	18.5	White	Thin
P721N	12.7	1.62	3.4	24.6	White	Thick
954063	12.7	1.82	3.2	21.9	White	Int.
IS0452	13.1	1.56	4.3	19.0	White	Int.
IS4225	11.5	1.71	4.4	30.7	Red	Int.
954100	13.2	1.73	3.5	34.7	White	Int.
M-35-1[c]	12.6	1.77	3.5	34.6	White	Thin
954130	13.1	1.56	3.5	26.1	White	Thin
IS1461	12.0	1.69	4.0	20.6	White	Int.
P7210	13.3	1.84	3.7	23.4	White	Thick
850649	12.5	1.80	3.8	23.5	White	Thick

a. Protein, ash, and fat determined by American Association of Cereal Chemists (AACC) approved methods (AACC 1975). All values reported on a dry matter basis.
b. Unmarked samples grown at West Lafayette, Indiana 1980 crop year.
c. Samples grown at Halfway, Texas 1979 crop year except for CS-3541 (1980 crop year).
d. Int. = intermediate
TKW = 1000 kernel weight

humidity controlled cabinet set at 26.7° C dry bulb and 19.7° C wet bulb to a final moisture content of 11.5 ±0.6%. The average number of floating kernels (from triplicate determinations) in a 1.327 sp gr solution of tetrachloroethylene and odorless kerosene were counted and expressed as a percent of 50.

Pearling Index

A Strong-Scott barley pearler (Burrows Equipment Co., Chicago, Illinois with a carborundum wheel was used to mill a 20-g sample (10.5% moisture) for 45 sec. The pearled grain was sifted by hand on a U.S. No. 20 sieve to remove any adhering floury particles, and the overs were weighed. The weight of the pearled grain subtracted from 20-g is reported as a percentage of the original sample and is called pearling index. Pearling index determinations were made in triplicate. The lower the pearling index value the harder was the grain.

Particle Size Index

Before testing, the moisture content of 100 g samples from each cultivar was adjusted to 12.0 ±0.4% moisture. The moisture adjustment was accomplished by adding water and allowing the samples to equilibrate in airtight containers for 1 week. The particle size index was determined in triplicate by grinding a 20-g grain sample in a Falling Number model KT-30 grinder (Fall Number AB, Stockholm, Sweden) fitted with coarse burrs at gap setting zero. The ground sorghum meal was sifted on a Ro-tap shaker (W. S. Tyler, Inc., Mentor, Ohio) for 1 min with U.S. Nos. 20, 30, and 40 sieves (sieve openings 850 µm, 600 µm, and 425 µm, respectively). The material passing through the test sieve was weighed, and the results were expressed as a percentage of the original sample. This percentage is called the particle size index. The lower the particle size index, the harder was the grain.

Kafirin Protein

The kafirin protein content of whole and pearled sorghum grain was determined in duplicate. Pearled grain was prepared by first milling the sorghum for 15 sec in a Strong-Scott barley pearler equipped with a carborundum wheel. The same sample was then milled in a second laboratory barley pearler equipped with a wire wheel brush (Rooney and Sullins 1969) to obtain a 70% yield of pearled grain. Both whole and pearled grain samples were ground to pass a 0.4-mm screen in a Udy Cyclo-Tec mill (UD Corp., Boulder, Colorado). Kafirin protein determinations were performed by modifying the method suggested by Esen (1980). Two hundred mg of ground whole or pearled grain was accurately weighed into a 30 ml Pyrex™ culture tube provided with a screw cap. Then 10 ml of 60% (V V) tertiary butanol was added, the tubes were sealed, horizontally positioned on a reciprocal shaker, and agitated for 2 hr at 60 cycles per min. The tubes were heated in a 70°C water bath for 15 min, shaking every 5 min. The extracted protein was separated from the residue by centrifugation at 1000 × g for 20 min. Three ml aliquots of the protein extract were placed in 75-ml test tubes and dried overnight under vacuum over a sand bath heated to 45 to 50° C. The nitrogen content of the original grain and dried kafirin extracts were determined by Berthelot's colorimetric assay (Apostolatos 1980). Nitrogen was converted to protein by multiplying N × 6.25.

Statistical Analysis

The results from various methods for measuring hardness were analyzed by the analysis of variance, and the significance of differences among genotypes was determined by Scheffe's method of multiple comparison (Nie et al. 1975; Hicks 1973). The relationships of results from different methods were evaluated by coefficients of simple and multiple linear correlation.

Results and Discussion

Physical Hardness Measurements

The hardness values obtained for percent vitreousness, kernel density, pearling index, and particle size index for the 15 sorghum cultivars studied are presented in Table 2. The best differentiation of the sorghum cultivars was obtained by the particle size index test, which ranked the samples into eight significantly (P = 0.05) different groups, regardless of the screen size used for calculating the particle size index (Table 2). Percent vitreousness, kernel density, and pearling index hardness indices ranked the samples into only six, four, and seven, respectively, significant (P = 0.05) different groups. A comparison of the standard deviation and coefficient of variability for each hardness test (Table 2) reflects the test's differentiation of the sorghum cultivars. As expected, the variability of the individual kernel tests (percent vitreousness and kernel density) was somewhat greater than the bulk sample tests (particle size index and pearling index).

The rankings obtained for the sorghum cultivars on the basis of percent vitreousness, kernel density, particle size index, and pearling index were quite different (Table 3). For example, M-35-1 was ranked as being much harder than expected from the percent vitreousness measurement (Tables 2 and 3) by kernel density, particle size index (No. 20) and pearling index measurements. Other exceptions may also be found when comparing the rankings of a cultivar when grain hardness was determined by the various methods used in this study. The discordance of the results among these methods suggests that the same mechanical properties and or physical characteristics of the grain are not measured by each hardness test. The validity of the percent vitreousness test is based on the assumption that the physical characteristic of higher proportions of hard endosperm are usually associated with higher values of hardness in sorghum. However, the firmness (plastic property) of the hard or soft endosperm may not be the same throughout the kernel or the same in all sorghum cultivars, thus accounting for differences between percent vitreousness and particle size index measurements. On the other hand, the pearling index test may be influenced by the size of the kernels and the positioning of the hard endosperm in the kernel, as well as the proportion of hard endosperm.

Percent Floaters Measurements

Wicher (1961) reported a rapid procedure for classifying maize into four hardness categories according to the percentage of floating kernels in a 1.275 sp gr solution. Therefore, the 15 sorghum

Table 2. Percent vitreousness, kernel density, particle size index, and pearling index of the 15 sorghum cultivars used.[1]

Genotype	Percent vitreousness: Number of observations	Percent vitreousness: Mean	Density[2] (g/cc)	Particle size index[3] (U.S. Sieve No.) 20	30	40	Pearling index[3]
SC283-14	27	88[a]	1.392[a]	72.9[a]	46.3[a]	25.2[a]	26.8[a]
954062	28	62[b]	1.349[ab]	80.0[b]	52.4[b]	30.0[b]	47.4[b]
954114	28	61[bc]	1.351[ab]	81.1[bcd]	55.0[cd]	32.5[cd]	49.3[bc]
CS-3541	27	61[bc]	1.325[bc]	79.6[b]	53.6[bc]	32.4[bcd]	54.2[c]
IS0469	20	58[bcd]	1.338[bc]	79.2[b]	52.6[b]	31.8[bc]	66.5[e]
P721N	22	56[bcd]	1.330[bc]	80.1[bc]	53.3[bc]	30.5[bc]	46.2[b]
954063	29	55[bcd]	1.329[bc]	82.2[cd]	54.3[bc]	31.7[bc]	60.0[d]
IS0452	32	55[bcd]	1.326[bc]	83.2[de]	56.9[de]	34.7[de]	70.4[e]
IS4225	25	52[bcd]	1.323[bc]	85.6[f]	61.6[f]	39.6[f]	67.1[e]
954100	24	49[cd]	1.334[bc]	81.2[bcd]	55.1[cd]	32.4[bcd]	46.6[b]
M-35-1	27	47[d]	1.344[b]	80.2[bc]	56.6[de]	36.2[e]	50.0[bc]
954130	27	47[d]	1.313[bc]	84.4[ef]	57.4[e]	34.7[de]	70.8[e]
IS1461	27	26[e]	1.292[cd]	91.0[g]	68.8[gh]	46.2[h]	90.2[g]
P7210	28	12[f]	1.258[d]	90.4[g]	67.4[g]	42.6[g]	80.2[f]
850649	28	10[f]	1.253[d]	91.6[h]	70.1[h]	46.2[h]	84.0[f]
SD		9.9	0.037	0.48	0.53	0.58	1.19
CV (%)		20.2	2.83	0.58	0.92	1.65	1.96

1. Within each column, values with the same letter are not significantly different ($P = 0.05$).
2. Means of 30 determinations.
3. Means of triplicate determinations.

cultivars used in our study were similarly tested in a 1.327 sp gr solution. The 1.327 sp gr solution was selected, on the basis of known kernel densities, to provide maximum separation between the 15 sorghum cultivars used in this study.

The data obtained on the basis of the percent floaters parameter for the 15 sorghum cultivars are shown in Table 4. The floaters parameter ranked the samples into only four significantly ($P = 0.05$) different groups, as was the case with kernel density. The coefficient of variability (17.1%) associated with the floaters test was rather large compared with that of the kernel density test (2.83%) (Table 4). As expected, the rankings obtained for the sorghum cultivars on the basis of kernel density and percent floaters were very similar.

Chemical Hardness Measurements

Work by Hamilton et al. (1951) showed that the hard endosperm of maize contained approximately two times as much alcohol soluble protein (prolamine or zein protein), expressed as a percent of total protein, as did the soft endosperm portion of the kernel. In a more recent study on sorghum, Seckinger and Wolf (1973) found differences in the amounts of alcohol soluble protein bodies present in the hard and soft portions of the endosperm. These workers showed that the protein bodies or granules in the soft endosperm are not so tightly packed as in the horny areas and are much smaller. Accordingly, the 15 sorghum cultivars were tested for alcohol soluble protein (prolamine or kafirin protein) content in order to establish if this chemical property was associated with hardness in sorghum. As the germ (embryo and scutellum) portion of the sorghum kernel is rich in protein and may account for 7.8 to 12.1% by weight of the kernel, kafirin determination extractions were performed on both whole kernel and pearled sorghum.

The data obtained for percent kafirin of total protein on whole and pearled grain is shown in

Table 3. Ranking of the 15 sorghum cultivars on the basis of percent vitreousness, kernel density, particle size index, and pearling index hardness parameters.[1, 2]

Percent vitreousness	Density	Particle size index (U.S. Sieve No.) 20	30	40	Pearling index
A^{a}	A^{a}	A^{a}	A^{a}	A^{a}	A^{a}
B^{b}	C^{ab}	E^{b}	B^{b}	B^{b}	F^{b}
C^{bc}	B^{ab}	D^{b}	E^{b}	F^{bc}	J^{b}
D^{bc}	K^{b}	B^{b}	F^{bc}	G^{bc}	B^{b}
E^{bcd}	E^{bc}	F^{bc}	D^{bc}	E^{bc}	C^{bc}
F^{bcd}	J^{bc}	K^{bc}	G^{bc}	D^{bcd}	K^{bc}
G^{bcd}	F^{bc}	C^{bcd}	C^{cd}	J^{bcd}	D^{c}
H^{bcd}	G^{bc}	J^{bcd}	J^{cd}	C^{cd}	G^{d}
I^{bcd}	H^{bc}	G^{cd}	K^{de}	H^{de}	E^{e}
J^{cd}	D^{bc}	H^{de}	H^{de}	L^{de}	I^{e}
K^{d}	L^{bc}	L^{ef}	L^{e}	K^{e}	H^{e}
L^{d}	I^{bc}	I^{f}	I^{f}	I^{f}	L^{e}
M^{e}	M^{cd}	N^{g}	N^{g}	N^{g}	N^{f}
N^{f}	N^{d}	M^{g}	M^{gh}	M^{h}	O^{f}
O^{f}	O^{d}	O^{h}	O^{h}	O^{h}	M^{g}

1. A, SC283-14; B, 954062; C, 954114; D, CS-3541; E, IS0469; F, P721N; G, 954063; H, IS0452; I, IS4225; J, 954100; K, M-35-1; L, 954130; M, IS1461; N, P7210; O, 850649.
2. Within each column, values with the same letter are not significantly different ($P = 0.05$).

Table 5. It can be seen that the widest range of values for the 15 cultivars was obtained with pearled grain as compared with whole grain. However, the samples were ranked into seven significantly ($P = 0.05$) different groups when the determination was made on whole grain, as compared with only six groups for pearled grain. A comparison of the standard deviation and coefficient of variability for whole and pearled grain reflects the reason for the improved differentiation when whole grain was used.

Relation Between Hardness Test Parameters

Physical Hardness Parameters

Linear relationships with high correlation coefficients (r-values) were obtained among all the physical methods used to evaluate grain hardness (Table 6). The percent vitreousness parameter was more highly correlated with kernel density, particle size index, and percent floaters than with pearling index. In fact, the percent vitreousness parameter accounted for 92% of the difference in grain hardness as measured by kernel density and 88, 90, 84, and 90% when measured by the Nos. 20, 30, or 40 particle size index and percent floaters, respectively. However, the percent vitreousness of the grain accounted for only 69% of the variation in pearling index.

A comparison of the associations between kernel density with the other hardness parameters, reveals that density was highly correlated with percent floaters, particle size index, and pearling index (Table 6). It is also clearly seen in Table 6 that pearling index has a slightly better association with kernel density than with the percent vitreousness parameter.

The relationships between particle size indices (Nos. 20, 30, or 40) and all other hardness parameters are very good, regardless of the screen size used to calculate the indice (Table 6). Although, the No. 20 particle size index showed a slightly higher correlation with pearling index than the Nos. 30 and 40 particle size index parameters. Notice also that the association between the percent floaters parameter and pearling index was somewhat lower compared with percent floaters with the other hardness parameters.

Table 4. Kernel density and percent floaters of the 15 sorghum cultivars.[1]

Cultivars	Density[2] (g/cc)	Percent floaters[3]
SC283-14	1.392ᵃ	0
954114	1.351ᵃᵇ	19ᵃᵇ
954062	1.349ᵃᵇ	11ᵃ
M-35-1	1.344ᵇ	13ᵃ
IS0469	1.338ᵇᶜ	19ᵃᵇ
954100	1.334ᵇᶜ	37ᵃᵇ
P721N	1.330ᵇᶜ	23ᵃᵇ
954063	1.329ᵇᶜ	17ᵃᵇ
IS0452	1.326ᵇᶜ	30ᵃᵇ
CS-3541	1.325ᵇᶜ	30ᵃᵇ
IS4225	1.323ᵇᶜ	43ᵇᶜ
954130	1.313ᵇᶜ	37ᵃᵇ
IS1461	1.292ᶜᵈ	67ᶜᵈ
P7210	1.258ᵈ	93ᵈ
850649	1.253ᵈ	93ᵈ
SD	0.037	6.5
CV (%)	2.83	17.1

1. Within each column values with the same letter are not significantly different ($P = 0.05$).
2. Means of 30 determinations.
3. Means of triplicate determinations.

Table 5. Whole and pearled grain percent kafirin of total protein of the 15 sorghum cultivars used.[1]

Genotype	% Kafirin of total protein[2] Whole grain	Pearled grain
SC283-14	50.7ᵃᵇᶜᵈ	66.8ᵃᵇ
954062	43.5ᵈᵉᶠ	54.6ᵇᶜᵈ
954114	47.0ᵇᶜᵈᵉ	51.7ᶜᵈ
CS-3541	40.9ᵉᶠᵍ	59.1ᵃᵇᶜᵈ
IS0469	55.5ᵃ	62.5ᵃᵇᶜ
P721N	40.7ᵉᶠᵍ	46.6ᵈᵉᶠ
954063	42.6ᵈᵉᶠ	51.5ᶜᵈᵉ
IS0452	52.0ᵃᵇᶜ	58.2ᵃᵇᶜᵈ
IS4225	37.8ᶠᵍ	56.1ᵇᶜᵈ
954100	44.1ᶜᵈᵉᶠ	53.1ᶜᵈ
M-35-1	53.0ᵃᵇ	70.4ᵃ
954130	44.7ᶜᵈᵉᶠ	50.5ᶜᵈᵉᶠ
IS1461	45.8ᵇᶜᵈᵉᶠ	54.6ᵇᶜᵈ
P7210	34.0ᵍ	37.6ᶠ
850649	33.4ᵍ	38.6ᵉᶠ
SD	1.42	2.25
CV (%)	3.21	4.15

1. Within each column, values with the same letter are not significantly different ($P = 0.05$).
2. Means of duplicate determinations.

Kafirin vs Physical Hardness Parameters

The percent kafirin of total protein shows low correlation coefficients with all the physical hardness indices (Table 7). However, it is evident that the relationship between the physical hardness indices and percent kafirin of total protein improved when the determination was made with pearled grain as compared with whole grain.

The parameters, percent vitreousness, kernel density, and the No. 20 particle size index were all significantly correlated with percent kafirin of total protein for either whole or pearled grain, with kernel density showing the best relationship with the kafirin parameter (Table 7). It should be noted that no significant relationship was found between the kafirin parameter and pearling index or the No. 40 particle size index. Thus, the kafirin parameter is not useful for predicting the abrasive milling properties of sorghum and therefore was not included in the multiple linear regression analyses for predicting pearling performance.

Multiple Correlations for Predicting Abrasive-Milling Performance

Most of the commonly used mechanical methods for decorticating sorghum grain are abrasive-type dehullers equipped with carborundum stones or emery-coated abrasive disks. A recent report by Oomah et al. (1981) showed that a laboratory abrasive dehulling device can be used for evaluating the dehulling characteristics of sorghum grain. We do not know how our pearling index method relates to commercial sorghum decortication. However, we feel that the pearling index parameter is a useful guide for predicting the commercial abrasive-milling performance of sorghum. Therefore, the usefulness of the grain hardness parameters combined with kernel parameters (thousand kernel weight and kernel volume) were evaluated in multiple linear regression analysis on the basis of their ability to predict pearling index (abrasive-milling performance).

In the multiple linear regression analyses, signif-

Table 6. Correlations between results of kernel density, particle size index, and pearling index, and percent floaters hardness measurements for 15 sorghum cultivars.[a,b]

Methods of grain hardness evaluation	Percent vitreousness	Kernel density	Particle size index U.S. no. 20	Particle size index U.S. no. 30	Particle size index U.S. no. 40	Pearling index
Kernel density	0.96** (.92)					
Particle size index						
U.S. no. 20	−0.94** (.88)	−0.94** (.88)				
U.S. no. 30	−0.95** (.90)	−0.92** (.84)	0.98** (.98)			
U.S. no. 40	−0.92** (.84)	−0.88** (.77)	0.95** (.91)	0.99** (.98)		
Pearling index	−0.83** (.69)	−0.87** (.76)	0.92** (.84)	0.88** (.79)	0.88** (.78)	
Percent floaters	−0.95** (.90)	−0.97** (.94)	0.93** (.86)	0.93** (.86)	0.88** (.77)	0.79** (.63)

a. ** indicates significant at $P = 0.01$.
b. Values in parentheses are r^2 values.

icant correlations were obtained between pearling index and percent vitreousness, particle size index, or percent floaters when these hardness parameters were combined with either thousand kernel weight or kernel volume (Table 8). That is, the regression analyses indicates that combining these hardness parameters (percent vitreousness, particle size index, or percent floaters) with the kernel parameters (thousand kernel weight or kernel volume) significantly improved the relationships between hardness parameters and pearling index. Table 8 illustrates however that there were no significant improvements in predicting pearling index when thousand kernel weight or kernel volume were combined with kernel density as compared with using density alone.

The No. 20 particle size index, when combined with either of the kernel parameters, was more highly correlated with pearling index ($r^2 = 0.90$) than any of the other hardness parameters (Table 8). In addition, the Nos. 30 and 40 particle size indices, when combined with the kernel parameters, were also significantly correlated with pearling index ($r^2 = 0.86$ and $r^2 = 0.87$, respectively). The correlations between pearling index and percent vitreousness or percent floaters ($r^2 = 0.81$ and $r^2 = 0.77$, respectively), combined with kernel parameters, while being slightly lower than the relationships mentioned above, are also quite useful. These results illustrate that, regardless of the method of measurement, one of the most important properties that determines the pearling index or abrasive-milling performance of the sorghum kernel is endosperm texture. This agrees well with the findings of Maxson et al. (1971) and Kapasi-Kakama (1977).

The fact that the correlation coefficients between the hardness parameters and pearling index were equally improved by adding either thousand kernel weight or kernel volume to the relationship was not expected. Thousand kernel weight is a function of (a) kernel size and (b) kernel density, whereas kernel volume is a function of only kernel size, thus indicating that the kernel density component of the thousand kernel weight is probably the minor component and that kernel size has the major influence on thousand kernel weight.

The equations in Table 9 show the relation between the physical hardness parameters (percent vitreousness, kernel density, particle size index, and percent floaters) plus the kernel parameters (thousand kernel weight and kernel volume) for predicting pearling index or abrasive-

Table 7. Correlations between physical and chemical hardness measurements for 15 sorghum cultivars.[a]

Method of grain hardness evaluation	Percent kafirin of total protein[b]	
	Whole grain	Pearled grain
Percent vitreousness	0.59* (.34)	0.69** (.48)
Kernel density	0.68** (.47)	0.77** (.59)
Particle size index		
U.S. no. 20	−0.60* (.36)	−0.69** (.48)
U.S. no. 30	−0.58* (.33)	−0.61* (.37)
U.S. no. 40	−0.49 (.24)	−0.50 (.25)
Pearling index	−0.36 (.13)	−0.51 (.26)

a. ** and * indicates significance at $P = 0.01$ and $P = 0.05$, respectively.
b. Values in parentheses are r^2 values.

Table 8. Multiple linear regression correlations for predicting pearling index with grain hardness parameters and thousand kernel weight (TKW) or kernel volume.

Factors			
X_1	X_2	r-values[a,b]	P^c
% Vitreousness		−0.83** (.69)	
% Vitreousness	TKW	0.89** (.80)	0.025
% Vitreousness	Vol	0.90** (.81)	0.018
Kernel density		−0.87** (.75)	
Kernel density	TKW	0.88** (.79)	0.173
Kernel density	Vol	0.88** (.79)	0.165
PSI No. 20		0.92** (.84)	
PSI No. 20	TKW	0.95** (.90)	0.020
PSI No. 20	Vol	0.95** (.90)	0.027
PSI No. 30		0.88** (.78)	
PSI No. 30	TKW	0.93** (.86)	0.020
PSI No. 30	Vol	0.92** (.85)	0.022
PSI No. 40		0.88** (.78)	
PSI No. 40	TKW	0.93** (.87)	0.013
PSI No. 40	Vol	0.93** (.87)	0.013
% Floaters		−0.79** (.63)	
% Floaters	TKW	0.87** (.76)	0.030
% Floaters	Vol	0.88** (.77)	0.026

a. ** indicates significant at $P = 0.01$.
b. Values in parentheses are r^2 values.
c. P = the probability that X_2 does not aid in predicting Y.
PSI = Particle size index.

milling performance of the grain. These equations illustrate that in addition to endosperm texture, kernel size has an effect on pearling index. For example, these equations predict that a large kernel sorghum has better pearling performance than a small kernel, given that the kernel endosperm texture (as measured by percent vitreousness, particle size index, or percent floaters) is equal. This also agrees with the findings of Kapasi-Kakama (1977).

For hardness measurements that relate to sorghum milling performance, the pearling index and particle size index methods appear to be superior to percent vitreousness, percent floaters, and kernel density methods. The major fault associated with the percent vitreousness and percent floaters hardness methods is the large coefficient of variability (20.2 and 17.1%, respectively) obtained with the procedures (Tables 2 and 4). Of course, the large variability reduces the test's ability to detect small differences in hardness. Whereas the coefficient of variability for kernel density measurements is within reason (2.83%), the range of density values is quite small (Table 2), thus making it difficult to detect significant differences with the kernel density parameter.

Conclusions

Comparison of a number of methods of sorghum hardness evaluation showed that the particle size index and pearling index provide a rapid and sensitive measure of physicomechanical proper-

Table 9. Equations for predicting pearling index (PI) from grain hardness parameters and thousand kernel weight (TKW) or kernel volume (Vol).

Percent vitreousness (%V)
PI = 95.70 − 0.712 %V
PI = 124.09 − 0.727 %V − 1.11 TKW
PI = 126.67 − 0.774 %V − 1371.4 Vol

Kernel density (D)
PI = 619.26 − 421.98 D

Particle size index No. 20 (PSI 20)
PI = −194.33 + 3.08 PSI 20
PI = −170.95 + 3.04 PSI 20 − 0.824 TKW
PI = −180.65 + 3.14 PSI 20 − 926.9 Vol

Particle size index No. 30 (PSI 30)
PI = −67.94 + 2.24 PSI 30
PI = −43.99 + 2.24 PSI 30 − 0.977 TKW
PI = −50.70 + 2.34 PSI 30 − 1143.0 Vol

Particle size index No. 40 (PSI 40)
PI = −26.73 + 2.49 PSI 40
PI = −2.00 + 2.51 PSI 40 − 1.023 TKW
PI = −6.88 + 2.63 PSI 40 − 1216.9 Vol

Percent floaters (%F)
PI = 46.70 + 0.430 %F
PI = 74.84 + 0.399 %F − 1.074 TKW
PI = 74.03 + 0.422 %F − 1306.0 Vol

PSI = Particle size index

ties of sorghum related to hardness. Several other methods (e.g., percent vitreousness, kernel density, and percent floaters) ranked the sorghum cultivars in an order similar to particle size index or pearling index, but these indices were either less sensitive or more time consuming. A chemical method for measuring hardness (percent kafirin of protein) was poorly correlated with the other hardness methods investigated.

A multiple linear regression analysis revealed that the abrasive-milling performance of sorghum is related to all hardness parameters investigated. In addition, the analysis indicated that kernel size also had an effect on the milling performance. Cultivars with vitreous or hard endosperm texture yielded better pearling results than those with floury or soft endosperm. Sorghum grain with large kernel size appears to have pearling properties superior to grain with small kernels, given the same endosperm hardness.

Acknowledgment

We are indebted to Drs. John D. Axtell and Lloyd W. Rooney (Purdue University and Texas A&M University, respectively) for supplying the samples of sorghum grain used in the study. We also wish to thank Brenda Kirleis and Karen Clymer for their kind and efficient assistance during the preparation of this text.

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Hardness of Pearl Millet and Sorghum

Alicia de Francisco, E. Varriano-Marston, and R. C. Hoseney*

Summary

The hardness of grain from six populations of pearl millet and three cultivars of sorghum was determined by particle size analysis after milling the grains on attrition and roller mills. Millets grown in Sudan were, in general, softer than those grown in Kansas. However, kernel vitreosity did not parallel grain hardness as determined by particle size analysis. Furthermore, tempering either millet or sorghum before milling shifted the particle distribution to larger sizes compared with nontempered samples.

Grain hardness has always been a major concern of millers because it determines grinding time and energy expenditure as well as the performance and appearance of the final product. Grain hardness also concerns people in developing countries where much milling is done by hand with wooden or stone mortars or with hand-operated stone mills (Vogel and Graham 1979).

Although a substantial number of reports have dealt with techiniques to measure wheat hardness (Obuchowski and Bushuk 1980), only limited data are available on hardness of sorghums and pearl millets (Rooney and Sullins 1969, 1970; Maxson et al. 1971). We determined the hardness of various populations of pearl millet and cultivars of sorghum by characterizing particle sizes after milling the grains in attrition and roller mills.

Materials and Methods

Materials

Proximate compositions of the pearl millet samples studied are shown in Table 1. Pedigrees of the millet cultivars grown in Kansas were: HPM 1700 (P1263540 Tift 23 DB$_1$ 2 Tift 239 DB$_2$ 2* Serere 3A); HMP 550 (Tift 23 DB$_1$ *2PI185642); RMP I(S) (parentage from Serere 3A, Serere 17 and Tift 239 DB$_2$), and Serere 3A, developed by Serere Experiment Station, Uganda. Pedigrees of the Sudanese yellow and green millets selected from the marketplace in Khartoum, Sudan, were unknown but they represented "good" (green) and "poor" (yellow) quality grains, judged on flavor characteristics by villagers and on market prices (Badi 1979).

Sorghum cultivars SRAI W6 and SRAI W4,

Table 1. Proximate composition of pearl millets and grain sorghums.

Sample	Protein %	Ash %	Fat %
Pearl millets			
HMP 1700[a]	14.7	1.6	6.9
HMP 550[a]	13.6	1.8	7.1
RMPI(S)CI[b]	11.1	1.4	6.8
Serere 3A[c]	13.5	1.6	6.2
Sudan Yellow[d]	14.5	2.0	7.8
Sudan Green[d]	12.0	1.5	5.9
Grain sorghum			
SRAI W4[e]	9.3	1.5	3.5
SRAI W6[e]	9.8	1.2	2.8
Dwarf White[e]	13.5	1.8	3.2

a. Grown in Hays, Kansas, USA, 1977
b. Grown in Manhattan, Kansas, 1976.
c. Grown in Hays, Kansas, 1975.
d. Grown in Sudan.
e. Grown in Scott City, Kansas.

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were developed at the Seed Research Associates, Scott City, Kansas. The Dwarf White sample originated in Sudan but was grown in Kansas.

One additional pearl millet, HMP557A, had a proximate composition of 10.4% protein, 9.8% moisture, 1.6% ash, and 5.7% fat. It was grown near Mineola, Kansas, in 1979.

Grain Cleaning

The millet samples were cleaned in a model FC9 Kice aspirator (Kice Metal Products Co., Wichita, KS) to remove light-weight debris. Adhering glumes were removed in a Satake (Tokoyo, Japan) rice polisher, and broken and undersized kernels were removed by passing the grain over an 8-in. diameter Tyler Rotap sieve with 2362 μ openings. Glumes on sorghum kernels were removed by hand.

Moisture Determination

Moisture contents of millet and sorghum were determined by the American Association of Cereal Chemists (AACC) method (1976).

Milling and Sieving Studies

Grain samples (50 g) were milled in a Hobart coffee grinder attrition mill, Model 275 (Hobart Mfg. Co., Troy, Ohio), at the finest setting. The milled product was then collected and placed on a stack of 8-in. diameter Tyler Rotap sieves (Table 2) for 1 min to separate the different particle sizes.

The separated particles were combined into two fractions. One, called the fines, consisted of the overs of the 295, 208, 147 μ sieves and the pan fraction. The other fraction, the coarse particles, included the overs of the 1191, 833, 589, 417 μ sieves. Those two fractions were milled separately in a Ross E-2 laboratory mill equipped with 6-in. smooth rolls operated at a differential of 1 to 1.5. Roll gaps for fine and coarse fractions were 80 and 100 μ respectively. Then sieve analyses were performed on the Tyler Rotap sifter as described above. Standard deviations for two to three replicates of each sample ranged from ±0.14 to 0.89%.

Table 2. Tyler Rotap sieve stack used for particle size distribution.

U.S. equivalent	Opening (microns)
16	1191
20	833
30	589
40	417
50	295
70	208
100	147
pan	<147

Tempering of Millet and Sorghum

Sudan yellow and Serere millets were conditioned for 15 hr to 15, 18, and 21% moisture contents. Additional tempering of Serere to 18 and 21% moisture contents was done for 15 hr with 0.5% sodium metabisulfite as described by Badi et al. (1978). Sorghums were tempered to 18% moisture content.

Scanning Electron Photomicrographs

Samples of the fine fractions (< 417 μ) were dusted on double-stick tape mounted on aluminum stubs. Coarse fractions (> 417 μ) were mounted on stubs with conductive silver paste. Samples were coated with 150-Å gold-palladium (60 : 40) and then viewed and photographed in an ETEC U-1 autoscan electron microscope at an accelerating voltage of 20 KV.

Results and Discussion

Millet

Visual observations of representative hand-dissected kernels of pearl millet (Fig. 1) showed that the populations differ in proportions of translucent and opaque endosperm. Serere 3A, RMPI(S)CI, and Sudan green visually have higher proportions of translucent endosperm than do HMP550 or Sudan yellow. It has generally been assumed that opaque and soft endosperms are synonymous. To test that assumption, we used a series of milling and sieving operations to study the relationship between vitreosity (and opacity) of millet samples and physical hardness, as determined by particle size distribution after grinding.

Grinding pearl millet samples in the Hobart mill did not differentiate the samples by particle size

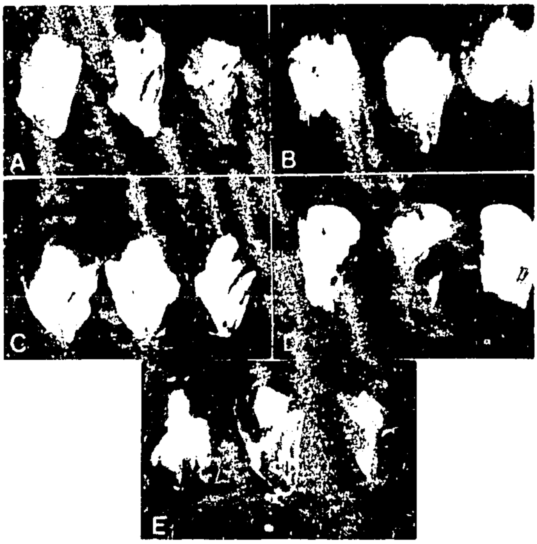

Figure 1. Pearl millet kernels showing distribution of opaque and translucent endosperm in various populations: (A) Serere 3A, (B) HMP550, (C) Sudan Green, (D) Sudan Yellow, and (E) RMPI (S) CI.

(Fig. 2). If the opaque endosperm was soft, it should have broken into smaller particle sizes during Hobart milling. Soft wheat similarly ground gave a finer particle size distribution (Fig. 3). Further grinding of the millet fine particle fraction (< 417 μ), presumably originating from the opaque endosperm, in a Ross laboratory mill equipped with smooth rolls, did not change the particle size distribution of the fine fraction. Thus, that fine fraction is characterized by strong bonds between starch granules and protein matrix (Fig. 4), which is typical of hard endosperm particles.

Milling the coarse fractions (> 417 μ), which contained the major portion of the pericarp, with Ross smooth rolls shifted the particle size distribution to finer sizes (Fig. 5). The reduction in particle size probably does not reflect grain softness but simply that larger particles are easier to reduce.

In general, the millet samples could be divided into two groups according to particle size distribution after Ross milling (Fig. 5). Group I (rela-

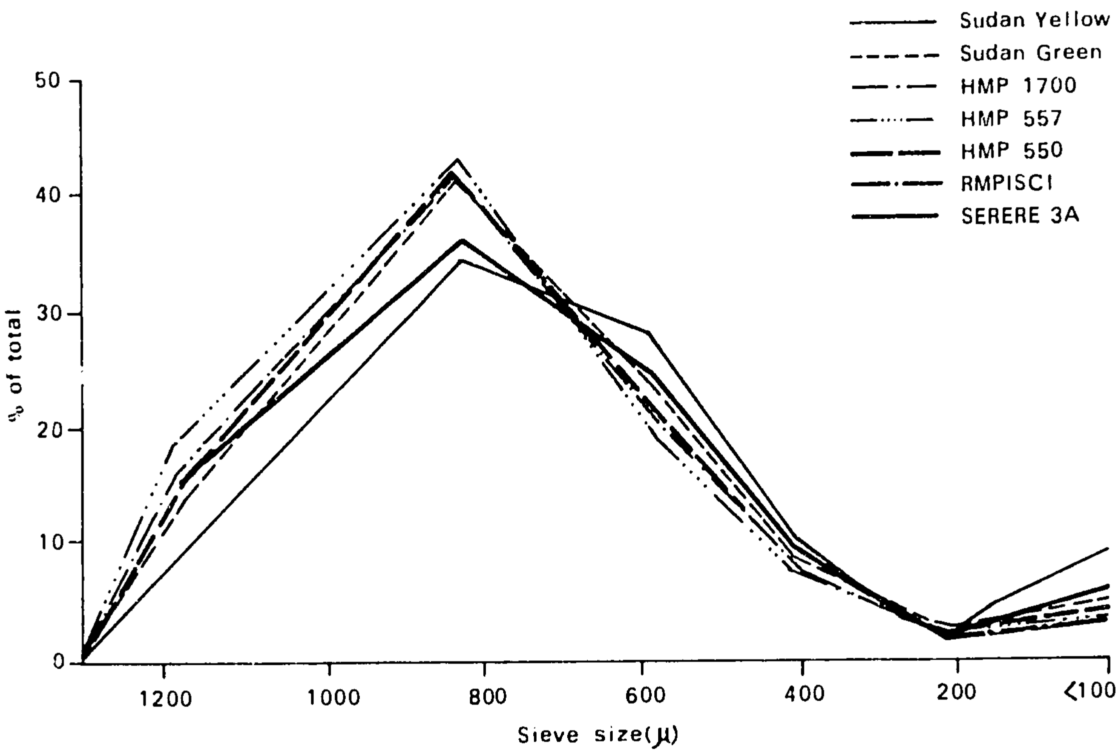

Figure 2. Particle size distribution of pearl millet samples ground in a Hobart mill.

tively large particle sizes) included all the millets grown in Kansas. Millets obtained from Sudan form the second group and gave smaller particle size distributions. Those results show that the large endosperm particles of the millets from Sudan were more easily disrupted during milling

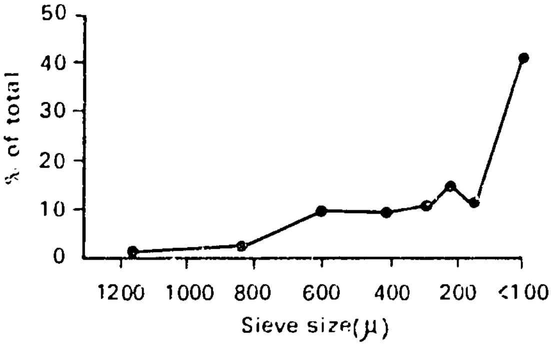

Figure 3. Particle size distribution of soft wheat ground in a Hobart mill.

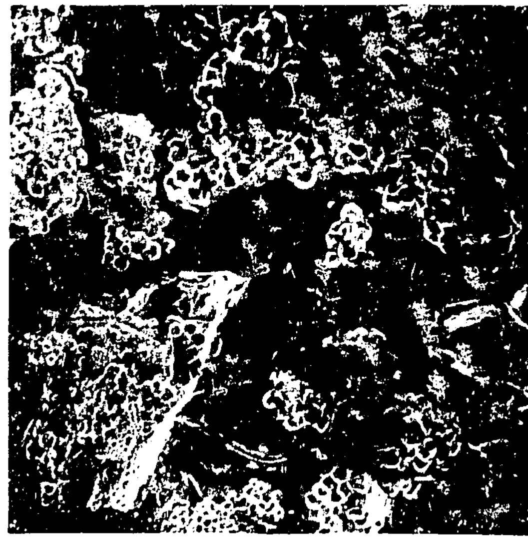

Figure 4. Scanning electron micrograph of millet particles after roller milling the fine fraction (< 417μ) produced on the Hobart mill.

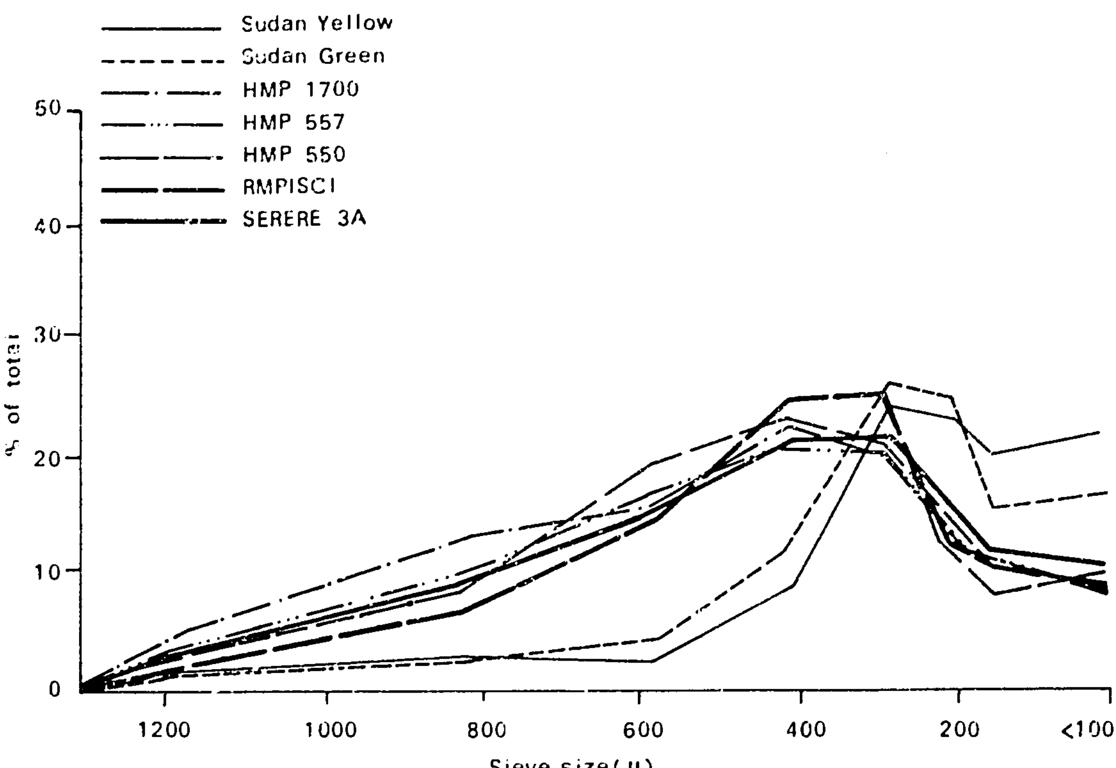

Figure 5. Particle size distribution of millet after smooth-roll-milling the coarse fraction (> 417μ) produced on the Hobart mill.

and, therefore, softer than were the large particles from millets grown in Kansas. Millets from Sudan, while softer than the other millets, were still much harder (i.e., gave larger particle sizes) than a soft wheat (Fig. 3).

Sorghum

To determine if sorghums showed the same milling characteristics as pearl millets, we ground three experimental sorghum lines, SRAI W6, SRAI W4, and Dwarf White (PI400226) in the Hobart mill. All gave similar particle size distributions (Fig. 6). Milling the coarse fractions (> 417 μ) from the Hobart mill on the Ross smooth rolls gave similar particle size distributions for SRAI W6 and W4, but the Dwarf White had reduced particle sizes. Those results indicate that Dwarf White is softer than the other sorghum cultivars. This is contrary to what might be expected from its higher proportion of translucent endosperm (Fig. 7).

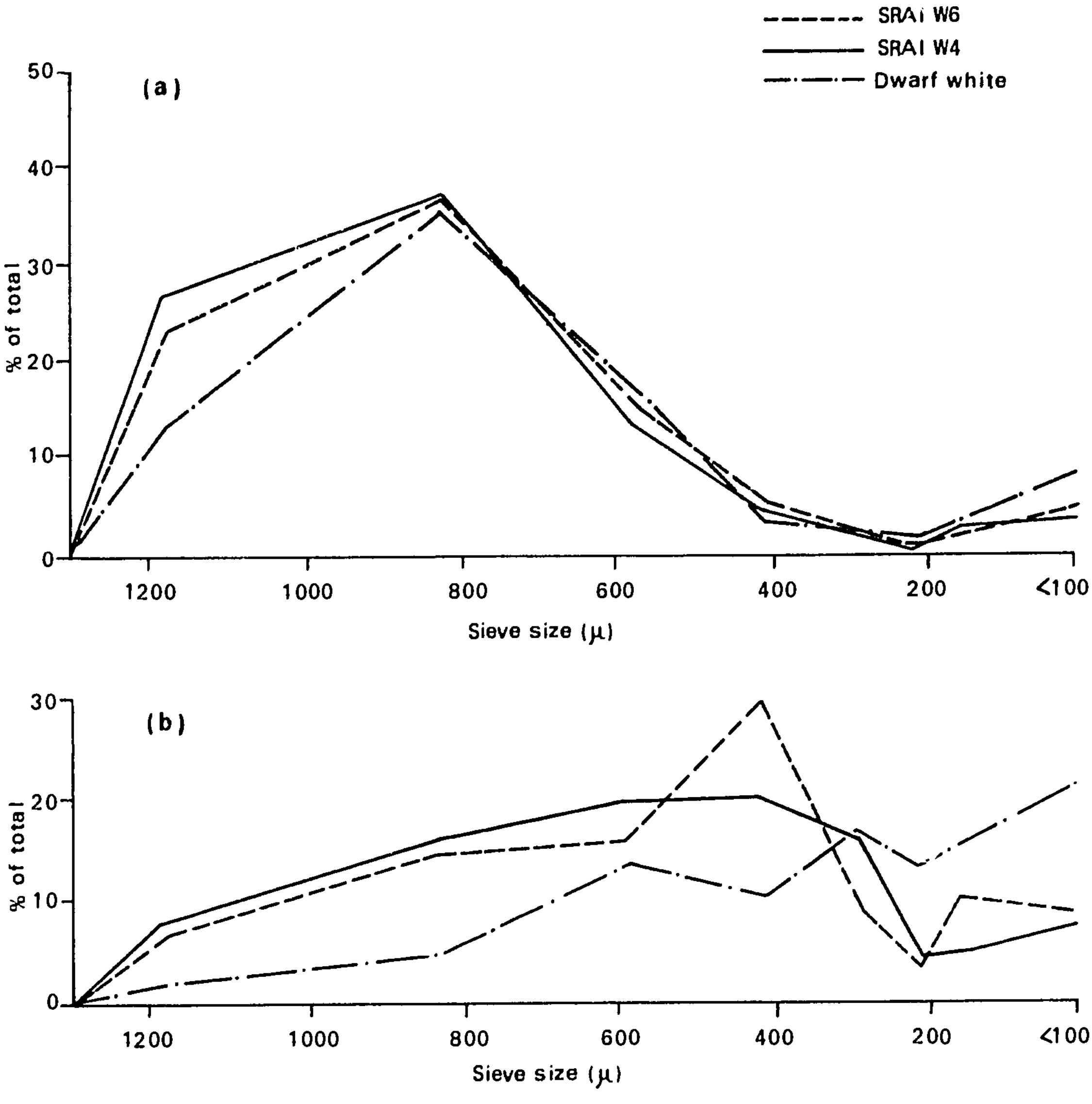

Figure 6. Particle size distribution of sorghums ground in a Hobart mill (a). The distribution of the coarse fraction (> 417μ) after passing through smooth rolls is shown in (b).

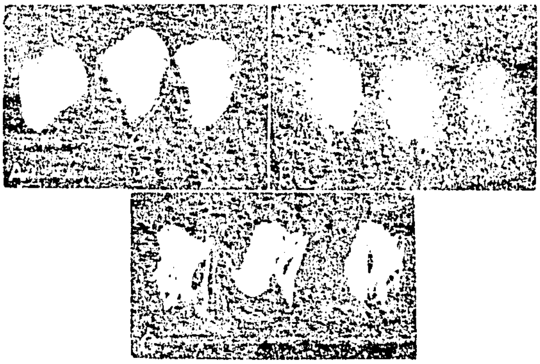

Figure 7. Sorghum kernels showing distribution of opaque and translucent endosperm in various cultivars: (A) SRAI W6, (B) SRAI W4, and (C) Dwarf White.

Tempering Studies on Millet and Sorghum

1. Millet

To determine the effect of tempering on the size of particles produced, we tempered Serere 3A and Sudan yellow millets to moisture contents of 15, 18, and 21 %, then ground the samples in the Hobart mill and sieved them as previously described. Tempering and subsequent milling did not significantly change the particle sizes compared with the nontempered samples (compare Figs. 8a and 9a with Fig. 2). When the coarse fractions ($> 417\ \mu$) were passed through the Ross smooth rolls and sifted, the particle size distribution showed that tempering produced larger particle sizes (Figs. 8b and 9b). For both millet samples, as the tempering level (moisture content) was increased, the particle size of the products increased (less reduction as a result of milling). Thus, tempering appears to make the particles resistant to reduction. This is contrary to reports (for wheat) showing that tempering causes the endosperm to break into finer particles (Butcher and Stenvert 1973).

The factor responsible for grain hardness in wheat is the strength of the protein-starch bond (Simmonds et al. 1973; Simmonds 1974), which is weakened by water so the water may be responsible for the softening effect during wheat tempering.

However, as shown above, tempering with water did not decrease the particle size distribution, i.e., it did not soften millet (Fig. 8b). We, therefore, tempered Serere 3A to 21 % moisture with 0.5 % sodium metabisulfite, a starch-protein bond weakening agent (Badi et al. 1978), ground it in the Hobart mill, and sifted it as described above. The particle distribution after grinding in the Hobart mill was the same as we had observed with the water temper (Fig. 8a). Similarly, passing the coarse fraction ($> 417\ \mu$) through Ross smooth rolls did not alter particle size distribution from that of the water temper (Fig. 8b). Therefore, sodium metabisulfite shows no advantage in particle size reduction over tempering with water.

2. Sorghum

Tempering all three sorghums to 18 % moisture and grinding in the Hobart mill increased the number of particles exceeding 1191 μ (compare Figs. 6a and 10a), again suggesting that the tempering process made the larger particles more resilient and thus more resistant to breakage. When the coarse fraction ($> 417\ \mu$) of tempered sorghums was passed through the Ross smooth rolls, the resulting distribution was shifted to larger particle sizes (compare Figs. 6b and 10b), particularly the coarse fraction of Dwarf white. Thus, sorghum and pearl millet respond to tempering similarly.

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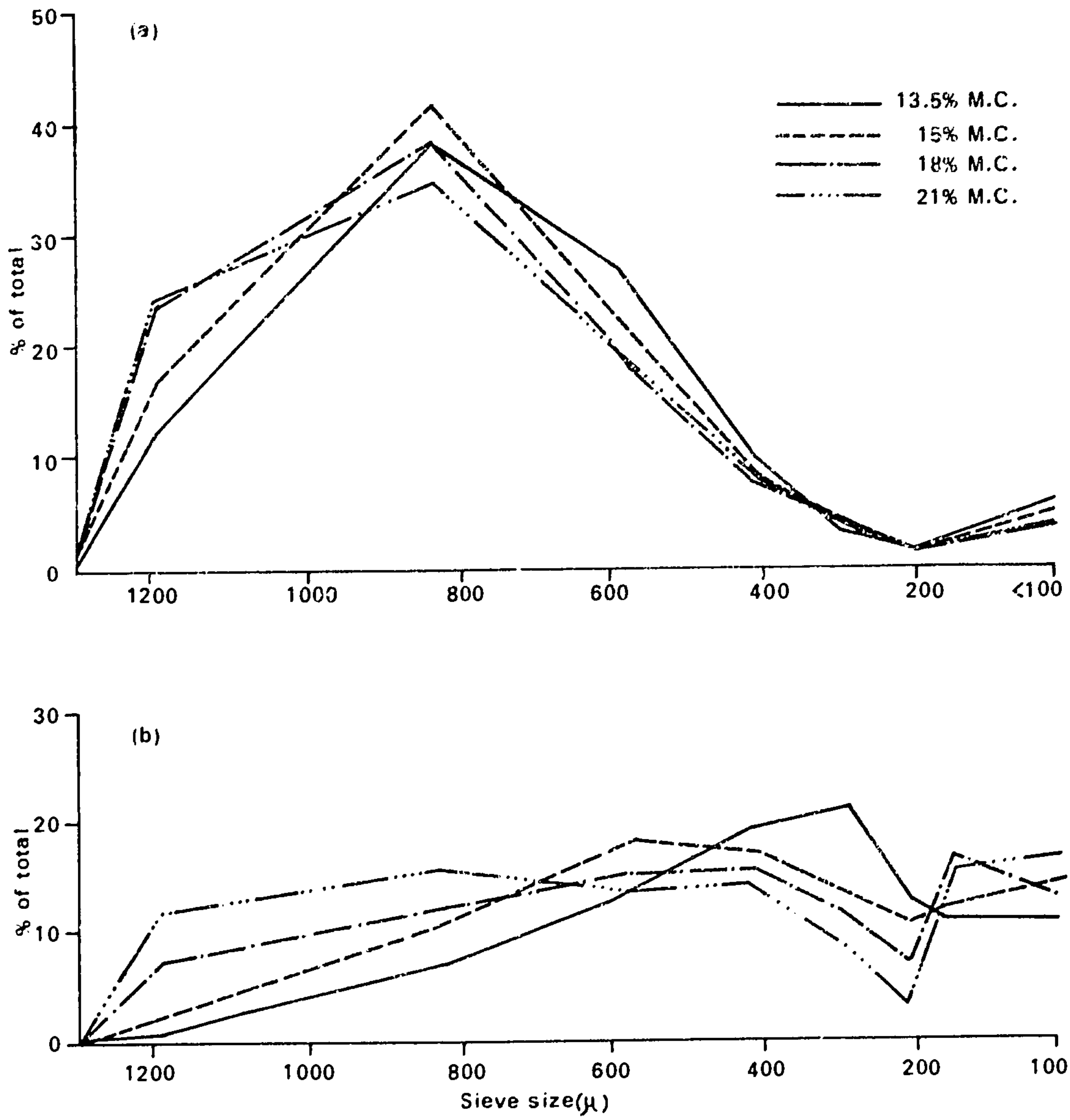

Figure 8. Particle size distribution of tempered Serere 3A millet ground in a Hobart mill (a). The distribution of the coarse fraction (> 417μ) after passing through smooth rolls is shown in (b).

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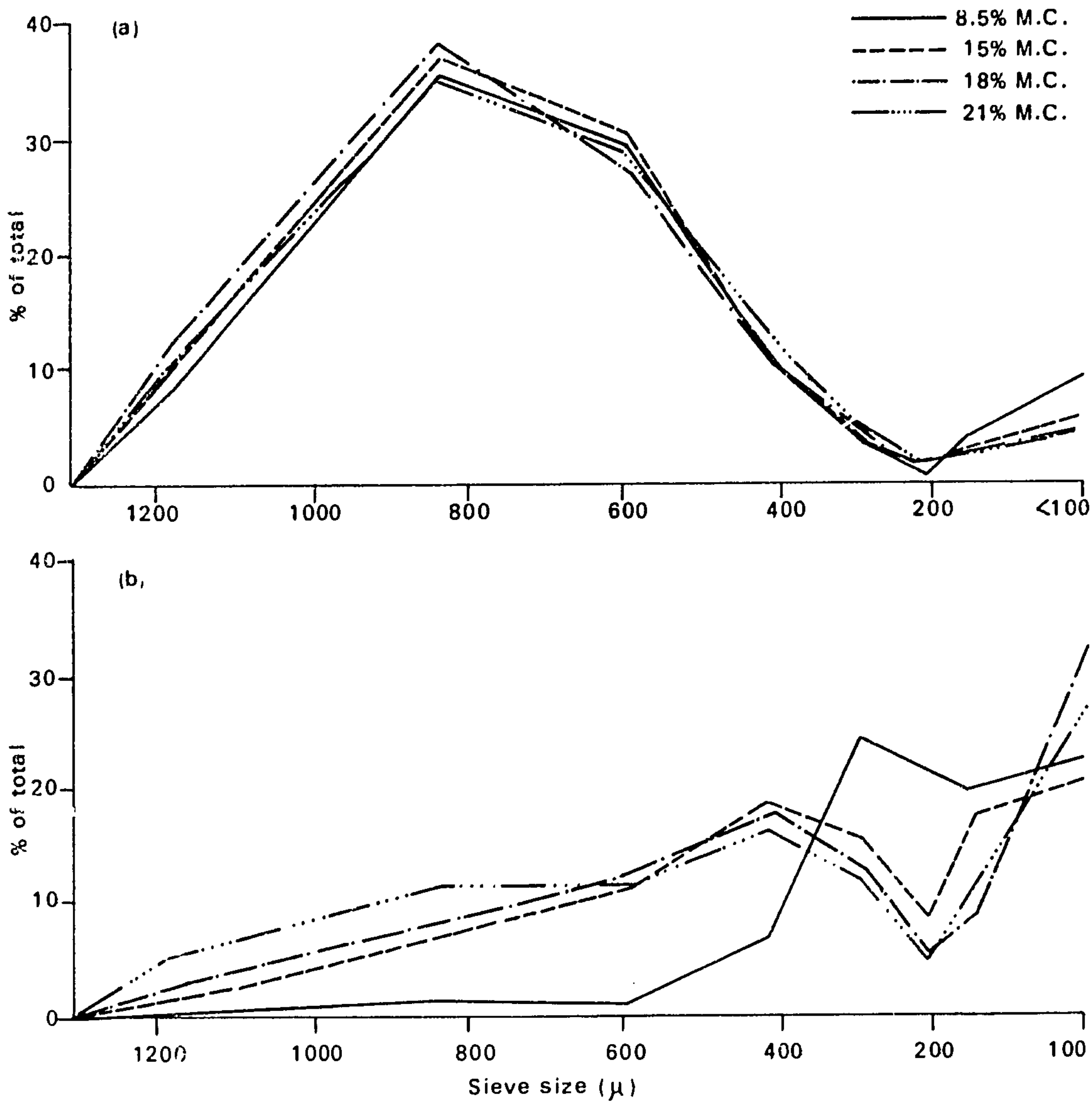

Figure 9. Particle size distribution of tempered Sudan Yellow millet ground in a Hobart mill (a). The distribution of the coarse fraction (> 417μ) after passing through smooth rolls is shown in (b).

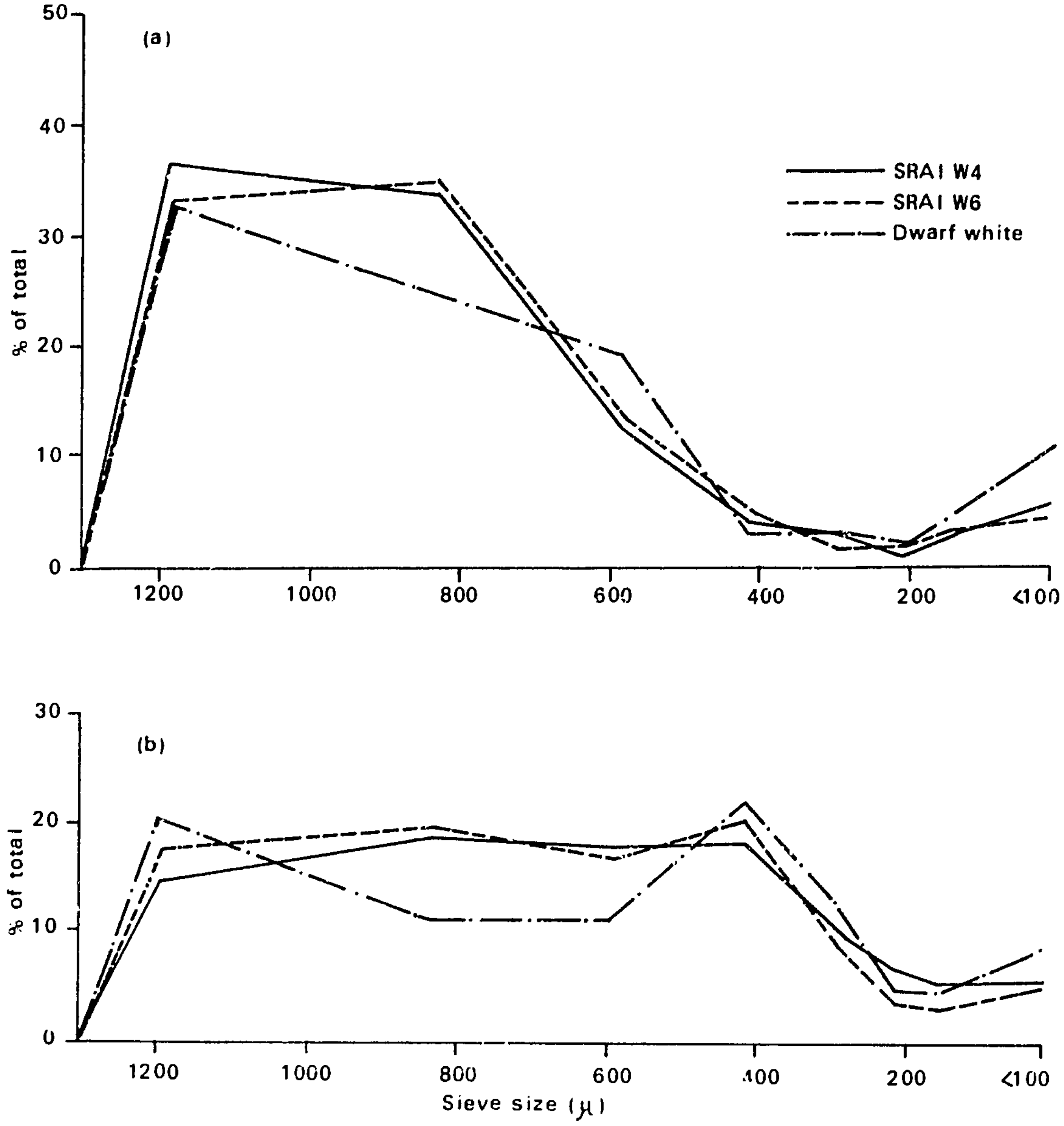

Figure 10. Particle size distribution of tempered sorghum ground in a Hobart mill (a). The distribution of the coarse fraction (> 417μ) after passing through smooth rolls is shown in (b).

Thermal Properties of Sorghum Starches

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Summary

The differential scanning calorimeter (DSC) and the Brabender visco/amylo/graph were used to measure the thermal properties of sorghum starch, pure endosperm, and flour. The gelatinization temperature of the waxy starch was higher than that of the nonwaxy starch in measurements by the DSC, while the pasting temperature or apparent gelatinization temperature of the nonwaxy starch was higher by the visco/amylo/graph. Sorghums with WxWxWx, WxWxwx, Wxwxwx, and wxwxwx alleles were compared. The gelatinization temperature of sorghum starches measured with the DSC increased as the number of waxy alleles (wx) in the endosperm increased. However, it appeared that a two waxy allele (Wxwxwx) difference was required before the differences in the gelatinization temperatures were significant. The specific heat of sorghum starch can be accurately measured on finely milled flour. The swelling and solubility properties of sorghum starches and starch cooking properties are good indicators of textural properties of food made from sorghum. However, these properties can change if the environment in which the plant grows and matures changes.

The differential scanning calorimeter (DSC) has been used to determine the thermal properties of a wide variety of foods including cereal based products. The quality of sorghum may be related to differences in gelatinization temperature, specific heat and other properties.

The DSC is an effective way of obtaining objective information on thermal properties. It is not useful for routine analyses of breeding samples because it costs too much and uses relatively small (<0.1g) samples.

The physical properties of starches change upon heating or cooling especially in the presence of moisture. Kulp and Lorez (1981a and 1981b) were able to enhance the bread-making properties of potato starch and decrease that of wheat starch by treating the starches with heat under controlled low moisture conditions. The kinetic studies of McIver et al. (1968) and Colwell et al. (1969), indicated that nucleation was instantaneous during retrogradation of gelatinized starch at any storage temperature. Biliaderis et al. (1980) observed double endothermic peaks and lower gelatinization energies for starches heated with low moisture content. Wada et al. (1979) reported that the gelatinization temperature of unisolated starch was higher than that of the isolated starch. Bathgate and Palmer (1972) reported that small barley starch granules had higher gelatinization temperatures than the larger granules.

Sorghum is the staple food in many areas of the world, including Africa and Asia, and it is of growing importance as a replacement for maize in traditional foods such as *tortillas*, *tô*, and *ogi*. However, little is known about the thermal properties of sorghum starches and flours. Since sorghum is an important food source, a knowledge

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of the thermal properties of sorghum starches and flours will help to determine why certain sorghum cultivars produce sorghum porridges with excellent quality while others do not. Once a basic difference in property has been demonstrated, a simple technique to measure it might be developed.

This study was designed to measure with the differential scanning calorimeter the gelatinization temperature, specific heat, and gelatinization energy of sorghum starches; to determine the effect of endosperm type on gelatinization temperature, and to evaluate the effects of moisture and temperature on the specific heat of sorghum starch. The cooking properties of sorghum starch and flour were measured with the visco amylo graph and with the swelling power test.

Materials and Methods

Sorghum Samples

Sorghum samples used in this study included: 25 varieties from the International Food Quality Trials (IFQT) grown at ICRISAT Center, Hyderabad, India, in the postrainy seasons of 1979 and 1980, S-29 and 940 sorghums grown at ICRISAT Center, Kamboinse, Upper Volta, in 1980, Kafir sorghums with nonwaxy (WxWxWx), heterowaxy (WxWxwx and Wxwxwx), and waxy (wxwxwx) endosperms, and a commercial sorghum flour (Krause Milling Company, 4222 West Burnham, Milwaukee, WS53215). The samples represent a wide variation of sorghum colors, endosperm texture, and endosperm types.

Starch Isolation

Starch was isolated by the wet milling procedure of Norris and Rooney (1970) and incubated with pronase until protein was less than 0.3%. Then, the pure starch was defatted with several 24-hr washings in methanol and dried overnight in a forced air oven at 60° F.

Pure Endosperm

The pure endosperm of the Kafir series was obtained by pearling the grain in a Strong Scott barley pearler fitted with a carborundum wheel for 30 sec, and then carefully scraping the germ and residual pericarp tissues off the endosperm with a razor blade. The pure endosperm was ground in a Udy cyclone mill to pass through a 2.54-mm screen.

Moisture content of starch and pure endosperm was measured by the AACC method (AACC 1976). The method of Ring et al. (1980) was used to measure the amylose content of starch and endosperm.

Measurement of the swelling power and solubility of starch was conducted as described by Leach et al. (1959) as modified for small samples. Starch (0.3g) was weighed into 40-ml glass centrifuge tubes with screw caps. Exactly 30 ml distilled water was added from a burette and the cap was screwed on tightly. Then the tube was shaken in a water bath, at a preset temperature, at a rate that kept the starch particles suspended. Shaking was for 30 min with gentle manual swirling of the tube at 10-min intervals to ensure complete suspension of the particles. At the end of 30 min of shaking, the cap was removed, the tube was wiped dry on the outside and centrifuged at 2200 rpm for 7 min. The supernatant was carefully decanted into a 100-ml flask, filled to volume and a 20 ml aliquot was pipetted into an aluminum weighing dish and dried at 130° C for 3 hr. The weight of the solubles was determined and used to calculate solubility. Weight of the paste in the tube was also determined and used to calculate swelling power. Starch swelling power and solubility was calculated using the formula by Leach et al. (1959).

Measuring Thermal Properties with Differential Scanning Calorimetry

Gelatinization Temperature Range

Starch and pure endosperm of known moisture contents were mixed with appropriate amounts of distilled water and scanned on a differential scanning calorimeter 2 (DSC 2) (Perkins Elmer Corporation, Norwalk, Conn.), from 318° K to 363° K. Scanning rate was 10° K min at a sensitivity of 2 m cal sec. Nitrogen, at 20 psi pressure was used to flush the sample chamber and circulating water was used to cool the DSC head back to 318° K after each scanning. Indium (melting point 429.8° K) was used as a standard to calibrate the equipment and transition temperatures, T_o, T_p, and T_e, representing onset, peak, and end gelatinization temperature, respectively, were read on the thermogram.

Gelatinization Energy

The gelatinization energy (-ΔH cal/g) was determined by measuring the area under the peak with a planimeter and comparing it to the area obtained for the transition of indium, which has a melting transition of 6.79 cal/g. The calculation was:

$$\Delta Hs = (\Delta Hin) \frac{(As)}{(Ain)} \frac{(Win)}{(Ws)}$$

where ΔHs is the transition energy of the sample (cal/g), ΔHin is enthalpy change for melting of indium (6.79 cal/g), As is the area under sample transition (planimeter units), Win is the weight of indium in mg, and Ws is dry weight of sample in mg.

Specific Heat

Three separate DSC thermograms were required for the determination of specific heat of sorghum. These were: thermograms for sample and its container, empty sample container, and standard material (sapphire) and its container. Scans were subdivided into 10° K portions and the area under each portion was measured with a K&E planimeter. The specific heat of the sample was calculated from the equation:

$$C_p = \frac{C_p \text{ ref (WR/WS) (SAM area + BAS area)}}{\text{(REF area + BAS area)}}$$

where: C_p is specific heat of the sample in cal/g°K, C_p ref is specific heat of reference (sapphire), WR is weight of reference sample (sapphire) in mg, WS is weight of sample in mg, REF area is area under thermogram for reference in planimeter units, and BAS area is the area under the thermogram for the empty pan in planimeter units. The SAM area is area under sample thermogram in planimeter units. The specific heat of distilled water by this method ranged from 0.978 cal/g° K at 343° K to 1.035 cal/g° K at 443° K, after corrections had been made for differences in pan weights between the empty (baseline) pan and the reference and sample pans, respectively.

Amylogram

The Brabender visco/amylo/graph (Type VAV, model 3042, C. W. Brabender Instruments Inc. 50 E Wesley Street, South Hackensack, New Jersey) was used to measure the cooking properties of isolated starches and flour from the International Food Quality Trial (IFQT) sorghums. A10%(dwb) starch slurry (4.5g starch in 42 mls of distilled water) was cooked in a small amylograph bowl at 75 rpm using a 125 mcg sensitivity cartridge. A 12% (dwb) sorghum flour (5.44 g in 42 ml H_2O) was also cooked under similar conditions.

Results and Discussion

The swelling power and solubility at 80° C of starches from 1979 IFQT sorghum samples are presented in Table 1. The starch swelling power is highly correlated with solubility (r = 0.80). However, both swelling power and solubility are highly negatively correlated with amylose content of the starches, r = −0.93 and −0.73, respectively. This is in agreement with the findings of Schoch (1969), Elder and Schoch (1959) and Leach (1965), where the linear fraction reinforced the molecular network within the starch granule and prevented starch solubilization and swelling.

Swelling and solubilization properties of starch from S-29 and 940 sorghums were evaluated to determine whether differences in the stiffness of *tô* (an African stiff porridge food) observed for these sorghums (ICRISAT 1977), were due to the differences in the swelling and solubility patterns of the starches (Figs. 1 and 2). Starch from the two sorghums exhibited the two-stage swelling pattern observed in maize and sorghum starches (Leach 1965; Elder and Schoch 1959; Schoch 1969). However, the starch from S-29 sorghum was higher in solubility and swelling than starch from 940 sorghum at 90° C. This probably explains the firm *tô* observed for flour from S-29 compared with *tô* made from 940 flour. The differences existed only at 90° C. Thus, the swelling power of the starches from the IFQT samples should be repeated using a temperature of 90° C or higher.

Effect of Endosperm Type on Gelatinization Temperature

The onset (To), peak (Tp), and end (Te) gelatinization temperatures for the waxy, heterowaxy, and nonwaxy starches, and pure endosperm of Kafir sorghum as measured on the DSC are presented in Table 2. The gelatinization temperatures of 26 other nonwaxy sorghums including S-29, and 940, obtained with the DSC are presented (Table 2). The gelatinization temperatures increased as the number of waxy alleles (wx) in the endosperm increased. The mean onset of gelatinization temperature for the nonwaxy sorghum starch was

Table 1. Swelling power and solubility properties of starches from 1979 IFQT sorghums.

Varieties	Swelling power[1]	Solubility[2]	Amylose %[3]
M-35-1	13.2 ± 0.9bcd*	8.8 ± 0.3cd*	24.9ab*
CSH-5	12.0 ± 1.8cde	7.2 ± 0.1efgh	24.0bcde
M50009	12.7 ± 0.8bcde	7.7 ± 0.2efg	23.1defg
M50013	13.2 ± 1.1bcd	10.1 ± 1.0b	22.9defgh
M35052	12.4 ± 1.2bcde	7.3 ± 0.2efg	23.1abc
M50297	12.6 ± 0.5bcde	5.8 ± 0.2ij	24.6abc
P721	12.6 ± 0.8bcde	6.9 ± 1.0fgh	22.9defg
CO4	12.8 ± 0.9bcde	7.5 ± 0.2efg	24.2efgh
Patcha Jonna	12.8 ± 0.3bcde	8.7 ± 0.4cd	22.1efgh
Mothi	12.6 ± 0.6bcde	8.1 ± 1.0def	22.9defgh
E-35-1	12.6 ± 1.6bcde	9.1 ± 0.5c	24.7abc
IS158op	22.5 ± 2.2a	14.9 ± 1.1a	4.5a
WS1297	11.6 ± 1.0e	7.0 ± 0.3fgh	21.6gh
Swarna	11.8 ± 1.1de	8.1 ± 0.3def	23.7bcde
S-29	12.4 ± 0.4bcde	6.4 ± 0.7ghi	24.0bcde
S-13	12.8 ± 1.7bcde	7.8 ± 0.2defg	23.7bcde
IS2317	13.6 ± 1.8bc	9.3 ± 0.2bc	22.8defg
IS7035	12.5 ± 1.1bcde	7.0 ± 0.8fgh	23.5bcde
IS7055	12.4 ± 0.4bcde	7.0 ± 0.6fgh	21.5h
IS9985	12.7 ± 0.7bcde	6.3 ± 0.2hi	23.6bcde
IS8743	12.8 ± 1.0bcde	9.2 ± 0.1bc	22.3fgh
Dobbs	13.8 ± 1.0b	8.4 ± 0.1cde	23.3cdef
CS3541	13.2 ± 1.2bcd	4.7 ± 0.5j	21.6gh
Segaolane	11.8 ± 0.9de	7.3 ± 0.5efg	22.5efgh
Ouga Market-1	12.5 ± 0.7bcde	7.2 ± 0.2efgh	25.7a

1. Swelling power was determined at 80° C and is a mean of four replications.
2. Solubility was determined at 80° C and is a mean of eight replications.
3. Amylose was measured as the percent of pure isolated starch on a dry weight basis, and is a mean of three replications.
* Within each column values with the same letter are not significantly different.

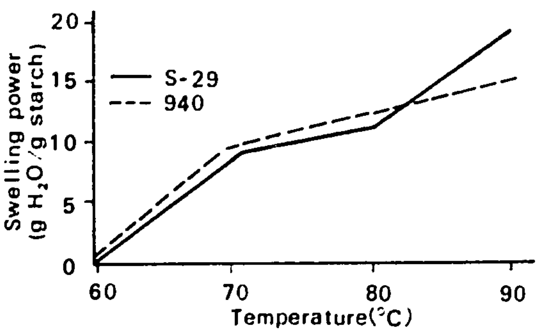

Figure 1. Swelling power of S29 and 940 sorghum starches.

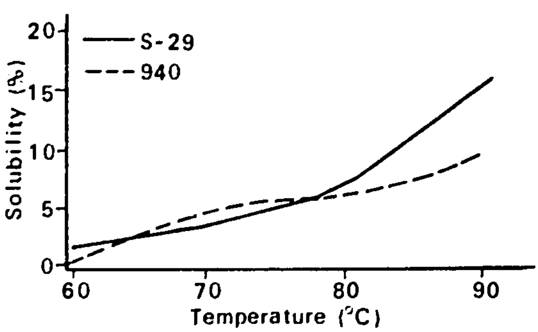

Figure 2. Solubility of S-29 and 940 sorghum starches.

Table 2. Gelatinization temperatures and gelatinization energy of sorghum starches and ground endosperm determined with the Differential Scanning Calorimeter (DSC).

	Gelatinization temperatures[1]						Gelatinization[2] energy	
	Pure endosperm			Isolated starch				
	To_1	Tp_2	Te_3	To	Tp	Te	−ΔHg cal/gm	% Amylose[3]
Kafir-1 (WxWxWx)	72.9±1.0	75.7±1.0	79.2±1.7	72.6±0.9	75.3±0.9	78.9±1.0	3.11	23.9
Kafir-2 (WxWxwx)	72.9±0.7	75.4±0.4	78.1±0.5	73.0±0.6	76.5±0.6	80.0±0.5	3.48	23.9
Kafir-3 (Wxwxwx)	74.3±0.7	78.0±0.5	80.9±0.5	75.8±0.5	78.4±1.1	81.6±1.0	4.07	19.6
Kafir-4 (wxwxwx)	73.2±0.3	77.6±0.1	81.9±0.9	75.6±0.1	78.2±0.2	81.1±0.4	4.03	3.5
IS-158 (wxwxwx)	-	-	-	73.5±0.7	77.6±0.2	82.8±0.9	3.49±0.12	-
S-29 (WxWxWx)	72.5±3.4	74.8±2.9	77.5±2.3	72.1±0.5	74.3±0.3	77.0±0.7	-	-
940 (WxWxWx)	72.0±3.6	74.3±3.1	76.3±2.5	71.9±0.3	74.0±0.3	77.6±0.8	-	-
IFQT Sorghums[4] (WxWxWx)1979	-	-	-	71.0±1.0	75.6±0.9	81.1±1.1	3.21±0.39	23.3±1.7

1. Gelatinization temperatures as determined by the DSC are means of four replications.
2. Gelatinization energy values are means of eight replications.
3. Amylose percentages are means of three replications on isolated starch.
4. Mean of 24 nonwaxy samples of sorghum starch isolated from the International Food Quality Trials (IFQT) grown in 1979.

71.0, and all the starch was gelatinized at 81.1° C. The gelatinization temperature of the waxy Kafir starch ranged from 75.6 at the onset to 81.1° C at the end of gelatinization, while waxy IS158 starch had a gelatinization temperature range of 73.5 to 83.8° C. Data on the Kafir series indicated that the genotype of the grain must be at least two alleles apart, (WxWxWx to Wxwxwx or WxWxwx to wxwxwx), before a significant difference can be detected in gelatinization temperature. Wootton and Bamunuarachchi (1979a), reported that the gelatinization temperature of waxy maize was higher than that of high amylose maize measured with the DSC. Biliaderis et al. (1980) reported that the gelatinization temperature (pasting temperature) of waxy maize was lower than that of high amylose maize. However, Biliaderis et al. used an 8% starch suspension with the amylograph so the correct term should have been pasting temperature. At this concentration, the waxy starch with the higher swelling power thickens before the nonwaxy and the viscosity sensor picks up the change in viscosity. In this study when the amylograph was used, we also observed a lower apparent pasting temperature for the waxy sorghum than the nonwaxy sorghum (Table 3). However, the DSC data is a calorimetric measure of the enthalpy change in the starch granules and would be a more accurate measure of gelatinization temperature than the amylograph.

Table 3. Effect of starch concentration on gelatinization energy (−ΔHg) for nonwaxy Kafir starch.

Concentration	Mean[1] −ΔHg(cal/g)	Grouping[2]
15%	4.62	A
20%	4.50	A
12%	4.45	A
25%	3.71	B
8%	3.11	C
3.33%	2.77	D

1. Data are means of at least eight replications.
2. Means with the same letters are not significantly different at the 95% confidence level.

Gelatinization Temperature of Isolated Versus Unisolated Starches by the Differential Scanning Calorimeter (DSC)

The gelatinization temperature of the isolated starch as measured by the DSC was not significantly different from that of the unisolated starch in the endosperm. The mean gelatinization temperatures for the isolated Kafir starches were 74.5, 77.1, and 80.4° C for the onset, peak, and end gelatinization temperatures, respectively. This is contrary to the observations of Wada et al. (1979), who showed with the DTA that the gelatinization temperature of isolated potato, Indian lotus, taro, and sweet potato starches was lower than the gelatinization temperature of the unisolated starches. However, Wada et al. used chunks of samples as opposed to the finely milled endosperm samples used in this study. The distribution of heat to the endosperm was more efficient in our experiment than in theirs because of the smaller particle size of our flour and this would explain the differences in observations.

Gelatinization Energy

The mean gelatinization energy for the nonwaxy IFQT sorghum starches was 3.21 ±0.39 cal g (Table 2). This was not different from the gelatinization energy of the nonwaxy Kafir starch (3.11 cal g). The gelatinization energy of the waxy starches, 3.49 and 4.03 cal g for IS158 and waxy Kafir sorghum, respectively, was higher than the gelatinization energy of the nonwaxy starches. The difference in the gelatinization energy of the nonwaxy (WxWxWx) and the heterowaxy (Wxwxwx) starches was significant, as was the difference between gelatinization energy of the waxy (wxwxwx) and heterowaxy (WxWxwx) Kafir starches.

Effect of Starch Concentration on Gelatinization Energy

Table 3 summarizes the effect of concentration on the gelatinization energy of nonwaxy Kafir starch. It appeared that water was not a limiting factor until starch constituted 25% of the mixture. As water percentage decreased, the gelatinization energy decreased further to a low of 2.77 cal g at 33.3% starch concentration. The decrease in gelatinization energy associated with increasing starch concentration indicates that gelatinization was incomplete in the absence of adequate moisture content. Donovan (1979), Stevens and Elton (1971), Wootton and Bamunuarachchi (1979a, 1979b) and Biliaderis et al. (1980) also reported a decrease in gelatinization energy of starches when the starch concentration was above a critical point. The critical concentration would be different in starches from different sources.

Specific Heat of Sorghum Flour as a Function of Temperature and Moisture

The specific heat of sorghum flour increases as moisture content and temperature increase (Figs. 3 and 4). The effect of temperature on the specific heat is more obvious in flour with low moisture content (3.0 and 9.3%), than in flours with higher moisture contents. This might be due to the lowered efficiency of heat transfer caused by the limited moisture content, which translates into higher apparent specific heat. The specific heat of starch isolated from the flour was not significantly different from that observed for the flour at comparable moisture content. This implies that the apparent specific heat of the flour was actually the specific heat of the starch in the flour; protein and oil in the flour did not significantly affect the specific heat of the starch as measured by the DSC.

Cooking Properties of Sorghum Starches

A summary of the Brabender visco amylo graph cooking properties of starch and flour of sorghums from the 1979 and 1980 International Food Quality Trials (IFQT) is presented in Table 4. Figure 5 contains the mean cooking properties of starch and flour from the 1980 IFQT sorghums. The pasting temperature of the isolated nonwaxy sorghum starches ranged from 70.0 to 73.4°C with a mean of 71.9°C for samples from the 1980 IFQT sorghums while waxy sorghum starch from the same samples was 69.0°C. The mean gelatinization temperature for nonwaxy sorghum flour was 81.2 compared to 71.5°C for the waxy. This is in agreement with other determinations of the pasting temperature of starches, using the amylogram (Biliaderis et al. 1980; Schoch 1969). The pasting viscosity was higher in the waxy than in the nonwaxy isolated sorghum starch because the waxy sorghum starch contained no linear fraction to restrict its swelling. However, the starch was very unstable and thins extensively due to its high fragility. The waxy sorghum starch did not have a significant setback viscosity because it lacks the linear fraction, while the nonwaxy sorghum starch and flour retrograded strongly and were stable to stirring at 50°C.

The visco amylo graph cooking properties of

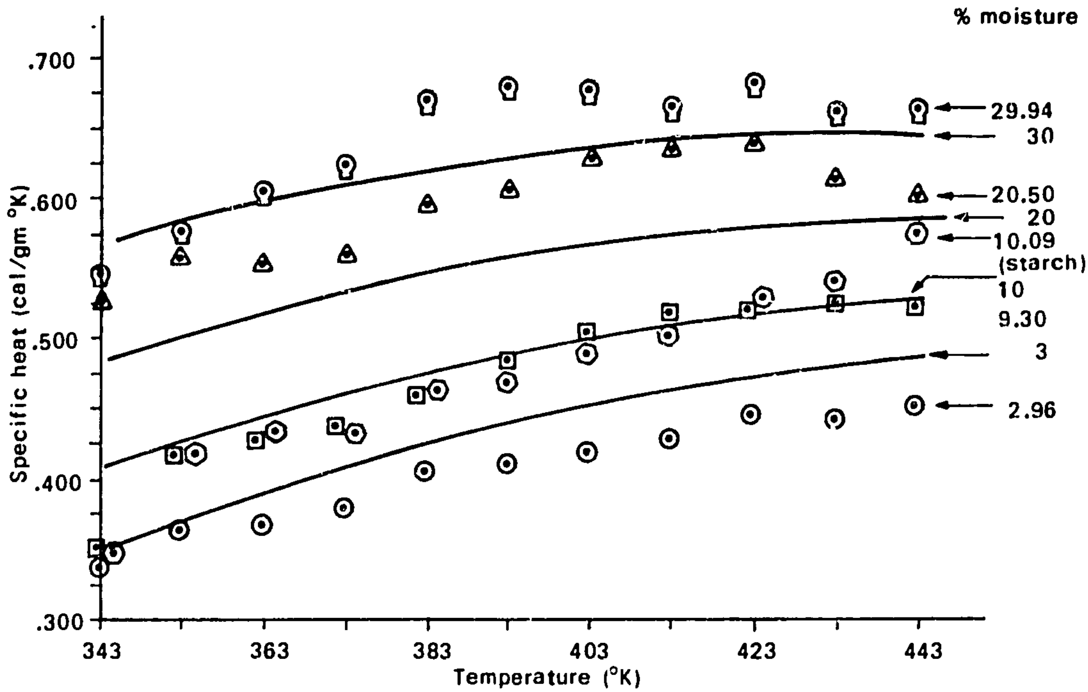

Figure 3. Specific heat values for sorghum starch and flour at different moisture levels. Note: Points shown represent experimental values. Lines drawn are calculated theoretical values.

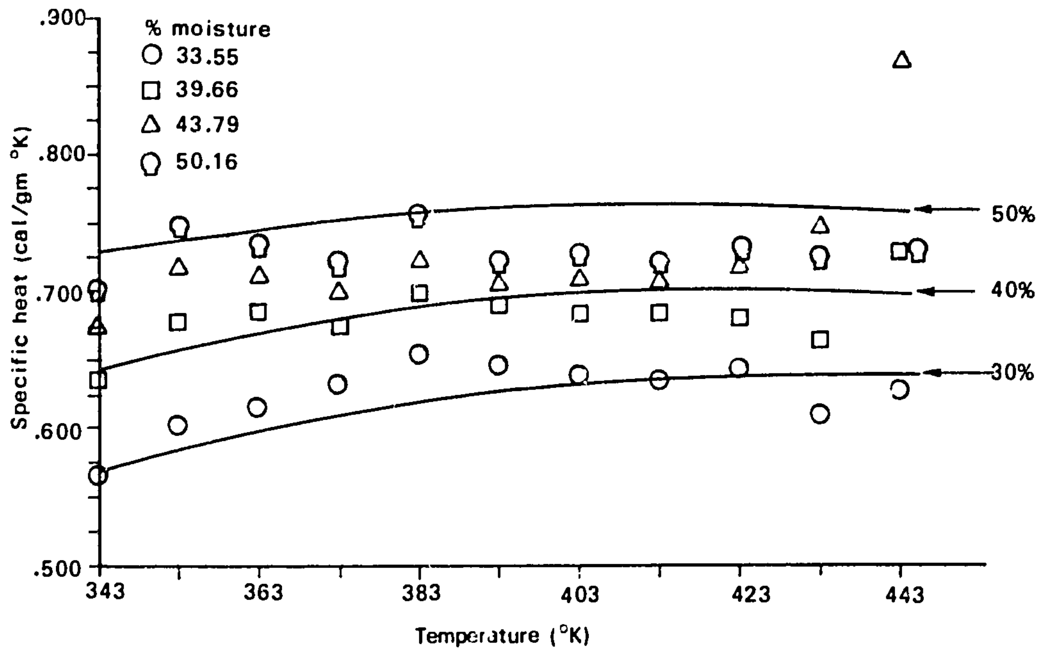

Figure 4. Specific heat values for sorghum flour at different moisture levels. Note: Points shown represent experimental values. Lines drawn are calculated theoretical values.

isolated sorghum starch differ from that of the unisolated sorghum starch in the flour (Table 4). The mean pasting temperature of 1980 nonwaxy IFQT sorghum flours was about 10° C higher than the mean pasting temperature of the isolated starch. The difference in the pasting temperature of isolated and unisolated starch was due to restriction of swelling by the cell walls and endosperm protein matrix. This restriction delays the recognition by the amylograph sensor, of the

Table 4. Mean visco/amylo/graph cooking properties[1] of isolated sorghum starches and flour in the International Food Quality Trials (IFQT).

Samples	Pasting temperature (°C)	Pasting viscosity (BU)	Viscosity		
			1 hr at 95°C	at 50°C	1 hr at 50°C
1979 Nonwaxy IFQT Starch	74.6 ± 1.9	957 ± 129	488 ± 85	818 ± 137	896 ± 127
N = 24 Range	68.5 to 77.5	750 to 1170	390 to 675	610 to 1030	700 to 1130
1980 Nonwaxy IFQT Starch	71.9 ± 0.9	788 ± 78	430 ± 55	930 ± 153	1323 ± 265
N = 24 Range	70.0 to 73.4	640 to 970	320 to 520	675 to 1250	780 to 1915
1980 Nonwaxy IFQT Flour	81.2 ± 3.8	504 ± 110	351 ± 52	939 ± 124	743 ± 82
N = 24 Range	76.0 to 88.0	265 to 720	240 to 410	780 to 1280	620 to 925

1. Mean viscosity was in Brabender units (BU).

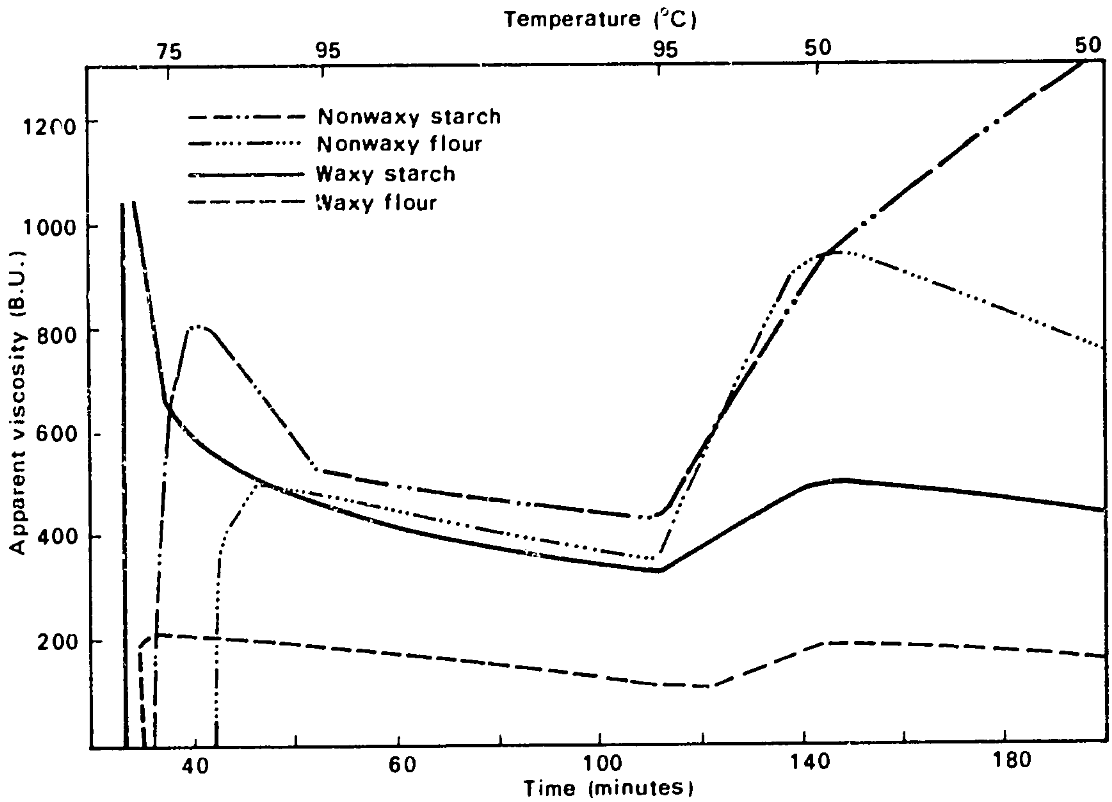

Figure 5. Mean visco amylo graph cooking properties of starch and flour from the 1980 IFQT sorghums.

pasting viscosity in the nonwaxy sorghum. However, the swelling power of the waxy starch was sufficient to offset the restriction. Thus the gelatinization temperature of starch in the waxy sorghum flour was not significantly different from that of the isolated waxy starch. Also some heat is required to raise the temperature of the other fractions of the flour as it cooks which results in a longer time for the starch to reach pasting viscosity and translates into a higher pasting temperature for the unisolated starch.

Range of Pasting Temperatures

The effect of starch isolation on the pasting temperature range is presented in Figure 5. Isolated starches have narrower pasting temperature ranges than the unisolated starches. Heat transfer to the pure starch is direct and fast and there is little difference in the pasting temperatures of the granules. The sharpness of the pasting peak of sorghum flour is dependent on the amount of other fractions present, the size of the endosperm particles constituting the flour, and the strength of the endosperm protein matrix. Starch granules from small flour particles will tend to paste before those in the larger particles since the heat reaches the center of the smaller flour particles faster. Differences in the amount of damaged starch and endosperm particles during milling are important and undoubtedly affect the cooking properties significantly. More work is needed to determine these effects.

Pasting Viscosity

As expected, pasting viscosity was highest for the isolated waxy sorghum followed by isolated nonwaxy sorghum starches. The lowest pasting temperature was observed in the waxy sorghum flour. While the waxy sorghum starch has higher swelling power than the nonwaxy starch in the free swelling state, the nonwaxy sorghum starch can better withstand the external pressure imposed by the endosperm matrix, since it is not as fragile as the waxy starch on pasting, and thus the pasting viscosity of the nonwaxy flour was higher than that of the waxy. The effect of the endosperm matrix on the stability and retrogradation properties of isolated versus unisolated starches was more pronounced and uniform in the waxy than in the nonwaxy sorghums. The nonwaxy sorghum flour paste was less stable after setback. This was because other flour fractions such as protein, fat, and endosperm cell wall prevented the formation of a strong micellar bond between the linear fractions in the paste resulting in a breakdown of the hydrogen bonds as the paste is sheared. There was no significant correlation between the cooking properties of the isolated starch and flour.

Effect of Environment on Starch Cooking Properties

The cooking properties of starch from the International Food Quality Trial sorghums grown at ICRISAT Center, Hyderabad, India in the postrainy season of 1979 was compared with the cooking properties of starch from the same varieties grown in the same place and same season in 1980 (Table 4). The mean pasting temperature, pasting viscosity, setback viscosity and stability of starch pastes from these sorghums were significantly different in the 1979 and the 1980 crops as was the *tô* (an African stiff porridge food) prepared from their flours (Da et al. 1981). Ring et al. (1981) observed that the amylose contents of starch from the 1979 and 1980 IFQT sorghums were significantly different and concluded that the environment affects the amylose content of sorghum starches. We believe that the difference in the amylose content is partially responsible for the differences observed in the cooking properties of these sorghums. But, amylose content is not a good predictor of *tô* quality of sorghum flour.

Conclusion

The differential scanning calorimeter and the Brabender visco amylo graph were used to evaluate the thermal properties of isolated and unisolated sorghum starches. Results show that the gelatinization temperature of isolated sorghum starch was the same as that of the finely milled endosperm when measured with the DSC. However, the pasting temperature of sorghum flour was 10° C higher than that of isolated starch when measured on the Brabender visco amylo graph. The disparity in the results was due to differences in the parameters that the equipment was measuring. The Brabender visco amylo graph records the pasting viscosity which is apparent gelatinization temperature and is affected by starch concentration even when there is enough moisture for complete gelatinization. The DSC measures the enthalpy change in the starch and is a more exact quantification of gelatinization temperature than the pasting temperature of the amylograms. The mean gelatinization temperatures of waxy and nonwaxy starches of the IFQT sorghums were not significantly different by both methods of measurements.

The gelatinization temperature and gelatinization energy of sorghum starch and endosperm increased as the waxy gene (wx) in the starch increased. A difference of two waxy alleles (Wx or wx) is required before the difference in gelatinization temperature is significant.

The specific heat of sorghum starch was the same as that of the flour from which it was extracted; therefore, starch isolation and purification might be unnecessary to obtain a good estimation of the specific heat of sorghum starch. The specific heat of sorghum starch increases as the temperature and moisture of the sample increases.

The swelling and solubility properties of sorghum starches are in general correlated with the amylose content of the starch and might be good indicators of the textural properties of food made from sorghum. However, these properties are affected by the environment and change from year to year in grain from the same variety if there is a significant difference in the environment during growth and maturation of the sorghum variety.

Acknowledgment

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Quality of Sorghum for Use in Indian Foods

H. S. R. Desikachar and A. Chandrashekar*

Summary

Sorghum varieties with a low gelatinization temperature (GT), high peak viscosity (PV) and setback, and high water uptake give doughs with better rolling quality. Adequate water retention in the roti *after baking is necessary for good eating quality; otherwise the product may be too dry and chewy. Addition of pregelatinized starch or puffed cereal flours to sorghum flour increases its water absorption capacity and thus improves the rolling quality of dough and eating quality of the* roti.

Overstickiness is an undesirable characteristic in mudde. *It has been found that varieties with high GT and low PV and setback can give* mudde *with adequate consumer acceptability.*

Sorghum semolina has high resistance to water absorption during cooking as compared with wheat or maize semolina, the reasons for which need further study. Size reduction of the semolina or extraction with ter. butanol improves hydration properties. Heat processing of sorghum increases cold slurry viscosity but decreases hot paste viscosity, while germination brings about a considerable reduction in the viscosity. Varietal differences in puffing and cooking qualities of sorghum have been noted and studied.

There are two aspects to the problem of quality in sorghum. One relates to differences in sorghum varieties with regard to various desired culinary uses. The other relates to a comparison of sorghum with other grains for food uses. Some work relating to sorghum food quality carried out recently at the Central Food Technological Research Institute (CFTRI), Mysore is reviewed here.

The main use of sorghum in India is as a dry pan cake (*roti* or *chapati*) prepared from a whole-meal flour. To a smaller extent, the flour is simply cooked into a thick semisolid or solid porridge called *mudde, kali, sankati* or dumpling. A limited quantity is used in the form of puffed and malted products.

Roti Quality

Differences in *roti* quality consist of two distinct aspects: (a) the ease with which the dough can be rolled into thin pancakes for baking, and (b) the eating quality of the prepared *roti* in respect of softness, chewing property, dryness, absence of bitterness, etc. Although varietal differences have been known to consumers and breeders alike, the reasons for such differences have not been fully understood.

Our recent studies at CFTRI have shown that the plasticity of sorghum dough mostly arises from the gelatinization of the starch when the dough is prepared with hot or boiling water. When the dough is made with cold water, adhesiveness is much less and difficulties are experienced while rolling the dough into thin *rotis*.

Generally, the extent of heat modification of the starch when the dough is made with boiling water determines its rolling behavior. Our studies have shown that the gelatinization temperature (GT), paste viscosity (PV), water uptake of the flour, and above all, starch damage during grinding into flour affect rolling quality of the dough. Varieties that have a high water uptake, low GT, and high peak viscosity and setback have a good rolling score (Table 1). Varieties which exhibited high water uptake at 70° C were also those which had high starch damage during milling (Table 2).

Studies with sorghum *roti* as well as *rotis* prepared from wheat, maize, and pearl millet

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Table 1. Viscoamylographic[a] and textural properties of sorghum in relation to dough rolling properties.

Group	Rolling score of dough	Brabender Viscoamylographic data: Gelatinization temperature (GT) (°C)	Peak viscosity (PV) (BU)[b]	Setback (BU)	Dough characteristics: Water absorption (%)	Texturometer values[c] (p_1/s_1)
I	1 (poor)	74.8[d] ±1.5(9)	218 ±19(7)	425 ±40(6)	103 ±2.2(8)	3.53 ±0.3(9)
II	2-3 (moderate)	72.4 ±0.8(18)	266 ±13(16)	572 ±21(16)	107 ±1.7(10)	4.63 ±0.8(8)
III	>3 (good)	70.7 ±0.6(18)	396 ±18(13)	630 ±32(13)	106 ±1.5(11)	5.32 ±0.5(18)

Test for significant differences

	GT	PV	Setback
Group I[e] vs Group III	*	**	*
Group I vs Group II	NS	NS	*
Group II[f] vs Group III[g]	NS	**	NS

* Significant at 1% level; ** Significant at 0.1% level; NS = Not significant.

a. Viscoamylography was done on 10% slurries of polished—60 B.S. mesh—sorghum flour.
b. BU = Brabender units.
c. Texturometer values are the ratio of peak p_1 (resistance to flow of the dough) and corresponding dip s_1 (stickiness of the dough) in General Foods Texturometer. This would represent adhesiveness of the dough.
d. All figures are mean ±S.E. Figures in parenthesis indicate number of varieties on which tests were done.
e. Group I—Patcha Jonna, Hy2255, My316-5, E-35-1, Patancheru, P-721, SPV105, SB1079 (caught in rain), CS3544.
f. Group II—BP53, GPR-370, A2273, M35602, Moti, IS1584, My3599, My35626, CS3541, SB1085, Rati, SB 1079, SB2612, M3605, IS1054
g. Group III—M-35-1, CSH-8, M-64-77, CSH-1, CSH-6, M35608, IS9327, E116, IS11025, CSH-5, SB1103, SB1066, Local.

indicated that a definite relation exists between eating quality of *roti* and its moisture content at the time of consumption. An optimal moisture content gives *rotis* good acceptability. Higher moisture tends to give a soggy product, while moisture less than the optimum may give *rotis* that are dry, tough, and even chewy and leathery (Table 3). A dry chewy product requires unnecessarily long mastication for consumption.

There are enormous differences in the water uptake of dough from different ceral grains. Maize has the highest water uptake; wheat and millet have low water uptakes. Sorghum comes in between maize and wheat (Table 3). We have some data to show that the softness rating of *roti* in sorghum varieties may be related to the dough water uptake. Poor quality sorghum flours with a low water uptake in dough may be upgraded by adding gelatinized starch, puffed cereal flours, or maize flour, which increase water uptake of the dough. Also after the *roti* is prepared, its eating quality can be improved by a small quantity of water sprinkled on it and allowed to equilibrate.

It would be preferable to breed varieties that have an inherent ability to hold more water while the dough is being made. Incidentally, *rotis* that are not acceptable and appear dry because of low moisture can be made acceptable by reducing the moisture in the *roti* to a level sufficient to make the *roti* crisp and friable. Such *rotis* could even be ground to a coarse powder for consumption.

Dumpling (*Mudde*)

Dumpling, or *mudde*, is another form in which sorghum is consumed in certain parts of India and Africa. A desirable characteristic for *mudde* is that

Table 2. Starch damage, water uptake at 70°C, and dough rolling scores of sorghum varieties.

Variety	Enzymic starch damage* (OD)	Water uptake 70°C	Rolling score
SB2401/kharif	0.60	3.80	2.5
SB1079/rabi	0.60	3.00	4.5
SB2401/rabi	0.62	4.73	3.5
SB1079/kharif	0.57	3.45	1.5
SB1066/rabi	0.85	6.02	4.0
CS3544	0.57	3.75	1.0
SB1085/kharif	0.65	4.95	3.5
SB1103/kharif	0.65	4.55	4.0
Local jowar	0 58	4.45	4.0
SB901	0.60	4.40	3.5
SB1066/kharif	0.65	5.00	4.0
CSH-5	0.67	6.09	4.0
CS3541	0.64	4.36	4.0
SB1085/rabi	0.55	4.70	3.0

Test for correlation: Starch damage vs water uptake at 70°C*
Water uptake at 70°C vs rolling score*

* Significant at 1% level.

Starch damage measured in terms of reducing sugars released on treatment with glucoamylase for 15 hr as per methods of Bernfeld (1955) and Chiang (1977).

OD = Optical Density.

the cooked product should have sufficient adhesiveness to be rolled into a ball or cylinder, but it should not be oversticky when it is fragmented into small pieces for consumption. Our results have shown that those varieties that have a high GT, low PV, and low setback give *mudde* with good consumer acceptability. It may be recalled that these are the properties of varieties unsuitable for *rotis*. Therefore, varieties unsuitable for *roti* preparation generally stand a chance of being suitable for making *mudde*. Data relating *mudde* quality to tackiness and viscoamylograph characteristics are presented in Table 4.

Puffing Quality

Sorghum, like maize and paddy, can be puffed (popped) by subjecting it to high-temperature, short-time roasting. Varietal differences in puffing and volume expansion during puffing have been determined for common sorghum varieties (Table 5). The expansion in volume during puffing varied from 6 to 23 times among sorghum varieties. No definite relation between physicochemical characteristics and puffing expansion has been found. Puffed sorghum is extremely agreeable and crisp like popcorn when freshly made and may be a good method for popularizing sorghum. Puffed

Table 3. Characteristics of *chapati/roti* from cereal flours.

Material	Water required to make dough (g/100g flour)	Time of baking (sec)	Moisture % in *roti* after baking	Chewing characteristics of *roti*	Chewing count	Tearing characteristics
Sorghum	85.0	105	36.2	Requires moderate effort	26	Crumply and easy to tear
Wheat	65.0 (cold water)	90	31.0	Requires much effort	38	Slightly difficult to tear
Maize	105.0	120	40.2	Disperses in mouth	24	Crumply and easy to tear
Bajra	72.0	105	32.2	Requires much effort	30	Slightly difficult to tear
Wheat 60% + maize 40%	92.5	105	35.8	Requires moderate effort	34	Easy to tear to pieces
Wheat 60% + sorghum 40%	67.5	100	30.4	Requires moderate effort	35	Easy to tear

Source: CFTRI Annual Report 1977.

Table 4. Varietal differences in physical and organoleptic properties of sorghum *mudde* (dumpling).

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

a. Poor: BP53, Patcha Jonna, Patancheru, P721
Moderate: GPR370, GPR148, CSH-8, M64-71, CSH-1, CSH-6, A-2283
Good: H2269, M3165, E-35-1, M-7777

b. Tackiness is measured as the force required to release a plate in contact with the dough measured, as per method of Manohar Kumar et al. 1976.

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

BU = Brabender Units.

Table 5. Varietal differences in puffing expansion and viscosity of puffed sorghum.[a]

Variety and source	Volume expansion (ml/g)	Cold paste viscosity cps[b]	Cooked paste viscosity cps
CSH-1 (Dharwad)	6.2	88	1600
CSH-5 (ICRISAT)	7.5	30	1600
M-35-1 (ICRISAT)	7.6	45	2200
SB901 (Dharwad)	8.0	183	2080
NK300 (ICRISAT)	9.0	152	1520
323 × 1085 (Dharwad)	9.0	200	1880
Swarna (ICRISAT)	10.0	116	2320
SB2612 (Dharwad)	10.0	332	1920
SPV126 (Dharwad)	10.0	480	1600
CSH-5 (Dharwad)	11.0	220	1880
SB3541 (Dharwad)	12.5	144	1120
RA7 (ICRISAT)	14.0	790	6700
SB2415 (Dharwad)	14.0	124	1800
SPV 516 (Dharwad)	15.0	56	2200
SB1085 (Dharwad)	16.0	470	720
SPV354 (ICRISAT)	18.0	94	480
SPV351 (Dharwad)	19.0	160	400
SPV352 (ICRISAT)	22.0	700	1600
SB2401 (Dharwad)	23.0	550	520

Source: Chandrashekar, Malleshi, and Desikachar (unpublished).

a. Viscosities were determined on 15% slurries, using a Brookfield syncoelectric viscometer at a speed of 100 rpm and appropriate spindles.

b. Cps = cm/second.

sorghum flours have low viscosity when stirred into hot/boiling water and therefore lend themselves to preparation of weaning foods for babies where low paste viscosity and high caloric density would be required.

Cooking Quality of Sorghum Semolina

Semolina prepared from cereal grains is quite popular in India and Middle Eastern countries, with wheat semolina being the most popular. Such semolina can also be prepared from sorghum and maize. Their hydration properties however are different from that of wheat (Fig. 1). Their rate of water uptake is very slow, although the water uptake of flours or starches prepared from them is comparable and even better (Fig. 2). Probably the cell wall content, protein matrix enveloping the starch granule, or other factors are responsible for this relatively slower hydration behavior. Extraction with isobutyl alcohol for solubilizing the prolamine and weakening possible protein starch interaction improves the hydration only to a small extent (Fig. 1). Reducing the size of the semolina hastens the uptake of water.

Cooking Quality of Pearled Sorghum

Varietal differences in water uptake during cooking of pearled sorghum grains in water have also been noted. Those with a higher water absorption generally had lower GT and higher peak viscosity and setback than those with a comparatively lower water uptake (Table 6).

Paste Viscosity in Relation to Processing

The effect of heat processing and malting on the viscographic characteristics of sorghum has been studied. It has been found that malting brings

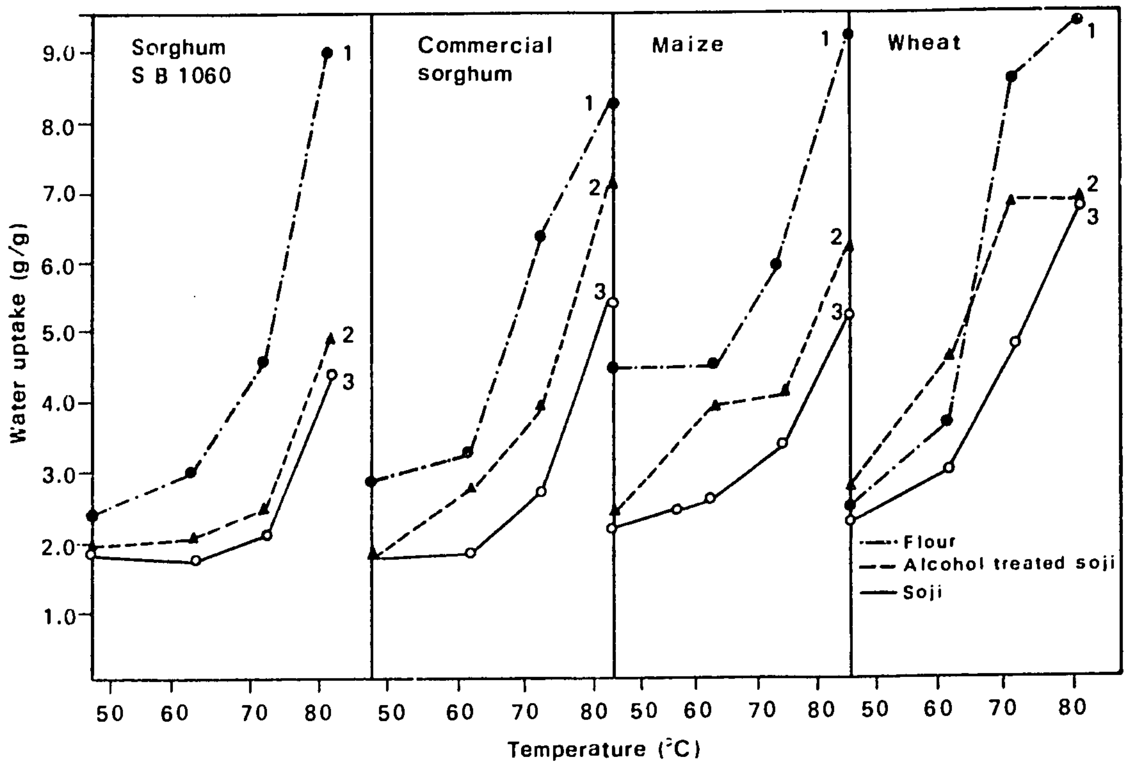

Figure 1. Comparative water uptake of flour and soji (semolina) from sorghum, maize, and wheat.

about maximum starch modification and lowering of viscosity. Puffing, as well as wet heat treatment such as parboiling or steaming, bring down the starch viscosity to some extent (Table 7). This effect has also been observed with other grains, although the extent of viscosity change varies with different cereals.

In a study of the comparative amylase activity of different grains during germination, it has been found that ragi and pearl millet developed high α amylase activity in the early stages of germination. Sorghum required a longer period (3–4 days) to catch up with the other millets (Table 8) and could be used for producing malted flour suitable for use in weaning foods. Varietal studies on suitability for malting need to be undertaken to identify the varieties that would have high amylase activity.

Table 6. Water absorption during cooking and viscoamylograph characteristics of polished sorghum.

	Water absorbed (g) per g of grain	GT (°C)	PV (BU)	Setback (BU)
BP53	1.24	72.0	220	500
E-35-1	1.25	73.5	440	780
CSH-1	1.32	69.0	245	490
GPR148	1.34	78.0	320	580
M-35-1	1.35	72.0	220	420
My316-5	1.37	78.0	150	240
CSH-6	1.41	69.0	320	555
H2259	1.53	81.0	260	360
M-64 77	1.54	73.5	440	780
Patcha Jonna	1.61	72.0	400	600
P-721	1.60	72.0	410	780
Patancheru	1.68	67.5	430	760
CSH-8	1.75	70.5	390	700
GPR370	1.75	69.0	460	540
A2283	2.18	69.0	400	640

Source: Chandrashekar and Desikachar, unpublished.
Grains were cooked in boiling water for 3 hr.
B = Brabender Units.

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Table 8. Elaboration of amylase activity[a] during germination of cereals.

	24 hr	48 hr	72 hr	96 hr
Pearl millet	52	110	125	115
Ragi	26	64	178	150
Sorghum	15	50	158	185
Maize	10	45	80	120
Italian millet	12	38	114	105

Source: Malleshi and Desikachar 1981.
a. mg maltose produced by 1 g of material at 37° C in 15 min.

Table 7. Cold and cooked paste viscosities of sorghum (CSH-5) subjected to different treatments.

	20% slurry (cold) cp units	10% slurry (cooked) cp units
Control	24	2000
Parboiled[a]	20	300
Flaked to 3 mm thickness[b]	200	400
Toasted for 10 min at 100° C	28	600
Puffed at 260° C for 30 sec	3600	240
Malted[c]	28	40

Source: Raghavendra Rao and Desikachar 1981.
a. Soaked in water at 60° C for 3 hr, steamed for 30 min, and dried.
b. Soaked in cold water for 30 min, cooked in steam at 15 psig for 1½ hr, and flaked.
c. Soaked in water for 18 hr, germinated for 48 hr, dried and kilned at 80° C for 30 min.

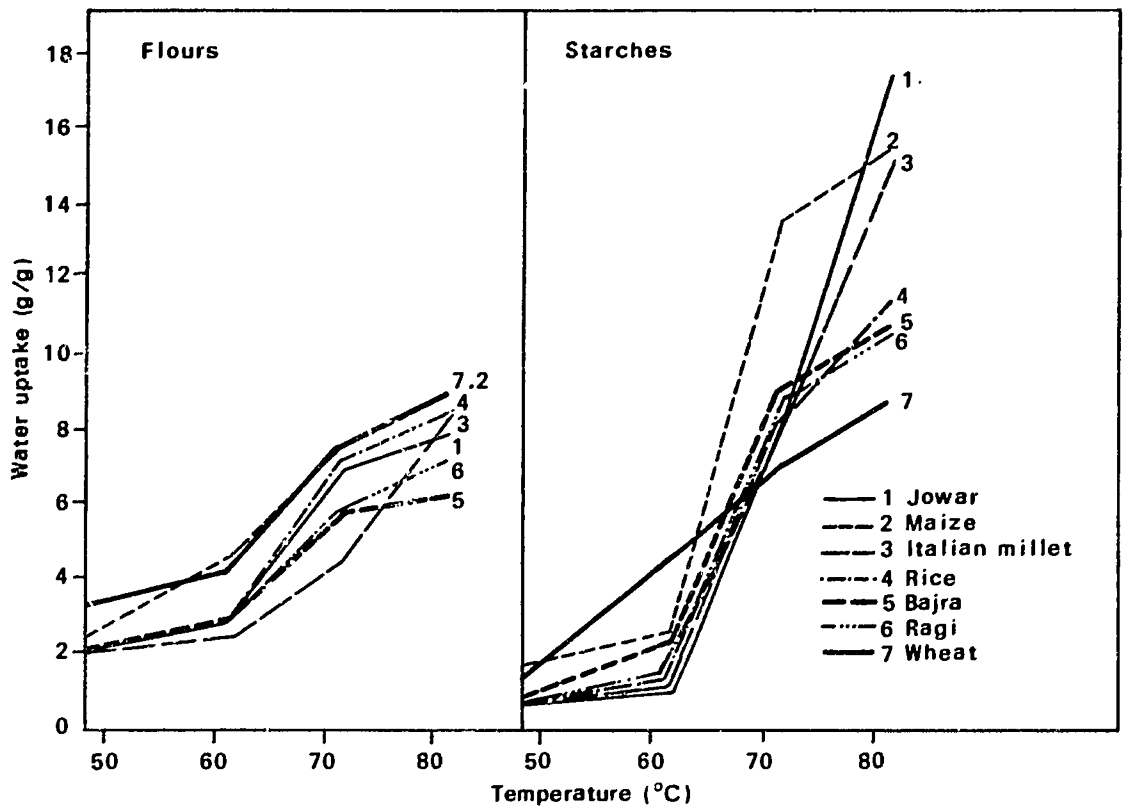

Figure 2. Comparative water uptake of cereal flours and starches at different temperatures.

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Variation in Amylose Content among Sorghums

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Summary

An automated method of determining amylose content of sorghum endosperm and isolated starch, based on the amylose-iodine blue complex, was applied to sorghum samples from the world collection. The mean apparent amylose content as a percentage of starch of sorghum endosperm was 22.0 for 567 normal sorghums. For 24 samples of sorghum grown at ICRISAT in India in 1979 and 1980, the mean amylose content was 23.1 and 27.4% from isolated starch and 22.2 and 24.9% of starch in ground endosperm. For 24 sorghums grown at Lubbock, Texas, in 1979, the mean was 26.2 for amylose as a percent of isolated starch and 23.0 for amylose as a percent of starch in endosperm. In general, the amylose content was 2 to 3 points lower when amylose was expressed as a percentage of starch in pearled grain compared with isolated starch. The amylose content of sorghum was affected by environmental as well as genetic factors. In general, apparent amylose content appears to have less effect on cooking characteristics of sorghum than on those of rice.

Amylose content of sorghum may be related to differences in rheological and keeping properties of sorghum foods such as porridges, *rotis, tortillas,* and *kisra.* The amylose content of rice is a very important parameter used to select rice cultivars with good cooking and eating qualities. Amylose content in rice ranges from 10 to more than 30% of the milled rice. Rice with low, intermediate, and high gelatinization properties exists. These groups are generally delineated by low (10–20%), intermediate (20–25%) and high amylose (25–30%) (Bollich and Webb 1973). High amylose rice cooks dry, has high volume expansion, a high degree of flakiness, and becomes hard upon cooling. In contrast, the low amylose types are moist and sticky when cooked under optimum conditions. The intermediate types cook moist and tender and do not become hard upon cooling.

The starch-iodine blue method has been automated and used successfully for measurements of amylose content in milled rice (Juliano 1971). It is especially useful in evaluating the quality of rice lines in crop improvement programs.

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The amylose content of 210 nonwaxy sorghum cultivars varied from 21 to 28% of starch according to Deatherage et al. (1955). The range in amylose content of sorghum from the current World Collection of sorghum has not been determined. The work reported here was designed to develop and use an automated method to determine the variation in apparent amylose content among sorghums from the World Collection and to determine if apparent amylose content plays an important role in sorghum food quality.

Materials and Methods

Samples

Apparent amylose content of the endosperm of several hundred nonwaxy sorghums was determined over an 18-month period. The samples of sorghum grown at a given location were usually considered together since environmental conditions during grain maturation affects amylose content (Paule 1977; Juliano et al. 1965). Major groups included in the study were: 25 samples of grain from the International Food Quality Trials (IFQT) grown at ICRISAT Center, Hyderabad, India in the postrainy seasons of 1979 and 1980, 24 samples from a sorghum food quality test grown at Lubbock, Texas in 1979, and samples from replicated yield trials in Lubbock and Dallas in 1977. Other groups included samples grown in the ICRISAT nurseries at Cinzana, Republic of Mali; Kamboinse, Upper Volta; Hyderabad, India; and local varieties of sorghum from Guatemala and Honduras. Where possible, samples were obtained from experiment station nurseries with growing conditions carefully delineated. Space does not permit detailed descriptions here. However, the samples included grains of different colors, endosperm textures, and types.

Amylose Determination

The amylose content of sorghum endosperm and starch was determined by a modified version of the automated iodine-blue method described by Juliano (1971) and Webb (1972). The sorghum endosperm was ground through a 0.1-mm screen on the UDY cyclone grinder. A sample (0.075 g for endosperm, 0.050 for starch) was wetted with ethanol and solubilized in 10 ml of 1.0 N NaOH at room temperature. Then, the sample was diluted to 100 ml with distilled water and an aliquot was analyzed. The standards for amylose were purified defatted sorghum starches with 24.0, 23.1, and 17.1 % amylose content and a waxy sample with 0 % amylose content as determined by the iodine binding technique (Staley 1973). During development of the method, numerous modifications were attempted to achieve maximum levels of amylose. These values (amylose as percent endosperm, and amylose as percent starch in endosperm) should be referred to as apparent amylose since they are lower than values obtained by iodine binding of purified starch.

Starch Determination

Total starch was measured by the amount of glucose multiplied by 0.91. Glucose was measured with Hexokinase (Technicon Method No. SF4-0046FA8). The glucose was obtained by complete hydrolysis of the gelatinized sample with glucoamylase as described by Johnson (1981).

Preparation of Sorghum Endosperm

A 5.0 g sample of sorghum was pearled for 30 sec in a modified barley pearler (Rooney and Sullins 1969). The pericarp and most of the germ were removed by the wire brush. A blast of air was used to remove bran and fine particles. The cleaned endosperm chunks were subjectively valued from 1 to 5 according to the following criteria: pericarp removal, breakage, endosperm coloration (staining due to pigment leaching from the pericarp) and overall acceptability for use in amylose analyses. Ratings were: 1 = excellent, 2 = good, 3 = needs improvement, 4 = unacceptable, and 5 = very unacceptable. Those rated 1 and 2 were acceptable and all others were manually sorted or scraped with a razor blade to obtain a sample that rated 2. The pearled grain was ground through a 1.0-mm screen with a Udy cyclone hammer mill.

Isolation of Sorghum Starch

Sorghum was wet milled by the procedure of Norris and Rooney (1970). The wet starch was further purified by several successive treatments with proteases followed by exhaustive washings with methanol to remove protein and lipids. Finally, the starch was refluxed with methanol for 48 hr. A greater proportion of the small-size starch granules compared to large granules was unavoidably lost during the starch purification process. This loss could change the value of the amylose content of the starch.

Results and Discussion

In a preliminary experiment, amylose content of ground whole sorghum, ground pearled sorghum (endosperm), and isolated starch was compared (Table 1). These data suggested that ground pearled sorghum could be used for amylose determination although the mean amylose value was lower than that for isolated starch. It was clear that ground whole sorghums could not be used for amylose analyses. Furthermore, the pearled sorghum had to be carefully examined to insure that the pericarp and most of the germ tissue were removed. Any germ or pericarp tissue that remained on the pearled kernels significantly affected the amylose determination. Therefore, pearled sorghums were carefully examined and much of the remaining germ, pericarp, or stained endosperm was removed prior to grinding. Obviously, the time spent in milling and further dissecting pearled sorghum kernels to obtain the endosperm was considerably less than that required for isolating and purifying starch by wet milling methods. This method of estimating amylose in pure endosperm has been used quite effectively in rice quality evaluation (Webb 1972; Juliano 1971).

Table 2 shows the effect of particle size, and solubilization time is presented in Tables 3, and 4. The Udy Cyclone Sample Mill with 1.0-mm screen gave a satisfactory particle size (Table 2). In general, 48 hr gave complete solubilization of the sorghum endosperm and of isolated starch. Extended soaking for several days did not significantly affect the amylose values (Tables 3 and 4). This feature is useful since it permits accumulation of a large number of samples for analyses. Samples kept in alkali for more than 14 days did show some increase in amylose content. Therefore, samples were not stored in the alkali for more than 10 days.

A comparison of amylose content in isolated starch and sorghum endosperm samples from five sorghum varieties is presented in Table 5. These sorghums varied in amylose content from nearly zero for waxy sorghum (wxwxwx) to 24.0% for the nonwaxy (WxWxWx) isolated starch by standard potentiometric amylose determinations. The automated starch-iodine blue method is not a measure of the absolute value of amylose in the samples as it especially gives high values for waxy starches. The amylose content in isolated starch was highly significantly correlated with the amylose content as percent of starch in sorghum endosperm ($r = 0.96$ d.f. $= 3$) and as percent of sorghum endosperm on dry weight basis ($r = 0.94$ d.f. $= 3$).

The conclusions drawn from the preliminary work were that sorghum endosperm, relatively free of pericarp, stains and germ tissue could be solubilized in alkali for 48 to 72 hr and the amylose content would be from 2 to 3% points lower than the amylose content of starch isolated from the same sorghum.

In another test to determine reproducibility of the automated method, endosperm of CS3541 was ground and stored in a sealed container. The sample was included as a check in several sets of amylose analyses. The mean apparent amylose

Table 1. Amylose content[a] of whole grain, endosperm, and isolated starch of sorghum.

Variety	Amylose as % of whole grain	Amylose as % of starch in whole grain	Amylose as % of endosperm	Amylose as % of starch in endosperm	Amylose as % of isolated starch
G766W	11.7	14.6	18.1	21.1	24.5
TAM680	11.3	14.0	18.1	20.2	23.0
NK300	9.7	12.2	17.9	20.9	24.1

a. Data were average of three replications on sample dry weight basis. Samples were soaked in sodium hydroxide for 3 days.

Table 2. Effect of particle size on amylose content[a] of sorghum endosperm soaked in sodium hydroxide for 3 days.

	Screen size			
	0.4 mm diameter		1.0 mm diameter	
Variety	Amylose	% amylose/starch	Amylose	% amylose/starch
M35-1	18.5	21.4	18.6	21.5
G766W	17.3	20.1	18.0	20.9
SC0283	17.5	20.3	17.6	20.4

a. Amylose content is average of three replications expressed on a sample dry weight basis.

Table 3. Effect of solubilization time on amylose content[a] of isolated starch and endosperm from Funks G766W sorghum.

Time	Amylose as % of isolated starch	Amylose as % of starch in endosperm
1 hr	14.9	16.4
6 hr	20.8	19.6
12 hr	24.2	21.4
18 hr	22.8	21.3
1 day	23.0	21.2
2 days	23.2	22.0
3 days	23.3	21.6
5 days	24.3	21.0
6 days	23.2	20.7
11 days	24.2	21.7

a. Amylose values are means of three replications on sample dry weight basis.

Table 4. Effect of solubilization time on the amylose content[a] of sorghum endosperm and isolated starch.

Time (hr)	Amylose as % in isolated starch[a]	Amylose as % of starch in endosperm[a]
24	25.0	21.1
48	26.1	22.8
72	26.7	23.4
96	26.7	22.6

a. Each value is the mean of three observations on sorghum endosperm and sorghum starches respectively, from 72 sorghum varieties. Data were means on sample dry weight basis.

content for 10 observations of the starch in the endosperm was 23.9 ± 0.3%. For practical purposes, we accept a difference of 2% points in amylose contents above 15% as significant.

The method looks promising to relate differences in amylose content to sorghum food quality and to screen samples from the World Collection of sorghums for amylose content.

Isolated Starch and Endosperm

A set of 25 sorghum varieties was grown in India in 1979 and 1980 and sent to collaborators around the world for exhaustive quality tests and analyses (Murty and House 1980). Mean amylose data of isolated starch and endosperm for the sorghum samples grown in 1979 and 1980 are presented in Table 6. These data indicate that the amylose content of these starches vary significantly and that the amylose content of sorghum endosperm is generally 2–3% points lower than that of isolated purified starch from the same sorghum sample. A close evaluation of the data on individual sorghum endosperm samples show that some sorghums, especially P-721 and WS1297, gave low amylose values for endosperm; but the values for isolated starch were the same as in the other samples. In general, these samples were those with undercoats and/or extremely soft endosperm; properties that cause extreme difficulty in the complete separation of endosperm from pericarp and germ and also results in stained endosperm. Environmental conditions during grain maturation

Table 5. Amylose content of starch and endosperm in sorghum samples used as standards.[a]

Sorghum	Amylose as % of endosperm	Amylose as % of starch in endosperm	Amylose as % in isolated starch: Automated method	Amylose as % in isolated starch: Potentiometric method
Nonwaxy WxWxWx	14.1 ±0.9 n = 7, c.v. = 6.3%	22.4	23.9 ±0.7 n = 10, c.v. = 2.7%	24.0
Heterowaxy WxWxwx	13.7 ±0.6 n = 8, c.v. = 4.6%	21.9	23.9 ±0.7 n = 12, c.v. = 2.8%	23.1
Heterowaxy Wxwxwx	10.5 ±0.6 n = 5, c.v. = 6.1%	15.5	19.6 ±1.3 n = 15, c.v. = 6.6%	17.1
Waxy wxwxwx	3.6 ±0.5 n = 2, c.v. = 18.7%	5.0	3.5 ± .0 n = 2, c.v. = 0.8%	—
G766W, nonwaxy	18.2 ±0.0 n = 2, c.v. = 0.4%	21.9	24.3 ±0.3 n = 2, c.v. = 1.9%	24.0

a. All amylose values computed on sample dry weight basis.

Table 6. Mean and variations about the mean of amylose content[a] of isolated starches and endosperm of International Food Quality Trials sorghum samples grown in 1979 and 1980.

	Amylose % in isolated starch		Amylose % of starch in endosperm		Amylose % of endosperm	
	1979	1980	1979	1980	1979	1980
Mean	24.9	27.4	20.9	23.1	16.5	17.9
SD	±1.6	±1.6	±2.3	±1.4	±1.8	±1.1
CV(%)	6.2	6.0	11.0	6.1	11.0	6.1
Minimum	22.0	25.3	17.3	20.9	15.2	14.5
Maximum	26.7	29.5	25.0	25.2	18.4	20.4

a. Amylose values are on sample dry weight basis.

and postharvest handling have a significant effect on the texture and staining of the endosperm. Therefore, analysis of sorghum endosperm for amylose content should be conducted on pure endosperm and extremely low values should be rechecked on isolated, purified starches. Though these samples were quite variable in color and endosperm texture, the C.V. of 6.5% (isolated starch), and 8.0% (unisolated endosperm starch) for the combined 1979/80 amylose values of the nonwaxy Indian samples was encouraging and suggested that the method was a useful indicator of apparent amylose content.

Sorghums with White Pericarp and without Testa

In 1979, 24 sorghum varieties were grown at Lubbock, Texas to provide samples of sorghum with white pericarp for amylose evaluations and for food quality trials. Amylose content of isolated starches and endosperm was determined (Table 7). For these samples, the amylose content of sorghum endosperm was 3.2% points lower and also had a lower variability than that of isolated starch. An ANOVA indicated that amylose content was significantly different among the varieties;

but, on a practical basis we conclude that there was probably insufficient variation in amylose content among these sorghums to effectively influence food properties. Amylose content of pearled P-721 was 16.3% which probably was explained by the poor separation of pericarp and germ during dry milling. The poor separation accompanied by low apparent amylose values was also observed for P-721 samples grown in India in 1979. The amylose content of the isolated starch was similar to the other sorghum samples. Most of the sorghums were similar in genetic background which could explain the relatively narrow range.

Table 7. Summary of amylose content of sorghums grown at Lubbock, Texas in 1979.

	% Amylose in isolated starch	% Amylose of starch in endosperm
$\bar{x}$	26.2	23.0
n	21	24
LSD*	0.91	1.1
SD	±1.1	±1.3
CV(%)	4.4	5.8
Range	24.8 – 27.0	21.5 – 25.0**

* 5% level of significance.
** Excluding a value of 16.3 for P-721.

Correlations among amylose content of isolated starch and that of endosperm are presented in Table 8 for the combination of samples grown at Lubbock in 1979 and India in 1979 and 1980. One waxy sorghum variety was included in the Indian samples. The apparent amylose content in sorghum endosperm was significantly correlated with amylose content of isolated starch, which suggests that the method of determining amylose on sorghum endosperm is useful. The coefficient of correlation between amylose content in sorghum endosperm and amylose content of isolated starch (r = 0.79), was lower than that (r = 0.96) obtained for the same comparison in the preliminary experiments. The analysis of starch and expression of amylose as a percentage of starch in the endosperm did not improve the correlation and should be eliminated.

Environmental Factors Affecting Amylose Content

The environmental conditions in which the grain is grown apparently affects the level of amylose content in sorghum (Table 9). Although the data are limited, the values for apparent amylose content of M35-1 vary from 18.4 to 25.0% of the

Table 8. Comparison of amylose contents of isolated and unisolated (endosperm) starches from selected sorghum cultivars grown in Lubbock, Texas, USA (1979), and in India (1979 and 1980).

Variables	Min	Max	Mean	r	d.f
Amylose % isolated starch vs amylose % starch in endosperm	5.6	29.3	25.5	0.79++	68
	5.6	27.2	22.1		
Amylose % isolated starch vs amylose % in endosperm	5.6	29.3	25.5	0.79++	68
	4.6	21.2	17.7		
Amylose % in endosperm vs amylose % starch in endosperm	4.6	21.2	17.7	0.96++	71
	5.6	27.1	22.4		
Amylose % isolated starch vs % starch in endosperm	5.6	29.3	25.5	0.06	69
	73.1	86.7	80.0		
Amylose % starch in endosperm vs % starch in endosperm	5.6	27.2	22.1	0.05	71
	73.1	86.7	79.9		
Amylose % in endosperm vs % starch in endosperm	4.6	21.2	17.7	0.26	71
	73.1	86.7	79.9		

++ Highly significant.

starch in endosperm. Therefore, information on amylose content in sorghum should be collected with the realization that among nonwaxy sorghums environmental effects may exert more influence on amylose content than genetic differences. In 1970, we obtained data on amylose content of starch of two common sorghum hybrids grown in performance tests at 10 Texas locations which indicated that environment had a much greater effect on amylose content than heredity (Rooney, unpublished data 1970). The hybrids were genetically similar; however, the environmental conditions which ranged from the subtropics of Weslaco, Texas to the temperate conditions of the high plains of West Texas caused significant differences in the apparent amylose contents observed in the hybrids. Amylose content of rice is similarly significantly affected by environment as well as heredity (Paule 1977; Juliano et al. 1965).

The mean apparent amylose content of the sorghum samples grown in India in 1980 was 2.5% points higher than the mean for the 1979 crop. This is especially significant in that both crops were grown in the *rabi* season and at the same site which should have minimized differences.

Table 9. The effect of environment on amylose content of M35-1 sorghum endosperm and isolated starch.

Location/Year			Starch of endosperm %	Isolated starch %
India	1977	*rabi*	20.4	
India	1978	*rabi*	18.4	
India	1979	*rabi*	22.8	24.0
India	1980	*rabi*	24.2	25.3
Lubbock	1978		21.3	
Lubbock	1979		25.0	26.0
Temple	1977		20.7	
Dallas	1977		20.1	
Mean of 24 varieties grown in India, 1979, *rabi*.			20.9	24.9
Mean of same 24 varieties grown in India, 1980, *rabi*.			23.1	27.4

Variation in Apparent Amylose Content

A frequency distribution curve for 495 nonwaxy samples (425 sorghum genotypes) is presented in Figure 1. These samples represent considerable

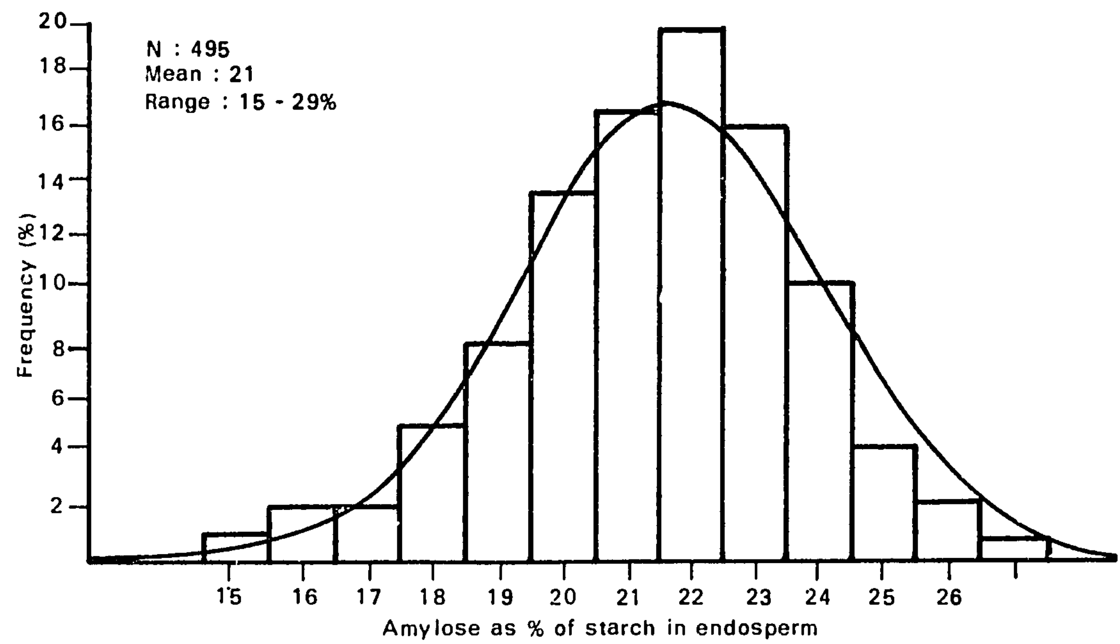

Figure 1. Percent amylose of sorghum for 495 samples.

genetic variability. However, they were grown under different conditions around the world. The range of amylose as a percent of starch (5.2 to 28.6) in waxy and nonwaxy endosperm is the same as the range (10 to 30%) of amylose that is common for milled rice (Paule 1977; Juliano 1979).

Frequency distribution for amylose content in sorghum endosperm for smaller numbers of sorghum selections grown at specific sites and years is presented in Figures 2, 3, 4, and 5. Presumably, the effect of environment would be decreased and differences in amylose content in these samples would be due to differences in the sorghum cultivars. Differences in maturity, yield level and other factors undoubtedly affect amylose content even within a replicated nursery, so it is impossible to conclude that a genetic variation for amylose content occurs among nonwaxy sorghum samples. Samples from the World Collection (Fig. 2) varied considerably in pericarp color, testa, and endosperm texture. Some of these samples have poor milling properties which might be responsible for the low apparent amylose content observed in them. Insufficient quantities of seed prevented isolation of starch to confirm the validity of the lower amylose values.

Sorghum mutants were grown in Dallas and in College Station, Texas during 1977 for amylose analyses. These mutants included several sugary, yellow endosperm and high lysine types which are difficult to mill into pure endosperm. The waxy mutants were excluded. The apparent amylose content ranged from 15.2% to 23.0%. Specifically, the amylose as percent of starch in endosperm was 19.7, 22.9, 21.6, and 17.0% for SC0170 (normal), SC0170-SU_2, SC0170Su_1, and IS4526, respectively. For isolated starch, the amylose values were 27.3, 28.1, 27.8, and 24.9%, respectively. Analyses of the isolated, purified starch eliminated most of the differences observed in Figure 6. The milling properties of some of the sorghum mutants were questionable and contamination with germ would explain the lower apparent amylose values for these sorghums.

Conclusions

Ground sorghum endosperm can be analyzed for amylose content with good precision by a colorimetric procedure using the Auto-Analyzer. The values for amylose determined on the endosperm are generally two to three percent points lower than the amylose content obtained by analysis of defatted, isolated starch.

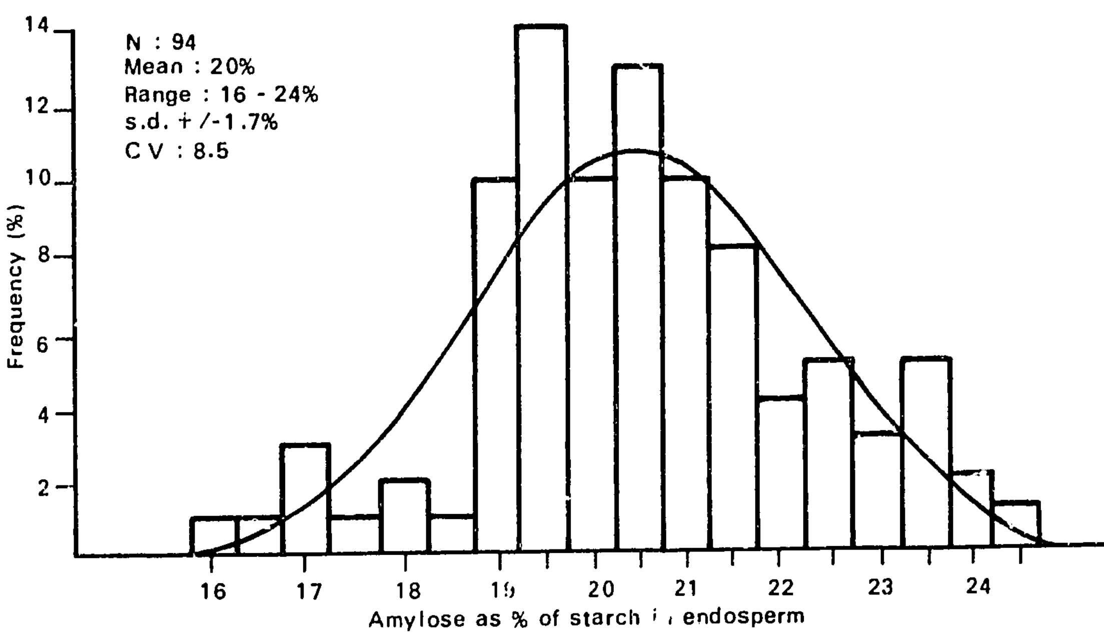

Figure 2. Percent amylose of sorghum grown in India, 1977.

Sorghum endosperm can be prepared by milling 5.0g of sorghum in a modified rice or barley pearler for 30sec. The procedure is simple and provides a quick method of preparing large numbers of samples. Some hand dissection and inspection of the pearled kernels is necessary. Some samples with pigmented and/or floury endosperm cannot be analyzed accurately because of con-

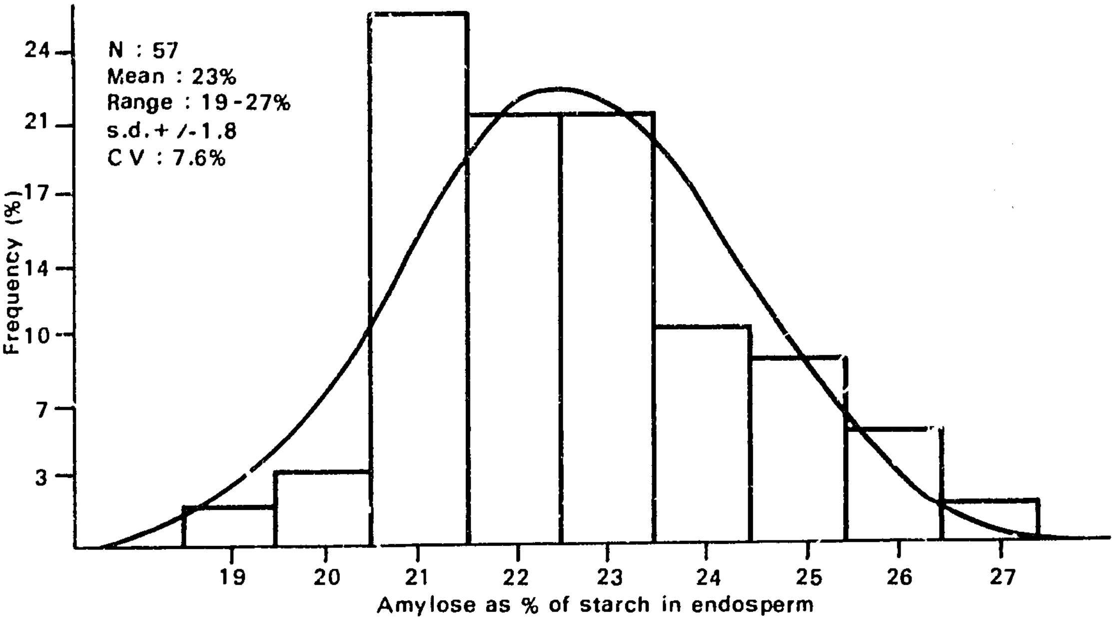

Figure 3. Percent amylose of sorghum grown in Dallas, Texas, 1977.

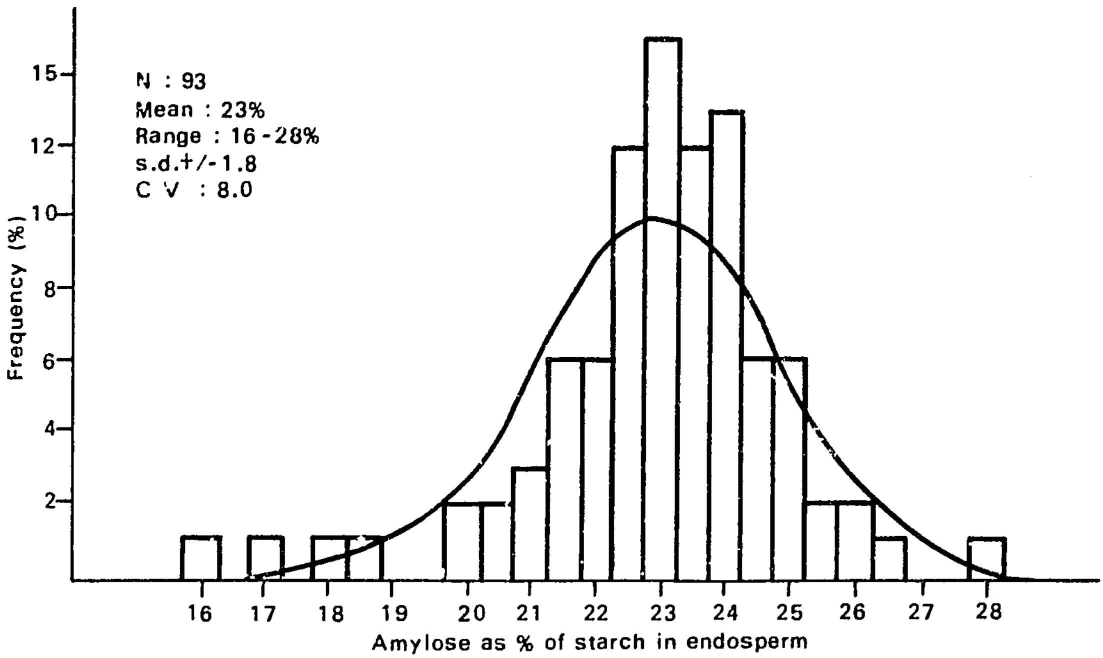

Figure 4. Percent amylose of sorghum grown in Lubbock, Texas, 1979.

taminating pericarp and/or staining, and starch must be isolated.

The ground endosperm must be incubated in 1.0 N NaOH at room temperature for 24 hr to completely solubilize the amylose. A 48-hr incubation gave consistently repeatable values. The diluted solubilized samples can be stored for 10 days without change in amylose content.

Amylose content as a percent of starch in endosperm and amylose content of dry endosperm were highly correlated with amylose content of the respective isolated sorghum starches ($r = 0.79$, $r = 0.79$ d.f. $= 71$). Since the correlations were the same, there was no need to determine starch content of the endosperm.

Contamination of endosperm with bran and germ can substantially lower the apparent amylose content; therefore, samples with low amylose

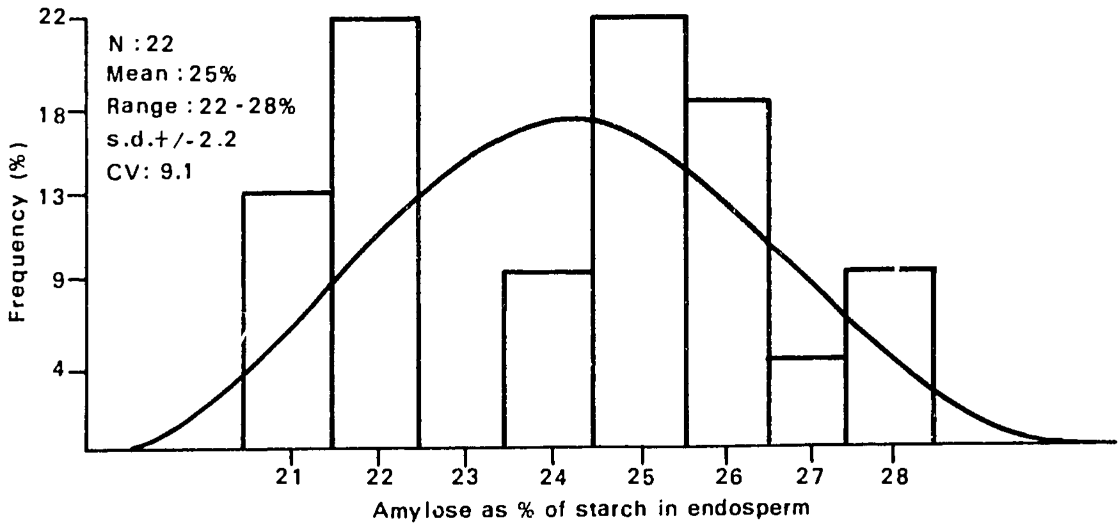

Figure 5. Percent amylose of sorghum grown in Cinzana, Mali, 1980.

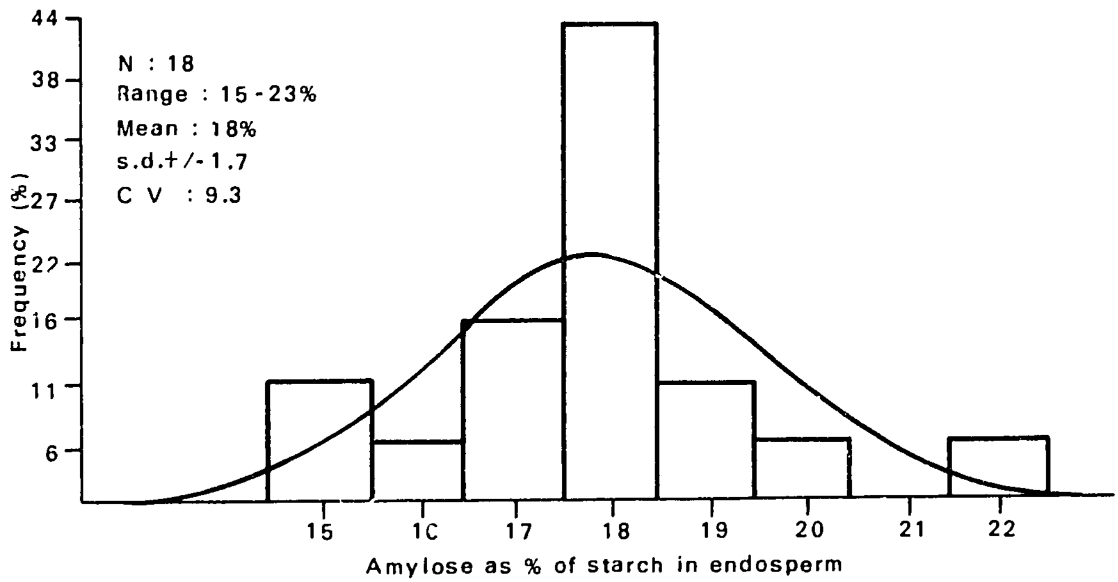

Figure 6. Percent amylose of sorghum endosperm mutants grown in Dallas, Texas, 1977.

content should be confirmed by isolation of the starch.

It appears that both environment and genetic factors affect the level of amylose in nonwaxy sorghums. However, significant heritable differences in amylose content have not been clearly demonstrated in nonwaxy sorghums.

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Properties of Sorghum Grain and their Relationship to *Roti* Quality

V. Subramanian and R. Jambunathan*

Summary

Physicochemical characteristics of 45 sorghum genotypes were determined. The 100-grain weight, grain hardness, protein, water soluble protein, amylose, and sugars contents in the grain showed considerable variation. The roti *quality of flour from the 45 genotypes was evaluated for color, appearance, taste, flavor, and texture by a trained taste panel. The texture of dough was measured using an Instron machine. Relationships between the physicochemical characteristics of grain and* roti *qualities were identified. The quantity of water soluble protein, amylose, and sugars jointly influenced the* roti *quality of the sorghum genotypes studied.*

Sorghum grains are used as the staple food in several regions of Africa, China, and the Indian subcontinent particularly in the semi-arid tropics. It has been well established that chemical components such as protein, starch, lipids, and ash of wheat flour influence the breadmaking quality (Pomeranz et al. 1979). Studies on rice (Juliano 1979) indicated the importance of amylose and protein on the cooking and eating quality of rice. Physicochemical characteristics of sorghum and their effect on sorghum food products have not been well documented. Miller and Burns (1970) studied the relationship between the starch characteristics and organoleptic qualities of sorghum bread and reported that varieties with high amylopectin content were preferred for sorghum bread. However, Miche et al. (1976) indicated that the role of lipids during pasta manufacture and the role of amylose, amylopectin of sorghum starch, and other protein fractions had not been investigated. The role played by chemical or physical factors of sorghum grain on food quality appears to be a complex phenomenon. Our work on *roti* evaluation (Subramanian and Jambunathan 1980) revealed that physicochemical factors jointly influence the *roti* quality of sorghum. In this paper the properties of sorghum flour and their relationship to *roti* (*chapati*) quality from 45 cultivars are discussed.

Materials and Methods

Physical Properties

Forty-five sorghum cultivars of varying grain characteristics (Table 1), grown at ICRISAT Center during the postrainy seasons of 1979 under uniform field conditions, were studied. Grain hardness (kg/cm^2) was measured as the force required to break the grain using a Kiya hardness tester. Whole grains were ground to flour in a UDY Cyclone Mill to pass through a 60-mesh sieve. The flour was defatted using n-hexane for further analysis. The swelling capacity of flour was determined by treating 0.5 g flour in 15 ml water and the contents were kept in a heating block maintained at 90° C for 1 hr. The volume and weight increase of flour were determined and expressed as the ratio between initial volume and final volume (v/v) or weight (v/w). The solute content of the water extract of flour at 90° C, designated as the water soluble flour fraction (WSFF), was determined as follows. A quantity of flour, 0.5 g, was heated with 15 ml water for 1 hr at 90° C with periodical shaking. The contents were cooled and centrifuged. The supernatant was made up to 50 ml. An aliquot was evaporated to dryness and the weight of the dissolved solids was designated as WSFF.

* Subramanian is Biochemist; Jambunathan is Principal Biochemist, ICRISAT.

Table 1. Grain characteristics of 45 sorghum cultivars.

Cultivar	Grain color	Corneousness[a]	Grain hardness (kg/cm²)	100-seed weight (g)
PJ-7R	White with red spots	3	6.4	4.32
PJ-16R	Creamy white	3	6.0	3.90
PJ-18R	Light yellow	3	6.3	4.04
PJ-19R	White with brown spots	3	6.6	4.14
PJ-1K	White with red spots	3	6.0	4.44
PJ-2K	White with red spots	4	5.6	4.68
PJ-4K	White with red spots	4	6.3	4.65
PJ-12K	Creamy white	4	6.4	5.45
PJ-14K	Creamy white	3	6.3	2.77
PJ-31K	Creamy white	4	6.1	4.65
PJ-32K	Creamy white	4	6.8	4.88
Maldandi local	Creamy white	4	7.3	3.93
Karad local	Creamy white	3	6.8	3.70
SS-2	White with brown spots	3	6.7	3.53
Pickett-3	White with red spot	3	8.2	3.31
GM-2086	Light brown	4	6.6	4.05
Simila	Light brown with subcoat	4	7.2	2.65
NJ-1346	Creamy white with brown spots	2	8.3	3.38
NJ-1953	Creamy white	4	7.9	4.53
Dholio	White with brown spots	4	5.2	5.01
Surat-1	Creamy white	4	5.9	4.49
Aispuri	Dull white	4	5.0	3.57
K. white grain	White with brown spots	3	7.2	3.57
Vidisha 60-1	Dull white	4	5.4	4.26
BP-53	Dull white	4	7.0	4.60
FR-178	White with brown spots	3	6.1	3.19
H-102	Creamy white	3	6.0	3.61
H-107	White with brown spots	3	6.7	3.54
SPV-35	White with red spots	3	7.8	3.38
S-302	White with red spots	3	7.8	4.11
269	Creamy white	3	7.9	3.27
285	Creamy white	3	6.5	3.01
296	Dull white	4	6.7	4.09
370	Creamy white	3	7.4	3.13
1235	Creamy white	3	7.5	2.75
IS-12611	Dull white	3	11.8	4.24
E-12-5	Creamy white	2	11.8	3.38
E-35-1	White	2	6.7	3.54
Bodgawanda-wani	White with pink spots	4	6.6	3.88
Mau-wani	White with pink spots	5	3.0	2.65
Vani-Wani	White with pink spots	4	5.2	3.20
Naraliguti Wani	White with pink spots	4	6.1	3.77
Pandori-Wani	Creamy white	5	4.9	2.30
Bilora-Wani	Creamy white	4	7.3	4.57
Lahi-Wani	White	3	5.6	4.22

a. Corneousness was measured on a scale of 1-5, where 1 is more corneous and 5 is floury.

Chemical Characteristics

Protein was determined by the microKjeldahl method (AOAC 1970). Water soluble protein of flour was extracted by shaking 1 g flour in 15 ml water at room temperature. The extraction was repeated with 10 ml water and the extracts were combined and made to 50 ml. A 10 ml aliquot was treated with trichloroacetic acid (TCA) to yield a final concentration of 10%. The resulting precipitate was dissolved in 1 ml of 0.1 N NaOH and the protein content was determined by the method of Lowry et al. (1951). The amino acid composition was determined using Beckman (120-C) amino acid analyzer. Starch content was estimated using the enzyme glucoamylase as reported by Singh et al (1980). Total amylose was determined according to Williams et al. (1958); water soluble amylose was estimated colorimetrically (Juliano et al. 1968). Total sugars were determined by the phenol-sulphuric acid method (Dubois et al. 1956) and the reducing sugars by using Nelson Somogyi reagent (Somogyi 1952). Fat and ash contents were analyzed by the AOAC (1970) methods. For gel filtration chromatography of the water soluble protein, a solution containing 5 mg protein was applied on a Sephadex G.100 column (82 × 1.5 cm). The protein was eluted using 0.01 M phosphate buffer (pH 7.6) containing 0.01 M mercaptoethanol, 0.4 M sodium chloride and 0.05% sodium azide. Absorbance of the eluent was recorded by a LKB 8300 UVCORD monitor.

Dough and *Roti* evaluation

Dough quality was evaluated subjectively for kneading and rolling qualities. Dough stickiness was evaluated using an Instron machine. Dough was prepared by mixing 50 g flour with 40 ml water. After kneading well, the contents were divided into three equal parts by weight. The dough was placed in the back extrusion cell of the Instron machine (Model 1140) and compression was made. The force required for back extrusion, area and slope of the curve were determined from the recorded tracings.

Rotis were made as per the procedure outlined by Subramanian and Jambunathan (1981). The organoleptic properties such as color and appearance, flavor, taste, texture, and general acceptability were evaluated with a trained taste panel consisting of 12 persons.

Results and Discussion

Physicochemical Characteristics

The grain hardness showed a wide variation of 3 to 12 kg (Table 1). The range and mean values of physicochemical characteristics of sorghum flour are given in Table 2. Swelling capacity of flour varied from 5 to 8 on a volume basis. The WSFF ranged from 19 to 35 mg/100 g. The protein content of the 45 cultivars varied from 8 to 14%. The protein content in the water soluble fraction of the flour ranged from 0.3 to 0.9% of grain. Gel filtration of water soluble proteins on Sephadex G-100 in phosphate buffer at pH 7.6 yielded two major peaks (Fig. 1). Though variation was observed for the amino acid composition of the water soluble fraction of the two cultivars (Table 3), further studies are needed to draw proper conclusions.

Starch is the major constituent of sorghum grains. The role of starch in the breadmaking quality of wheat is well known due to its effect on water absorption (Alsberg 1927). The starch content of the grain of the 45 sorghum cultivars varied from 62.6 to 73.3% and the amylose content ranged between 21.2 and 30.2% (Table 2). Hulse et al. (1980) reported that the amylose content in 100 sorghum lines ranged from 7.1 to 31.3%. Waxy sorghums are reported to have a low amylose content. The water soluble amylose of the 45 cultivars ranged from 4.8 to 12.7% of the grain. Sorghum grains contain five different sugars, i.e., sucrose, stachyose, raffinose, glucose, and fructose in varying proportions (Subramanian et al. 1980). The fat content in sorghum samples varied from 2.3 to 4.7% and ash from 1.3 to 2.2% (Table 2).

Relationship among the Physicochemical Characteristics

The relationship among the physicochemical characteristics of sorghum grain has been worked out and some are given in Table 4. The 100 grain weight showed a negative association with protein while it was positive with amylose. Swelling capacity of flour was not associated with any of the chemical factors. Protein content showed a strong negative relationship with starch and water soluble amylose contents in the grain and was positively related with water soluble protein, and

Table 2. Physicochemical properties of sorghum grain.[a]

	Range	Mean	± s.e
Physical characteristics			
Flour swelling capacity (v/w)	8.7–12.8	10.4	0.30
Flour swelling capacity (v/v)	5.4–8.0	6.5	0.19
WSFF (mg/100 g)[b]	19.4–35.4	26.4	0.86
Chemical characteristics (percent in grain)			
Protein	8.0–14.1	10.6	0.10
Water soluble protein	0.3–0.9	0.6	0.009
Starch	62.6–73.3	68.7	2.36
Total amylose	21.2–30.2	27.2	0.88
Water soluble amylose	4.8–12.7	8.5	0.20
Soluble sugars	0.7–1.6	1.0	0.03
Reducing sugars	0.05–0.4	0.1	0.004
Fat	2.3–4.7	3.3	0.06
Ash	1.3–2.2	1.6	0.01

a. based on 45 cultivars.
b. Water soluble flour fraction.

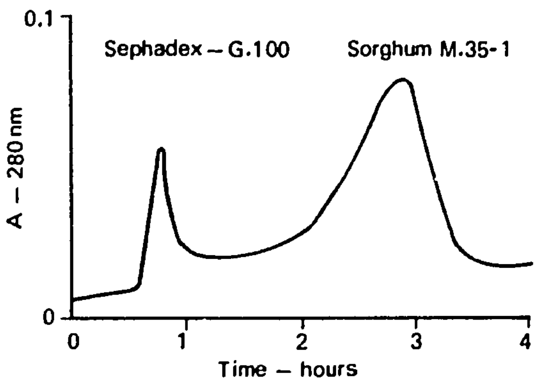

Figure 1. Gel filtration elution profile of water-soluble proteins.

ash contents. The starch content was positively associated with water soluble amylose. Miller and Burns (1970) observed that amylose content was directly related to starch content in sorghum. Soluble sugars content showed a positive correlation with protein and a negative correlation with amylose.

Table 3. Amino acid composition of the water soluble fraction (g/100 g protein).

	Cultivars	
Amino acids	FJ. 12-K	IS-12611
Lysine	6.77	8.42
Histidine	2.01	2.43
Arginine	5.08	6.17
Aspartic acid	8.38	9.39
Threonine	4.04	4.45
Serine	3.60	3.85
Glutamic acid	12.16	14.77
Proline	7.44	5.53
Glycine	5.38	6.21
Alanine	6.46	7.13
Half cystine	Tr	0.67
Valine	6.03	6.82
Methionine	1.00	1.57
Isoleucine	3.19	3.08
Leucine	5.57	6.45
Tyrosine	2.41	2.90
Phenylalanine	2.79	3.54
Total	82.31	93.36

Dough Quality

Although sorghum grains do not contain gluten, when sorghum flour is mixed with water and kneaded, it produces a sticky dough. A good quality dough should be sticky and easily rollable into a *roti* without any breakage. The stickiness of good and poor doughs was measured using an Instron machine and the profiles are shown in Figures 2a and 2b. A sticky dough yields a profile requiring less force for deformation but has a steep slope. A poor dough becomes compressed in the cell and is not extruded back; consequently, the force required for compression increases. The slope is comparatively steady and higher for cultivars like IS-12611 and M-35-1 having good dough characteristics (Table 5).

Table 4. Correlations (r) among physicochemical characteristics of sorghum grain.

Characteristics	Protein	Water soluble protein	Amylose	Water soluble amylose
100-grain weight	−0.44**	0.44**	0.33**	0.70**
Flour swelling capacity	−0.27	0.14	−0.04	0.07
WSFF[a]	−0.25	−0.25	0.16	0.38*
Protein	1.00	0.40**	−0.27	−0.66**
Water soluble potein	0.40**	1.00	0.12	0.41**
Starch	−0.75**	−0.49**	0.22	0.74**
Amylose	−0.27	−0.12	1.00	0.36**
Water soluble amylose	−0.66**	−0.41**	0.36*	1.00
Soluble sugars	0.36*	0.51**	−0.52**	−0.55**
Reducing sugars	0.25	0.18	−0.53**	−0.37**
Ash	0.46**	0.60**	−0.44**	−0.52**

n = 45; * Significant at 5% level. ** Significant at 1% level.
a. Water soluble flour fraction.

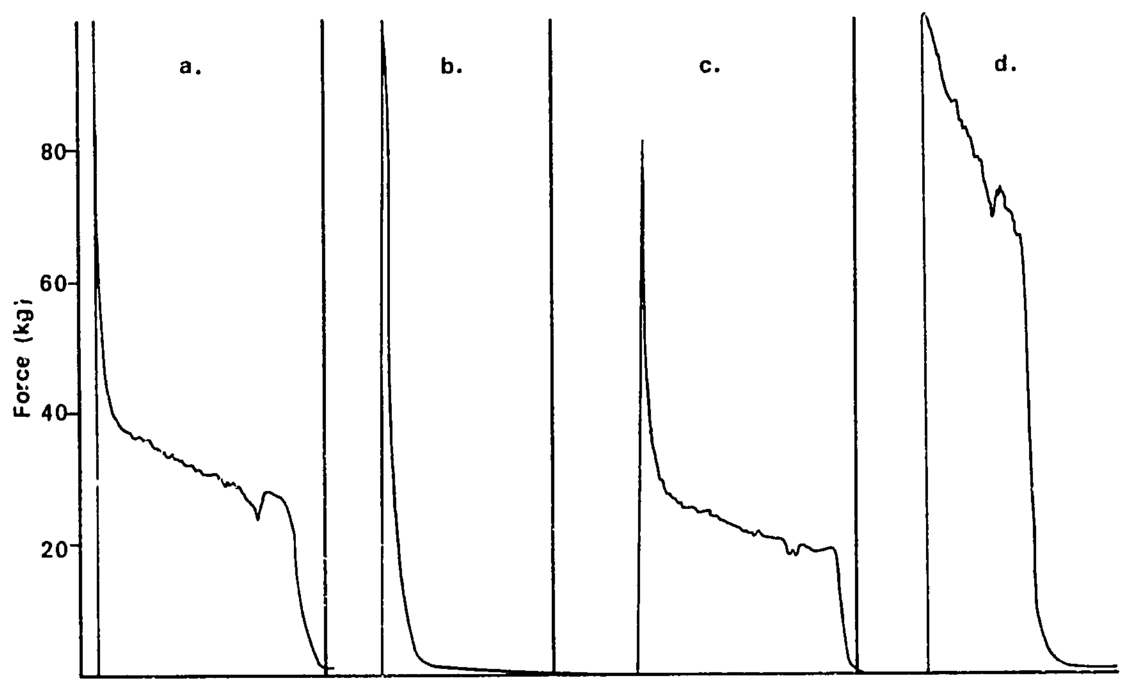

Figure 2. Force-distance curves of sorghum dough (Back extrusion—Instron). Dough was prepared by mixing 50 g flour with 40 ml water or water extract of flour. a: IS. 12611 flour + water; b: Simila flour + water; c: IS. 12611 flour + water extract of Simila flour, and d: Simila flour + water extract of IS. 12611 flour.

Our preliminary experiments showed that water extracts of sorghum flour (water solubles) influenced the dough stickiness. Studies were made with two cultivars possessing good and poor dough stickiness. The flour of IS-12611 yielded a good sticky dough and that of Simila yielded a dough with less stickiness. The flour samples were each extracted with water. The water extract obtained from Simila flour was added to the flour of IS-12611 to make the dough. However, this did not alter the dough characteristics appreciably as shown in Figure 2c. On the other hand, when the water extract from IS-12611 flour was added to Simila flour to make the dough, the stickiness of the dough was improved considerably as shown in Figure 2d. This indicates that water soluble components play an important role in the quality of dough and there is a need to characterize the nature of these components.

Relationship between *Roti* Quality and Physicochemical Characteristics

The association between the physicochemical characteristics and the taste panel score was studied. Pomeranz (1980) indicated that the problems of relating chemical composition and structure of wheat flour components to functional properties in breadmaking were complicated by several factors. Our earlier studies indicated that the physical factor WSFF and the chemical factors, i.e., water soluble amylose, sugars and ash contents jointly influenced the *roti* quality (Subramanian and Jambunathan 1980). A comparison of the mean values of WSFF, water soluble protein, and total amylose contents in flour for some cultivars having poor and good *roti* qualities is presented in Table 6. The flour samples having a lower amount of WSFF and higher amounts of water soluble protein and total amylose produced good *rotis*. The earlier studies with 25 cultivars involving samples from the International Sorghum Food Quality Trials (Murty and House 1980) indicated that amylose percent in grain was positively associated with overall *roti* and *tô* qualities.

With the objective to study the relative contribution of the flour components to *roti* quality, stepwise multiple regression was adopted by considering *roti* quality characters as dependent variables and the physicochemical characters as independent variables. The results are given in Table 7. The color and appearance of *roti* showed a positive relationship with water soluble protein and total amylose, and negative relationships with starch and reducing sugars. The texture of *roti* showed strong relationships with protein and total amylose, and a negative association with soluble sugars. Taste was inversely related to reducing sugars, WSFF and flour swelling capacity, while a positive relationship was observed with water soluble protein. Flavor also showed a positive relationship with protein, amylose and ash contents. The joint effect of flour components on *roti* quality needs to be studied in detail. This would assist in developing a rapid screening methodology that could be used for testing early

Table 5. Textural characteristics of dough from eight sorghum cultivars measured with a back extrusion cell in an Instron machine.

Cultivar	Rolling quality[a] (cm)	Kneading quality[b] (score)	First point[c] (kg)	Yield point[c] (kg)	Work done[c] (sq cm)	Slope[c]
Simila	14	3	(a single peak—no extrusion)			
P-721	16	3	"			
PJ-12-K	22	3	12.5	20.0	10.8	0.25
Karad local	22	2	19.3	25.7	15.3	0.24
269	24	1	27.5	39.0	24.1	0.40
IS-12611	24	1	35.0	48.8	28.4	0.49
IS-1235	23	1	43.3	53.7	32.4	0.40
M-35-1	24	1	41.8	58.0	34.3	0.60

a. Rolling quality was measured as the maximum diameter rollable into *roti* from dough made from 50 g flour.
b. Kneading quality was scored subjectively over a scale of 1 to 3, where 1 is good and 3 is poor.
c. Values recorded from Instron machine using a back extrusion cell.

Table 6. Comparison of physicochemical characters of sorghum cultivars having poor and good *roti* qualities.

Cultivar	Grain color	Mean *roti* quality score[a]	WSFF[b] (mg/100 g)	Water soluble protein in whole flour (%)	Total amylose in whole flour (%)
Poor *roti* types					
PJ-16R	Creamy white	1.5	29.8	0.30	25.1
PJ-19R	White with brown spots	1.8	28.9	0.44	24.8
PJ-2K	White with red spots	1.9	33.9	0.34	27.1
Simila	Light brown	1.7	26.6	0.63	21.5
Mau-Wani	White	1.9	35.0	0.62	22.2
Mean ± SD		1.8 ± 0.15	30.8 ± 3.15	0.47 ± 0.14	24.1 ± 2.04
Good *roti* types					
285	Creamy white	3.1	26.3	0.60	29.9
E-35-1	Creamy white	3.1	19.4	0.71	29.9
IS-12611	Dull white	3.3	24.7	0.58	28.8
Bodgawanda Wani	White with brown spots	3.1	22.0	0.60	28.0
Vidhisha 60-1	Dull white	3.0	29.2	0.85	28.2
M-35-1 (Check)	Creamy white	3.3	21.0	0.80	28.2
Mean ± SD		3.2 ± 0.11	23.8 ± 3.33	0.69 ± 0.11	28.8 ± 0.79

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

generation materials in a breeding program.

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Table 7. Stepwise multiple regression coefficients for the physicochemical characters and *roti* quality of sorghum grain.

	Regression coefficient	Computed T	R^2	Level of significance
Roti color and appearance				
Grain hardness	0.18	3.54	0.65	**
Water soluble protein	1.34	2.65		*
Reducing sugars	−6.28	−4.79		**
Starch	−0.12	−3.40		**
Roti texture				
Protein	0.19	3.73	0.62	**
Total amylose	0.10	3.20		**
Water soluble protein	1.23	2.39		*
Soluble sugars	−1.69	−3.23		**
Ash	1.30	2.57		*
Roti taste				
Water soluble protein	1.26	2.90	0.62	*
Reducing sugars	−2.28	−2.28		*
Flour swelling capacity	−0.19	−2.00		*
WSFF[a]	−0.02	−1.55		+
Roti flavor				
Protein	0.11	3.05	0.41	**
Total amylose	0.07	3.32		**
Ash	0.61	2.20		*
Fat	−0.16	−1.55		+
General acceptability				
Water soluble protein	0.81	2.42	0.48	*
Reducing sugars	−3.46	−4.12		**
Protein	0.10	2.41		*
WSFF	−0.23	−1.83		+

a. WSFF: Water soluble flour fraction.
** Significant at 1%
* Significant at 5%
+ Significant at 10%

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Cultivar Differences for Gel Consistency in Sorghum

D. S. Murty, H. D. Patil, and L. R. House*

Summary

The potential of gel consistency tests in the evaluation of sorghum food quality was investigated. Gel spread of cooled thin porridges exhibited significant cultivar differences and was affected by season, available soil moisture, dehulling and grinding methods. Gel spread was negatively associated with corneousness of the grain and particle size index of the flour. It was also associated with the roti *and* ugali *properties assessed by taste panelists.*

The flow of cold flour-KOH gels in test tubes varied among cultivars and deserves more investigations. The value of gel consistency tests in sorghum quality improvement programs is discussed.

Sorghum (*Sorghum bicolor* L. Moench) grain is consumed in the semi-arid tropics in several forms and the preferred color, taste, texture, and keeping quality varies with the food. Generally, light-colored products are preferred to dark-colored products. The elusive quality, taste, is difficult to define; astringent taste is disliked. Food quality studies on a number of sorghum cultivars in various countries have shown that the texture of the fresh and stored food has a major effect on consumer acceptance (Murty and House 1980). Physicochemical tests which require small samples of grain and can predict the texture of the food are valuable to breeders engaged in quality improvement programs. Viscosity measurements of pastes or gels made from milled rice flour or starch have been used to predict the texture of cooked rice. Cagampang et al. (1973) and Perez (1979) measured the consistency of cold gels of rice flour that had been dispersed in KOH at 100°C and found that the length of gel flow in a test tube for unit time was a varietal character. Gel consistency of milled rice was correlated with amylose content, amylograph measurements, and hardness of cooked rice measured by the Instron food tester (Juliano 1979; Perez 1979). The potential of two different gel consistency tests in predicting sorghum food quality was investigated and the results of these studies are reported here.

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Gels from Porridges

Preliminary observations indicated that thin porridges of sorghum like *ugi* form characteristic gels when stored overnight, particularly at 0 to 15°C. This principle led to the standardization of simple "gel spread" measurements without resorting to the use of chemical agents that promote gelling properties. Fine sorghum flour was obtained by milling the grain samples on a Domestic Milcent (Size-2) Grinder equipped with two carborundum stones (50 cm diameter × 6 cm) held vertically and powered by a 0.5 hp motor. A freshly made flour dispersion of 10 g flour in 70 ml tap water was stirred into 140 ml of boiling water and the suspension was allowed to boil for approximately 10 min. As soon as the bubbling and frothing stopped, the porridge was poured into 20 × 52 mm petri dishes (with a drop of oil smeared to the inner surface) and cooled in a refrigerator at 10°C for 3 hr. The gel was transferred to a smooth glass surface by inverting the petri dish. The diameter of the gel mass that spreads out on the glass was measured after 5 min and was expressed as gel spread in mm. Viscosity and cohesiveness of the gel determines the extent of gel spread.

Grain samples from 25 sorghum cultivars selected for the International Sorghum Food Quality Trials in 1979 and 1980 were evaluated for their gel spreading quality. Average gel spread of two independent observations made on three different weeks for the 24 nonwaxy cultivars varied from 56 to 77 mm and 56 to 73 mm in the years 1979 and 1980, respectively (Tables 1 and 2). The data showed that variation due to genotypes was very large and significant for both years. Gel spread measurements using flour from nonwaxy grains dehulled by the traditional mortar and pestle method exhibited, on an average, 2 mm lower values than those from whole grains (Table 1). We obtained gel spread measurements on flour samples of a wide range of sorghum cultivars: accessions from the World Collection, improved cultivars, and advanced generation progenies from several varietal crosses. Among 995 nonwaxy genetic stocks studied in 1979 and 1980, gel spread of postrainy season harvests varied from 54 to 75 mm while that of rainy season harvests varied from 57 to 90 mm. Waxy grain samples like those of IS-158 produced fluid gels which spread beyond 100 mm. The gel spread (mm) showed a high degree of reproducibility and varied with the cultivar. Murty et al. (1981a) investigated the gel spread quality of six cultivars grown under different nitrogenous fertilizer levels and did not observe any significant effect of nitrogen level on gel spread quality. In another study involving 10 cultivars grown under different levels of soil mois-

Table 1. Mean gel spread (mm) of 25 sorghum cultivars grown at ICRISAT Center in the postrainy season for International Sorghum Food Quality Trials.

	Gel spread		
	1979	1980	
Cultivar	Whole grain	Whole grain	Dehulled grain[a]
M35-1	58	60	58
CSH-5	58	59	60
M50009	60	59	55
M50013	59	58	58
M35052	59	56	56
M50297	56	57	58
P-721	74	73	70
CO-4	62	59	59
Patcna Jonna	63	60	58
Mothi	56	57	54
E35-1	57	55	53
IS-158 (Waxy)	102	111	90
WS-1297	77	68	64
Swarna	57	59	56
S-29	59	56	54
S-13	60	57	55
IS-2317	62	61	59
IS-7035	59	60	58
IS-7055	68	63	57
IS-9985	62	63	56
IS-8743	58	58	57
Dobbs	71	68	60
CS-3541	59	59	56
Segaolane	56	58	58
Market	57	58	57

a. Standard error of mean = h4.

Table 2. Analysis of variance (mss) of gel spread of flour from whole grain of 24 sorghum cultivars.

Sources	1979			1980		
	d.f		mss	d.f		mss
Replications	2		12.16	2		8.48*
Genotypes	17[a]		94.03**	23[a]		56.36**
Error	34		7.55	46		2.28
Mean		62			60	
CV(%)		4.4			2.5	
CD(5%)		4.4			2.4	

a. In 1979 only 18 cultivars were studied in three replicates, whereas in 1980 all 25 cultivars were studied. However, the waxy was excluded from analysis of variance for both years.

ture, gel spread values were significantly (at 5% probability level) affected by available soil moisture level (Murty et al. 1981a). Average gel spread values of 16 cultivars grown in the rainy season and postrainy season showed statistically significant differences (Murty et al. 1981a). The rainy season harvests and postrainy season harvests exhibited a mean gel spread of 66.4 and 58.7 mm, respectively. Milling methods were observed to be contributing to variation in gel spread (Table 3). Coarse and fine flour samples from four cultivars exhibited a mean gel spread difference of 4.2 mm; the coarse flour produced thicker gels.

Association of Gel Spread with Grain and Food Properties

Studies on grain samples of 74 cultivars showed that corneousness of the grain was negatively correlated with gel spreading (r = −0.57) (Murty and House 1980). Particle size index of the flour measured according to the methods of Waniska (1976) also showed negative correlation with gel spread (r = −0.42). Observations on 25 cultivars of the International Sorghum Food Quality Trials carried out in 1979 showed that gel spread values were negatively correlated with percent amylose (−0.81) and percent water soluble amylose (−0.69) (Murty and House 1980).

The association of sorghum gel spread with *roti* texture was studied using grain samples from 260 cultivars. The *roti* texture of the corresponding grain samples was determined by a trained taste panel of five members subjectively on a scale of 1 to 5, where 1 represented the most desirable (Murty et al. 1981a; Murty and Subramanian 1981). It was noted that intermediate gel spread values of 61 mm were associated with desired *roti* texture although the correlation coefficient was low when the entire range of material was studied (0.22, $P > 0.01$). Gel spread was negatively correlated (−0.62) with overall *roti* quality (Murty and House 1980). Gel spread and *ugali* texture properties of 108 cultivars showed that desired *ugali* texture scores by Kenyan taste panelists were correlated (r = −0.34, $P > 0.01$) with thick gels (54 to 62 mm). Similarly, gel spread values and softness scores of *soru* from the 25 sorghum cultivars of the International Sorghum Food Quality Trials (Subramanian et al. 1981) showed a negative correlation (−0.59).

Flour-KOH Gels

The possibility of applying gel consistency tests of rice (Perez 1979) to sorghum flour was examined. Fine flour from whole grains of sorghum (throughs of 40 US standard sieve) was used for determining gel consistency properties. The flow of gels was sensitive to slight changes in either the concentration of flour or the normality of the alkali. Maximum varietal differences were obtained with 0.8 g flour in 10 ml of 0.4N KOH. Whole grain flour (0.8 g) was wetted in a 200 × 25 mm (Pyrex No. 7920) glass tube (with 0.5 ml of absolute alcohol to avoid clumping of flour). Ten ml of 0.4N KOH was added and the suspension was thoroughly shaken. The tube was heated in vigorously boiling water contained in a beaker heated by a hot plate for 20 min and then cooled for 5 min. The test tube was again thoroughly shaken and cooled in an ice waterbath at 2°C for 1 hr. The test tube was removed from the ice bath and carefully laid flat on a graph paper fixed to a table. The distance the gel flowed was measured after 1 hr for 25 sorghum cultivars obtained from two independent observations made during five different weeks (Table 4). The analysis of variance of the data showed highly significant differences between cultivars (Table 5). The KOH gel consistency tests were repeated on the 25 samples using flour from grain dehulled by traditional methods. Other procedures were the same as those described for whole grain flour, except that 1.0 g flour was used. The mean gel flow of the 25 cultivars varied significantly. Gel flow of whole grain flour samples ranged from 30 to 92 mm while that of dehulled grain flour samples ranged from 49 to 115 mm. Samples of grain from these 25 cultivars were evaluated with the help of taste panels for the quality of three food recipes, i.e., *roti*, *sankati*, and *soru* (Murty et al. 1981b; Murty et al. 1981c). Gel flow of flour samples from whole grains of the 24 nonwaxy genotypes was found to be positively associated with *roti* texture ($r = 0.41$, $P > 0.05$), *sankati* texture ($r = 0.54$, $P > 0.01$), and *soru* texture ($r = 0.44$, $P > 0.05$). These observations indicate that there are highly significant differences in the flowability of KOH gels of sorghum cultivars and that more extensive studies are necessary to establish the utility of KOH gel consistency tests in evaluating sorghum food quality.

Value of Gel Tests to Sorghum Food Tests

Results presented indicate that gels from porridges show genotypic variation in consistency. Gel consistency expressed as gel spread was associated with kernel texture and flour particle size index. Intermediate gel spread values were associated with good *roti* texture while thick gels were associated with desirable *ugali* texture. Scheuring et al. (1981) reported the use of gel tests to predict the keeping quality of alkali *tô* and found that very thick gels were associated with good *tô* characteristics. As gel spread tests require small quantities of grain and are associated with textural properties of some sorghum foods, they seem to have some potential as simple laboratory tests to aid selection in the early generations of breeding. Further studies on gel spreading using a wide range of genetic stocks coupled with a range of food tests might throw more light on its utility in predicting sorghum food quality.

Table 3. Effect of grinding pressure on gel spread (analysis of variance).

Source	d.f	Mean sums of squares
Replications	5	3.4
Grinding pressures	2	86.8**
Error (a)	10	2.2*
Genotypes	3	779.6*
Genotypes × Grinding pressures	6	8.7
Error (b)	45	6.6

** Significant at 1% probability. * Significant at 5% probability.

Table 4. Mean gel flow (mm) of 25 sorghum cultivars grown in the postrainy season at ICRISAT Center, 1980.

Genotype	Whole grain	Dehulled grain
M35-1	73	69
CSH-5	85	86
M50009	78	75
M50013	70	76
M35052	78	70
M50297	62	66
P-721	49	61
CO4	81	103
Patcha Jonna	56	81
Mothi	64	84
E35-1	66	101
IS-158	63	59
WS-1297	63	69
Swarna	92	82
S-29	91	78
S-13	64	100
IS-2317	63	77
IS-7035	52	85
IS-7055	31	49
IS-9985	61	108
IS-8743	84	88
Dobbs	38	62
CS-3541	59	115
Segaolane	84	92
Market-1	87	86

Table 5. Analysis of variance (mss) of gel flow of 25 sorghum cultivars.

Source of variation	d.f	mss	
		Whole grain	Pearled grain
Replications	4	322.86**	553.82**
Genotypes	24	2509.93**	2632.35**
Replications × Genotypes	96	92.16	85.22
Sampling error	125	22.13	68.97
Mean		68	81
%CV		14.16	11.41
CD5%		8.5	8.2

** Significant at 1% probability.

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Polyphenols and Their Effects on Sorghum Quality

L. G. Butler*

Summary

The condensed tannins and other polyphenols of sorghum grain provide agronomic advantages, such as bird resistance, but can be harmful in the diet, severely reducing weight gains of rats and chicks. We report here our investigation of the assay, purification, characterization, distribution, metabolism, detoxification, genetics, and significance of sorghum polyphenols. Binding of proteins, the probable basis of tannin's dietary effects, is quite protein-specific. Proteins rich in proline may be selectively bound by tannin out of a >100-fold excess of other proteins. Proline-rich proteins such as those in seeds and in saliva may bind and inactivate tannins that would otherwise disrupt metabolism. A promising approach for overcoming the antinutritional effects of tannin is chemical detoxification. Wetting high-tannin, bird-resistant sorghum grain with dilute aqueous ammonia (0.2% NH_3) for a few hours before feeding or processing lowers the assayable tannin, eliminates the capacity of the grain to bind extraneous proteins such as those in the digestive tract, and increases rat and chick weight gains up to those of low-tannin controls.

To the biochemist concerned with the chemical properties and biological functions of the phenolic materials of plants, sorghum is of special interest because of the amount and variety of phenols it produces. One of the most conspicuous characteristics of sorghum is the red pigmentation formed in mature plants in response to damage, stress, or infection. The anthocyanin pigments responsible for this color are polyphenols. Other types of polyphenols such as condensed tannins have been recognized in the seed of many sorghum lines. Although not all of the biological effects of polyphenols in sorghum grain have been elucidated, they generally are beneficial in the field and harmful in the diet.

Sorghum polyphenols serve to protect the seed, unguarded by a husk like that of maize, against attack by insects (Woodhead et al. 1980) and birds (Hoshino et al. 1979) and against preharvest germination (Harris and Burns 1970). It is also likely that phenolic materials protect the sorghum plant against diseases caused by fungi, bacteria, and viruses (Friend 1981). Regrettably these agronomic advantages of sorghum polyphenols are accompanied by nutritional disadvantages. Diets containing high-tannin sorghum produce low growth rates for chicks (Chang and Fuller 1964; Vohra et al. 1966) and rats (Jambunathan and Mertz 1973; Maxson et al. 1973; Schaffert et al. 1974; Dreyer and Niekerk 1974). Other antinutritional effects of polyphenols have been reported (Price and Butler 1980).

Our overall goal is the minimization of the conflict between sorghum producers, for whom polyphenols are generally beneficial, and sorghum utilizers, for whom polyphenols are generally harmful. We assume that the agronomic benefits of sorghum polyphenols are sufficiently important to ensure that high-tannin sorghums will continue to be produced; that is, the problem of polyphenols in sorghum will not be solved simply by elimination of high-tannin varieties.

Ideally the "tannin problem" could be solved by identification or development of sorghums in which the beneficial agronomic effects of polyphenols are retained or enhanced, while the antinutritional effects are eliminated. Even if the same polyphenol components are responsible for both beneficial and harmful properties, a metabolic modification of polyphenols to nontoxic forms at maturation could help to solve the problem. While we seek for sorghums with the desired properties,

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we also are devising detoxification procedures, preferably simple, specific, and rapid, which can be inserted between sorghum production and utilization. In this way sorghum producers can continue to enjoy the agronomic benefits of polyphenols without harming utilizers. We have made considerable progress, but it is clear that detoxification is a solution to the tannin problem which can be much more readily achieved on a large scale in formulating animal feeds, than on a household scale for human food.

Chemistry of Sorghum Polyphenols

Structures and Nomenclature

The major polyphenols found in "high-tannin" sorghum grain are the condensed tannins. The structure shown in Figure 1 has been proposed for sorghum tannins by Gupta and Haslam (1978); it is an oligomer of five to seven flavan-3-ol units. In strong acids such flavan-3-ol oligomers depolymerize to yield monomeric anthocyanidin pigments (cyanidin in the case of sorghum tannin) so they are designated as proanthocyanidins. In addition to these oligomers, many monomeric and dimeric flavanols have been reported in sorghum and some of these form anthocyanidins in acid.

Assays

We have modified several chemical assays to increase their suitability for sorghum polyphenols, and have developed new assays. It is now possible to reliably measure the amount of tannin present in sorghum grain by several independent techniques which detect different features of the molecular structure. For dry, untreated mature grain, chemical assays for "tannins" usually correlate well with the much more time-consuming measurement of antinutritional effects as determined with feeding trials with rats and/or chicks. For screening purposes, chemical assays save a great deal of time and effort. Equally important to us, comparison of the results of independent assays for different features of the polyphenols is quite useful in chemical characterization. Thus we routinely run a rather complex series of assays in order to get maximum information from our samples.

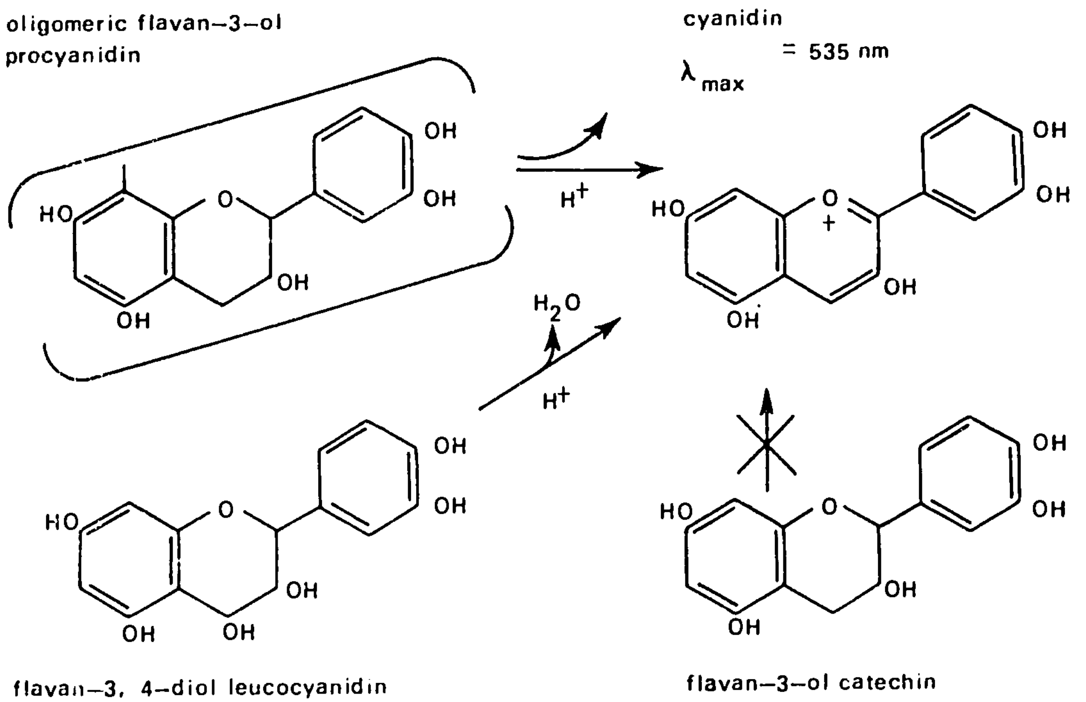

Figure 1. Various flavan-3-ols and their susceptibility for conversion to cyanidin.

Prussian Blue

This assay (Price and Butler 1977) measures the total content of phenolic hydroxyl groups, and thus is not specific for tannins. It can be used as an assay for tannin in sorghum because in high-tannin varieties the phenolic groups of tannins constitute a large proportion of all the phenols present in the grain. This reducing power assay is convenient because it can be carried out on ground grain directly, on an extract, or even on single seeds out in the field. It is routinely used by a commercial feed producer. The chemical basis for this assay is the reduction by phenolic hydroxyl groups of Fe^{+3} to Fe^{+2}, which is then complexed with ferricyanide to yield the characteristic blue pigment.

Ortho Diphenols

Not all sorghum polyphenols have the 3',4'-dihydroxy substitution patterns shown in Figure 1; in some cases the 3'-hydroxyl group is absent. We use the ortho diphenol assay of Waite and Tanzer (1981) to conveniently distinguish between such forms. The chemical basis for this assay is the specific reaction of nitrite with ortho diphenols to produce a bright red chromophore in alkali.

Vanillin

Perhaps the most widely used assay for sorghum tannins is the vanillin reaction (Burns 1971). Its principal advantage is that the only plant phenolics with which it gives a positive test are the condensed tannins and some flavanoids (Ribéreau-Gayon 1972, p 45). We modified this assay to include a reagent blank which corrects for color of the seed extract (Price et al. 1978a). This modification improves the accuracy of the assay (El Tuhami et al. 1980) but may not be necessary for routine analysis (Earp et al. 1981). Catechin is used to standardize the vanillin assay, although the absorbance produced with catechin is not linear with concentration, its (weight) extinction coefficient is much less than that of tannin, and the time course of the reaction of catechin and tannin are entirely different (Price et al. 1978a).

We find that using glacial acetic acid as solvent rather than methanol eliminates several of these problems (Butler et al. in preparation). Moreover, color production in glacial acetic acid, in contrast to methanol, is approximately the same for equimolar concentrations of monomers, dimers, and trimers, suggesting that under these conditions vanillin reacts only with a terminal unit of each oligomer. Thus, the assay in glacial acetic acid apparently measures the molar concentration of proanthocyanidin oligomers rather than the weight percent.

Polyphenol Assays of Leaves

Spectrophotometric assays of tannins and flavanoids in plant tissue other than seeds are formidable because of interference by chlorophyll. We find that the affinity of tannins and related polyphenols for insoluble polyvinylpyrrolidone (PVP, Polyclar AT), which has often been used in plant extracts to bind phenolic materials which would otherwise inhibit extracted enzymes (Loomis and Battaile 1965), makes possible the assay of these materials in the absence of chlorophyll (Watterson and Butler in preparation).

From a methanol extract of sorghum leaves (the procedure works as well with seeds) we adsorb the phenolics on PVP and wash with methanol to remove unbound pigments such as chlorophyll. We have not found a solvent capable of eluting phenolics in good yield which is also compatible with subsequent tannin assays, so we assay polyphenols while they are bound to PVP. The vanillin reaction is not suitable for assaying bound phenolics because the pigments formed remain bound to the insoluble PVP and therefore cannot be measured spectrophotometrically. The Prussian blue reaction can be adapted to PVP-bound phenolics, but the sensitivity is considerably diminished. An assay based on the depolymerization of proanthocyanidins (condensed tannins) to anthocyanidin pigments in hot acidic n-butanol (Swain and Hillis 1959) proved to be suitable. The flavylium ion pigment products are not bound by PVP and are easily measured after removal of PVP by centrifugation. We call this the anthocyanidin production assay.

Using this assay we find no detectable condensed tannins in the leaf tissue of some 50 varieties of sorghum. However we do find, in leaf tissue of about one-third of the lines examined, a related material bound to PVP which when in HCl-butanol is rapidly converted to a pink anthocyanidin-type pigment *at room temperature*. The pigment is labile and is rapidly destroyed on heating under the conditions where proanthocyanidins are converted to stable anthocyanidins such as cyanidin. This material was partially purified from methanolic extracts of sorghum leaves (variety IS 9958) by adsorption on a porous polystyrene resin, washing with methanol to remove chlorophyll and other pigments, and elution with 1 : 1 (v/v) acetone: H_2O (Watterson and Butler in preparation). This material has the properties of a flavan-4-ol similar to that previously reported by Bate-Smith (1969) to be present in sorghum. Bate-Smith (1969) identified the flavan-4-ol as luteoforol (Fig. 2); similar material was reported in seed of several sorghum varieties (Bate-Smith and Rasper 1969). In dilute aqueous solutions of mineral acids, flavan-4-ols readily convert to the anthocyanidins, as shown for a flavan-3, 4-diol in Figure 1 (Ribéreau-Gayon 1972). The absence of a hydroxyl group at position number three confers somewhat unusual properties; catechin, a typical flavan-3-ol, does not form cyanidin, its corresponding anthocyanidin, under these conditions (Ribéreau-Gayon 1972). The anthocyanidin with the hydroxylation pattern of luteoforol is luteolinidin (Fig. 2), which has previously been reported in sorghum glumes (Bate-Smith 1969) and mesocotyls (Stafford 1965).

The flavanoid which we find in sorghum leaves (we find similar material in the seed of the same lines) does not have all the properties reported (Bate-Smith 1969; Bate-Smith and Rasper 1969; Stafford 1965) and expected for luteoforol. For instance, the flavan-4-ol we find is negative in the assay for ortho-diphenols (Waite and Tanser 1981). We have tentatively identified the flavan-4-ol as apiforol (Fig. 2). Its corresponding yellow anthocyanidin, apigenindin, has been reported in sorghum mesocotyls (Stafford 1965) and glumes (Bate-Smith 1969). Bate-Smith (1969) found luteoforol in sorghum glumes, but did not find apiforol.

The significance of the presence of the unusual flavan-4-ol in sorghum seeds and vegetative tissue is not yet known. Its distribution is independent of that of tannins (see later section). It is apparently monomeric and it does not precipitate protein in our assays. It does not give a positive response in the vanillin assay (Prince et al. 1978a). The properties and distribution of this material will be described in a forthcoming publication (Watterson and Butler in preparation).

Protein Precipitation

Perhaps the property of tannins which is most closely correlated with their biological effects is their capacity to bind and coagulate protein. We have developed two methods for measuring the protein precipitating capacity of sorghum tannins.

In order to measure the amount of tannin in a tannin-protein precipitate, buffered serum albumin is mixed with a tannin-containing extract and the resulting precipitate, after centrifugation and washing, is dissolved in an alkaline detergent solution to which $FeCl_3$ is added, forming a violet-colored complex. This assay is very simple, convenient, and reproducible (Hagerman and Butler 1978).

In order to measure the amount of protein in tannin-protein precipitates we use radioiodinated

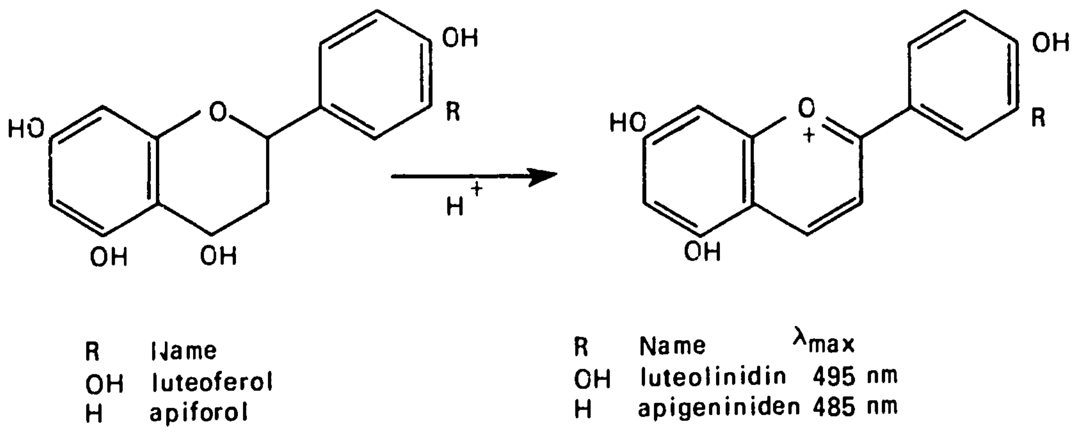

Figure 2. Conversion of flavan-4-ols to anthocyanidins.

protein (Hagerman and Butler 1980a). This assay is particularly suited to measurements of the relative affinity of various proteins for tannin, by competition with a standard radiolabelled protein (Hagerman and Butler 1981) (see later section). To make this assay more convenient, we are now adapting it to a spectrophotometric assay, using hemoglobin as the standard protein (Schultz et al. 1981). The investigation of the tannin-protein interaction is facilitated by the capability to independently quantitate both components of the complex.

Tannin Specific Activity and Degree of Polymerization

As mentioned previously, information quite useful in characterizing sorghum polyphenols can be obtained from multiple chemically-independent assays of the sample. For example, we have described a parameter called tannin specific activity (Hagerman and Butler 1980a), which we define as the ratio of the protein precipitating capacity to the total content of phenolic groups in the sample (assays described above). This parameter is used to monitor tannin purification procedures. The tannin specific activity increases to a characteristic maximum value as nontannin phenolics are eliminated during purification.

Another characteristic parameter of considerable interest is the degree of polymerization of the proanthocyanidin (tannin). Bullard and Elias (1980) and Glennie (1981) report that sorghum polyphenols increase in size during ripening. An increase in degree of polymerization of sorghum tannin during maturation might be responsible for the apparent decrease in tannin content of several varieties during maturation (Davis and Hoseney 1979; Price et al. 1979a; Bullard and Elias 1980). As mentioned above, the vanillin assay carried out in glacial acetic acid provides a measure of the molar concentration of the flavan-3-ol oligomers. The anthocyanidin production assay is probably the most useful for estimating the total number of flavan-3-ol units present. The ratio of the values in the anthocyanidin production assay to the vanillin assay in glacial acetic acid should be proportional to the degree of polymerization. We are currently determining this ratio throughout the maturation process to determine how the degree of polymerization changes during maturation.

Polyphenol Extractability and Purification

The preparation of pure condensed tannins from sorghum is laborious, so that few laboratories undertake it, and no preparation suitable for use as a standard in tannin assays is readily available. A biochemical supply house could help to overcome this serious problem (Gupta and Haslam 1980; Price et al. 1978a) by making available purified condensed tannin, preferably obtained from sorghum grain, for use as a standard.

Polydispersity

The length and composition of flavan-3-ol oligomers is not directly coded on DNA (Gupta and Haslam 1978) as are the structures of proteins. The system is therefore inevitably polydisperse (like starch) so that it may not be possible to obtain a homogeneous (monodisperse) sample even though it is "pure" (free from nontannin components).

Capacity for Binding to Diverse Materials

Effect of H^+ on Extractability

Maxson and Rooney (1972) first observed that extraction of sorghum with 1% HCl in methanol often gives larger amounts of tannin than the conventional extraction with methanol alone. Cummings and Axtell (1973) identified several lines of sorghum in which methanol does not extract significant amounts of tannin, but acidic methanol does extract tannin. These lines were called group II sorghum; group III sorghums have tannin extractable in methanol, and group I sorghums do not have significant amounts of tannin. We showed that similar amounts of tannin are extracted in both solvents for several sorghums, that the rate of extraction is slower for group II sorghums, that HCl concentrations higher than 1% extract considerably more tannin, and that tannins are rather unstable in acidic methanol (Price et al. 1978a).

Group II sorghums are of considerable interest because of the apparent absence of antinutritional effects associated with the tannin of these lines (Cummings and Axtell 1973). We have therefore adapted our assay procedures to distinguish polyphenols extractable in methanol and polyphenols extractable in acidic methanol but not in methanol. Each sample is extracted twice with methanol (the extracts are combined for assays) and the residue is then extracted twice with 1% HCl in methanol. The extracts were assayed by the tests described in an earlier section. This procedure has been applied to over 100 lines of sorghum, approximately half from the World Collection at Purdue and half from a wide variety of other sources.

Representative results, showing tannin content by the vanillin assay and flavan-4-ol content, for both types of extracts are shown in Figure 3. It should be emphasized that the acidic methanol extractions were carried out on the residue which remained after two methanol extractions, so the acidic methanol extractable material clearly has different properties in the seeds from that which is extractable in methanol. The results indicate that both types of polyphenols usually occur together rather than independently of each other as we previously suggested (Price et al. 1978a). Many group III sorghums contain considerable tannin extractable only with acidic methanol in addition to their methanol-extractable tannin; IS 6881 is unique in that it contains a relatively large amount of tannin which is essentially all extractable in methanol.

The distinction between extractability in the two solvents is not limited to tannins, but extends to the apparent flavan-4-ol. As with tannins (as measured by the vanillin assay), the amount of flavan-4-ol extractable in methanol is usually greater than that extractable in acidic methanol although where the opposite is true for tannins it is also true for flavan-4-ols (IS 3441). Line IS 9958 is of especial interest because the content of flavan-4-ol in its leaf tissue is the highest of any of the lines which we have examined (Watterson and Butler in preparation), and in leaf tissue it is readily extracted in methanol, while extraction of flavan-4-ol from the seed requires acidic methanol. This line, as well as RS 610 and 954035 illustrate that flavan-4-ols occur independently of tannin. The opposite case, in which tannin is present in the virtual absence of flavan-4-ol, is less common (IS 4904).

Flavan-4-ols and condensed tannins which require acidic methanol for extraction are completely soluble in methanol in the absence of acid, once extracted from the seed. The parallel in extractability between these types of materials (Fig. 3) suggests that in the seed they occur together in structures not accessible to methanol in some lines of sorghum, rather than covalently bound to a component of the grain, as we previously suggested for group II tannins (Price et al. 1978a). We are hopeful that investigations of seed structures by electron microscopy, such as those reported by Rooney et al. (1980), will lead to a solution of why some sorghum polyphenols are extractable only with acidic methanol. We are currently characterizing tannin extractable only in acidic methanol and find it to be comparable to methanol-extractable tannin with respect to protein precipitating power and chemical assays, although its affinity for Sephadex LH-20, used in the purification (below), seems to be less than that of methanol-extractable tannin.

Effect of Water on Extractability of Tannin

We have made several types of observations which illustrate the profound effect of water on the extractability of sorghum tannin. These data were obtained exclusively with methanol-soluble tannin so that the effect of acid on extractability is not involved here. An experiment designed to test the effect of germination of sorghum on the level of assayable tannin is shown in Table 1. Germinated samples, if assayed without drying, had virtually no extractable tannin by either assay, but after drying the amount of extractable tannin was much greater. The two lines were not equally affected by drying; only in BR 64 did the amount of assayable tannin in germinated and dried grain approach that of the ungerminated grain. Reichert et al. (1980) reported decreases in assayable tannin of sorghum grain on germination or imbibition of water, acid, and alkali, *without* drying the samples before assay.

We reported that the assayable tannin content of several mature high-tannin sorghums, harvested at moisture content of 16% or greater, increases by as much as 190% on drying (Price et al. 1979a). Immature sorghum also showed large increases in assayable tannin on drying in air, as compared with lyophilization, but was found to be extremely sensitive to handling and drying procedures (Price et al. 1979a).

We find no effect on assayable tannin of the addition of a limited amount of water (15% of seed weight) to whole grain just before grinding, to ground grain just after grinding, or to the methanol extract. Larger amounts of water added to ground grain, as in preparation of a batter for cooking,

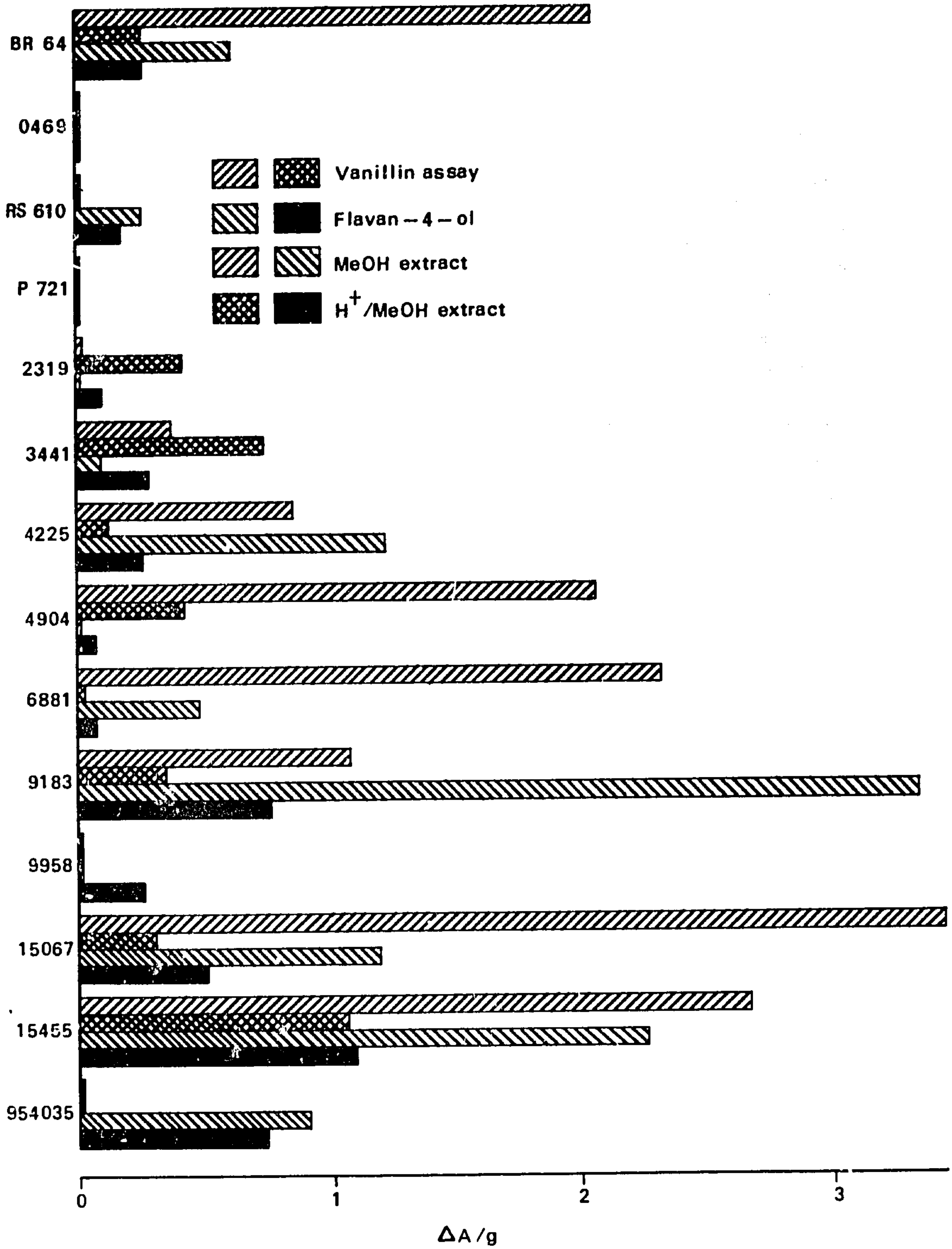

Figure 3. Occurrence and distribution of tannin-related materials.

extract protein and tannin and permit formation of insoluble tannin-protein complexes from which tannin cannot be extracted (Price et al. 1980).

Binding to Protein during Extraction and Purification

Sorghum tannins prepared in our laboratory by conventional methods including chromatography on Sephadex LH-20 (Strumeyer and Malin 1975; Davis and Hoseney 1979) contain up to 20% protein. In the purification procedure we developed (Hagerman and Butler 1980b) we introduced two additional steps which greatly aid in the removal of protein.

We first extract the ground grain with ethanol to remove alcohol-soluble protein. In the varieties we used (NK 300 and BR 64) absolute ethanol extracts no more than 15% of the methanol-extractable phenolics, but this may not be true in all varieties. The subsequent methanol extract is fractionated conventionally by ethyl acetate extraction and chromatography on Sephadex LH-20. The other new step we introduced is extraction of the partially purified tannin, in aqueous solution, with liquified phenol. This efficiently removes protein from the tannin, which remains in the aqueous phase. On recovery and characterization of the tannin-associated proteins from the phenol phase it was found that they consist of components of MW 89,000, 67,000 and 15,000. The first two are extremely hydrophobic; the 89,000 MW protein has twice as much proline (21%) as any other amino acid. Similar high MW proline-rich hydrophobic proteins were shown to be present in the prolamine (alcohol soluble protein) fraction of both high and low-tannin sorghum (Hagerman and Butler 1980b).

Binding of Sorghum Polyphenols to Chromatography Media

Another major problem in purification is that complex polyphenols such as tannins tend to bind quite strongly to a wide variety of materials. Our experience is similar to that of Kaluza et al. (1980) who found less than 30% recovery of phenolics on certain support materials. Our attempts at using high performance liquid chromatography (HPLC) on sorghum polyphenols produced complex but irreproducible patterns followed by permanent blockage of the column. Separation by HPLC may be possible on acetylated materials (Glennie et al. 1981). We are investigating a promising new technique, continuous counter-current chromatography (Ito and Bhatnagar 1981), in which chromatography is carried out with two liquid phases and no solid phase, so that complete recovery of the sample is anticipated. We hope eventually to resolve the various lengths of oligomers.

Tannin-Protein Interactions

The interactions of tannins with protein are thought to be responsible for the biological effects of tannins, so we have examined several features

Table 1. Effect of germination ± drying on assayable tannin of sorghum.[a]

Sorghum	Treatment	Drying	Tannin Assays: Vanillin ΔA_{500}/100 seeds	Tannin Assays: Protein precipitation ΔA_{510}/100 seeds
BR64	Untreated		3.42	2.83
	Germinated	No	0.05	0.06
	Germinated	Yes	2.43	2.71
IS4225	Untreated		2.50	1.46
	Germinated	No	0.05	0.06
	Germinated	Yes	0.51	0.47

a. Germination (~80%) was carried out for 5 days at room temperature, washing 2X daily with fresh water so that no mold growth was observed. Drying was for 24 hr at room temperature.

of this interaction. All our results were obtained with tannin purified from high-tannin sorghum grain according to our procedure (Hagerman and Butler 1980b).

Chemical Basis

Hydrogen bonding is often suggested as a principal means of stabilizing tannin-protein complexes. The results of our studies of the effect of hydrogen bond forming solutes and solvents on the strength of the interaction are consistent with this type of complexation (Hagerman and Butler 1981). However, the effects of methanol and ethanol are qualitatively different from those of dimethyl formamide and dioxane, and suggest that hydrophobic interactions also contribute to the stability of the complex (Hagerman and Butler 1980a), in agreement with Oh et al. (1980). The profound inhibitory effect of water on the extractability of tannin, as mentioned above, is also consistent with a nonpolar interaction of tannin in situ, because water should readily extract hydrogen-bonded materials which are intrinsically water-soluble.

Specificity

Tannins are generally considered to be nonspecific binding agents for proteins. The relative capacity of several purified polyphenols for binding β-glucosidase has been determined (Haslam 1974) but when we began this work we were aware of no previous work on the protein specificity of the interaction with tannins. Very recently reports on the protein binding specificity of Chinese gallotannin have appeared (Watanabe et al. 1981 a,b).

Tannin-associated Proteins

Proteins are the most persistent contaminant in "purified" tannin. The proteins which are associated most strongly with tannin are not a random mixture of all seed proteins as would be expected if tannins bind all proteins equally well. Rather, the tannin-associated proteins consist of three minor components, two of which are high molecular weight prolamines, and one of these is quite rich in proline (Hagerman and Butler 1980b).

Pepsin-indigestible Proteins

In an in vitro digestion assay with porcine pepsin, there is no insoluble undigested protein residue when low-tannin varieties such as RS 610 are ground finely and digested (Lebryk and Butler, unpublished). With bird-resistant high-tannin varieties, an insoluble pepsin-indigestible residue is observed. The protein residue, presumably indigestible because of its association with tannin, has been identified as the prolamine fraction of the seed protein. Apparently sorghum tannin has a higher affinity for these alcohol-soluble hydrophobic storage proteins than for other seed proteins with more conventional properties (Lebryk and Butler, unpublished).

Competitive Binding Assays

We have applied to the tannin-protein interaction, the methodology for elucidating the specificity of antigen-antibody interactions (Hagerman and Butler 1981). The technique involves competition of a wide variety of purified proteins and other materials with a standard preparation of isotope-labeled protein (usually bovine serum albumin) (BSA) for binding by purified sorghum tannin. We find that the tannin-protein interaction is extremely specific for the protein. The relative affinity of various well-characterized purified proteins differs by over three orders of magnitude. No low molecular weight compounds have affinity for tannin comparable to that of proteins and polyvinylpyrrolidone (Hagerman and Butler 1981).

Characteristics of High-Affinity Proteins

High Molecular Weight

The larger the protein, the stronger the binding of tannin, if other factors are equivalent. Short peptides of two to four amino acids do not bind strongly enough to be detected (Hagerman and Butler 1981). The interaction appears to be highly cooperative.

Isoelectric pH

The affinity of a protein for tannin is greatest at the isoelectric point of the protein (Hagerman and Butler 1978) although some proteins bind strongly over a wide pH range (Hagerman and Butler 1981).

Looseness of Structure

The more open the structure, the more strongly proteins bind tannin. Compact globular proteins have a low affinity for tannin; the affinity can be increased by unfolding the structure, maximizing accessibility for tannin binding (Hagerman and Butler 1981).

High Proline Content

Perhaps the most important factor controlling the affinity of a protein for sorghum tannin is the amount of proline that it contains. Under standard conditions in which sorghum tannin precipitates ten times its own weight of BSA, if 13,000 MW polyproline or 16,000 MW proline-rich protein (40% proline) of rat parotid gland (Meunzer et al. 1979) are mixed with the BSA in amounts equivalent to only 3% of the weight of BSA, precipitation of BSA on subsequent addition of tannin is inhibited by 50%. In contrast, a 20-fold (by weight) excess of bovine pancreatic ribonuclease had no discernible affect on the amount of BSA precipitated (Hagerman and Butler 1981). Proline-rich proteins have extended, rather than compact, structures because proline does not fit into the α-helix. Moreover, the hydrogen bond to the carbonyl oxygen of a peptide bond involving the α-imino group of proline is stronger than that of any other amino acid (Hagerman 1980). The affinity of a protein for tannin can be predicted with reasonable accuracy from its proline content.

Significance of Tannin Protein Interactions

Specificity

Tannins can selectively bind and precipitate a particular protein out of a 100-fold excess of another protein (Hagerman and Butler 1981). This high degree of selectivity may be functionally significant. Tannins may have an especially high affinity for certain foreign proteins, possibly those associated with a pathogen. This proposed function of selective binding for protective purposes is analogous to that of antibodies in animals.

On Germination

The protein-binding capacity of tannin, which protects the seed during maturation and possibly during storage, can present a formidable threat during germination, where it could interfere with enzyme-mediated metabolic activity. Like Reichert et al. (1980), we find that on germination the tannian eventually diminishes in extractability. We suggest that during germination the tannins become accessible to the proline-rich prolamines of the endosperm, which bind them strongly and completely, thus protecting other proteins in the seed. Our observation of pepsin-indigestible prolamines in germinating high-tannin sorghum, not present in similarly germinated low-tannin sorghum (Lebryk and Butler, unpublished) supports this suggestion. We propose that germinating high-tannin sorghum seeds sacrifice a portion of their prolamine to complex with tannin, thus protecting themselves against their own protective agent.

In the Diet

The tannin present in many high-tannin sorghums (2-3% dry weight) is sufficient, under optimum conditions, to bind considerably more protein than is present in the seed. Thus it is likely that, although conditions may not be optimal, dietary tannins may be available to bind proteins of the digestive tract and interfere with digestion and absorption. Now that the specificity of tannin-protein interactions is becoming apparent (Hagerman and Butler 1981), it is possible to focus on proteins within the digestive tract which would seem to be capable of most strongly binding dietary tannin. In this connection it may be appropriate to call attention to the presence in saliva of proteins extremely rich in proline (Meunzer et al. 1979), with a very high affinity for tannin (Hagerman and Butler 1981). The function of these proline-rich proteins is not known. I tentatively suggest that they serve to bind and inactivate dietary polyphenols, and thus minimize the potentially harmful effects which might otherwise occur further down the digestive tract. It will be of considerable interest to determine whether polyphenol-rich diets result in an increase in secretion of these proline-rich salivary proteins.

Detoxification of Sorghum Tannin

A wide variety of approaches to the elimination of the antinutritional effects of tannin in sorghum have been applied. My colleagues here at Purdue have observed some beneficial effects of extraction with alkali (Armstrong et al. 1974), supplementation with methionine (Armstrong et al. 1973), and dehulling (Chibber et al. 1978). Our approach is to utilize the chemical reactivity of the tannins, seeking a simple in situ treatment to convert them to nontoxic forms. Others have also employed this approach, utilizing formaldehyde (Daiber 1978) or acids and alkalies (Reichert et al. 1980) as detoxifying agents.

Effect of Cooking

The amount of tannin extracted from ground high-tannin sorghum grain by methanol and the capacity of the unextracted grain to bind extraneously added protein are greatly diminished if sufficient water is added to make a batter, even if the batter is subsequently dried (Price et al. 1980). Cooking the batter lowers these already low values even further. Unfortunately, the nutritional value of the grain is not at all improved by these treatments (Price et al. 1980). In fact, the weight gain of rats was actually lowered by making a batter and cooking it, or by boiling whole sorghum grain. Thus, our evidence indicates that cooking does not overcome the antinutritional effects of sorghum, and may actually worsen them. Moreover, we have observed that some types of cooking may lower the nutritional value of even low-tannin sorghum (Price et al. 1978b).

Effect of Germination

In addition to the effects of moisture on the extractability of sorghum tannin, germination can cause a significant decrease in assayable tannin (Table 1). This effect occurs to different extents in different lines (Table 1), and germination for several days is difficult to carry out on a large scale without problems associated with mold growth.

Effect of Ammoniation

Treatment of high-tannin sorghum with NH_3, either at atmospheric pressure or at 80 psi, caused a decrease in assayable tannin of up to 90%, and gave a modest increase in the weight gains of chicks (Price et al. 1978b). Treatment with concentrated NH_4OH (30% NH_3), 0.11 liter per kg of grain, proved to be more effective, so that weight gains of both rats and chicks on treated high tannin grain were equal to those on untreated low-tannin grain (Price et al. 1978b).

In subsequent experiments we showed that a wide variety of aqueous alkalies effectively reduce the assayable tannin in sorghum grain (Price et al. 1979b). Treatment with aqueous solutions of K_2CO_3 and CaO gave improved weight gains with chicks, but the effects are complex because these treatments actually gave a depression of weight gains on control low-tannin sorghum. In contrast, treatment with dilute aqueous NH_3 (4% NH_3 in water, 2.4 M NH_4OH) had no effect on low-tannin controls yet improved the weight gain on treated high-tannin sorghum to that of low-tannin sorghum (Price et al. 1979b). The incidence of bowed legs, which is associated with chicks on high-tannin diets, was also reduced by the ammoniation treatment to the level of low-tannin controls. The apparent "detoxification" (decrease in extractable tannin, protein binding capacity, and incidence of bowed legs in chick diets; increase in rat and chick weight gains) of high-tannin sorghum grain by aqueous ammonia presumably involves an oxidation of phenolic groups, which would be expected in moist alkaline conditions. Our attempts at anaerobic treatments have produced equivocal results.

In subsequent experiments we have found that water plays an important role in the detoxification process. Tempering the grain for 12 hr with water reduces the amount and concentration of NH_4OH needed for detoxification, as well as the time required. Alternatively, using slightly more liquid than the grain can completely adsorb further reduces the time and NH_4OH concentration necessary to achieve detoxification (Riedl and Butler, unpublished). In the in vitro pepsin digestion assay, the large pepsin-indigestible prolamine fraction found in high-tannin sorghums (but not present in low-tannin sorghum) is eliminated by the ammoniation treatment.

From our experiments it can be suggested that treatment of high-tannin sorghum grain with approximately 0.5 liter of 0.1 N NH_4OH (0.2% NH_3) per kg of grain for 12–24 hr at room temperature, with or without subsequent drying, will greatly improve the nutritional quality. Although weight gains on treated grain are equivalent to those on untreated low-tannin sorghum, the feed/gain ratio usually is not quite as low as for low-tannin grain. Treatment of whole grain is more effective than treatment of ground grain. Grinding before detoxification apparently increases the accessibility of tannins to sensitive seed components.

This detoxification procedure is rapid and simple, uses a minimum of ammonia and leaves no ammonia odor. It can be readily incorporated into the processing of grain for preparation of formulated feeds. It is particularly attractive in situations where high-tannin grain is available at lower cost than low-tannin grain.

Genetics of Polyphenol Distribution

Rooney and his collaborators (Rooney et al. 1980; Earp et al. 1981) have provided valuable information about sorghum genotypes and their relation to seed characteristics and polyphenol content. Dr. Rooney provided samples of known genotypes, which we subjected to our complete battery of polyphenol assays. Each assay was run on methanol extracts and on acidic methanol extracts of the residue. Recall that the anthocyanidin production assay without heating detects flavan-4-ols (leucoanthocyanidins) such as apiforol and luteoforol, and the same assay with heating detects oligomers of flavan-3-ols (condensed tannins).

Analysis of Known Genotypes

Samples 1–11 are classified as Group I sorghums because they do not contain significant levels of tannin, as shown by the low values in the protein precipitation, vanillin, and heated anthocyanidin production assays (Table 2). Samples 12–14 are Group II sorghums, because their tannin is extractable in acidic methanol but not in methanol. Samples 15–17 are typical high-tannin sorghums, classified as Group III because they contain methanol-extractable tannin, although it should be noted that they also contain significant amounts of Group II type tannin, extractable only in acidic methanol.

Monomeric flavan-4-ols such as apiforol can be present in either Group I (low-tannin) sorghum, samples 9–11, or in Group III sorghum, samples 15–17. A small amount of flavan-4-ol may be present in Group II sorghum, samples 12–14, where this material shares with tannin the characteristic of extractability only in acidic methanol. Even in low-tannin genotypes which do not have flavan-4-ols, samples 1–8, the Prussian blue assay indicates that phenolic materials extractable in acidic methanol but not extractable in methanol are present in amounts approaching those of the methanol-extractable phenolics. Some of these relationships of the genotypes are summarized in Table 3 to facilitate assignment of roles to particular genes.

Comparisons with Lines of Unknown Genotype

Our assays on a large number of sorghum lines of unknown genotype gave results that correspond well with those in Table 2. With regard to the distribution of the various polyphenolic components we have assayed, the following points can be made: (1) The characteristic in which certain lines have some polyphenols extractable in acidic methanol but not in methanol is not confined to the condensed tannins but is also true of flavan-4-ols and other nontannin phenolics. Thus, this may be a characteristic of the seed rather than the polyphenol, although our preliminary evidence suggests that the differently extractable tannins are also chemically different; (2) Tan plants (IS 0469, 121087, and 121089 are typical of the lines we have examined) have extremely low levels of not only polyphenols but all phenolics, as determined by the Prussian blue assay; (3) Lines such as P721, 10354 and IS2939, like tan plants, have very low levels of polyphenols and total phenolics, but can be distinguished from the tan plants by their content of pigments which produce a high blank value in the vanillin assay (Price et al. 1978a). These pigments are absent in tan plants; (4) Flavan-4-ols and condensed tannins occur independently, although lines which contain flavan-4-ols but not tannin appear to be more abundant than lines which contain tannin but not flavan-4-ols; and (5) Lines in which flavan-4-ols are present in the leaf invariably also contain this material in the seed. A few cases in which it is present in the seed but not in the leaf have been identified.

Purple Testa Sorghum

Considerable interest has recently been expressed in sorghum lines with purple testa, due to the suggestion that they may be bird-resistant but not nutritionally harmful (York 1981). We have run our battery of tannin assays on IS9747, a tall, late-

Table 2. Analysis of tannins of known sorghum genotypes.

Sample/Genotype		Tannin Assays: Prussian Blue (eq/g)		Protein precipitation (mg BSA/g)		Vanillin (ΔA_{500}/g)		Anthocyanidin production (ΔA_{550}/g)				Remarks/Grain
								MeOH		H$^+$MeOH		
		MeOH	H$^+$/MeOH	MeOH	H$^+$/MeOH	MeOH	H$^+$/MeOH	Cold	Hot	Cold	Hot	
1. RRyyIIZZss	$b_1b_1B_2B_2$	0.15	0.18	1	0	0	0	0	0	0	0	(77CS2)
2. rryyiiZZSS	$b_1b_1B_2B_2$	0.14	0.12	1	0	0	0	0	0	0	0	(Tx2536)
3. rryyIIZZSS	$b_1b_1B_2B_2$	0.20	0.17	0	1	0	0.1	0	0	0	0	(TAM428)
4. rryyIIZZSS	$b_1b_1B_2B_2$	0.23	0.19	2	1	0.1	0.1	0.1	0	0	0	(Tx430)
5. rryyiiZZ?ss	$b_1b_1B_2B_2$	0.26	0.18	5	2	0.1	0	0	0	0	0	(Colorless yellow end)
6. rrYYIIZZSS	$b_1b_1B_2B_2$	0.44	0.36	6	1	0	0.1	0	0	0	0	(lemon yellow)
7. RRyyiizzSS	$b_1b_1B_2B_2$	0.28	0.19	9	0	0.1	0	0	0	0	0	(white semi-chalky non-brown)
8. RRyyiizzSS	$b_1b_1B_2B_2$	0.20	0.09	1	4	0	0	0	0	0	0	
9. RRYYiiZZ?ss	$b_1b_1B_2B_2$	0.35	0.29	5	2	0.2	0.1	6.5	0	4.1	0	(red trans, non int)
10. RRYYIIZZ?ss	$b_1b_1B_2B_2$	0.35	0.27	5	3	0	0.1	9.7	0	3.5	0	(red trans, int)
11. RRYYIIZZ?SS	$b_1b_1B_2B_2$	0.48	0.33	5	1	0	0.1	11	0.3	4.6	0	(red trans, int)
12. RRyyii?zzss	B_1-B_2-	0.20	2.40	5	16	0	6.8	0	0	0.8	17	(brown)
13. Unknown		0.22	0.86	3	3	0	2.1	0	0	0.4	7.2	
14. Unknown		0.29	0.95	0	2	0	2.3	0	0	0.3	7.6	
15. RRYYiizzSS	$B_1B_1B_2B_2$	1.52	0.67	33	5	9.2	1.3	11	13	2.2	5.7	
16. RRYYIIZZ?ss	$B_1B_1B_2B_2$	2.40	0.73	53	0	18	1.6	9.1	23	1.8	5.6	
17. RRYYIIZZSS	$B_1B_1B_2B_2$	6.62	2.44	95	6	40	6.8	16	49	8.3	15	

maturing line, with purple testa. Because our sample contained seeds with widely varying sizes, we separated them into three size groups and extracted and analyzed them separately. The data (Table 4) with all five assays shows that this is a typical Group II sorghum, with rather high levels of tannin that is extractable only with acidic methanol. The data, which are presented on the basis of equal weights of seeds, also show that the relative amount of tannin present is manyfold greater in the small seeds than in the large seeds. The small seeds may have been harvested before they were mature, at which time the tannin content is expected to be much lower (York 1981). Flavan-4-ols were found to be absent from this seed. As suggested by York, the bird resistance and nutritional value of purple testa sorghum is of considerable interest.

Polyphenols and Bird Resistance

The beneficial agronomic characteristic most securely correlated with the presence of tannins in

Table 3. Occurrence of condensed tannins and related materials in various sorghum genotypes.

Group III Tannins and Monomeric Flavan-4-ol		
RRYYIIZZSS	$B_1B_1B_2B_2$	
RRYYIIZZ(?)ss	$B_1B_1B_2B_2$	
RRYYiizzSS	$B_1B_1B_2B_2$	
Group II Tannins only		
RRyyiizzss	B_1-B_2-	(brown)
Monomeric Flavan-4-ol only		
RRYYIIZZSS	$b_1b_1B_2B_2$	(red trans, int)
RRYYIIZZss	$b_1b_1B_2B_2$	(red trans, int)
RRYYiiZZss	$b_1b_1B_2B_2$	(red trans, non-int)
None		
RRyyIIZZss	$b_1b_1B_2B_2$	(77C52)
rryyiiZZSS	$b_1b_1B_2B_2$	(Tx2536)
rryyIIZZSS	$b_1b_1B_2B_2$	(TAM428)
rryyIIZZSS	$b_1b_1B_2B_2$	(Tx430)
rryyiiZZ(?)ss	$b_1b_1B_2B_2$	(Colorless yellow end)
rrYYIIZZSS	$b_1b_1B_2B_2$	(Lemon yellow, has considerable phenolics)
RRyyiizzSS	$b_1b_1B_2B_2$	(White semi-chalky non-brown)

Table 4. Tannin assays on sorghum with purple testa [IS9747].[a]

		Tannin assays				
Seed size	Extractant	P.B.[b] ΔK	Protein precipitation ΔA_{510}	Vanillin ΔA_{510}	o-Diphenol ΔA_{500}	Anthocyanidin ΔA_{545}
Large	MeOH	82	.018	.004	.012	.002
	H^+ MeOH	287	.084	.077	.189	.171
Medium	MeOH	82	.012	.003	.026	.001
	H^+ MeOH	507	.251	.215	.357	.279
Small	MeOH	84	.10	.000	.019	.002
	H^+ MeOH	860	.550	.583	.852	.580

a. All samples of equal weight, blanks subtracted, average of duplicates.
b. P.B. = Prussian blue assay; ΔK is Klett colorimeter reading, with blank subtracted.

sorghum grain is bird resistance. Birds show an astonishing degree of selectivity between sorghum lines of differing polyphenol content. Yet assigning the capacity for bird repellancy to particular polyphenol components has proved to be rather difficult (Bullard et al. 1980).

Our modest field trials for bird resistance of promising sorghum lines were done in early 1979 at the Lajas, Puerto Rico Agricultural Experiment Station, in cooperation with R. Bullard and C. Royal of the Denver Wildlife Research Center, and in 1980 at the Southwest Indiana Purdue Agriculture Center, Vincennes, Indiana. The results, which have not yet been published, were consistent in both locations. Low-tannin lines used as controls were rapidly and completely destroyed, usually within 3 weeks after flowering. Group III lines showed little damage until late in the season, after which they too eventually were severely damaged. We were most interested in Group II sorghums, which we hope would show a desirable combination of bird resistance and good nutritional value. The Group II sorghums tested were IS2863, 3441, 4806, 7031, 7579, 8768, and 955026. Unfortunately, none of these lines showed a significant degree of bird resistance, but were destroyed at essentially the same rate as low-tannin controls.

A somewhat different approach is suggested by the observation of our colleague, Dr. John Rogler, that certain samples of high-tannin bird-resistant sorghums such as BR 54 occasionally fail to show their expected antinutritional effect even though chemical assays for tannin demonstrate that the usual high levels are present. An example is found in Price et al. (1979b). After storage for several months, a sample which previously gave the usual depressed weight gains of chicks gave normal weight gains. We may eventually be able to devise treatments, even simpler than ammoniation, which trigger natural detoxification processes such as occur on germination, and readily obtain full nutritional value of the grain.

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Rheological Techniques for Texture and Quality Measurement of Sorghum Food Products

K. C. Diehl, Jr.*

Summary

Of the many physical properties available, rheological properties provide the most direct and convenient methods for measuring indicators of quality and texture. With the use of sound rheological methods and the avoidance of potential adverse influences, good results can be obtained without expensive equipment and cumbersome equations.

Rheological methods are presented for solid and liquid foods. Some of the methods require a universal testing machine such as an Instron, while others utilize a much simpler instrument. Experimental configurations and examples are presented for measuring the response of solid and liquid sorghum foods which can be used with any of the rheological methods.

In general, the objective measurement of food texture will involve measuring some physical property of a food by standard procedures or an appropriate instrument or device. The sensation of texture by humans involves some psychological response to the effort required to bite or chew a food. In this context, the physical properties which are most appropriate for objective texture measurements would be rheological properties, since rheology is the study of deformation and flow of matter. However, other properties have been used as indirect texture measurements (Szczesniak 1973a).

There are numerous examples of instruments which measure rheological properties or indicators of rheological properties (Mohsenin 1978; Szczesniak 1973b). They vary widely in their complexity and ease of performance. These instruments may intend to imitate a particular mechanical action such as chewing or finger compression, or they may intend to measure some inherent characteristics of the food one wishes to evaluate, such as maturity, genetic differences of a raw product, or the effect of a processing variable on the characteristic in question. Often, it is not known what the characteristic represents except that it appears to be some indicator of texture or quality.

Many examples exist in the literature where very basic rheological properties have been related to texture and quality. Because of the supporting theory and experimental techniques, these properties are more likely to be an absolute characteristic of the food within the limits of normal variation. Besides being used as texture indicators, these basic properties can be used to design handling equipment and help prevent food damage. However, these techniques can, but not necessarily, involve rather expensive and complex instrumentation.

Even though rheological properties would appear to be inherent texture or quality indicators, it should be noted that they have nothing to do with texture or quality indication until they have been demonstrated to be such. This is usually done by correlating a specific property to organized human sensory evaluations, examples of which have been discussed by Abbott (1973). The intent of this review is to introduce some rheological techniques which can be easily performed and do not require expensive instrumentation. Hopefully, they will find immediate use or stimulate the search for methods which may be more appropriately related to a particular attribute. A broad spectrum of possibilities can be found in Mohsenin (1978), Kramer and Szczesniak (1973), Rha (1975), Scott Blair (1953), and Sherman (1970).

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This discussion will first focus on the concept of how forces and deformations are imposed on solid and liquid foods. The distinction between solid and liquid foods is not always clear since nearly all foods can be classified as viscoelastic. That is, regardless of how solid the food is, it will flow to some extent. While this is the inherent behavior of foods, it can cause some problems experimentally. As long as sound and consistent experimental techniques are used, good results can be routinely obtained.

Solids

Forces and deformations are the basic measurements in any rheological measurement. Figure 1 shows the deformation or change in height of a cube of a food material due to an externally applied force. The extent to which the material deforms depends in general on the composition of the food, the rate of forcing or deformation, specimen geometry, and environmental factors such as temperature. If all these variables are kept constant, the amount of deformation which occurs due to a given force or weight will indicate the materials' response. This response is the rheological property which we seek. Thus, if one variable is changed, such as composition of the food, the variation in the rheological property may show the influence of the change. Also, since the property measures the response of the food to a force system, it will hopefully give some indication of a person's perception of the strength or weakness of the food.

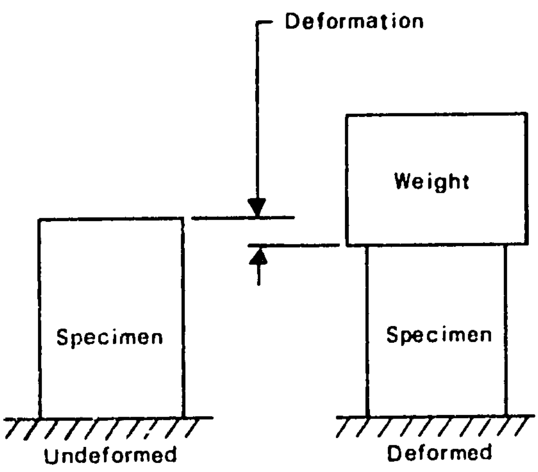

Figure 1. Illustration of the change in height (deformation) due to an applied weight that is a characteristic property of the food.

An individual specimen of food that is being tested has a certain composition, but this composition may not be consistent throughout the specimen. Food materials should have properties that are constant at every location and in every direction. These conditions exist to widely varying degrees in foods. Since they may be uncontrollable, as large a sampling as is practical should be tested to obtain a representative average.

When one attempts to measure a rheological property, it is important that the test be performed at a constant rate of force or deformation throughout the test and at the same rate of application for all experiments and all comparison studies. A food material that is tested at two different rates of application may typically appear stronger at the higher rate. As we will see, there is a basic difference in performing a test at a constant rate of force and a constant rate of deformation. But the basic response measured by either method will be the same.

Of equally paramount importance is the specimen size and geometry. The specimen height and area over which a force is distributed can greatly affect a measured property. Intuitively, this is apparent. If two specimens of equal length but unequal cross-sectional area are compressed an equal amount, the specimen with the larger area would obviously require more force. The same is also true for specimens of equal area but unequal length. Thus any comparison tests should always use the same specimen size and geometry.

If a food has a unique size and shape when it is to be used as a test specimen, any variation in the size or shape could give misleading differences in measured properties. To overcome this problem, it may be desirable to physically remove a portion of the food and shape it into a more consistent form. This is done quite frequently with fruits and vegetables.

Environmental conditions such as temperature and humidity can have significant effects on rheological properties, particularly if a food has a very large or very small percentage of its composition as water or oil. Enzymatic and microbial activity could change the structure of the food and thus introduce an undesirable variable. These factors should always be minimized unless one of them is a variable whose influence is to be measured.

Rheological Methods for Solids

There are many rheological methods available for measuring the response of solids but of these, four probably find the most use. Two of these require a universal testing machine such as an Instron. The Instron deforms the food at a constant rate or velocity. These machines are referred to as universal because there are many testing devices and geometries available which can be mounted on the testing machine. Some of these will be discussed later in the applications section. In these machines, as the specimen is being deformed at a constant rate, the force is measured automatically by a load cell and recorder.

The other two methods to be discussed do not require an expensive testing machine. Instead, a simple, inexpensive instrument as that illustrated in Figure 2a can be constructed. Use of this instrument requires more care by the user, since the deformation must be recorded manually. A rod with a plate attached to the top end on which a container or weight can be placed is supported vertically by a fixed frictionless sleeve. This part of the instrument serves much the same purpose as an Instron testing machine. By adding the water continuously to the container at a constant flow rate, a constant rate of force test can be performed. In Figure 2a, compression of a specimen by a plate attached to the lower end of the rod is shown for illustration purposes. This plate can be replaced by a rod or blade or any other device which will physically contact the test specimen, so that actions other than compression can be imposed on a specimen.

The two methods that are utilized on a testing machine such as an Instron are the constant rate of deformation method and the relaxation method.

Constant Deformation Rate

A specimen is deformed continuously until the specimen ruptures. If force and deformation were being recorded continuously, these types of responses would be similar to those shown in Figure 3a. The information which can be obtained is the initial slope of the force-deformation recording and the force at rupture, if it occurs. The slope of the line is a measure of the stiffness of the food analogous to the stiffness of a spring. The slope of the line (stiffness) is mathematically equal to the force divided by the deformation.

Relaxation

The specimen is compressed at a constant deformation rate until it reaches a predetermined

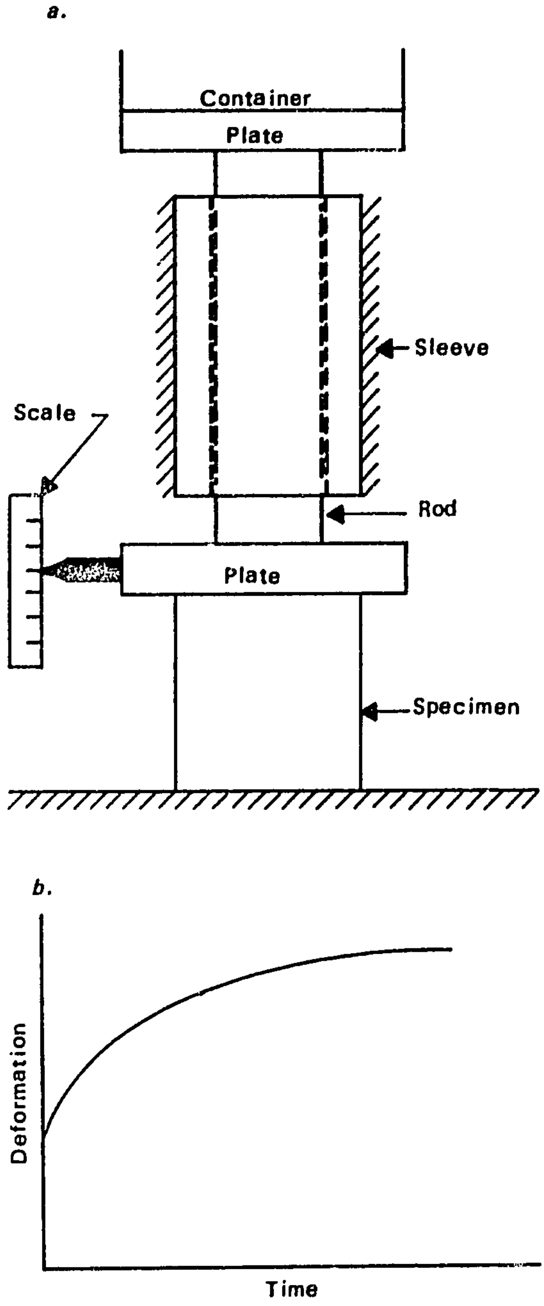

Figure 2. a—a simply constructed device for texture measurement; b—the response of a food subjected to a constant weight over time.

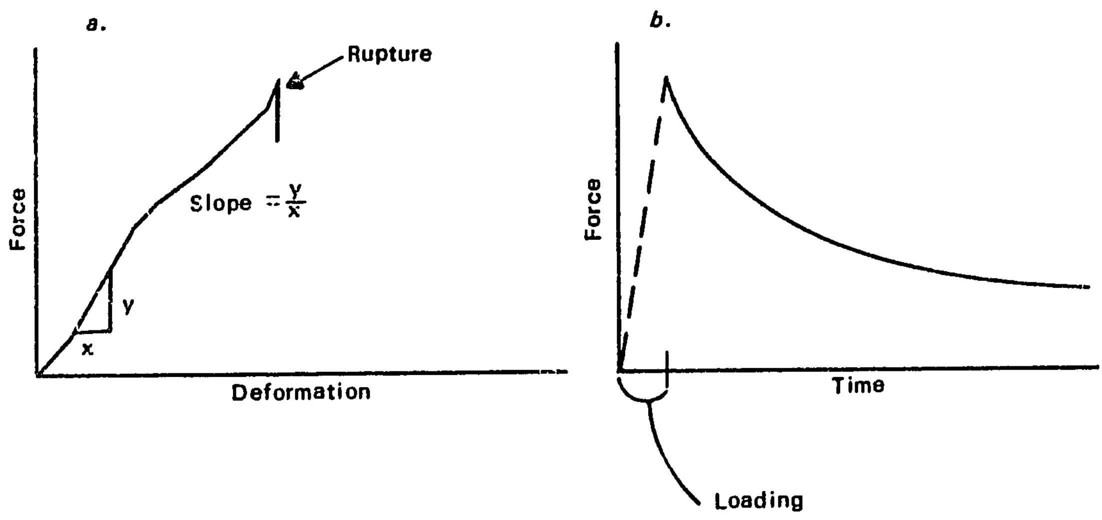

Figure 3. a—response of a food due to a constant forcing rate or a constant deformation rate; b—relaxation response of a food.

amount of deformation. This amount of deformation is then held for a given length of time. A continuous recording of this response would be similar to that shown in Figure 3b. The force remaining after a given length of time can be recorded and used as a quality or texture indicator. Interestingly, some food materials may completely dissipate the forces, if given enough time.

The other two methods which can be performed are the constant rate of forcing method and the constant force or creep method.

Constant Forcing Rate

With the lower plate of the instrument shown in Figure 2a in contact with the specimen, a constant forcing rate can be obtained by adding water continuously into the container at a constant flow rate. If the force and deformation could be recorded continuously, the recording would probably be similar to that in Figure 3a. However, a dial gauge or ruler can be used to measure the responding deformation. The deformation to breakage or the weight of water necessary to break the specimen can be measured. Also, stiffness can be measured by reading the deformation obtained after a given time period measured from the initiation of the water flow. The container, rod, and plate should be as light as possible or a lever system may need to be used to balance out this initial weight. It is important to leave the specimen as undisturbed as possible before the test. Under the smallest deformation, all food materials flow to varying extents because of their viscoelastic behavior, which could affect reproducibility.

Creep

Using the same configuration shown in Figure 2a, a predetermined weight of water is put into the container at constant flow rate. The same effect can be obtained by carefully and quickly putting a weight on the top plate. The amount of deformation caused by the constant weight compressing the specimen can be measured right after the cessation of water flow and after some given time period has elapsed. The deformation would be similar to that shown in Figure 2b if it were continuously recorded. If the deformation were recorded immediately after the cessation of water flow or immediately after the weight were placed on the plate, stiffness of the specimen could also be determined by the method.

Applications

In the four methods presented above, the specimens were discussed as being compressed. With the use of grips, specimens could be tested in tension (stretched). However, tension testing can be more difficult to perform, and if the test specimens are not properly shaped, rupture can prematurely occur where the specimen is held.

Waniska (1976) used a tensile test on an Instron machine to measure the stiffness, breaking strength, and deformation of rectangular specimens of *chapaties*. Among 23 sorghum lines tested, endosperm type and non-waxy endosperm texture affected the measured properties. Waxy endosperms had lower strength and stiffness and a greater deformation to breakage than nonwaxy types. Rizley and Suter (1977) used the tensile test to show that sorghum variety SC-301 with a corneous endosperm texture made tortillas which were stronger than those made with sorghum variety K-60 with an intermediate endosperm texture. Another intermediate variety, TAM-670, produced *tortillas* of greater strength and deformation than a commercial white corn *tortilla*.

Tensile testing can be performed with the instrument shown in Figure 2a if it is turned upside down and the container is hung on the rod. Water is then added at a constant rate for constant rate of force testing or a weight is hung on the rod for creep testing.

It should be noted that for both the tension and compression test configurations, the specimen height and cross-sectional area can be varied to increase or decrease the force or weight required for a given response. The chosen dimensions should then be kept constant for replications and comparisons.

The compression test can be used for other specimen shapes, but again, the size and shape should be kept as constant as possible. For example, intact spherical specimens (Figure 4) can be easily used (Agricultural Engineers Yearbook 1981), but the radii of curvature at the points of contact measured 90° apart must be the same for each specimen. This may be impossible unless the shape of the specimen can be controlled.

We are currently using this procedure in our laboratory at Texas A&M University, with good results, to determine the stiffness and strength of sorghum kernels. In our tests, the kernels are cut in half with a razor blade and the cut surface is sanded flat. The same methodology and restrictions apply for the half-kernels. Using the instrument shown in Figure 2a, a half-kernel of sorghum would likely require about 5–7kg of water added at a constant rate to cause rupture. As mentioned above, the radii of curvature from sample to sample need to be the same. A small circle template can be used for measuring the curvatures. We hope to show a relationship between fracture strength and grinding energy. The measurement of the weight of water needed for rupture may indicate differences in varieties but this is yet to be shown.

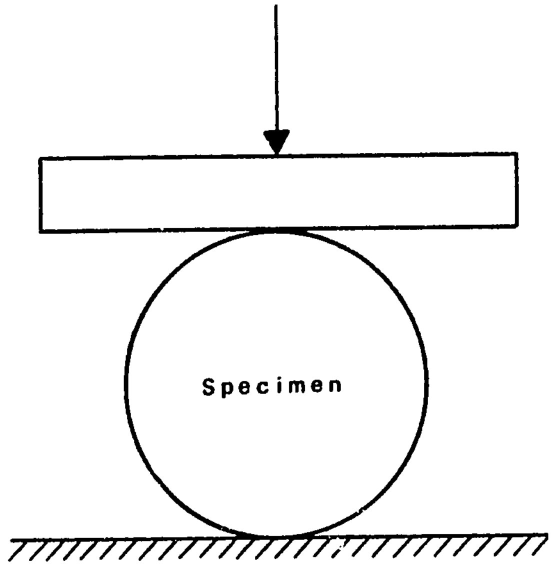

Figure 4. Illustration of a method to measure the response of spherical or cylindrical foods.

Nguyen and Kunze (1981) have used this test to study the relaxation properties of rice as affected by drying and storage treatments. By using the instrument in Figure 2a and the constant weight test (creep), similar studies can be performed.

The die or punch loading configuration (Figure 5a) is one that can be applied to many shaped and sized specimens. The original theory was first developed by Boussinesq (1885) and has been used on fruits (Bourne 1965). Since this test involves the penetration of a rod in the specimen, the diameter of the rod can be adjusted to obtain reasonable forces. That is, for a particularly strong food material, less penetration force will be needed if the diameter is made smaller and vice versa for a weak food material.

The punch test works well for testing gel stiffness and puncture force (Figure 5b). Very small forces are needed for stiffness measurements, so the weight of the rod in the instrument shown in Figure 2a would be sufficient. The ratio of the weight of the rod to the resulting deformation would be a measure of stiffness. When performed carefully, experience has shown that the stiffness measurement is more reproducible than the puncture force. The container in which the gel is placed

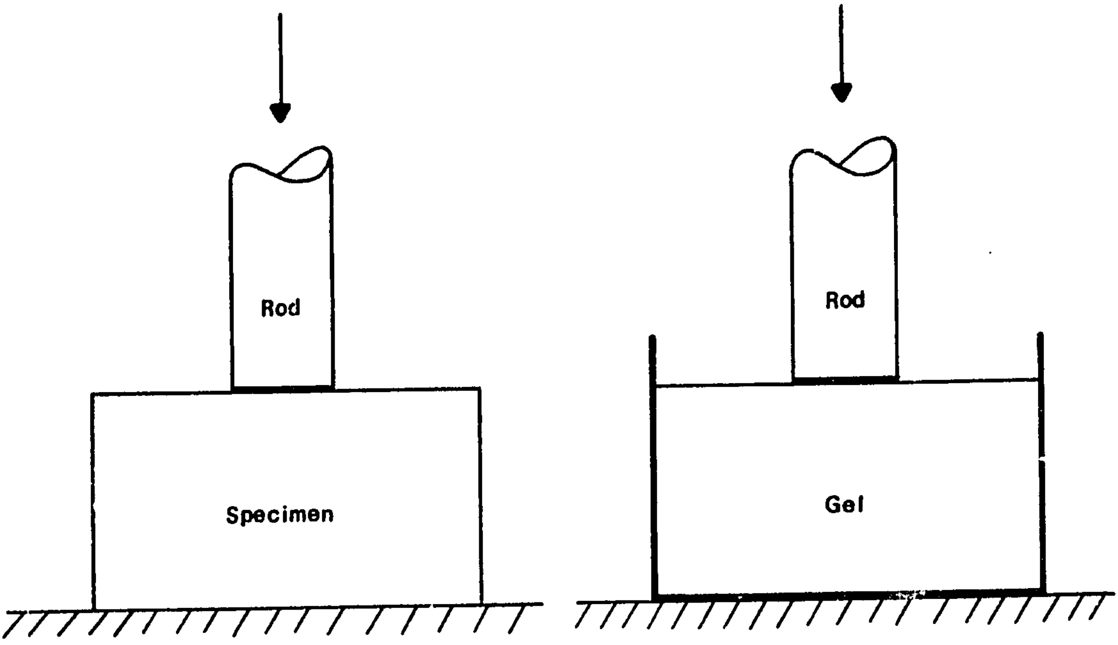

Figure 5. Illustration of a method to measure the stiffness or firmness of a, *a solid food, and* b, *a gel using a rod.*

should be the same for each specimen. This type of measurement should be well suited for stiff gruels and *tô*. The punch test also may be well suited for testing biscuits and similar products.

Similar to the die loading configuration are several which are often called shear tests but are not truly pure shear. The first, shown in Figure 6a, is performed by clamping a flat rectangular specimen of food on two sides. A plate with a rectangular cross-section, whose thickness is approximately the same as the gap between the clamps, is forced through the food. The same idea can be used with a clamp between two washers. A cylindrical rod is then pushed through the centered hole (Figure 6b). These test configurations lend themselves nicely to testing foods that are shaped as thin strips, such as *chapati* or *tortillas*. Unpublished data taken in cooperation with the Cereal Quality Laboratory at Texas A&M University indicate that the maximum force measured with a multi-blade device (Kramer Shear Cell, ⅛" thick blades) is a very good indicator of textural changes in *tortillas* over a 3-day period when measured daily. Future research will test a single blade configuration similar to Figure 6a to determine its usefulness using the constant rate of force procedure.

The Warner-Bratzler shear device (Bratzler 1932), the idea of which is shown in Figure 6c, has been frequently used to indicate the tenderness of meat. Typically, a cylindrical plug of food is torn as the center plate moves through the two adjacent plates (Figure 6c).

For long, circular, or square cross-sectional specimens, the three-point bending configuration has found some use, particularly when the food is brittle (Figure 7). Deflection of the specimen is measured at the mid-point where it is the greatest, or the weight of water necessary to cause breakage can be measured.

Liquids

Liquid foods can vary widely from pastes to watery solutions. The basic property that we wish to measure is its resistance to flow or viscosity. Just as with solids, this involves measuring forces

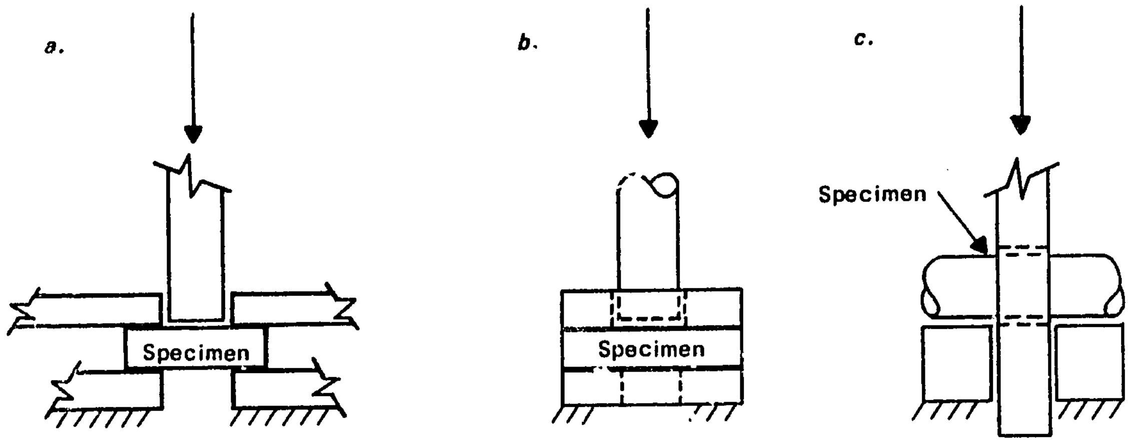

Figure 6. Illustration of methods to measure the shear response of foods that are thin, a *and* b, *or are circular* c.

and deformations, except that deformations are now continuous for given time periods. This is the definition of viscous flow. Without proper instruments, measuring a true viscosity can be a difficult task. The two most common concepts utilized in viscosity are concentric-cylinder rotational devices and capillary devices. Van Wazer et al. (1963) give an excellent review of these viscometers and other methods, some of which will be discussed below. Researchers having access to standard or calibrated viscometers are encouraged to use them whenever possible. The discussion which follows will suggest ways to measure indicators of viscosity in the absence of standard viscometers and will concentrate on capillary types, since they are the simplest to construct. None of the techniques discussed should be taken as measures of true viscosity, though this is possible under the right conditions.

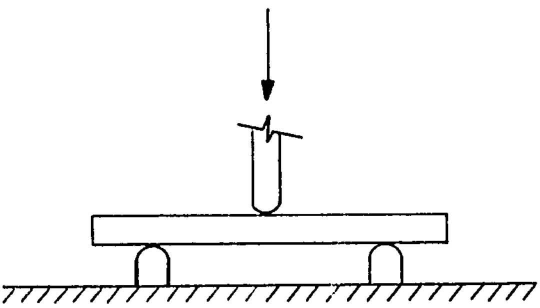

Figure 7. Illustration of a method to measure the response of brittle or hard foods.

Liquids have two general classifications, i.e., Newtonian and non-Newtonian. The basic distinction is that the viscosity of a Newtonian liquid does not change, regardless of how fast or slow the liquid is caused to flow. This is shown in Figure 8a where shear rate and flow rate mean the same thing.

The shear rate is a function of the rate of flow in the test apparatus, the geometry of the apparatus, and the degree of non-Newtonian behavior. It is the last of these that makes viscosity measurement difficult. It is possible to measure two liquids at two different shear rates and measure the same viscosity if the two liquids have different flow curves (Figure 8b). This indicates, just as with solids, the importance of keeping the rate constant for all comparison tests.

As Figure 8a shows, it is possible to measure the same viscosity for two liquids with different flow curves at the same shear rate. This problem may be unlikely to occur, but it is worth noting, since most researchers will probably desire a single point or single shear rate measurement.

Rheological Methods for Liquids

There are three basic methods used to measure the viscosity of liquids with capillary viscometers. They are the constant flow rate method, the constant pressure or force method, and the gravity flow method.

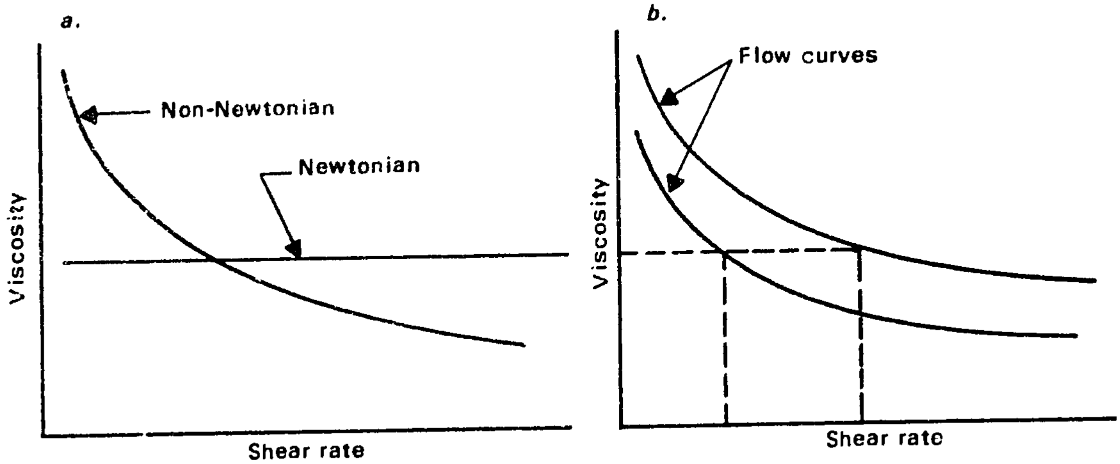

Figure 8. Effect of shear rate on viscosity measurement.

Constant Flow Rate

This method is, in concept, exactly like the constant deformation rate method for solids. Using a plunger traveling at a constant velocity, the liquid is forced through a capillary or orifice. This action is usually accomplished with an Instron machine. The force recorded during extrusion should be constant and is a measure of the viscosity.

Constant Force

This method is, in concept, exactly like the constant force (creep) method for solids. Due to a constant force or weight acting through a plunger, a liquid should flow through a capillary or orifice at a constant flow rate. The weight or volume of liquid which exits the capillary for a given time interval is the measure of viscosity. An alternate measurement is the length of time required for the plunger to travel a prescribed distance.

Gravity Flow

In this method, the liquid is allowed to flow through the orifice due to its own weight. The length of time required for the fluid to flow from a graduated line near the top of the pipette to a graduated line near the bottom will give an indication of the viscosity. Since the pressure causing the flow changes due to the change in liquid height, this method is suitable in theory only for Newtonian liquids. In practice, this method should also give adequate results for non-Newtonian liquids.

Applications

For thin Newtonian fluids, a pipette may serve as a simple gravity flow capillary device. Whether a liquid is Newtonian or non-Newtonian will doubtlessly be unknown beforehand, so preliminary experiments will give an indication as to the usefulness of this method.

A modification of the capillary concept, which is widely used in some industries but has the same disadvantages as the pipette, is the orifice device. The length of time required for a liquid to flow through a hole in the bottom of the cup is used as an indicator of viscosity. The size of the hole can be varied, depending on how thick or thin the liquid is, but the same hole should always be used for comparisons of liquids.

The two methods presented above may not have much application to cereal grain products, unless some type of beverage is made with a grain. In this case, the viscosity indicator may indicate a change with the type of grain, or the relative mixture of various grains used to make the beverage. The sensitivity of these methods may not be great enough to distinguish differences in low viscosity liquids.

The constant flow rate method has been used by Khan et al. (1981) to evaluate cooking procedures for maize *nixtamal* used for making *tortillas*. The force required to extrude the *nixtamal* measured by an Instron was used for evaluation. The device used is sometimes called an extrusion cell (Figure 9a). The orifice was designed to be small enough to rupture the kernels as they passed through the orifice. This device has more recently been used to measure the progress of cooking in corn and sorghum.

The plunger of the extrusion cell could be attached to the instrument shown in Figure 2a. Under a constant weight, the time required to force the liquid through the orifice or the time required for the plunger to travel a given distance is measured. In using these measurements for comparison studies, the same weight should be used for all measurements. For some materials, the weight required to initiate flow may be too great, making this procedure unfeasible.

A similar device which is well suited for thick materials is the back extrusion cell (Figure 9b). A disk attached to a downward moving rod situated concentrically in a cup pushes the material back up past the disk. The diameter and height of the disk can be adjusted to obtain suitable weights for using the constant force method using the instrument shown in Figure 2a. The length of time required for the disk to travel a given distance at constant weight is recorded.

Subramanian (1981) has used this device mounted on an Instron to measure differences between what was described as good and bad *roti* dough. This device has been used in our laboratory in preliminary experiments for the same purpose that the extrusion cell was used by Khan et al. (1981), as previously described.

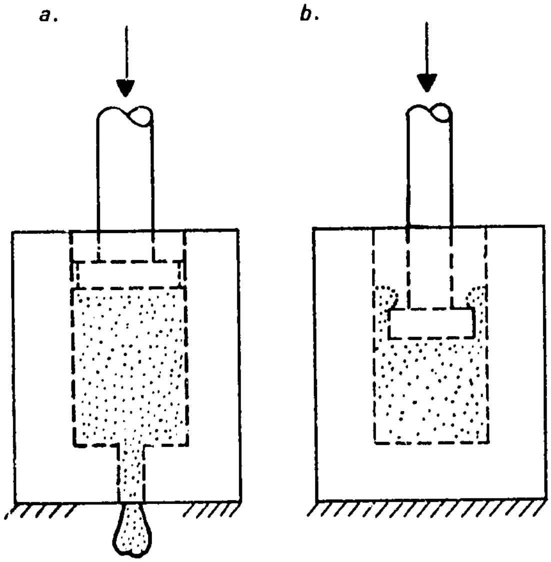

Figure 9. Illustration of capillary extrusion a *and back extrusion methods* b *for thick pastes and liquids, and soft cooked grains.*

Penetrometers are a class of viscometers which are similar in concept to the back extrusion cell. A wide variety of shapes of penetrometers have been used in the past, a brief review of which can be found in Szczesniak (1973b). The consistency of materials tested with penetrometers has varied from thick liquids through pastes to gels. A penetrometer consists simply of a cylindrical rod moving concentrically down into a cup containing a liquid or into a dish containing a gel. Application to gels is where the penetrometer finds the most convenient use. This is the same configuration that was suggested for measuring gel stiffness and penetration force (Figure 5b), except that the depth to which the rod travels into the gel before stopping is measured. The tip of the rod is often conical to facilitate penetration. This shape finds frequent use for foods and is often called a cone penetrometer. A discussion of the principles involved in this device can be found in Haighton (1959). Akingbala (1981) has used this device to measure the penetration of *tô*.

Stickiness is not truly a viscosity measurement but may be a very important texture or quality attribute. Sherman (1969) has noted that stickiness depends on both the cohesive forces in the food and the adhesive forces between the food and with whatever it comes into contact. A measure of stickiness can be obtained by pulling two parallel plates apart, again at a constant rate. Kumar et al. (1976) used this method, operating it on an analytical balance, to measure an indicator of stickiness in rice. Akingbala (1981) has also used this method to measure the stickiness of *tô*. A plate on one side of a balance scale was squeezed against a fixed plate which contained a sample of *tô*. Using a burette, water was added to the other side of the scale until the plate separated from the *tô*. A pointer attached to the balance beam indicated on a dial the angle through which the scale traveled before separating (Figure 10). The measurement of the angle traveled seemed to distinguish differences in stickiness of *tô* made from different sorghum varieties. This same measurement can be made on an Instron machine. With the pen at half-scale, the sample is compressed a prescribed distance between two plates

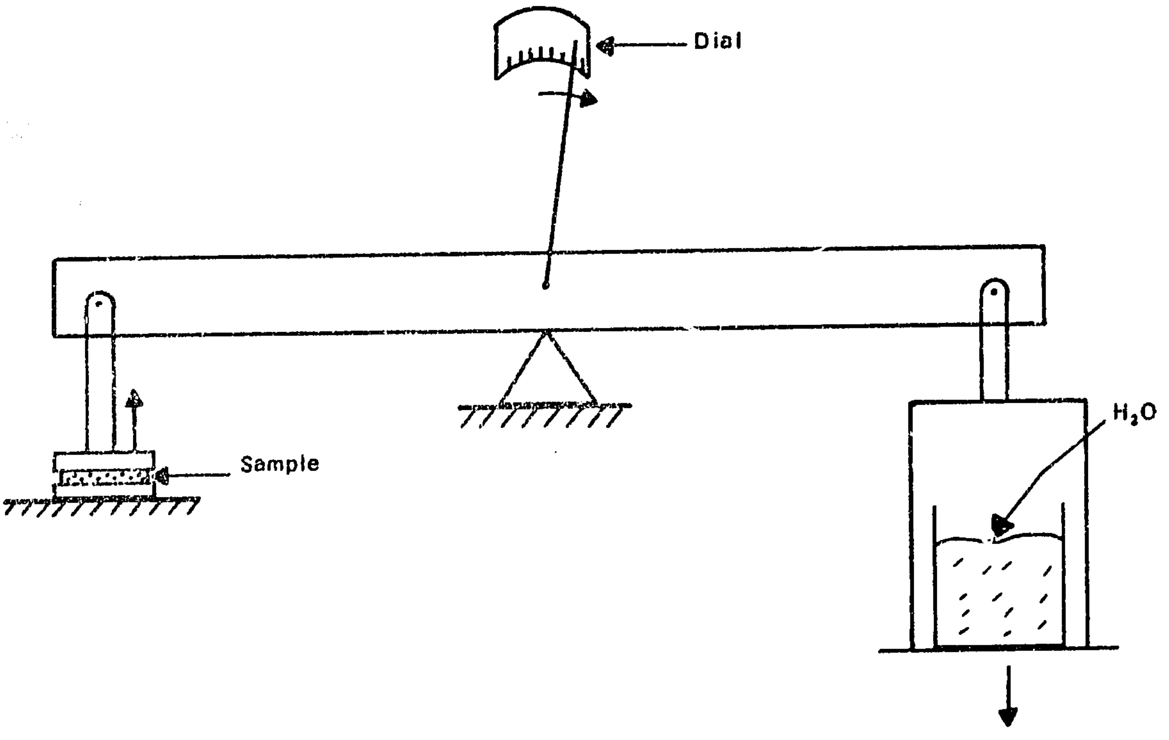

Figure 10. Illustration of a method for measuring stickiness.

and then pulled apart. The force required to pull the plates apart would be registered below the half-scale line. This measurement is part of the General Foods Texturometer procedure used on the Instron by Bourne (1968).

The Bostwick consistometer (Szczesniak 1973b) is used to measure the distance a thick liquid travels down an inclined trough. The liquid can be loaded on the trough while horizontal and then elevated to the desired angle.

Hoseney et al. (1979) used a simple spread test to examine the effects of yeast, reducing agents, and oxidants on a sample of fermenting wheat dough. Spread was measured as the width of the rounded dough divided by the height. The measurements were made at 15-min intervals up to 60 min.

Conclusions

The rheological methods and applications discussed above are intended to provide a base which researchers unfamiliar with rheology can use or build upon in determining the texture or quality of specific products. While the parameters suggested as texture indicators are not fundamental rheological properties, they should provide good results if attention is given to the precautions previously discussed. Many of the techniques presented do not require an expensive testing machine. For this reason, a greater responsibility falls on the user to perform the experiments consistently, since this is the main advantage of a universal testing machine. Again, it is up to the individual user to determine if a particular measurement is an indicator of texture or quality, since these are subjective determinations apart from rheological measurements.

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Color of Sorghum Food Products

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Summary

Color of sorghum milled products and foods is an important aspect of quality that must be measured. Color measurements on sorghum grain, roti *and* tortilla *samples using the Hunter Lab Color Difference Meter and the Munsell Soil Color Charts showed that Munsell Color Charts are effective for a rapid and inexpensive assessment of a large number of samples from quality breeding programs. It would be possible to obtain standardized color schemes to assess a wide array of sorghum food products among laboratories. Sophisticated instruments such as the Hunter Lab Color Difference Meter can be used for fundamental studies to back-up crop improvement programs.*

Color has long been a criterion of product quality and plays a major role in the acceptance or rejection of food products. Flour color was important to the Romans, who prided themselves on making the finest, whitest flours. Even today many people still equate flour color with quality for use in food products. If sorghum is to compete with wheat and maize products in urban areas, highly refined products will be required.

The color of sorghum flour and sorghum products plays an important part in their acceptance. In many cases where traditional foods are concerned, a white color is not required, but in general it is preferred. The accepted color is conditioned by what people are used to, and unaccustomed variability is often viewed with distrust.

In the International Sorghum Food Quality Trials (ISFQT), brown sorghums produced food products that were unacceptable (Murty and House 1980). In general, white sorghum grains produced the most acceptable colored food products, but considerable variation in color of some products was acceptable. For example, *sankati* made from sorghums with a subcoat was acceptable while *rotis* made from sorghums with a subcoat were not acceptable (Murty et al. 1981a,b). Thus, it is important to measure color of grain, flour, and the food products in an efficient manner. The purpose of this paper is to review methods to determine color that can be applied in practical breeding programs. Color measurements range from matching the color of the product with that of a standard by subjective evaluation, to measuring the components of color with expensive and sophisticated color analyzers.

Subjective Measurements of Color

An effective method used over the years for wheat flour color measurements was a "Slick" or Pekar test, which compared the color of one flour sample with that of a standard flour (Pomeranz 1971). The flour samples are laid side by side and pressed into a thin layer to form a smooth surface. Then, the color is visually compared. The test is more accurate when the flour samples are wetted and compared. For sorghum flour, the test reflects the level of phenols in the product, the granulation of the flour, and the carotenoid pigments in the endosperm. The major factor affecting the color of sorghum flour is the level of polyphenols, which is related to the amount of contamination of endosperm with pericarp and testa (bran in milling terminology). The use of a test like the Pekar test can be effective especially when standard color plates are used to serve as control samples.

Color Meters

A number of colorimeters have been designed to

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measure the color of a sample in terms of the intensity of the three primary colors: red, blue, and yellow. For instance, the Hunter Lab Color Difference Meter measures color in terms of lightness (L), redness (+a) or greenness (−a), and yellowness (+b) or blueness (−b) in a sample. The signs of the 'a' or 'b' readings determine the color value and intensity of the three primary colors. The Agtron photoelectric colorimeter works essentially in the same manner. These instruments are calibrated with standard color plate and provide unprejudiced, reproducible results with a minimum of operating skill and training.

Although the instruments are simple to operate, data must be interpreted with an awareness of the factors affecting color. The relatively high cost of these instruments and the need for sophisticated maintenace, constant voltage and other factors, in general, preclude their use in sorghum quality selection except as back-up instrumentation to establish more simple, economical methods.

Sorghum Color Measurements with the Hunter Lab Color Difference Meter

The color of sorghum grain and *tortillas* as measured by the Hunter Lab Color Difference Meter for ISFQT samples grown in 1979, is presented in Table 1. The procedures followed were the same as those described by Johnson et al. (1979). The Hunter Lab Color Difference Meter is not able to distinguish among sorghums with a testa since it only measures surface color. Thus, a person must be familiar with kernel properties of sorghum to evaluate color data on the whole grain. The surface texture of *tortillas* affects color measurements significantly and numerous measurements are required to obtain a reliable reading. This is expecially true when *tortillas* are unevenly cooked. The ΔE values in Table 1 are a way of condensing color measurements into one value. In general, ΔE values were highest for sorghum *tortillas* with the darkest, most unacceptable color.

The Hunter Lab Color Difference Meter has been used to measure the color of fresh and stale (stored 24 hr) *tô* (Akingbala, in press) and *ogi* (Akingbala et al. 1981).

Munsell Soil Color Charts

The Munsell Soil Color Charts (Anon. 1975) display different standard color chips systematically arranged according to their Munsell notations, on cards carried in a loose leaf notebook. The arrangement is by three simple variables that combine to describe all colors and are known in the Munsell system as Hue, Value, and Chroma. The Hue notation of color indicates its relation to red, yellow, green, blue, purple, yellow-red, green-yellow, blue-green, purple-blue, and red-purple; the Value notation indicates its lightness; and the Chroma notation indicates strength (or departure from a neutral of the same lightness). The colors displayed on individual cards are of constant Hue, designated by a symbol. Vertically, the colors become successively lighter from the bottom of the card to the top by visually equal steps; that is, their Value increases. Horizontally they increase in Chroma to the right and become grayer to the left. The Value notation for each individual column and row are indicated on the chart.

As arranged in the notebook, the charts provide three scales: (1) radial, or from one chart to the next in Hue, (2) vertical in Value, and (3) horizontal in Chroma. The charts provide color names as well as the Munsell notation of color. The Munsell notation is used to supplement the color names wherever greater precision is needed. The Munsell notation is especially useful for international correlation, since no translation of color names is needed.

The Munsell notation for color consists of separate notations for Hue, Value, and Chroma, which are combined in that order to form the color designation. The symbol for Hue is the letter abbreviation of the color of the rainbow (R for red, YR for yellow red, Y for yellow) preceded by numbers from 0 to 10. Within each letter range, the Hue becomes more yellow and less red as the numbers increase. The middle of the letter range is at 5; the zero point coincides with the 10 point of the next redder Hue. Thus 5YR is in the middle of the yellow red Hue, which extends from 10R (zero YR) to 10YR (zero Y).

The notation for Value consists of numbers from 0 for absolute black, to 10 for absolute white. Thus a color of Value 5/ is visually midway between absolute white and absolute black. One of Value 6/ is slightly less dark, 60% of the way from black to white, and midway between Values of 5/ and 7/.

The notation for Chroma consists of numbers beginning at 0 for neutral grays and increasing at equal intervals to a maximum of about 20. For

Table 1. Grain, *roti*, and *tortilla* color measured with the Hunter Lab Color Difference Meter and the Munsell color charts.

Sorghum samples	Apparent grain color description	Grain color[a]				Grain[b] color Munsell	*Roti* color Munsell	*Tortilla* color[a]			
		L	a	b	ΔE[c]			L	a	b	ΔE[c]
P721	White	59.1	3.1	19.1	20	2.5Y 8/2	5Y 6/4	49.9	−0.4	15.8	29
E35-1	White	58.8	2.2	17.4	20	5Y 8/2	5Y 8/2	53.8	−0.3	15.2	25
IS158[d]	White	62.2	2.3	19.1	17	5Y 8/2	5Y 7/3				
Market-1	White	62.2	2.6	17.6	17	5Y 8/2	5Y 8/2	49.7	−1.1	14.3	30
S29	White	61.1	3.3	18.1	18	2.5Y 8/2	5Y 8/2	48.6	1.6	12.0	31
IS2317	Light gray	58.9	0.8	14.4	21	5Y 7/1	2.5Y 6/2	29.7	0.4	4.7	51
WS1297	Light gray	59.3	1.0	12.6	21	5Y 7/1	2.5YR 5/2	33.9	0.85	5.3	44
IS7035	Light gray	5[illegible].4	1.0	12.6	24	5Y 7/1	2.5YR 4/2	36.0	0.38	6.9	45
M35-1	Pale yellow	56.6	[illegible]	19.6	22	5Y 8/3	5Y 8/2	46.4	−2.0	15.2	33
CSH-5	Pale yellow	56.0	[illegible]	19.8	23	5Y 8/3	5Y 8/2	49.4	−2.4	16.6	29
M50009	Pale yellow	52.2	3.6	18.2	26	2.5Y 8/4	5Y 8/3	48.1	−2.0	15.4	31
M50013	Pale yellow	52.7	3.9	18.9	26	2.5Y 8/4	5Y 8/2	48.1	−1.4	16.0	30
M35052	Pale yellow	52.3	4.0	18.1	27	2.5Y 8/4	5Y 7/3	49.9	−1.1	14.3	29
M50297	Pale yellow	56.5	3.2	19.1	22	2.5Y 8/4	5Y 8/3	54.3	0.7	15.4	25
Mothi	Pale yellow	53.3	3.2	17.8	25	5Y 8/3	5Y 8/3	51.1	−1.8	16.8	27
Segaolane	Pale yellow	51.8	4.5	17.0	27	2.5Y 8/4	2.5Y 8/2	51.0	−0.6	14.2	28
Swarna	Pale yellow	54.2	4.4	19.2	25	2.5Y 8/4	2.5Y 8/2	52.2	−0.8	15.3	27
S-13	Pale yellow	53.7	4.0	18.2	25	2.5Y 8/4	5Y 7/3	54.3	−0.7	15.4	25
CS3541	Pale yellow	52.0	4.8	19.2	27	2.5Y 8/4	5Y 8/4	46.0	1.2	15.3	33
Patcha Jonna	Yellow	43.7	6.1	19.3	35	5Y 7/8	5Y 6/6	41.5	5.8	17.3	37
IS9985	Yellow	50.6	5.9	19.9	28	10YR 7/6	2.5Y 8/2	52.0	0.23	15.8	27
CO-4	Light red	41.6	16.4	17.2	37	10R 6/8	10YR 6/4	46.8	3.0	14.1	32
IS8743	Dark reddish gray	34.4	14.0	12.6	45	10R 4/1	5YR 5/4	35.6	2.9	10.7	44
IS7055	Reddish brown	38.0	8.6	14.0	42	5YR 4/4	2.5YR 5/4	26.6	5.5	4.6	55
Dobbs	Pinkish gray	44.4	7.8	16.8	35	7.5YR 7/2	2.5YR 5/4	26.9	4.7	4.1	54

a. Grain and *tortilla* color was measured with a Hunter Lab Color Difference Meter with L = 78.2, a = −2.3, b = 22.4 as standard. "L" measures color intensity. Increasing "b" = increasing yellow color. Decreasing "b" = increasing blue color. Increasing "a" = more red. Decreasing "a" = more green.

b. The number and letters describe the Hue, Value, and Chroma of standard Munsell color plates that matched the *roti* and grain color.

c. $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$ where Δ indicates the difference between observed and standard L, a and b values, respectively.

d. Hunter Lab Color Difference Meter data were not collected for *tortillas* of IS158.

absolute achromatic colors (pure grays, white, and black) which have 0 Chroma and no Hue, the letter N (neutral) takes the place of a Hue designation. In writing the Munsell notation, the order is Hue, Value, Chroma with a space between the Hue letter and the succeeding Value numbers, and a virgule between the two numbers for Value and Chroma. If expression beyond the whole numbers is desired, decimals are always used. Thus the notation for a color of Hue 5YR, Value 5, Chroma 6, is 5YR 5/6, a yellowish red. Thus, the Munsell values can be related to values obtained with the Hunter Lab Color Difference Meter. But, the Munsell color can be evaluated without an instrument by selecting the best match of product color with standard Munsell plates.

The color plates can be purchased at low cost to provide the range in color values expected for a product. It is estimated that the human eye can perceive several million different colors under optimum color-matching conditions. It is economically impractical to match every possible color. Thus visual interpolation is required.

Sorghum Color Measurements with Munsell Color Charts

Color measurements obtained on grain samples of 25 sorghum cultivars of ISFQT-1979 are presented in Table 1 in comparison with those obtained with the Hunter Lab Color Difference Meter. It was observed that apparently the white gray and pale yellow group of grain samples could be further distinguished by different Hue, Value, and Chroma values of Munsell charts. Variation in a, b, and ΔE values of the Hunter Lab Color Difference Meter was associated with variation in the Hue, Value, and Chroma values of Munsell. The white grain samples P721 and E35-1 showed different a and b values while the Munsell Color Chart also distinguished them by different Hue values. Even minute differences among a and b values of Market-1 and S-29 were reflected in different Hue values of Munsell. Light gray sample IS-7035, which has a testa, showed the least a and b values while the Munsell chart distinguished its color as 5Y 7/1. Among the pale yellow samples, the b values of M35-1 and CSH-5 were the highest while the Munsell Color Chart also distinguished these samples with 5Y 8/3. Similarly, differences in a, b and ΔE values among the two yellow samples were adequately reflected in the Munsell notation. Higher ΔE values were associated with darker shades in the Munsell system. Thus, the Munsell Color Charts are as effective in color description as is the Hunter Lab Color Difference Meter.

At ICRISAT, Munsell Soil Color Charts were used to measure the color of several hundred sorghum grain and *roti* samples (Murty et al. 1981b). Repeated color measurements on grain samples drawn from check cultivar bulks over several weeks showed that color comparisons with Munsell Charts are highly repeatable within ± 1 limits of Chroma. This was also true with *roti* color observations made on samples drawn from the same cultivars replicated in the field in various experiments (Table 2).

The Munsell Soil Color standards have been

Table 2. Grain color of six sorghum cultivars grown in a split plot experiment with four treatments replicated three times.[a]

	Replication 1	Replication 2	Replication 3
P-721	2.5Y 7/2[b]	5Y 7/2	5Y 7/3
	5Y 6/3	5Y 7/2	5Y 7/2
	5Y 6/2	5Y 6/2	5Y 6/3
	5Y 6/3	2.5Y 7/2	5Y 6/3
CS3541	5Y 8/3	5Y 8/2	5Y 8/2
	5Y 8/3	5Y 7/3	5Y 8/3
	5Y 8/3	5Y 8/2	5Y 8/3
	5Y 8/3	5Y 8/2	5Y 8/2
SPV351	5Y 8/2	5Y 8/2	5Y 8/2
	5Y 8/3	5Y 8/3	5Y 8/3
	5Y 8/2	5Y 8/2	5Y 8/2
	5Y 8/2	5Y 8/2	5Y 8/2
E35-1	5Y 7/3	5Y 8/2	5Y 8/2
	5Y 8/3	5Y 8/2	5Y 8/3
	5Y 7/2	5Y 8/3	5Y 8/2
	5Y 8/2	5Y 8/3	5Y 8/2
SPV393	5Y 8/2	5Y 8/3	5Y 8/3
	5Y 8/2	5Y 8/2	5Y 8/3
	5Y 8/3	5Y 8/2	5Y 8/3
	5Y 8/3	5Y 8/3	5Y 8/2
M35-1	5Y 8/3	5Y 8/2	5Y 8/3
	5Y 8/2	5Y 8/3	5Y 8/3
	5Y 8/3	5Y 8/2	5Y 8/3
	5Y 8/3	5Y 8/3	5Y 8/3

a Grain color observations are according to Munsell notation.
b Each observation pertains to a sample from a treatment.

used to designate color of *tortillas* (Bedolla and Rooney, unpublished data 1981) and *tô* (Akingbala and Rooney 1981, unpublished data). The Munsell color values for *tortilla* and *tô* were obtained by using tristimulus values measured with the Hunter Lab Color Difference Meter to produce Munsell Color notations. *Tortilla* colors ranged from 10Y to 10YR, lightness Values of 7 to 8, to Chroma of 1 to 6. The y[illegible] and yellow red Hues described *tortillas* Hue very well.

We have accumulated sufficient data on color measurements of sorghum and sorghum products to permit accurate acquisition of Munsell plates (Anon. 1975). A set of standard plates can be purchased for as little as $10 per set provided 20-30 sets are purchased, or the whole soil color classification manual can be purchased for about $30-40. Therefore, we recommend to those who want to determine color in sorghum food products to try the Munsell standard charts as an inexpensive practical method of evaluating color.

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Phytin Content of Sorghum and Sorghum Products

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Summary

Thirty varieties of sorghum grown in India during 1979 and 1980 were analyzed for phytate and total phosphorus by a semiautomated method. Levels of phytate phosphorus (phytate-P) ranged from 0.17% to 0.38% (dwb.), accounting for 80–87% of the total phosphorus present in the kernel. Analysis of grain fractions obtained from six varieties through traditional hand-milling techniques showed that the bran contained the highest levels of phytate-P, with lesser amounts in the whole grain and dehulled grain, respectively. Difference in phytate-P levels in these fractions was due to varietal effects and was related to the degree of milling. The phytate-P content in tô *and* tortilla *and the intermediate products were determined. The level of phytate-P in sorghum was similar to that of other cereals.*

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth largest cereal food crop in the world and is grown throughout Asia, Africa, and North America (Rooney et al. 1980). In sorghum, as in other cereals and oilseeds, phytic acid is the major storage form of phosphorus (de Boland et al. 1975; McCance and Widdowson 1935). Current interest in phytic acid is due to recent nutritional studies that have shown phytic acid to chelate di- and trivalent cations, particularly Fe, Ca, Na, and Mg, rendering them unavailable for use by the body (Davies and Nightingale 1975; Radhakrishnan and Sivaprasad 1980). Phytic acid also binds strongly with protein at pH levels below the isoelectric point (Cosgrove 1966). Thus, the presence of phytic acid is considered detrimental to the nutritional quality of the grain.

The purpose of this study was to isolate and quantify phytate-P in sorghum cultivars, milling fractions, and processed products. Knowledge of the location and levels of phytate-P in sorghum cultivars with diverse kernel characteristics and its fate during processing may aid in selecting cultivars with improved nutritional quality for food.

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Materials and Methods

Samples

Samples chosen for phytate-P and total phosphorus (total-P) analysis included 30 sorghum cultivars grown at ICRISAT in Patancheru, near Hyderabad, India. Twenty four varieties representing 15 white cultivars (no testa), 3 white (with testa), 2 brown (with testa, dominant spreader), 1 lemon yellow (no testa), and 3 red (no testa) were grown in 1979. Six cultivars (4 white, 1 lemon yellow, 1 yellow endosperm) all lacking a testa layer, were grown during 1980. The 1980 samples were milled in India by D. S. Murty (ICRISAT) using traditional methods of tempering and decortication with a carborundum mortar and wooden pestle.

Tô, a thick African porridge, was prepared from dehulled CS3541 grain (grown at Halfway, Texas in 1980) according to the laboratory procedure of Johnson (1981). Three preparation methods, acid, neutral, and alkali, produced *tô* with a pH of 5.0, 6.6, and 8.9, respectively. Fresh *tô* samples were freeze-dried, ground, and analyzed.

Tortillas were prepared according to the laboratory procedure of Bedolla et al. (unpublished) from CS3541 (grown at Halfway, Texas in 1980) and a white food grade maize hybrid. Samples were collected at major steps in the *tortilla*-making process (*nixtamal, masa,* and *tortilla*), and then dried to 10% moisture. Total phosphorus (total-

P) and phytate phosphorus were determined by the method developed by Doherty (1981).

Results

Sorghum Phytate-P

Phytate-P levels in the 30 whole grain sorghum samples ranged from 1.72 to 4.07 mg/g dry wt, with IS-5758 containing the greatest amount and M35-1 the least (Table 1, Fig. 1). The overall mean for total-P and phytate-P in the whole grain sorghums was 3.94 ±0.55 and 3.21 ±0.47 mg/g dry wt respectively. These levels are typical for sorghum (Hulse et al. 1980). Levels of 1.6 to 4.3 mg/g dry wt have been reported for whole grain varieties (Wang et al. 1959). Phytate-P levels in sorghum are no higher than those in wheat (3.35 mg/g dry wt), barley (3.04 mg/g dry wt), and maize (2.80 mg/g dry wt) but are significantly lower than soybean (7.30 mg/g dry wt) and other oilseeds (Lolas et al. 1975; de Boland et al. 1975; Doherty 1981).

Forty to fifty percent of both phytate and total-P can be removed by dehulling (Fig. 1). Phytate-P constituted 82-91, 56-84, and 85-95% of the total-P in whole grain, dehulled grain, and bran, respectively. Differences between levels in these fractions were dependent upon varietal effects, extent of milling, and initial level of total-P present in the grain.

Duncan's multiple range test showed statistical differences ($\alpha = 0.05$) in phytate and total-P levels between cultivars and their subsequent milling fractions (Fig. 1). The order of decreasing

Table 1. Total-P and phytate-P levels in 24 whole grain Indian samples grown in 1979.

	Total-P Mg/g sample (dwb)		Phytate-P					
Variety	$\bar{x}$	s	$\bar{x}$	s	% Phytate-P of total-P	Endosperm type	Testa	Pericarp color
P-721	4.49	0.10	3.52	0.03	78.4	Nonwaxy	None	White
Mothi	4.21	-	3.12	0.13	74.1	Nonwaxy	None	White
Patcha Jonna	4.34	-	3.42	0.02	78.4	Nonwaxy	None	Lemon Yellow
Dobbs	4.33	0.09	3.31	0.07	76.4	Nonwaxy	Present	Brown*
E35-1	3.92	0.06	3.04	0.13	77.6	Nonwaxy	None	White
M50009	3.62	0.07	3.07	3.09	84.8	Nonwaxy	None	White
M50013	4.32	0.04	3.17	0.05	73.4	Nonwaxy	None	White
M35-1	3.88	0.12	3.36	0.04	86.6	Nonwaxy	None	White
IS-2317	4.01	0.11	3.26	0.13	81.3	Nonwaxy	Present	White
IS-8743	4.39	0.18	3.53	0.09	80.4	Nonwaxy	None	Red
CSH-5	3.34	0.11	2.57	0.02	76.9	Nonwaxy	None	White
Swarna	3.58	0.08	2.85	0.02	79.6	Nonwaxy	None	White
Segaolane	4.28	0.09	3.48	0.13	81.3	Nonwaxy	None	White
S-13	4.54	0.21	3.77	0.05	83.0	Nonwaxy	None	White
CO4	3.79	0.02	3.00	0.04	79.1	Nonwaxy	None	Red
WS-1297	3.87	0.13	3.28	0.09	84.8	Nonwaxy	Present	White
IS-158 OP	3.59	0.14	3.25	0.05	90.5	Waxy	None	White
M-35052	3.20	0.17	2.62	0.04	81.9	Nonwaxy	None	White
IS-7055	4.50	0.11	3.80	0.02	84.8	Nonwaxy	Present	Brown*
S-29	4.56	0.10	3.57	0.04	78.3	Nonwaxy	None	White
M-50297	4.07	0.03	3.54	0.07	87.0	Nonwaxy	None	White
CS3541	4.25	0.06	3.34	0.01	78.6	Nonwaxy	None	White
IS-9985	3.93	0.01	3.32	0.11	84.5	Nonwaxy	None	Red
IS-7035	3.71	0.01	3.03	0.06	81.7	Nonwaxy	Present	White

* Spreader is dominant.

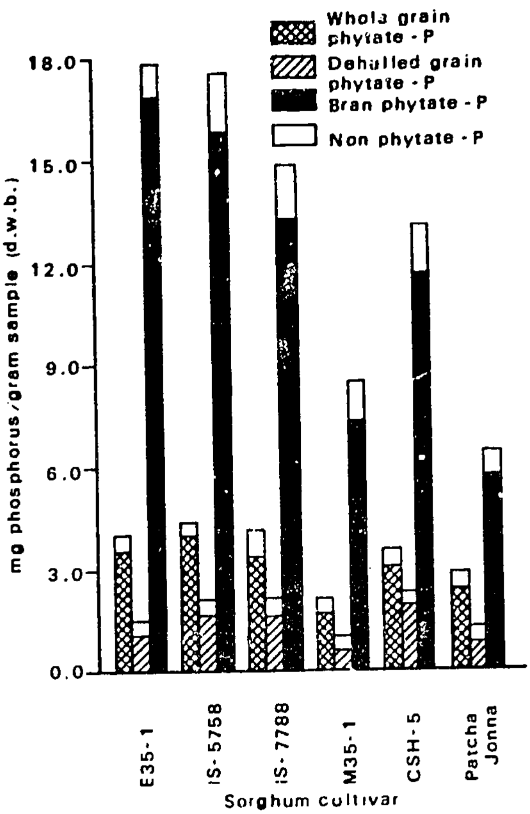

Figure 1. Effect of hand milling upon phytate and total phosphorus levels in six sorghum cultivars grown in India during 1980.

phytate-P content for the fractions obtained through traditional milling methods was: bran > whole grain > dehulled grain. This suggests that the bran-aleurone area is a significant phytate and total-P reservoir in sorghum.

In a similar study with bran and germ fractions obtained from a commercial dry milling procedure, highest levels of phytate-P were found in the germ followed by the bran. The grits (endosperm) contained the least phytate-P (Wang et al. 1959). The ease and completeness of milling plays a major role in the level of phytate-P found in the grain fraction. For example, the soft floury endosperm of IS-7788 had an increase in the level of phytate-P in the milled grain as compared with the whole grain (Fig. 1). Variety IS-7788 was rapidly broken into various kernel fractions with only a small amount of pericarp being removed. Since the pericarp contains little phytate-P, the actual level in the "milled" grain was slightly higher (0.3%). In general, bran fractions obtained by traditional hand milling techniques would have a greater percentage of germ present. Commercial dry milling techniques would yield a more "pure" bran fraction. Differences in the content of the milled or milling fractions obtained for this study would account for bran fractions containing 30 to 200% higher phytate-P levels than those reported by Wang et al. (1959).

A linear relationship was established between phytate-P and total-P ($R = 0.995$, C.V. = 6.30, d.f. = 81) when data from all sorghum samples analyzed were compiled. A linear regression equation ($y = 0.943x - 0.465$) was calculated suggesting the possibility of predicting phytate-P from total-P levels. This has, in fact, been done for wheat; oats, barley, and soybeans (Lolas et al. 1975). Linear regression analysis also suggests that increasing the level of total-P in sorghum does not significantly increase other phosphorus sources in the kernel (e.g., phospholipids, nucleic acids, etc.). The greater the level of total-P present, the larger the percentage is in the phytate form. Similar results were shown in oats (Miller et al. 1980).

Processed Products

Tortillas

Sorghum and white maize *tortillas* were prepared on two separate days. No statistical differences ($\alpha = 0.05$) in total-P were observed between production days or *tortilla* production steps for either grain. The overall mean for total-P in whole grain and products derived from it was 4.41 ± 0.33 mg/g dry wt (C.V. = 7.49) and 3.24 ± 0.24 mg/g dry wt (C.V. = 7.50) for sorghum and white maize, respectively. Phytate-P levels in maize were comparable to those reported by O'Dell et al. (1972). Statistical differences ($\alpha = 0.05$) in phytate-P levels between days and processing steps were observed in both grains (Table 2). In maize and sorghum, mean phytate-P levels in the *tortilla* were statistically higher than the whole grain suggesting that processing involved in *tortilla* production effectively concentrates phytate-P. This is reasonable since non-phytate phosphorus containing components (starches, sugars, protein) as well as parts of the kernel (germ, pericarp) are lost during the cooking/steeping process. Unavoidable differences in solubles lost in this step accounted for observed day effects. The maize and sorghum residues obtained from the cooking/steeping H_2O showed phytate-P levels of 0.87 ± 0.07 and 3.29 ± 0.5 mg/g dry wt for maize and sorghum, respectively. Total-P levels for sorghum and maize residues were 3.69 ± 0.08 and 3.46 ± 0.09 mg/g dry wt, respectively. Only trace amounts of phosphorus (< 5 ppm) could be detected in the steeping/cooking water for both grains.

Tortillas were prepared from whole grain which was boiled and steeped in an alkaline solution with a high Ca^{++} concentration. Metal chelates are generally insoluble at an alkaline pH (Cheryan 1980), accounting for low levels of phosphorus seen in the cooking steeping H_2O. Relatively the same amounts of total-P were lost from maize and sorghum in the cooking/steeping process. However, three times more phytate-P was lost from the kernel in the steeping and cooking water solids for sorghum. Thus, differences in total kernel components lost, or differences in relative amount of kernel components (bran, germ) lost would account for higher phytate-P levels in residues obtained from the cooking steeping process in sorghum *tortilla* production.

Reasons for a gradual increase in phytate-P from *nixtamal* to *tortilla* in maize *tortilla* production are unclear (Table 2). The formation of phosphorylated inositols which precipitate upon addition of Fe^{3+} appears to be occurring. A lower non-phytate phosphorus level logically accompanied this formation. These same general trends appear in sorghum *tortilla* production (Table 2); however, statistical differences ($\alpha = 0.05$) were not observed between *nixtamal* and *masa*. It appears that a larger number of samples prepared over a longer period of time need to be analyzed to determine if these general trends do occur.

Thick Porridges

In a study to evaluate the nutritional value of *tô* (Johnson 1981), a significant ($\alpha = 0.05$) decrease in phytate-P was observed for *tô* prepared from a red pericarp sorghum (TAM680), a red sorghum with testa and spreader (NK300), and a sample of *tô* made in Mali using acid conditions (Fig. 2). Decreases in phytate-P levels were accompanied with increases in nonphytate-P as found in other studies. This seems reasonable since phytic acid has a slight tendency to hydrolyze under acid conditions (Maddaiah et al. 1964).

Table 2. Mean phytate-P levels during maize and sorghum *tortilla* production.

Product	Sorghum $\bar{X}$	Maize $\bar{X}$
	Mg/g sample dry wt	
Whole grain	3.34^c	2.27^d
Nixtamal	3.66^a	2.76^c
Masa	3.65^a	2.87^b
Tortilla	3.78^b	3.02^a
	$\alpha = 3.69$	$\alpha = 2.81$
	C.V. = 4.35	C.V. = 5.38
	$\sigma = 0.16$	$\sigma = 0.15$

Numbers with the same superscript letter within a column are not statistically different at $\alpha = 0.05$.

Varietal differences were also observed after analyzing *tô* samples. *Tô* of TAM680 was significantly higher in phytate-P and *tô* of NK300 was significantly lower.

In this study, *tô* was prepared from CS3541. No statistical differences ($\alpha = 0.05$) were observed in total or phytate-P levels between the dehulled grain or *tô* produced at any pH level (Fig. 2). However, the same general trend of acid *tô* having a slightly reduced phytate-P level was observed (Fig. 2). The overall mean for phytate and total-P in *tôs* derived from CS3541 was 2.50 ± 0.04 and 2.86 ± 0.07 mg g dry wt, respectively. In general, phytate-P level in the whole grain is higher than the flour or *tôs* produced from them. This would be attributed to the dehulling of the grain in preparation of the flour for *tô*.

Conclusions

Sixty to ninety percent of the phosphorus in all samples analyzed was in the phytate form. These levels are comparable to those found in other cereals. The bran fraction contained the highest levels of phytate-P (5.67–16.90 mg g dry wt) and dehulled grain the lowest (0.56–1.92 mg/g dry wt). Phytate-P constituted 85–95%, 79–89%, and 56–84% of the total-P in the bran, whole grain, and dehulled grain, respectively, for traditionally hand-milled samples.

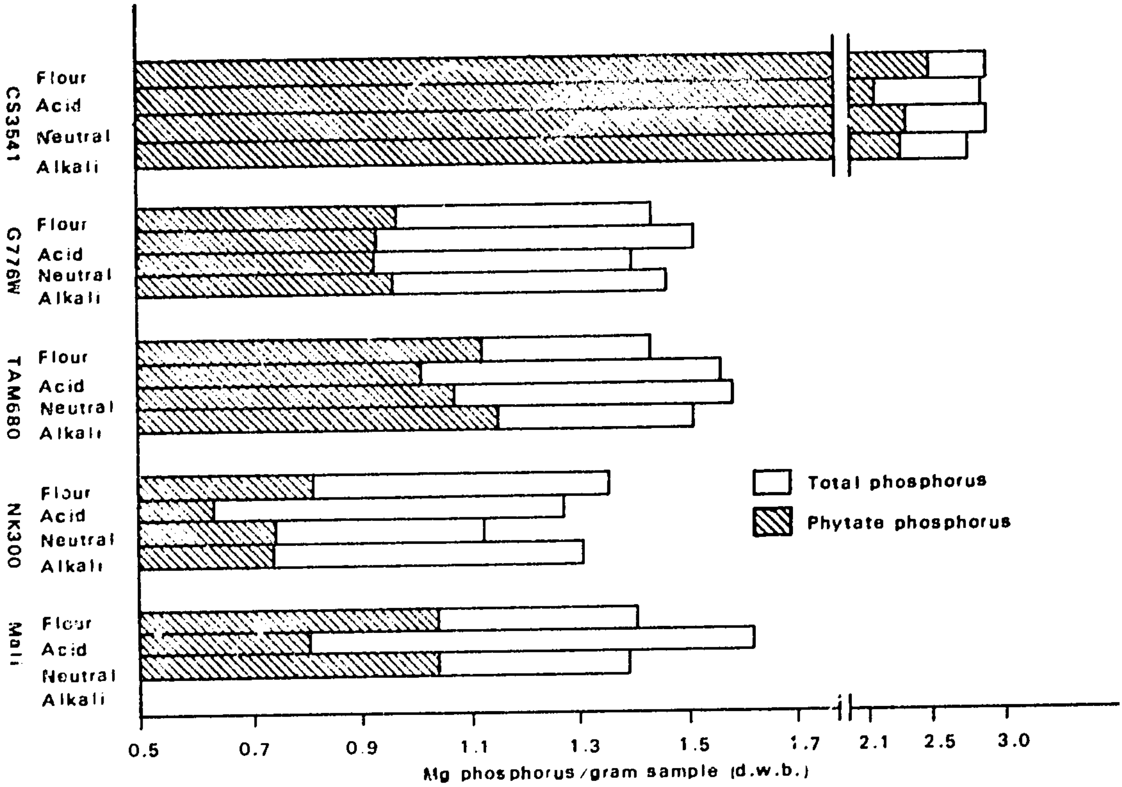

Figure 2. Effect of processing method upon phytate and total phosphorus levels in tôs prepared from five sorghum varieties. Grains of TAM680, NK300, and G766W were grown at Thrall, Texas, in 1976; CS3541 was grown in Lubbock, Texas; Mali refers to tô prepared in Mali by traditional methods, dried, and sent to our laboratory for analyses.

Varietal effects appeared to be the most critical factor in selecting a sorghum variety for human consumption that would contain optimum, available phosphorus. Extent of milling and type of processing would be a lesser concern since they do not selectively lower the nondigestible phytate-P levels. A strong linear relationship between phytate and total-P levels makes it unlikely that any attempt to increase nonphytate phosphorus by increasing total-P levels would meet with much success.

Phytate-P was effectively concentrated through loss of kernel components during *tortilla* production. A comparison of sorghum *tortillas* with those traditionally made from maize shows that sorghum *tortillas* in this study had three times more nonphytate-P available (0.63 mg/g dry wt) than maize tortillas (0.22 mg/g dry wt). Alkali conditions had no effect on breaking down phytates in *tortillas* or in the making of *tô*. However, acid conditions involved in the *tô* making process were conducive to the hydrolysis of phytates.

Acknowledgments

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Discussant's Comments

Session 5: L. Munck*

In the development of baking tests for wheat, special instruments have been designed which are used worldwide. These techniques have been helpful in the industrialization of baking technology. The situation for sorghum is, however, quite different from that of wheat. Here we have not one standard product such as wheat bread, but a wealth of sorghum foods which show a great deal of variation. The approach which has been demonstrated to us here in this symposium by several plant breeders is just the approach we need. The testing of the varieties is done with a minimum of equipment in cooperation with skilled local personnel.

On the other hand, we should take care of those simple methods for quality evaluation which are already developed for the other cereals and which might be relevant for certain sorghum foods.

We have used the falling number test (which is developed for wheat and rye) with great advantage to study starch gelatinization in sorghum.

The work presented by Dr. Subramanian and Dr. Murty would benefit if the basic quality of the undamaged sorghum could be differentiated from weathering damage, which is caused by germination and infection influencing the enzymatic status of the grain. The latter can be recorded with the falling number method, and a convenient plate method can be used to study amylase activity with radial diffusion (Heigaard, J., and Gibbons, G. C., Carlsberg Research Communication 44: 21, 1979).

Dr. Chandrasekhar's paper told us about the high potential value of sorghum, if properly processed. There is thus a high potential of water absorption in sorghum starch, which can be first realized when the starch granules are released from the surrounding protein matrix. The high starch damage when sorghum is milled could also reflect the strength of binding between protein and starch. These remarkable effects in sorghum may also be correlated with the nutritional availability of sorghum foods.

Dr. Rooney made a review of the work with amylose in sorghum. Obviously, the desired variability has not yet been obtained. On the other hand, concluding from the work with maize, a sorghum with high amylose content (80%) would be extremely difficult to digest in the raw state and to gelatinize. Such a sorghum could, however, be suitable in making starch films for industry.

Dr. Butler gave us a very extensive review about tannins. In a study in cooperation with Dr. Eggum, we have shown that the group II variety Feterita (which has a testa layer) gives much higher losses in the true digestibility of rats when fed as *ugali* compared with the group I Dabar variety. Fermentation, as is done in *kisra* making, or pH adjustment to pH 3.8, completely eliminated that difference after cooking. The biological value (of the available proteins), however, increased when the true digestibility of the proteins decreased. This is due to the binding of tannins to protein which Dr. Butler just described and which reduces the availability of the low lysine prolamines thus improving the amino acid composition and the biological value of the remaining proteins.

The difference in tannin content between the above discussed samples of Dabar and Feterita is insignificant in spite of their differences in true digestibility of protein after cooking an *ugali* at neutral pH. It is evident that the tannin analysis is not optimal as a quality control pointing out other polyphenolic compounds which could affect digestibility after cooking. These compounds have to be identified and be subjected to experimentation.

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Session 5—Laboratory Methods to Evaluate Food Quality

Discussion

Miche:
Dr. Rooney, how was amylose measured? Is fat in the amylose helix higher in sorghum, than in other cereals?

Rooney:
Starch was isolated and defatted. Then amylose was measured with the iodine blue method. Values are 2-3 absolute percent lower than analyses with endosperm. We believe that we measure "apparent amylose" and thus have difficulties with finding absolute values. However, the relative differences between samples are quite consistent.

Variation of amylose content would be of most interest considering the keeping quality and texture of traditional sorghum products at low and medium amylose levels.

Desikachar:
We have to find processes which eliminate genotypic variation. This could be done with milling and with the addition of maize flour, for example, to improve the water-binding capacity.

Scheuring:
Dr. Kirleis, your flotation method could be excellent for screening. How about the germinability of the treated seed?

Kirleis:
Contact with the organic solvent is short, so I expect no major problems (Note from Dr. Munck: In wheat and barley with carbon tetrachloride and petroleum ether mixture, seed germination is 50-80%. Seedlings tend to be weaker and should be kept in the greenhouse).

Mengesha:
Could the flotation method be ideal to screen the World Collection for vitreousity? So far we have only screened for factors of direct importance for plant breeders. Please give us some guidelines.

Rana:
B. R. Murty (Indian Agricultural Research Institute, Delhi) and his colleagues have documented the information available on sorghum germplasm, including vitreousity.

Pushpamma:
Dr. Subramanian, are there varietal differences in puffing quality while making *rotis*?

Subramanian:
Yes, there are significant varietal differences.

Pushpamma:
We found that reducing sugar and amylose content varies with storage of the grain.

Subramanian:
Grains were stored cold. In each experiment varieties were compared after identical storage treatment.

Guiragossian:
Are sorghum *rotis* sold commercially as *tortillas* are sold in Mexico?

Subramanian:
Only at a few places on a very small scale.

Rana:
What is the chemical background for stickiness in dough?

Subramanian:
The water soluble fraction and the pentosans seem to be important.

Lateef:

Do color and grain size have some association with the gel spread character?

Murty:

Among hundreds of white cultivars, there is a large variation for gel spread values, in spite of uniformity in color. Large grain size is generally associated with a relatively more floury endosperm which leads to higher gel spread values.

Obilana:

Have you found any correlation between gel consistency and taste?

Murty:

In the limited data which we have, there is no such correlation.

MacLean:

You work with a fixed ratio of water to flour in your gel spread method. This does not assure the optimal level of water to each variety. Is it the varietal differences or processing which is most important?

Murty:

Some varieties do not hold the water after storing the gel overnight—the gel shows water separation. This is one of the important characters of the flour that is inherent. We have to carefully standardize our tests and follow uniform methods to record true varietal differences. Both varietal differences and processing are important.

Obilana:

If we consider the genotype-processing interaction, we have a wealth of factors. I do not know where we will end with these laboratory tests.

Murty:

The food technological characters we study are no less complex than yield. They are also affected by several environmental factors such as climate, soil, moisture, etc. We have to consider food quality by replicated tests just as we test yield and its components. We have to recognize components of quality.

Rana:

Dr. Murty, what is the relationship between particle size and gel consistency?

Murty:

Particle size of flour was negatively associated with gel consistency. Fine flour produced thick gels. However, this is affected by the nature of the pericarp.

Scheuring:

We know that if we mill sorghum flour to a fine particle size, bad varieties improve the gel consistency. We have always to refer to a fixed level of fineness of flour to be able to reproduce our tests. We have to follow uniform grinding procedures.

Reichert:

Dr. Butler, the yield in the purification of tannins is only about 15%. You may select special types of tannins.

Butler:

Oxidation is a great problem. If one could work in an anaerobic environment it would have been ideal. We have a great deal of hope for a good purification technique for tannins—continuous countercurrent chromatography which avoids a solid phase on which tannins can be absorbed.

Deosthale:

After soaking the grain for 5 days, the protein precipitation power of the grain was reduced. When you dried the grain, it recovered. Why?

Butler:

We do not know if the condensed tannins are a substrate for polyphenol oxidase which might influence that mechanism. I have no explanation.

Miller:

Are there any maturity differences in the high tannin sorghum material tested at Puerto Rico which might explain the disparity in this material with regard to bird resistance?

Butler:

Bird resistance is relative. If there are only high-tannin varieties and no other food available, these varieties will be eaten. At more mature stages, some of the high-tannin varieties are less bitter and thus more readily eaten by birds.

Guiragossian:

Is the quick alkali test for whole seeds used by Dr. Rooney correlated with your tannin analyses?

Butler:

I do not know.

Rooney:

Our tests are very crude but seem well correlated with the color of the final product, e.g., *tortilla,* and from that standpoint, a practical test.

Chandrasekhar:

Dr. Diehl, do you think it is possible by rheological measurements to differentiate between starch and protein effects in processing?

Diehl:

It would be very difficult because they give a similar response. You have to complement it with chemical measurements.

Session 6

Factors Affecting Nutrition and Consumer Acceptance

Chairman: L. Busch

Discussant: R. Jambunathan
Rapporteur: K. E. Prasada Rao

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Consumer Acceptance of Sorghum and Sorghum Products

P. Pushpamma and Sally M. Vogel*

Summary

Consumer acceptance is one of the essential requirements for the successful adoption of any new cultivar of sorghum by farmers. In screening cultivars for better agronomic properties, grain characteristics that influence consumer acceptability need consideration. Though plant breeders are aware of the benefits to be derived from such screening, the lack of simple laboratory tests that use small samples of grain and are fast enough to screen large number of samples is a disincentive. To develop standard test procedures, it is necessary to identify grain characteristics influencing food quality attributes that have a major bearing on consumer acceptability of the grain. In addition to consumer and market surveys, utilization tests and consumer product tests can be used effectively to develop parameters to measure sorghum product quality attributes, which can be linked to physical or chemical grain characteristics. Acceptability of sorghum and sorghum products can be improved by introducing better and easy methods of processing and developing "high status" foods using refined sorghum flour or composite flour, in addition to breeding varieties with better food quality.

Success of any food grain or its product depends on acceptance by the consumer. Consumers' reactions are difficult to measure since acceptance and preference of food is conditioned by many complex factors—both attributes of the food and of the consumer.

Consumer preference refers to selection when presented with a choice and is frequently influenced by prejudices, religious principles, group conformance, status value, and snobbery in addition to the quality of food. Consumers exercise their preferences only when they are given an opportunity to select from a wide variety. Consumer preferences may indicate the optimum desirable characters, and the lowest level if rejected. However, in most of the grain characters there is a wide range between these two levels, which may be quite acceptable for the consumer.

Consumer acceptance is essentially weighed with consideration of cost along with traditional food processing and cooking procedures. Acceptance of food varies with the standard of living and cultural background. It is conditioned by economic factors and deep-rooted religious restrictions.

Though both acceptance and preference are primarily economic concepts, acceptance is more conditioned by the purchasing power of the consumer. On the other hand, preference can be described as what they would like to have in theory. Acceptance is what they actually do under given circumstances. While preference for a food is more or less a permanent phenomenon, acceptance indicates only the reaction of the consumer at a given time under existing circumstances. What is acceptable today may not be acceptable next year, since acceptance may change either with increased purchasing power or the availability of other foods or vice versa.

Importance of Grain Quality in Crop Improvement Programs

In the process of achieving food production targets, agricultural scientists concentrate their efforts on developing high-yielding varieties. As a result of this, a number of varieties with wide

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variations in grain characteristics are released into the market. However, people prefer to grow not only those grains that produce good yield but also those that taste good. Therefore, in order to screen varieties for consumer acceptability, simple laboratory tests, which can be easily applied to a very large number of small samples of grain, are required. Cultivars that are selected in these laboratory tests can be studied further. When the program reaches the stage of advanced testing, only a limited number of promising varieties would undergo large-scale processing and utilization tests. By comparing the quality of the product made, with that of a currently popular local variety, a better evaluation can be made of the prospective acceptance Subsequently in the final stages of the program, the selected lines can be evaluated in consumer product tests to determine their acceptance.

While there is a general awareness of the benefits to be derived from such a broad-based selection program, there is a need to develop standard test procedures. Research related to cultivar quality could help plot the cost effect relationships between laboratory determinations of physical, biochemical, nutritional, and functional characters of the grains, the performance of these grains in utilization tests, and their consumer acceptability.

Factors Influencing Acceptance of Sorghum

Status Value of Sorghum and Sorghum Foods

Among consumer attributes, prestige of the food is one of the most important characteristics. Though food is a physiological requirement, people often select a particular food for social reasons. In general, sorghum is not considered as socially acceptable as wheat and rice. Even in the Third World countries, where sorghum is used for human food, it is considered a coarse grain. It is mainly consumed in the dryland areas which are backward in all respects. Sorghum and sorghum products occupy a low position in status value of foods, not only because they are available at a cheaper rate compared with other staples like rice and wheat, but also because of certain poor food quality attributes of the grain. The dark color, high fiber content, pronounced flavor, grittiness of the flour, and difficulty to cook into soft products are some of the disadvantages in using sorghum for producing high-status foods like bread, biscuits, and pastries.

In addition to the poor palatability of sorghum foods, they are also low in digestibility compared with other cereals, especially varieties with high tannin content (Hulse, et al. 1980).

The third factor which is attributed to the low status of sorghum food is the poor nutritive image, which is held not only by consumers but also by a number of sorghum scientists. No doubt, the sorghum-eating population suffers more from nutritional disorders mainly because they consume very little non-cereal and other foods recommended in the dietary requirement, due to their low purchasing power. However, the adequacy of sorghum-based diets, when it is consumed in proper combination with other foods, has been tested in a longitudinal study with pre-school children by Pushpamma et al. (1979) and proved their ability to support desirable growth. The growth pattern of the children was even better than their counterparts, fed with rice based diets at home. Though not inferior to other cereals, since sorghum is more or less the single source for nutrients in a sorghum-eating population the quantity and quality improvement of protein and other essential nutrients will be of great significance.

So the sorghum breeders, while evolving new varieties, are confronted with the dual problem of ensuring preferred grain characters for consumer acceptance and of upgrading the nutritive value to improve the status of sorghum and sorghum products.

Preferred Grain Quality Characters in Sorghum

Appearance probably has the greatest initial influence in acceptance of food since visual characteristics significantly control selection. However, once the food is prepared and tasted, visual characteristics become secondary to cryptic and palatability characters.

Quality characters which could influence the consumer acceptability of the product may be classified into three major groups:—

1. Physical characteristics of Grain: Color, size, pericarp thickness, texture of the endosperm etc.
2. Chemical characteristics: Quantity and

quality of carbohydrates, proteins, fiber, and other constituents.

3. Food quality characteristics:

(a) Culinary characteristics, i.e., easiness in dehulling, volume after soaking, texture of the flour, swelling capacity, rolling capacity or ability to spread, hydration characteristics, gel formation, etc.

(b) Palatability characteristics: color, flavor, texture of the product, taste, mouth feel, keeping quality, etc.

Because of their links with consumers, food scientists and home economists can be of great assistance in evaluating consumer acceptability of cultivars developed in crop improvement programs. This can be done in two stages:

STAGE I. By developing objective techniques for measuring the product quality.

STAGE II. By relating the desired product qualities to the grain characteristics which can be measured in the laboratory with small samples of grains.

Physical Characteristics

Consumer preference apparently is based on visible characteristics of the grain that have been associated with good or at least acceptable food quality over the years.

Sorghum consumers can be classified into three categories based on the source of procurement of grain: (a) producer consumer (village), (b) consumer open market (urban and semiurban) and (c) consumer fair price shop.

Small and marginal farmers produce sorghum mainly for self consumption. This category is classified under producer consumer. These groups of consumers exercise their choice while selecting the variety for cultivation.

Larger farmers, who produce grain for sale in the market, select the variety based on agronomic characters and also on market value. Since the market price is based on demand by the consumer, grain characters do play an important role.

The information on consumer preferred characters of grain can be ascertained through consumer and market surveys. Suitability of one of the methods or the combination of both depends on the type of consumer under consideration.

Producer consumer

Very few surveys are conducted among rural consumers of sorghum to ascertain the grain characters preferred by them. In an attempt made in Andhra Pradesh (Pushpamma and Chittemma Rao 1981) information was obtained on adoption of improved varieties, reasons for continuing local varieties for cultivation, and reasons for preferring local varieties for consumption. In spite of the introduction of improved varieties for different agronomic conditions, the level of adoption was very low. Large farmers with more than 25 acres of farm holding and with a better level of education were the ones who switched over to improved varieties (Table 1). The poor spread of improved varieties appears to be mainly due to a lack of information about the availability of the improved varieties. For those who are aware, the lack or delay in supply of seed followed by lack of resources, unfamiliar management practices, and insecurity in yields are the reasons given for not adopting the improved varieties.

A stronger preference for the local variety for consumption than for cultivation was expressed (Table 2). In this study, color was the major characteristic perceived and expressed by all consumers with either definite liking or disliking. Marked regional differences are observed for the color preference.

Size and shape of the grain also influenced the selection of a variety to some extent (Table 3).

Table 1. Percentage of cultivators with varying farm size and educational level cultivating local and improved varieties of sorghum in Andhra Pradesh (sample 2000 households).

	Varieties		
	Native	Improved	Both
Farm size			
Small	93	4	3
Medium	89	3	8
Large	70	12	18
Educational status of head of the household			
Illiterate	94	2	4
Primary	85	5	10
Secondary	75	11	14

Poor acceptance of improved varieties for consumption is also partly due to consumers' apprehension of their "contribution to poor health," though not specifically defined.

An overwhelming majority expressed their preference for the "taste" of the local variety. The taste was the first and most often mentioned characteristic. The reason given most often for preferring a particular variety is: "it tastes good." It is possible that degree of liking and taste are synonymous in the minds of many consumers. But that would be difficult to measure because taste is a comprehensive word used for a complex factor derived from the interaction of several food and consumer attributes.

Information on other grain characters, such as size and shape of the grain and pericarp thickness, could be elucidated only after probing.

Culinary characters and preferences for sorghum product qualities, keeping quality of the products, and fodder quality all contribute to the overall acceptability of a variety.

In spite of all the efforts made through personal interview methods to collect information on preferred consumer characters, the survey was relatively unsuccessful because consumers prefer the local variety because they are used to consuming it. Since their experience is limited to the local cultivar, they do not appreciate even the subtle changes in grain characters that they consider might change the different cultivars and their suitability for sorghum products consumed in that

Table 2. Number of consumers preferring native and improved varieties of sorghum for cultivation and consumption.

Purpose	Native varieties	Improved varieties	Both
Cultivation	1365 (87)[a]	75 (5)	125 (8)
Consumption	1475 (94)	61 (4)	31 (2)

a. Figures in parentheses are percentages.

Table 3. Specific preference for color, size, shape, pericarp thickness, and taste of sorghum (percentage of cultivators in different regions).

	Telangana region	Rayalaseema region	Coastal region	Overall
Color				
Yellow	42	29	70	46
White	49	62	10	42
Red	1	1	16	5
No preference	8	8	4	7
Size				
Bold	68	83	74	75
Medium	24	14	21	20
Small	5	1	1	2
No preference	2	2	4	3
Shape				
Round	99	100	97	99
Any other	1	0	3	1
Pericarp				
Thick	38	2	3	14
Thin	55	95	93	82
No preference	7	3	4	4
Taste				
Sweet	35	52	33	40
Sweet with astringency	55	42	61	52
Tasty	10	6	6	8

area. Their preference is not because of selection, but mainly because of their adaptation to a particular variety and a rigid requirement for the local cultivar.

For this reason, analysis of the most acceptable and the least acceptable samples of sorghum varieties from a sorghum-consuming population is essential for comparison of physico-chemical characters and food quality attributes in the acceptable range of sorghum varieties. It may be possible to develop criteria for measuring acceptance of sorghum as well as its use for a particular food product, if a good association can be obtained between the degree of acceptance and some of the physico-chemical characters of the grain.

Urban and Semiurban Consumers

This section of consumers, who purchase the grain in the open market, has a greater choice than any other category of consumers. The consumer is prepared to pay a premium for the quality. The range in price structures of the grain in the market is a reflection of consumer preferences. Unlike rice and wheat, sorghum is graded through subjective parameters, i.e., experiences of the consumer. The evident characters like color, size, endosperm type, and even place of production are some of the criteria applied in determining the price.

Attempts are often made to develop parameters for predicting the acceptability of the variety in a given area by using market survey information on the demand for different varieties of sorghum by the urban consumers. In the surveys conducted by the Economics Program of ICRISAT, the possibility of deriving a consumer preference index by an appropriate combination of grain characters, both evident and cryptic, was indicated (von Oppen 1975).

Consumers Receiving Sorghum as Wages and through Fair Price Shops

Acceptability of any variety or product of sorghum by this group of consumers is one more of availability rather than preferences. They accept varieties with a wide range of characters and are more flexible to adopt the grain available. However, they may reject varieties with grain characters falling short of minimum levels of acceptability. One such example is the recent experience of the Food Corporation of India, which procured yellow sorghum varieties produced in one area and released them in a drought prone area, where consumers were used to white sorghum varieties. Consumers not only rejected the yellow sorghum but they even claimed that the grain was artificially colored and expressed the fear of health hazards. It is also a common experience that consumers under duress, i.e., during drought, floods, etc., may accept any type of grain but once the situation improves, they return to their normal pattern of selectivity.

Chemical Characteristics

The relationship between preferred product qualities and the chemical composition of the grain such as rice and wheat is well established. The influence of the nature and type of carbohydrates and proteins on the texture and the quality of the product such as bread, cookies, pastries, chapaties is well defined in some sorghum. To establish such relationships, basic information on the utilization of the grain and the preferred characteristics of the food product is essential.

Unlike rice and wheat, the form of utilization of sorghum varies widely from region to region and so the criteria used for measuring the quality of the product also varies. Though fairly reliable information regarding the forms of utilization of sorghum in different areas is available to sorghum workers (Vogel and Graham 1979), information on the food quality criteria used by the consumers for the different sorghum products is scanty. However, some progress has been made in linking the physico-chemical characters of the sorghum grain and their relationship to the quality of different sorghum products (Rooney et al 1970, Miller and Burns 1970, Viraktamath et al 1972, Rizley and Suter 1977, Khan et al 1980). The grain characters which showed definite relationship to the quality of the product were color, endosperm texture, and endosperm type.

Food Quality Characteristics

So far the standardized laboratory tests developed to determine various physical, bio-chemical, nutritional, and functional characters of sorghum have not been used successfully to predict consumer acceptance of the grain. Thus, in the final analyses of performance and food acceptability, cooking and processing trials must be done.

For testing the consumer acceptance of grain or its products, the most commonly used methods include in-home testing, in-location testing, and in-laboratory testing.

In-home Testing

The food sample is distributed among a selected number of families and the housewife is asked to use the grain or product and compare it with what they use normally at home.

IN-LOCATION TESTING. In this method, food samples are taken to a central location and distributed among the people. They are asked to give their opinion on the spot.

IN-LABORATORY TESTING. Either regular consumers of the particular grain/product or trained laboratory panel members compare and give a relative score. Though this method is faster and cheaper, it can be used only when (a) factors that influence the selection of grain/processed product/final product are known, and (b) the samples can be prepared using standardized recipes in the laboratory.

Limitations of the Laboratory Panel

Being a carefully selected small group of consumers, laboratory panel opinions and preferences may not be representative of the general population. As they are highly trained, they are hypercritical as compared with the general consumer. In addition, the influence of extraneous factors such as ease of processing and preparation, extraction rate, cooking time, shelf-life, and prestige is eliminated. In general, consumers may agree with the laboratory panel in direction, but not in magnitude.

Because of limitations in any single method described above, and the lack of information on important product characteristics and their weighted influence on consumer acceptance, utilization tests are recommended for testing the acceptability of sorghum grain and its products (Vogel and Graham 1979).

Utilization Tests

Three major steps involved in utilization tests are (a) investigating current practices to identify foods traditionally prepared at home, (b) standardizing the formula so that it can be exactly reproduced in the laboratory, and (c) developing evaluation procedures and standards.

Once common foods of sorghum are identified and standardized formulae are evolved, the resulting products should be tested by consumers. The first step is establishing criteria of consumer acceptability that reflect consumer preferences. The final use of evaluation procedures is to assist in the selection of new sorghum varieties that are at least equal in acceptability to those in current use. This is done by serving the consumers the sorghum products of a new variety prepared by the standardized procedure and asking them to compare the sample with what they normally have at home. The first question will be about the overall quality of the product—whether it is better, equal to, or not as good compared with the one prepared with local grain. This is followed by securing information on criteria used by the consumer for comparison, i.e., external characters (color, texture, shape), internal characters (color, texture, consistency), eating characters (aroma, mouth feel, taste, after-taste), and finally which of these characters are most important in order of preference in accepting the product based on which the score sheet can be designed with weighted averages. Figure 1 shows a typical general score sheet for identifying important product characteristics and a score card for evaluating stiff porridge is given in Figure 2.

From the basic information collected, a more objective, consistent and consumer representative evaluation procedure can be developed. Often this can be used to identify physical characteristics of the product, including volume or yield; compressibility; fragility; flexibility; ability to hold shape; specific gravity (lightness); spreadability; rate of forming droplets; and pH of the batter. Once product standards are developed, the product may be compared with these standards and rated as good, average, or poor.

Consumer Acceptance of Sorghum Products

Food use of sorghum across the semi-arid tropics (SAT) and the wide variety of products traditionally consumed in these areas are well documented. Most of these products are prepared from dehulled whole or cracked grain or ground flour. Dehulling and grinding of sorghum is still done manually in each individual household. Traditional methods of

1. EXTERNAL CHARACTERISTICS

Color

5 4 3 2 1

(most desired) (least desired)

Texture

5 4 3 2 1

Shape

5 4 3 2 1

2. INTERNAL CHARACTERISTICS

Color

5 4 3 2 1

Texture

5 4 3 2 1

Crumb (consistency)

5 4 3 2 1

3. EATING CHARACTERISTICS

Aroma

5 4 3 2 1

Mouth feel

5 4 3 2 1

Taste

5 4 3 2 1

After taste

5 4 3 2 1

Figure 1. Typical 5-score sheet on which the most important product characteristics are listed. Preferred qualities are given a higher score (in this case 5); the least preferred qualities lower values (in this case 1). Ratio: 1 = 30%; 2 = 30%; 3 = 40%.

1. EXTERNAL CHARACTERISTICS

COLOR		
light	neither light nor dark	too dark

SURFACE		
smooth, glossy	neither	dry, cracked

SHAPE – N/A

2. INTERNAL CHARACTERISTICS

COLOR – N/A

TEXTURE		
smooth or slightly granular	slightly too granular	lumpy or very granular

CONSISTENCY		
holds shape	flows slightly	too runny

3. EATING CHARACTERISTICS

AROMA		
characteristic of grain	no aroma or slightly off aroma	sour or off aroma

MOUTH FEEL		
smooth	slightly sticky	gluey, sticks to roof of mouth

TASTE		
bland, pleasant	slightly uncooked taste	raw starch taste

AFTERTASTE		
none	slight	bitter

Figure 2. A 3-score sheet designed to be used when evaluating a stiff porridge.

sorghum processing are more or less similar in all countries and are time consuming and labor intensive, thus deterring the utilization of sorghum as human food. Often in the areas where mechanical grinders are available there are no dehullers available, so whole sorghums are ground into flour. Whole grain flour has a high fiber content and products made from it have inferior texture, color, and digestibility. This is one of the reasons given for the low prestige value of sorghum products.

Methods of Improving Acceptability of Sorghum Products

Pearling

Advantages of pearling sorghum in improving the quality of the product and its acceptability are reported by several workers (Desikachar 1975, Badi and Hoseney 1976, Vogel and Graham 1979, Hulse et al 1980). Efforts to identify grain qualities suitable for pearling and milling have been made.

(Scheuring and Rooney 1977, Rooney et al 1970).

Mechanical Grinding after Dehulling

The advantage of introducing a dry mill designed specifically for sorghum and millets, that dehulls and grinds the grain into flour has been fairly well established in Botswana, Ghana, Nigeria, Senegal, and Sudan, through International Development Research Centre (IDRC) supported projects (Eastmen 1980). The acceptance of flour and the traditional products prepared with sorghum flour obtained after dehulling were researched by a specially designed consumer product test and by marketing studies in collaboration with the Prairie Regional Laboratory, Saskatoon, Canada. The consumer product test includes the testing of acceptability of flour for the preparation of common sorghum foods consumed in that area through in-home testing. Here the acceptability may not be based purely on the basis of product characteristics but on a combination of convenience and cost also. On the other hand, consumers may be willing to forego marginal differences in the quality if there are other compensating advantages. A typical example of a consumer product test used in testing the acceptability of milled flour for the preparation of *tuwo* is illustrated in Figure 3.

Use in Composite Flours

Several research studies have indicated the possibility of improving the acceptability of sorghum products by combining at various levels with wheat flour. Such composite flours can be used for producing high status foods like bread, biscuits, and other snacks (Hart et al. 1970, Narasimha et al. 1974, Haridas Rao and Shurpalekar 1976, Hulse et al. 1980). The possibility of feeding sorghum-based diets in schools and pre-school centers has been tested and results are very encouraging (Pushpamma et al. 1981). However, both the children and parents accepted only when the sorghum was processed and converted into high status foods similar to those prepared with wheat and rice. Interesting enough, the quantity of sorghum product consumed estimated on the basis of plate waste in such feeding programs was found to vary depending on the sorghum varieties used, which suggests the possibility of using this method for testing the acceptability of sorghum and sorghum products.

Refining and Processing

Use of refined and semirefined flours with pretreatment like malting, precooking, flaking, and puffing of sorghum grain or grits has been recommended for improving sorghum products and for diversified food uses (Desikachar 1975, Raghavendra Rao et al. 1976).

Marketing of Sorghum Foods

A limited number of sorghum and millet products are marketed on a commercial basis, and also some from home food processing units, which use only skill oriented recipes and methods. One such product is *fura*, a snack food often commercially prepared in ready-to-eat form. Similarly *ugi*, a thin porridge is marketed in street kiosks of major towns of Kenya. Sorghum products like flour, beer, germinated grain, bread, and snacks made at home are frequently sold at small daily or biweekly markets in sorghum-consuming areas. However in India, there is hardly any sorghum product available either in urban or rural markets.

In Sudan, efforts are being made to produce *kisra* commercially. For this purpose a pilot mill at the National Research Council (NRC) and the Food Research Centre (FRC) at Khartoum is installed to produce mechanically dehulled and ground flour. Light colored, finely ground, dry milled flour which is sold as "improved flour," costs only one-sixth of a high status food. The keeping quality of the flour is improved over traditionally milled procedures. In addition to *kisra*, breads, snacks, sweets, and pastries were prepared and served in the most prestigious hotels to expand the utilization of sorghum by upgrading the status of sorghum foods. Although the experimental data looked promising, to date sorghum utilization has not really been expanded since these efforts require considerable time to make a significant impact. These efforts should continue.

Food scientists and home economists can strengthen the efforts of sorghum breeders, by developing suitable processing technology and improving the food quality and prestige of sorghum products to satisfy the palate of sorghum-consuming populations.

SAMPLE QUESTIONNAIRE

Good afternoon. I am ______________ of the ______________

We are doing a study on *tuwo* and I wonder whether you would be willing to help us by answering a few questions and also by trying a flour in your home?

INSTALLATION QUESTIONNAIRE

1. May I have your name? ______________

2. Do you do the cooking for the family?

YES ☐ NO ☐

IF THE RESPONSE TO QUESTION 2 IS NO, COLLECT INFORMATION FROM PERSON WHO DOES THE COOKING

3. Number in household eating from the same pot ________

4. About how many times a week do you eat *tuwo*?

SEVEN OR MORE TIMES ☐
FIVE TO SEVEN TIMES ☐
THREE OR FOUR TIMES ☐
ONCE OR TWICE A WEEK ☐

NEVER ☐
END INTERVIEW AND RECORD AS NONPARTICIPANT

5. Do you usually buy *tuwo* or not?

YES ☐ NO ☐ GO TO QUESTION 8.

6. Which of the following is the prime reason for buying *tuwo*?

IT SAVES BUYING MANY INGREDIENTS ☐
IT IS TEDIOUS, UNINTERESTING TO MAKE ☐
IT SAVES TIME AND EFFORT ☐
I PREFER THE TUWO I BUY ☐
OTHER (PLEASE SPECIFY) ______________

7. About how much does it cost for enough *tuwo* to feed your family?

N____:____K GO TO QUESTION 9.

8. Which of the following is the prime reason you usually make *tuwo*?

IT SAVES MONEY TO MAKE IT ☐
MY FAMILY PREFERS THE TUWO I MAKE ☐
BECAUSE I KNOW WHAT IS IN IT ☐
WE LIKE IT HOT ☐
I ENJOY MAKING IT ☐
OTHER (PLEASE SPECIFY) ______________

9. For *tuwo* made at home, how many level full milk tins of sorghum are prepared for the family per meal?

________TINS NEVER MAKE ☐

Continued...

Figure 3. A typical questionnaire for use in testing the acceptability of milled flour for the preparation of tuwo.

HERE IS A BAG OF SORGHUM FLOUR WHICH WE WOULD LIKE YOU TO TRY. WE WOULD LIKE YOU TO USE IT IN THE NORMAL WAY YOU PREPARE TUWO. WOULD YOU BE WILLING TO TRY THIS FLOUR?

YES ☐ | NO ☐ END INTERVIEW AND RECORD AS NONPARTICIPANT

CALL BACK QUESTIONNAIRE

10. Have you had a chance to make *tuwo* from the flour that was left?

YES ☐ | NO ☐

IF THE ANSWER IS NO, THEN THE FOLLOWING TWO QUESTIONS APPLY:

(a) When might you expect to have tried the flour ______

(b) Would it be all right if I returned on ______

11. How did you find the flour to use? Would you say it was:

EASY TO USE ☐
NEITHER EASY NOR DIFFICULT ☐
DIFFICULT ☐

12. What did you like most about the flour? ______

13. What did you like least about the flour? ______

(Note: Because open-ended questions should be asked before close-ended questions, Questions 12 & 13 should precede Question 11.)

14. How was the *tuwo* made from the flour in comparison to that you normally serve? Would you say it was:

A		OR	B	
SUPERIOR	☐		MUCH BETTER THAN	☐
EQUAL TO	☐		A LITTLE BETTER THAN	☐
INFERIOR	☐		ABOUT THE SAME AS	☐
			ALMOST AS GOOD AS	☐
			NOT NEARLY AS GOOD AS	☐

15. Regardless of your overall comparison of the *tuwo* with what you usually serve, would you say that the ______ was
(insert colour, shape etc. in turn)

Continued...

Fig. 3. Continued.......

	Colour	Shape Retention	Texture	Flavour	Aroma
MUCH BETTER THAN	☐	☐	☐	☐	☐
A LITTLE BETTER THAN	☐	☐	☐	☐	☐
ABOUT THE SAME AS	☐	☐	☐	☐	☐
ALMOST AS GOOD AS	☐	☐	☐	☐	☐
NOT NEARLY AS GOOD AS	☐	☐	☐	☐	☐

16. Did you find the amount of water given in the instructions to be

TOO MUCH ☐
JUST RIGHT ☐
TOO LITTLE ☐

17. Did you have enough *tuwo* for your family or would you say you had

TOO MUCH ☐
JUST RIGHT ☐
TOO LITTLE ☐

18. Taking everything into consideration, how would you rate the *tuwo* from the flour? Which of the following statements would best indicate your feelings about this product?

EXCELLENT ☐
EXTREMELY GOOD ☐
VERY GOOD ☐
QUITE GOOD ☐
FAIRLY GOOD ☐
FAIR ☐
POOR ☐

(Note: Because general information should be asked before specific information, Question 18 should follow Question 10.)

19. What do you consider to be a fair price for this flour in a bag the size you had?

N______:______K

20. Which of the following statements would best describe your likelihood of buying this flour if it were sold at N______:______K.

I WOULD DEFINITELY BUY ☐
I WOULD VERY LIKELY BUY ☐
I MIGHT OR MIGHT NOT BUY ☐
I AM NOT LIKELY TO BUY ☐
I DEFINITELY WOULD NOT BUY ☐

21. Have you any other comments that might be helpful to us? ______________________________

____

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A Market-Derived Selection Index for Consumer Preferences of Evident and Cryptic Quality Characteristics of Sorghum

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Summary

A methodology has been developed for identifying relevant quality characteristics that determine consumer preferences for sorghum. The estimation results show that a complex mix of evident as well as cryptic quality characters are jointly affecting consumer preferences, as reflected in daily market prices. Two data sets (a) from one market over 4 years and (b) from four markets in 1 year were analyzed. The estimated coefficients of relevant qualities can be used as weights for predicting an index of consumer preferences for sorghum (SPI) for which the relevant quality characters are known. It is shown how 25 new sorghum samples are being ranked by SPI based on the two data sets.

The rankings from both data sets are highly correlated, indicating that for predictive purposes the SPI performs consistently, regardless of whether it is derived from time series data or from cross-sectional data.

The SPI is applicable for large-scale screening, although a few minor issues need to be resolved for increasing confidence and efficiency in its application.

A methodology to predict consumer preferences of newly bred sorghum varieties on analysis of market prices as a function of relevant grain characteristics is the central objective of the ongoing work at the Economics Program, ICRISAT. During more than 5 years of research, a number of issues have been resolved and the usefulness of market prices for deriving consumer preferences could be established. The results permit a rapid screening procedure of sorghum for consumer acceptance in India. However, further improvements in the methodology presented may be possible. Further work to extend this methodology for other countries is required.

Concept

The methodology proposed is based on the observation, in Indian wholesale markets, that on any market day the price for sorghum differs across different lots transacted and that these price differences are due to differences in quality. If it is possible to identify those characteristics which determine quality in a given country or region and to measure the contribution of these characteristics in the determination of price, then it is possible to analyze any new variety for the same quality characteristics and to predict its market value. Implicit in this approach is the assumption that price and income elasticities of demand for quality are constant across all income groups taken together and over time, so that the inferences drawn from past observations will hold for the future. This assumption may be debatable, but it can be shown that the price differentiation between good and poor quality will continue even if the proportion of good quality has considerably increased as long as total supply is met by an equivalent demand for human consumption (von Oppen 1978b). Once supplies exceed that demand and sorghum is used for other purposes, e.g., as animal food, things may perhaps change. However, before this stage can be achieved in most parts of the semi-arid tropics (SAT) the production of sorghum has to increase, which requires the adoption of high-yielding varieties for human consumption, and therefore requires

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screening of improved varieties for consumer acceptance.

Methodology

A multiple regression equation was calculated to estimate the relationship between market price and various quality characteristics. The advantage of the multiple regression equation is that it enables the effect of several independent factors to be estimated and in a complex system where several factors are expected to jointly affect the dependent variable, this approach is appropriate.

The relationship between consumer preferences and relevant quality characteristics is certainly such a complex system. As we shall see later, even though the linear correlation matrix shows hardly any direct association between variables, (Tables 1 and 2), the multiple regression equation explains 64% of the variation of the dependent variable. The methodology to arrive at these estimates involves various steps:

1. Collection of market samples.
2. Laboratory analysis for relevant qualities.
3. Statistical analysis.
4. Interpretation and verification of the results.

While developing this methodology, most of the above steps were tried in several different ways to find the most efficient one to arrive at reliable results. The method described below is the result of about 5 years of continuous efforts in refining the methodology (von Oppen 1976, 1978a, 1978b).

1. Sample Collection

In India, market samples of sorghum are best collected from large urban wholesale markets. Smaller primary markets, where the arrivals from the particular region surrounding the market often show little variability in quality, are less suitable for sample collection; also, at the other end of the market channel, retail traders were found to be a less reliable source for sorghum samples than wholesalers; e.g., the same original lot from a wholesale market may be offered by different retailers at different prices; furthermore, retailers often have only two different qualities to offer, while in the case of wholesale traders they normally have more than three different lots at a time. The fact that wholesalers are operating in the same market place not only facilitates the collection but it also assures that the prices quoted on a particular market day are in fact comparable.

On any market day normally about 15 to 20 different lots are available. However, our experience shows that for the statistical analysis to yield satisfactory results, a set of around 80

Table 1. Correlation matrix of transformed[a] variables in data set (A) Hyderabad, 1977/1980, combined.

Variables[a]	Log price	Yellow grain	Red grain	Slight mold	Severe mold	Glumes	Log dry volume	Log swelling incapacity	Log 100-seed weight	Log protein
Log price	1	-.44	-.31	-.64	-.52	.06	-.18	-.13	.54	20
Yellow grain		1	.21	.74	.39	-.28	.13	-.06	-.35	.27
Red grain			1	.16	.54	-.05	.038	-.04	-.005	.12
Slight mold				1	.44	-.23	.18	.004	-.37	.06
Severe mold					1	-.05	.28	-.01	-.11	-.08
Glumes						1	.53	-.01	.17	-.18
Log dry volume							1	.17	-.20	-.14
Log swelling incapacity								1	-.08	-.14
Log 100-seed weight									1	.12
Log protein										1

a. All the variables are transformed variables used in final regression.

observations is required. Therefore, the sample collection has to be repeated for several days until the number of samples is sufficiently large. The best time for sample collection was found to be during the peak marketing season, i.e., between January and March.

The analysis of data from samples collected monthly during the year 1979 in Hyderabad proved that after the peak marketing season, the grain becomes increasingly moldy. Moldiness and the size of the seeds tend to remain the primary factors affecting price and dominating the price formation, so that other factors appear to become irrelevant once the peak marketing season is over. Also during this post-season, less grain is being traded so that sample collection requires more time and effort. As will be explained below, for reliable results samples should be collected for several years, if possible, to reflect the long run average consumer preference and not that of only one season.

The amount of material needed per sample is less than 50 g and traders are quite willing to give that amount free of charge.

2. Laboratory Analysis

One objective in developing the methodology has always been to provide a simple and quick way for a rapid screening of a large number of samples, using only a very small quantity of seed. The tests involve the following procedures:

(1) determination of the 100-seed weight

(2) counting the number of seeds with slight and severe mold

(3) counting the number of seeds with glumes

(4) measuring the dry volume of 10 g of seeds by the water displacement method

(5) observing the swelling of the seed after 6 hr of soaking in ordinary tap water, by measuring the volume increase and the weight increase of the soaked grains

(6) analyzing the sample for protein content

Apart from (6) protein analysis, all other tests can be carried out by an untrained person and without sophisticated equipment. Because of the soaking time required, one person working by himself is able to handle about 20 samples per day. However, with several persons working in line, the number of samples, not only per day, but also per person were increased considerably.

The above list of tests is the outcome of several years of searching. Other measurements were tried but finally rejected because their contribution in explanatory power did not seem to justify the effort required to retrieve the information; such factors were moisture content, fat content, hardness of the grain, and color mix.

Color mix was excluded from the tests because in conjunction with information about the sorghum's origin, it indicates nutritive and digestive qualities.[1] Grain color alone rarely contributed more than a few percent in explanatory power but it made the results from samples taken in different places or periods appear to be more location or time specific than they actually are.

3. Statistical Analysis

The data obtained from the above tests were transformed before deriving the regression equation, for reasons given below. The original variables formed are:

(1) 100-seed weight in g

(2) percent of grains with light mold

(3) percent of grains with severe mold

(4) percent of seeds with glumes attached

(5) dry volume in cm^3

(6) swelling incapacity, i.e., increase in weight divided by increase in volume

(7) protein content, in percent

Since levels of market prices and quality mixes may vary from one day to the next, it was not possible to enter the prices and qualities directly into the analysis. It was decided to generate a reference point and to set the actual observations in relation to this reference. In the absence of any better way to define a reference quality, the average quality and the average price per market

1. This was the conclusion of a test in which five traders in Hyderabad market were given 92 samples of ICRISAT's World Collection of sorghum (see von Oppen 1978a). The traders were asked to hypothetically price the samples in line with present prevailing market prices. Analysis of these hypothetical prices showed that only the evident characteristics, i.e., color, seed size, glumes, and mold were reflected in the traders' assessment, while none of the cryptic characteristics such as dry volume, swelling capacity or protein contributed significantly. During the test, the traders had mentioned that for a correct assessment they would need to gain experience in trading with these varieties.

Table 2. Correlation matrix of transformed[a] variables in data set (B) four markets[b] combined, 1980.

Variables[a]	Log price	Yellow grain	Red grain	Slight mold	Severe mold	Glumes	Log dry volume	Log swelling incapacity	Log 100-seed weight	Log protein
Log price	1	−.24	−.26	−.56	−.59	−.20	−.28	.06	.30	.19
Yellow grain		1	.13	.33	.11	−.11	−.01	−.01	−.04	.08
Red grain			1	−.05	.29	.03	−.10	−.02	−.06	.28
Slight mold				1	.18	.14	.33	−.07	−.19	−.18
Severe mold					1	.18	.31	−.05	−.20	−.09
Glumes						1	.46	−.04	−.10	−.05
Log dry volume							1	.01	−.20	−.28
Log swelling incapacity								1	−.05	−.10
Log 100-seed weight									1	.20
Log protein										1

a. All the variables are transformed variables used in final regression.
b. Hyderabad, Bangalore, Poona, and Nagpur markets.

day were taken as a reference against which to compare the individual qualities and prices. This is not ideal but it makes the observations more comparable across market days, than they would be otherwise.[2]

4. Interpretation and Verification of Results

The estimated coefficients and t-values provide information about the direction and size of the effect a variable has on the price of sorghum. This information can be used to predict the price of any new variety; especially if the values of the variables observed in the sample cover a wide enough range to embrace those values of the new variety (Table 3). By analyzing a sample of the new variety for the same qualities as described above and by multiplying the quality values with the estimated coefficients and summing according to the functional form used in the estimation equation, a prediction about the relative preference of that particular variety is generated.

To verify whether such predictions have any merit one can easily compare the predicted results with results of other more laborious tests to identify consumer preferences such as consumer panel tests.

This was done by using the 40 participants in the ongoing village study in Kanzara of Maharashtra State as the consumer panel (Bapna and von Oppen 1980). A set of 15 different sorghum varieties procured in the Hyderabad market was tested by a double blind procedure and the preferences expressed by the villagers were compared with the predicted market prices. The results show that the predicted market prices correlated better with expressed consumer preferences than did actual market prices.

Interestingly, by calculating these relationships independently for every size group it was found that the different groups of households had different capabilities in expressing their preferences for sorghum; while large farmers reported the most inconsistent preferences of all, the small farmers did best, followed by the landless and the medium size groups. As was confirmed later, larger farmers are not really eating much sorghum in Kanzara

2. For further details about the estimation model see von Oppen (1976). By explaining price variability on a particular market day as a function of variability in quality, the analysis leaves out the quantity-consumer expenditure dimensions of the problem. In doing so, it is implicitly assumed that the price and income elasticities are independent of quality. Lancaster (1971) and Theil (1976) have shown that this is not true. However, data that would permit a Lancaster/Theil type demand analysis are not available (von Oppen et al. 1979).

because they prefer and can afford to eat wheat and rice. Therefore, when similar verification trials are to be conducted in the future a preselection of a suitable consumer panel may be advisable.

Results

The present state of knowledge in the field of market-derived consumer preferences for sorghum in India is reflected in the results reported below. First, the estimation results of different data sets will be presented and discussed, explaining price as a function of quality characteristics. Second, the estimated parameters will be used for computing predicted consumer preferences in India of 25 new lines from the ICRISAT Sorghum Improvement Program. Finally, the predictions derived from the different data sets will be compared and conclusions will be drawn.

The data sets analyzed below were generated in two major sample collection efforts to gain insight into consumer preferences for sorghum in India (a) over time and (b) across space. The data were generated according to the methodology outlined above from the following samples:

(a) A total of 334 sorghum samples collected over 4 years (1977-1980) in one market, i.e., Osmangunj, Hyderabad.

(b) A total of 358 sorghum samples collected in 1 year (1980) in four markets in the major sorghum growing regions of India, i.e., in the cities of Hyderabad, Nagpur, Poona and Bangalore.

Sorghum Quality Preferences Over Time

Table 4 summarizes the results of the statistical analyses. It is found that for the 4 years combined, the adjusted $\bar{R}^2 = 0.64$, i.e., 64% of the variation in price is explained by the variation in the variables included in the multiple regression equation or by undefined variables associated with the included variables. Not only evident quality characteristics (e.g., moldiness, seed size) are very significantly explaining the price, but also the so-called cryptic characteristics such as the dry volume, the swelling incapacity, and the protein content of the grain.

The presence of glumes does not seem to be clearly affecting the prices, as in some years this effect is negative, but in another it shows a positive relationship to price, which may mean that the amount of glumes in the sorghum was generally low enough to be no real problem, except perhaps in year 1977; in the year 1980 when there was a positive association between glumes and price this would have been so because glumes happened to be found more frequently on those preferred types, but without causing concern.

All other variables are well behaving, i.e., whenever statistically significant they have the expected sign. Nevertheless, an F-test on the stability of the results over time shows that there are significant differences in the explanation of price as a function of the quality variables from year to year against all years. This is so because some variables such as glumes show opposite effects from one year to another.

However, the objective of this exercise is not so much to *explain* the consumer's preference (which would require a much more elaborate set of variables to be measured with much finer laboratory tests, than used here); instead of explaining, the goal is to *predict*. The predictions based on any of these individual year's estimates would not differ significantly.

Sorghum Quality Preferences Across Regions

Table 5 shows the results from four different wholesale markets, where the sorghum samples were collected during different weeks between January and March 1980.[3] The data are listed for the individual markets alone and in various combinations.

Comparing the individual data across markets, it was found that similar to the Hyderabad data over time, with the exception of "glumes" all other variables behave well, i.e., whenever significant, they have the expected sign. Generally, however, more insignificant variables are found, than in Hyderabad for individual years. Apart from mold and 100-seed weight the remaining variables appear to be rather insignificant. The picture is in fact similar to that which was found for Hyderabad during the off-season, when the effect of the other variables was dominated by these three evident

3. Hyderabad: January and February 1980.
Nagpur: March 1980, first week.
Poona: February, 18th to 23rd, 1980.
Bangalore: February 25th to March 1st, 1980.

Table 3. Means and variabilities of untransformed variables in two data sets, A and B and breeder's samples.

Variables (units)	Data Sets: A Hyderabad 1977-1980 combined				B 4 market combined[a] 1980				Breeder's samples used for predictions			
	Mean	CV (%)	Maximum	Minimum	Mean	CV (%)	Maximum	Minimum	Mean	CV (%)	Maximum	Minimum
Price (Rs/100 kg)	108.3	16.5	155.0	65.0	117.7	14.4	155.0	80.0	–	–	–	–
Slight mold (%)	36.0	77.6	95.6	.7	47.0	45.3	87.0	2.3	47.2	28.0	69.0	27.8
Severe mold (%)	4.4	179.1	56.[illegible]	0	10.3	140.0	77.3	0	1.2	92.8	3.4	0
Glumes (%)	5.4	96.5	47.1	0	4.1	74.9	16.8	0	.089	364	1.6	0
Dry volume (cm^3 of 10 g)	7.85	3.0	9.2	7.5	7.88	3.1	8.5	7.5	7.66	1.7	7.9	7.4
Swelling incapacity (ratio)	1.04	5.8	1.47	.83	1.02	1.8	1.045	.745	1.015	1.2	1.039	1
100-seed weight (g)	2.73	16.3	3.64	1.68	2.80	17.2	4.74	1.68	3.19	7.14	3.80	2.81
Protein content (%)	8.1	13.1	11.4	4.9	7.5	14.3	11.3	4.6	9.95	13.0	11.6	7.3

a. Hyderabad, Nagpur, Poona, and Bangalore.

Table 4. Market price as a function of quality characteristics of sorghum in Osmangunj market, Hyderabad, 1977/1980, showing the coefficients for the multiple regression equation.

Equation: Year	Variables: Light mold	Severe mold	Glumes	Log dry volume	Log swelling incapacity	Log 100-seed weight	Log protein	Statistics: $\bar{R}^2$	Observations	Error mean square
1977	−0.037	−0.198	−0.337	0.892	−0.201	0.276	0.300	0.76	64	0.03269
	(−2.2)	(−3.1)	(−4.9)	(2.6)	(−2.3)	(3.9)	(3.9)			
1978	−0.118	−0.179	−0.008	0.394	−0.201	0.310	0.145	0.58	98	0.1330
	(−6.3)	(−1.5)	(−0.1)	(0.9)	(−0.7)	(5.2)	(1.9)			
1979	−0.075	−0.324	0.089	0.407	−0.697	0.388	0.095	0.68	102	0.13938
	(−3.4)	(−5.3)	(0.7)	(0.9)	(−1.4)	(5.2)	(1.2)			
1980	−0.118	−0.246	0.413	−0.390	0.388	0.291	0.096	0.72	67	0.06516
	(−4.9)	(−6.3)	(2.2)	(−0.7)	(0.4)	(3.5)	(1.1)			
1977 to 1980, combined	−0.092	−0.271	−0.056	0.635	−0.331	0.323	0.165	0.64	334	0.43040
	(−10.0)	(−9.5)	(−1.0)	(2.8)	(−3.1)	(9.7)	(4.3)			

Numbers in parenthesis are t-values.

Table 5. Market price as a function of quality characteristics of sorghum in four markets and groups of markets in 1980, showing the coefficients for the multiple regression equation.

Equation	Variables							Statistics		
Market or market group	Light mold	Severe mold	Glumes	Log dry volume	Log swelling incap-city	Log 100-seed weight	Log protein	$\bar{R}^2$	Observations	Error mean square
Hyderabad	−0.118 (−4.9)	−0.246 (−6.3)	0.413 (2.2)	−0.390 (−0.7)	0.388 (0.4)	0.291 (3.5)	0.096 (1.1)	0.72	67	0.06516
Nagpur	−0.041 (−5.1)	−0.056 (−3.7)	−0.048 (−1.4)	0.083 (0.8)	−0.051 (−0.6)	0.052 (3.7)	0.015 (0.7)	0.49	122	0.01584
Poona	−0.134 (−6.1)	−0.242 (−6.2)	−0.280 (−1.7)	0.146 (0.5)	0.277 (0.4)	−0.034 (−0.5)	0.070 (1.2)	0.66	80	0.05187
Bangalore	−0.229 (−9.5)	−0.249 (−10.6)	0.270 (−1.4)	0.628 (1.7)	−0.725 (−0.9)	0.076 (1.0)	−0.083 (−1.0)	0.73	86	0.09011
Hyderabad + Nagpur	−0.092 (−7.3)	−0.146 (−6.4)	0.097 (1.4)	0.210 (1.0)	0.064 (0.3)	0.111 (3.8)	0.056 (1.3)	0.50	190	0.14113
Hyderabad + Poona	−0.134 (−8.7)	−0.207 (−8.3)	0.102 (0.8)	−0.109 (−0.4)	0.398 (0.7)	0.126 (2.5)	0.062 (1.3)	0.67	148	0.13326
Hyderabad + Bangalore	−0.188 (−12.1)	−0.232 (−12.5)	−0.046 (−0.4)	0.308 (1.0)	−0.397 (−0.6)	0.125 (2.4)	−0.068 (−1.3)	0.70	154	0.17850
Nagpur + Poona + Bangalore	−0.104 (−9.8)	−0.181 (−13.0)	−0.136 (−2.0)	0.432 (2.5)	−0.090 (−0.5)	0.057 (2.1)	0.058 (1.8)	0.56	290	0.24730
Hyderabad + Poona + Bangalore	−0.167 (−13.6)	−0.221 (−13.9)	−0.123 (−1.2)	0.318 (1.4)	−0.074 (−0.2)	0.072 (1.7)	0.013 (0.3)	0.68	235	0.24361
Hyderabad + Nagpur + Poona + Bangalore	−0.120 (−12.4)	−0.189 (−14.2)	−0.046 (−0.7)	0.353 (2.1)	−0.045 (−0.2)	0.085 (3.2)	0.043 (1.4)	0.58	358	0.33913

characteristics. Possibly the time of data collection in the other market places might not have been chosen optimally, although it could not have been too far off, with *rabi* harvests generally appearing in the markets in February. Another more relevant explanation may be that just one year's, and here only a few days', data are not quite enough for getting a picture of the long run position of consumer preferences in a particular market. Given the many shortcomings of the methodology it is obvious that only very large data sets covering several years will bring out the true facts, by "washing out" the temporary phenomena which are irrelevant for the long run purpose of constructing a reliable quality preference index.

The tests of interregional stability of sorghum preferences in 1980 are consequently giving mixed results. While some combinations are statistically homogeneous, others are not. The market which brings in most noise is Nagpur, where the regression is explaining only 49% of the variability in price, and which is considerably below the others, with explanatory power ranging from 66% to 73%. The combination of all markets' data gives coefficients as presented in Table 5, row 10, comparing these coefficients with those measured in Hyderabad over time (Table 4, row 5), it is obvious that generally the orders of magnitude and statistical significance and $\bar{R}^2$ for all variables are lower.

However, taking these generally much weaker regional results and using them for prediction, it is found that the Hyderabad data over time and the regional data generate very similar results. For instance, using the coefficients from the Hyderabad time series regression equation for predicting the samples collected in the four markets, predicted and actual prices are found to be significantly correlated with a correlation coefficient of $r = .70$; vice versa using the regression results from the four markets for predicting Hyderabad prices yields predictions which correlate with actual prices to the degree of $r = .74$.

Predicted Consumer Preferences of 25 New Varieties

The Sorghum Improvement Program of ICRISAT provided 25 samples of new lines of sorghum for analysis according to the above methodology.

The 25 samples were analyzed only once for the above listed qualities, i.e., without replication. For each sample the amount found for a particular quality was multiplied by the respective estimation coefficient to get a weighted quality value; all of the weighted quality values in the equation were then added according to the functional form used in the estimation yielding a predicted value of consumer preference or a consumer preference index for sorghum (SPI).

The SPI is a market derived prediction of the relative price of sorghum based on the weighted quality characters, relevant to sorghum consumers.

In Table 6, two SPI's are presented which were calculated for the 25 new sorghum lines on the basis of estimation coefficients from two different sets of data as described above: (a) estimates from

Table 6. Consumer preferences of 25 sorghum samples valued and ranked by a preference index based on (A) estimations from one market over 4 years and (B), estimations from four markets in 1 year.

	Index A		Index B	
Sample no.	Valuation	Ranking	Valuation	Ranking
22	1.2099	1	1.1408	1
1	1.1688	2	1.1145	4
4	1.1330	3	1.0996	7
14	1.1318	4	1.1189	2
11	1.1311	5	1.0451	16
3	1.1267	6	1.1159	3
2	1.1233	7	1.1050	6
5	1.1173	8	1.0418	17
8	1.1166	9	1.0707	10
25	1.1082	10	1.0880	8
21	1.1040	11	1.1110	5
16	1.0955	12	1.0515	14
23	1.0938	13	1.0853	9
15	1.0928	14	1.0600	12
13	1.0847	15	1.0503	15
18	1.0832	16	1.0288	19
10	1.0822	17	1.0408	18
19	1.0812	18	1.0554	13
6	1.0729	19	1.0110	22
12	1.0630	20	1.0682	11
9	1.0375	21	1.0170	21
24	1.0302	22	.9939	24
7	1.0146	23	1.0038	23
17	.9963	24	1.0216	20
20	.9649	25	.9831	25

one market over 4 years and (b) estimates from four markets in 1 year.

Table 6 also lists the ranking of the 25 lines according to these two SPI. A comparison of both the rankings shows that they are highly correlated. In fact, the correlation coefficient is .83, which implies a correlation significant at 1 % level of probability. Inspection of Table 6 shows for instance that if one wanted to retain the 10 best samples and/or discard the 10 worst, then in both cases 8 samples would be selected by either index which are the same, while only 2 samples would differ depending upon which of the two SPI were applied. A comparison of the preferences predicted by the two SPI is also given in Figure 1, which depicts how a selection of the 10 best or 10 worst samples overlaps for 8 samples in each case. Naturally, anyone who feels that neither of the two SPI by itself but a combination of both provide a better criterion for the selection of quality, may want to choose instead of lines AA or BB in Figure 1, a cut-off line such as CC for compromise.

Unresolved Issues in Applying the SPI

The above example of applying the SPI on 25 sorghum lines is convincing because of its simplicity and consistency. However, several questions require further study in collaboration with the Sorghum Improvement Program for gaining more experience and confidence in applying the SPI.

(A) Replication of laboratory tests. The laboratory tests for quality of the 25 samples were

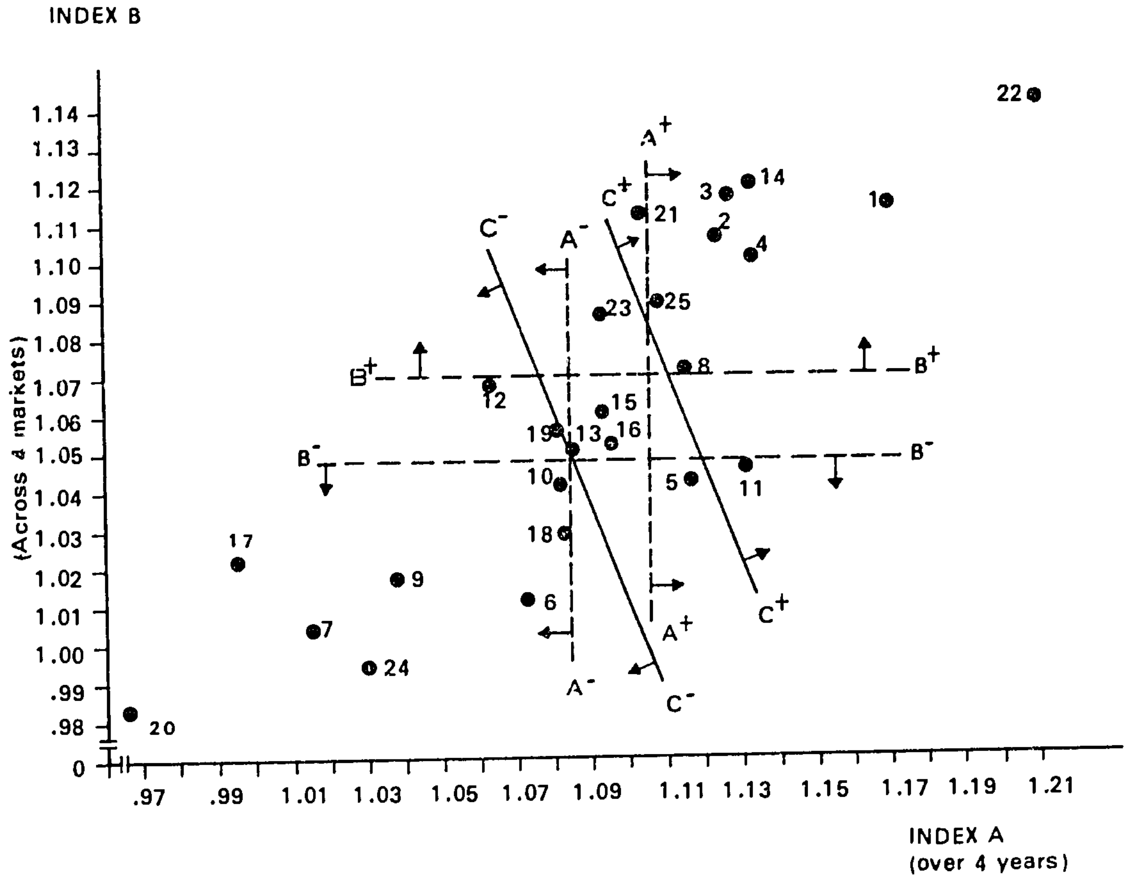

Figure 1. Valuation of 25 sorghum samples according to preference index A versus B and delineation of 10 samples of highest values and 10 of lowest based on these indices or on a combination index C. Note: For example, line A⁺A⁺ delineates the 10 highest value samples to the right; line C⁻C⁻ delineates the 10 lowest value samples to the lower left; the number with the dot indicates sample number.

initially done without replication and one mistake occurred in the determination of the 100-seed weight of a sample. Replications in the laboratory tests would help to avoid similar mistakes in the future, although this would, of course, increase the laboratory effort required for deriving the SPI.

(B) The impact of moldiness. As shown in Table 3, the proportion of molded grains in the market samples was on average 40% in the case of one market over 4 years, and 57% in the case of four markets in 1 year, and grain mold contributed importantly to the explanation of price in the estimate equations (Tables 4 and 5).

The sorghum breeders are sure that the material which they provided in the 25 samples was generally without mold. Nevertheless, some samples with grains that had a slightly dull appearance were classified as slightly moldy. This obviously affected the SPI of these particular samples in a negative way.

The classification may have been incorrect because without any particular training at the time of this first assessment, the person who analyzed the samples may have mistaken the dull grains for moldy ones; on the other hand, his assessment may also be indicative of what the average consumer would perceive, seeing the dull grain. However, in the future it will be necessary to resolve this issue and to establish in collaboration with the plant pathologists, some way of more clearly distinguishing moldy from unmoldy grains.

A more general issue arising at this point is that of the growing conditions of the seed material. If produced under protected and irrigated conditions, a cultivar's actual performance under farmers' field conditions may not be revealed; yield, but probably more so quality are likely to be affected. The value of the methodology would be greatly enhanced if material grown under farmers' field conditions could be used.

(C) Identification of other relevant quality characters. As it stands, the SPI predicts well and consistently identifies quality differences between grains that to the naked eye are almost identical in appearance; however, even though the quality characters included in the SPI are relevant, and explain about 60 to 70% of the market price variations, there is still a possibility that additional quality characters could be identified which might further improve the SPI.

For instance, particle size of the flour may be such a characteristic, which might be worth considering, once a standardized method exists for measuring it in a small sample.

(D) Verification of results in village tests. The ultimate answer, whether the SPI is applicable or not, can only be given by the sorghum consumer who lives in the village and whose "daily bread", i.e., his livelihood, depends upon sorghum. Similar to the test of a household panel of village consumers in Kanzara, mentioned above, in which market samples were used, further tests should be carried out using material from the Sorghum Improvement Program. Such tests with rural consumers would permit comparisons between the villagers' assessment and the SPI, or any other preference index. This would also provide a check about the possibility of extrapolating information about preferences derived from existing material traded in the market to new varieties not yet available in the market channels.

Conclusions

A method of identifying relevant quality characteristics, as reflected in market prices, has been developed. The degree to which each characteristic influences the market price of sorghum is estimated. These estimated coefficients serve as weights in jointly assessing all relevant qualities and predicting the overall consumer preference of any new sorghum line.

The preference index for sorghum (SPI) can be derived with the help of simple laboratory tests and routine statistical computations, so that a large number of samples can be screened in a short time.

The SPI was derived in one case from time series data and in another case from cross-section data and produced rankings for both cases which were highly correlated, thus indicating the robustness of this method of predicting consumer preferences.

A few issues require further attention of researchers including the following: the number of replications of laboratory tests required for reliability; guidelines for identification of mold; the possibility of including other relevant characters; and field verification of the SPI.

Resolving these issues will help to increase the confidence and efficiency for an application of the SPI in selecting sorghum lines for good consumer acceptance.

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Consumer Preferences and the Adoption of New Cultivars in Sahelian West Africa

W. M. M. Morris*

Summary

In West Africa, the per capita production of sorghum and millet is declining at about 1% a year. Only about 15% of total production is marketed. At the same time, wheat and rice imports into the region are increasing. Marketing of an industrially produced, high-quality sorghum or millet flour might increase demand, as has happened elsewhere in Africa.

Farmers use sorghum as a cash crop whenever they expect it to provide a greater return per man day of labor than other alternatives; this is usually the case in most countries of the region. In Senegambia, peanuts have traditionally been more profitable than sorghum.

Farmers and their families are fully aware of the cooking quality, flavor, and yield potential of each of the varieties available to them. Different generations within the family often have different preferences. Preferred varieties command a premium in the market. Sometimes farmer basis for the rejection of new varieties is founded on appearance and not on cooking or flavor; this is similar to the preference for brown-shelled over white-shelled eggs. In India, Mexican wheats were discounted in the market largely due to appearance; plant breeders then produced varieties with a yield potential of the Mexican, but resembling the traditional Indian varieties that were not differentiated in the market place.

Farmers' choice of varieties grown is not made only on food quality; rotational needs, soils, and other factors are also important. White or yellow and red or brown sorghums are generally considered as two different crops, with different prices and different uses.

About 85% of the sorghum and millet is consumed by the producers. In the past 15 years, the production of sorghum and millet in the Sahelian countries has increased at the rate of about 1.8%/year, while the population has increased at the rate of 2.8%/year, leaving a gap—a decline in the per capita production—of about 1% a year. The increase in production has almost all been by increasing the number of farmers and the hectares cultivated. Thus there has been no discernible trend in yields.

On the other hand, wheat imports have been increasing at 10% a year and rice imports have increased substantially in the coastal countries (Senegal, Mauritania, and the Gambia).

In general, the grain markets work quite well in these countries, in spite of certain governmental intenventions. These interventions seem to be decreasing. The capabilities of the governments do not include providing a guaranteed price because of the lack of ability to buy, store, and market a surplus crop—with perhaps 3 to 4 times the normal market supply. The market then lowers the price when there is a surplus, making the farmers reluctant to rely on food grains as a cash crop. In fact, after such a price decline, farmers tend gradually to return to the use of sorghum and millet as a cash crop. Currently, in all of the countries in the region, sorghum and millets are cash crops although in Senegal and presumably in Gambia, the return to labor (which is the major constraint of the farmer) is usually greater in producing peanuts than sorghum and millet.

The governments do not have a grain-grading scheme and so the farmers sell the governments grain of the minimal quality. This grain is difficult to store. The farmers have little problem in storing selected grain of the traditional varieties for a year or more.

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Farmers and their families are fully aware of the cooking qualities and flavor of the varieties available to them. Like gardeners, they choose critically the varieties which they grow for food, in regard to the yield per man-day of work, eating qualities (including processing), and storage losses.

Farmers may be classified by any of a group of variables indicating their managerial ability and their access to resources, particularly land. Those that score the lowest are barely able to provide for their own subsistence; and, struggling to provide this, they seek quantity rather than quality. To make up the gap they work more off their farms than do farmers of better managerial ability. At times of prolonged drought, many more families are obliged to suppress their preferences and the same applies to many city dwellers; they will eat any variety that they can acquire even if it is imported and even if it is insect infested.

The Sahelian farmer tends to exploit a whole group of ecological niches available to him, e.g., the plateau, fields on the slope, fields in the basfonds, flood recession land, irrigated land and so on. In planning his production, first he plans to satisfy the subsistence needs and then to maximize the return from the use of his remaining resources (typically labor and land). In many parts of the Sahelian countries, wives and dependent sons also are allocated fields to cultivate. This allocation may be fixed from year to year, i.e., a field continues to be cropped with the same crop or mixture until the yield becomes unacceptable, when the cropping will be changed, or the field fallowed. Alternatively, there may be a simple rotation, e.g., peanuts-millet or sorghum-peanuts, or a rotation may be required to control weeds, such as *Striga*.

For example, in a cotton zone the household head may plan first to satisfy the subsistence needs in millet and sorghum, then to grow as much cotton as the family can harvest, and then to use the remaining labor supply in producing sorghum for sale. The wives may have certain obligations to meet with their crop production, e.g., providing ingredients for the sauce to be eaten with the *tô*, and then they will grow what they believe to be their most profitable cash crop. The sons will also attempt to maximize the return to their labor on their private fields.

The choice of sorghum and millet varieties in a given area will be largely determined by soil type, topography, risk aversion, and consumer preferences. There is evidence that the higher the level of fertility, the lower the yield variability.

In some areas e.g., the peanut basin of Senegal and Vertisols in N. Cameroon, a single variety of sorghum or millet may be grown as a sole crop and the variety is relatively stable over a wide area. However, since each farmer selects his own seed for sowing his next crop there may be significant differences developed within a variety over time.

In other areas, where the weather risk is no greater, farmers may have sets of three varieties of millet and sorghum for the different soil types or topographies; one variety might be short season and one long season, and the third resistant to some major pest or disease. There may be one set of varieties for the light soils and one for the heavy soils. Sorghum and millet may be grown in association with each other and with other crops. The association is usually fairly near the optimum mixture; the tendency is for the total yield or value to increase over the "complementary" range but if more of the second (third etc.) species is introduced, the total yield declines, i.e., this is the "competitive" stage.

Varietal preferences are not likely to be uniform within a family; the parents or grandparents will probably prefer more traditional varieties. The younger family members may believe it more "modern" to eat pasta noodles or spaghetti which are available in many villages. The preferred varieties may not bring the greatest yields per ha nor per worker per year; as a result, they may also be higher priced in the market place. In many cases, the preferred variety will not appear on the market, with sales being limited to higher-yielding, less-desirable types. If the preferred varieties are lower yielding, it is expected that little will reach the market. Clearly, the family has to consume nonpreferred varieties at times, but we do not know how the housewife corrects for the defects in grain quality in her cooking.

It is reasonable to assume that there is a certain minimal standard of acceptability for any variety in relation to its proposed use, making allowance for the state of the supply. Red sorghum, say in Upper Volta or Cameroon, is considered to be a different crop from the yellow or white, with a different use and a different market price; it may even be sold germinated, ready for brewing.

I have never heard of the flour yield per ha nor per man year from different varieties; however, with milling yields ranging from under 50 to over 80% this will clearly be a factor in adoption and pricing.

The market responds to qualities that it can identify; the expertise of the farmer and of the housewife will certainly include identification of all of the local varieties and of grain quality (in terms of pest damage, light kernels, etc.).

The value of a symposium like this one is that it is likely to result in more meaningful and objective measures of grain quality, providing us with better information for the study of consumer preference and reducing the number of characters that remain cryptic. Thus the social scientist can better understand and describe the market and the consumer preferences. In the past, consumer and market surveys on sorghum in West Africa have used few, if any, measures beyond color.

Economists acknowledge that consumer preferences may have no rational basis and we can sometimes even put a value on this preference, e.g., the white or brown color of an egg shell. Brown shelled eggs command a premium of 2–5% in price in certain markets, although it is quite clear that there is no difference in the egg inside the shell. Consumers may even indicate reasons for such irrational preference; for example, brown shelled eggs are more nutritious, and white shelled anaemic.

It seems that the social scientist may have to collect a more complex set of data in marketing and consumption surveys on the one hand and on production on the other, in order to indicate the productivity and markets for preferred varieties. Meanwhile, most of us are already gathering an unmanageable quantity of data in farming systems research. The indigenous knowledge on varietal preference would be of value of all of us concerned with developing improved varieties.

If we can produce a sufficiently accurate prescription, which could be translated by the geneticist of the future into a gene formula, could the breeder breed it?

Effects of Supplementing Grain Sorghum Diets with Ascorbic Acid on Guinea Pig Growth Rates and Cholesterol Levels

Carol F. Klopfenstein, Elizabeth Varriano-Marston, and R. C. Hoseney*

Summary

During the first 3 weeks of feeding a casein-based diet, growth rates of guinea pigs were enhanced by supplementing the diets with 40 mg ascorbic acid (AA)/day. During that same period, equal growth rates were obtained for animals on casein diets supplemented with 2 mg AA/day and sorghum-based diets supplemented with 2 or 40 mg AA/day. Conversely, after the 3rd week, growth rates of sorghum-fed animals receiving 2 mg AA/day were less than for the animals receiving 40 mg/day. Animals fed casein diets supplemented with 40 mg AA/day had higher cholesterol levels after 40 days than animals on other diets. In general, serum cholesterol ester/free cholesterol ratios were not affected by ascorbic acid supplementation or the type of diet. Supplementing a casein-based diet with 40 mg ascorbic acid/day elevated liver cholesterol values. Ascorbic acid supplementation level influenced liver Zn : Cu ratios. Those ratios were highest for animals fed sorghum plus 40 mg AA/day. Changes in Zn : Cu ratios resulted because large doses of ascorbic acid decreased copper absorption in guinea pigs.

Sorghum grain is an important dietary staple for millions of people in the semi-arid areas of Asia and Africa; however, relatively little has been reported on its nutritional value for humans. Klopfenstein et al. (1981) have recently reported that liver cholesterol concentration in young guinea pigs fed a sorghum diet was much lower than in those fed wheat, rolled oats, or pearl millet diets. Klopfenstein et al. (unpublished) also found that guinea pigs fed sorghum diets supplemented with 20 mg of ascorbic acid per day grew poorly. When the same diet contained 60 mg of ascorbic acid per day, the animals grew well and had lower serum cholesterol levels than those given the 20 mg/day supplement.

It has long been established that 0.5 mg of ascorbic acid per day will prevent macroscopic scurvy in young guinea pigs (National Research Council 1978; Waugh and King 1932a,b; Mannering 1949), but the level required for optimum growth and health of that animal as well as for young humans is still uncertain. Interpretations of data are complicated by the wide biological variation in requirements among individuals (Williams and Deason 1967; Yew 1973, 1975). Furthermore, comparisons of data are difficult because of the diversity of diets used.

Ascorbic acid is also known to be involved in cholesterol metabolism (Holloway and Rivers 1981; Hornig and Weiser 1976; Bjorkhem and Kellner 1976). Administration of the vitamin caused significant reductions in human serum cholesterol in some cases (Heine and Norden 1979; Ginter et al. 1979; Spittle 1974; Sokoloff et al. 1966), but in other reports increased serum cholesterol was observed (Spittle 1974; Sokoloff et al. 1966; Klevay 1976).

In the present study, we wanted to confirm our previous reports on the growth promoting effects of supplementing grain sorghum diets with as-

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corbic acid. In addition, the effect of high levels of ascorbic acid on cholesterol status in guinea pigs was studied.

Materials and Methods

English Shorthair guinea pigs (Small Stock Industries, Inc., Pea Ridge, AR) were individually housed in wire-bottomed cages and fed Purina guinea pig ration during a 1-week acclimatization period. Four groups of eight animals each were fed casein- or sorghum-based diets (Table 1) supplemented with 2 or 40 mg of ascorbic acid per day in aqueous solution for 71 days. Water and pelleted feed were provided ad libitum to animals weighing 195 to 258 g, and daily growth records were kept. After 7, 26, 40, 57, and 71 days, blood samples from nonfasting animals were collected from a toenail vein in Microtainer™ serum separators (Bectin-Dickinson & Co., Rutherford, NJ). After allowing the blood to clot at 37° C for an hour, the serum was separated by centrifuging the Microtainers at 3440 × g for 20 min (Servall refrigerated centrifuge, M-head). Serum was immediately refrigerated and assayed within 5 days for total cholesterol (Allain et al. 1974). Low and very low density lipoproteins were removed by precipitation (Lopes-Virella et al. 1977) and high density lipoprotein cholesterol (HDLC) was determined (Allain et al. 1974). Serum triglycerides were determined according to Bucalo and David (1973).

Cholesterol esters and free cholesterol were determined by thinlayer chromatography. Serum was extracted with an ether-absolute ethanol solution (80:20) and the extract spotted on silica gel 60 precoated plates (Brinkman Instruments, Westbury, NY). The plates were developed in hexane-ether-acetic acid (80:20:1), dipped in a solution containing 3% cupric acetate in 8% phosphoric acid for 3 sec and then heated at 130° C for 30 min (Klopfenstein et al., unpublished). Cholesterol and cholesterol esters were measured densitometrically at 400 nm, and those values were used to calculate the ratios of esters to free cholesterol.

After 71 days on the diets, the animals were anesthetized, and their livers were removed, rinsed in cold tap water, blotted with paper towels, and frozen (−13°C) until analyzed. Lipids were extracted from the liver with chloroform-methanol (Klopfenstein and Clegg 1980). An aliquot of the extract was evaporated to dryness under nitrogen, the lipid residue redissolved in absolute ethanol and used to determine total liver cholesterol (Rosenthal et al. 1957). The Pierce Triglyceride C-37™ Rapid Stat Kit (Pierce Chemical Co., Rockford, IL) was used to assay liver triglycerides in a dried aliquot of the liver extract.

Serum samples were diluted 1:10 with 6% butanol in 0.05 N HCl (Center for Disease Control 1976) and used in the determination of zinc and copper by atomic adsorption spectrophotometry (Perkin Elmer, Model 460). One-g samples of liver and feed were wet-ashed in concentrated nitric-sulfuric acid (2:1). Nitric acid was added as needed to maintain a volume of about 50 ml until

Table 1. Composition of diets. (All diets were pelleted for ease of handling and feeding.)

Component	Casein-based (%)	Sorghum-based (%)
Vitamin free casein[1]	18.3	18.3
Skim milk powder[2]	18.3	0.0
Sucrose[3]	26.6	0.0
Soyabean oil[4]	9.0	8.0
Cellulose[5]	17.2	10.0
Cholesterol[6]	0.1	0.1
Sorghum[7]	0.0	53.1
Potassium acetate[7]	2.3	2.3
Magnesium oxide[8]	0.5	0.5
Vitamin diet fortification mix[9]	2.2	2.2
Briggs N salt mix[10]	5.5	5.5
Nicotinamide[1]	50 mg/kg	50 mg/kg
Ascorbic acid[11]	2 or 40 mg/day	2 or 40 mg/day

1. U.S. Biochemical Corp., Cleveland, OH.
2. ICN Nutritional Biochemicals, Cleveland, OH.
3. Domino Fine Granulated, Isis Foods, Kansas City, MO.
4. Crisco, Proctor and Gamble, Cincinnati, OH.
5. Alphacel, ICN, Nutritional Biochemicals, Cleveland, OH 49028.
6. Fisher Certified, Fisher Chemical Co., Fairlawn, NJ07410.
7. Dekalb (C46+, ground in Ross Experimental Mill with 9 × 6" corrugated rolls set at 0.10"), Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506.
8. Laboratory grade, Fisher Chemical Co., Fairlawn, NJ07410.
9. ICN Nutritional Biochemicals, Cleveland, OH (ascorbic acid deficient).
10. Formulated per Fox and Briggs, J. Nutr. 72(2): 1960, ICN Nutritional Biochemicals, Cleveland, OH44128.
11. USP grade, Malinckrodt, Inc., St. Louis, MO63147 (in aqueous solution).

the solution became very pale yellow. After evaporation to dryness, ash was dissolved and made to 100 ml volume with 0.1 N HCl.

Analysis of variance, Duncan's multiple range test (Duncan 1955), and the general linear models SAS statistical package (Helwig and Council 1979) were used to analyze the data.

Results and Discussion

Effects on Growth Rates

Figure 1 shows that from week 1 to week 3 the slope of the growth curve for the casein plus 40 mg ascorbic acid group was greater than that of the casein plus 2 mg ascorbic acid group ($P < 0.05$). During the first 3 weeks, slopes of weight gain curves for both sorghum diets (Fig. 2) and the 2 mg ascorbic acid supplemented casein diet (Fig. 1) were statistically the same ($P < 0.05$). Therefore, in young animals, 40 mg/day ascorbic acid supplementation enhanced growth rates only in casein-fed animals.

The slopes of the growth curves for the two casein-fed groups were the same from weeks 3 to 9 (Fig. 1), showing nearly identical weekly weight gains for animals with high or low ascorbic acid supplementation. Conversely, after the 3rd week, rate of growth of the sorghum-fed animals receiving 2 mg of ascorbic acid per day was less than for the animals receiving 40 mg ascorbic acid/day (Fig. 2, $P < 0.10$). During that period there were no statistical differences in the rate of weight gain among animals fed either casein diet or the sorghum plus 40 mg ascorbic acid/day diet ($P < 0.05$).

For guinea pigs, many investigators have found optimal growth rates when diets were supplemented with about 0.5 mg ascorbic acid/100 g of body weight day (Yew 1975; Collins and Elvenjem 1958; Crampton et al. 1944; Dann and Cowgill 1936; Coward and Kassner 1936). We supplemented casein-based diets with 2 mg of ascorbic acid per animal per day for 9 weeks and obtained good growth in guinea pigs. However, that level of supplementation in an isocaloric, isonitrogenous, and presumably nutritionally adequate, sorghum-based diet resulted in poor growth and unhealthy appearing animals.

The effect of ascorbic acid on guinea pig growth may be related to its role in the metabolism of certain amino acids. Grain sorghum's high leucine content has been implicated in its poor nutritional performance (Gopalan 1968; Belavady 1975). It is possible that ascorbic acid is involved in leucine metabolism. Leucine interferes in the nicotinamide adenine dinucleotide (NAD^+) biosynthetic pathway from tryptophan (Gopalan 1968; Belavady 1975; Yamada et al. 1979). Pyridine nucleotides (NAD^+, NADH, $NADP^+$, NADPH) and flavins transfer electrons to O_2 via a microsomal electron transport chain to furnish energy to aerobic organisms. Impairment of NAD^+ production could reduce microsomal energy production. Our earlier study (Klopfenstein et al., unpublished) suggested that ascorbic acid had a niacin-sparing effect in guinea pigs fed sorghum diets. It is possible that ascorbic acid compensates for leucine's interference in tryptophan conversion to

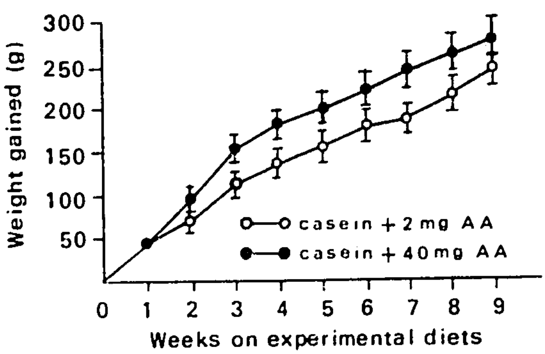

Figure 1. Cumulative weekly weight gain of animals fed casein-based diets. Values represent means ± SEM for 8 animals.

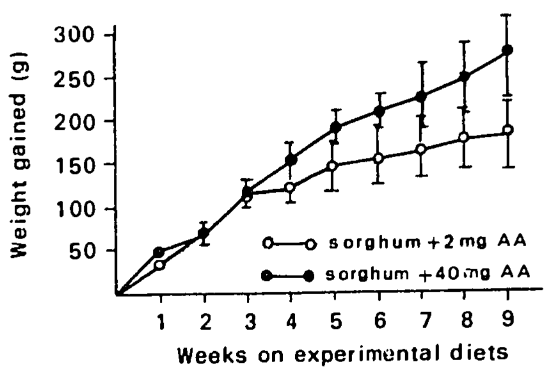

Figure 2. Cumulative weekly weight gain of animals fed sorghum-based diets. Values represent means ± SEM for 8–9 animals.

niacin nucleotide by substituting for NADH or NADPH in the electron transport chain (Fig. 3). According to Weber et al. (1974), a range of 12–24% of the electron transport to cytochrome b_5 (Fe^{2+}) may depend on Pathway B, Figure 3. Therefore, ascorbic acid might make a significant reduction in the NADH requirement. This could explain the faster growth rates of guinea pigs fed sorghum diets supplemented with 40 mg of ascorbic acid per day.

Effects on Cholesterol Levels

Between day 7 and day 26, serum cholesterol levels increased in all diet groups, but the increase was only significant for casein-fed animals ($P < 0.05$, Fig. 4). During that period ascorbic acid had no effect on serum cholesterol in animals fed either casein- or sorghum-based diets. Between 26 and 40 days, however, serum cholesterol again increased significantly in animals fed the casein plus high ascorbic acid diet, while cholesterol levels in animals fed the other three diets did not increase ($P < 0.05$). Serum cholesterol in casein-fed animals receiving 40 mg ascorbic acid per day remained elevated for the rest of the experiment.

Serum cholesterol ester/free cholesterol ratios were high in young animals, with no significant differences among diets (Fig. 5). Values declined rapidly and were lower for all diet groups after 40 days than at the start ($P < 0.05$). Between 26 days and 40 days total serum cholesterol increased rapidly in animals fed casein plus 40 mg of ascorbic acid per day (Fig. 4), but the ester/free cholesterol ratio rapidly decreased (Fig. 5), indicating that the increase in total serum cholesterol was due primarily to unesterified cholesterol. The ratio of esterified to free cholesterol appeared to be higher for animals fed the high ascorbic acid sorghum diet than for any other group, but the difference was significant only at 26 and 71 days (Fig. 5, $P < 0.10$). Our previous study (Klopfenstein et al., unpublished) showed higher cholesterol ester/cholesterol ratios in animals fed sorghum diets plus 60 mg of ascorbic acid per day than in those fed the same diets with 20 mg of ascorbic acid per day. We suggested that the increase could be caused by elevated lecithin-cholesterol acyl transferase (LCAT) activity. Increased LCAT activity was noted by Hanck and Weiser (1979) in leucocytes of guinea pigs fed a casein-fortified, 40% ground oats diet with high ascorbic acid supplementation.

At the conclusion of the experiment (71 days), serum cholesterol was highly correlated with liver cholesterol (Table 2). Liver cholesterol values were also higher in the high ascorbic acid casein-fed group than in either sorghum-fed group (Table 2, $P < 0.05$). That data showed that supplementing a casein-based diet with 40 mg ascorbic acid per day caused elevated liver cholesterol values in guinea pigs. Liver cholesterol/ester cholesterol ratios showed a pattern similar to liver cholesterol values (Table 2).

$$\text{A. NADH} \xrightarrow{\text{cyt } b_5\,(Fe^{3+})} \text{cyt } b_5\,(Fe^{2+})$$

$$\text{B. L-ASCORBATE} \xrightarrow{\text{cyt } b_5\,(Fe^{3+})} \text{cyt } b_5\,(Fe^{2+})$$

Figure 3. Electron transport to cyt $b_5(Fe^{2+})$.

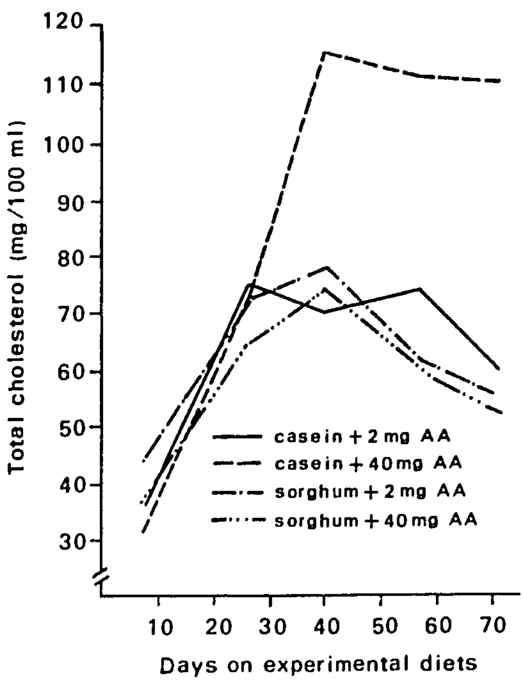

Figure 4. Change in serum cholesterol with time. Values represent LS means for 6–8 observations. Differences between values for casein + 40 mg AA/day and the other diets are significant at 57 and 71 days (P < 0.10). Cholesterol levels in animals on casein + 2 mg AA/day and sorghum + 2 or 40 mg AA/day diets are not statistically different.

Casein-based diets can cause hypercholesterolemia in rabbits (Carroll 1978; Terpstra et al. 1981) swine (Kim et al. 1978), rats (Yadav and Leiner 1977), and chickens (Kritchevsky et al. 1959). However, van Raaij et al. (1979) showed that a casein diet that caused definite hypercholesterolemia in rabbits had no effect on human serum cholesterol. We found that casein diets containing ≤25 mg ascorbic acid per day had no cholesterol-raising effect in guinea pigs (Klopfenstein et al., unpublished). Carroll et al. (1978) found that the hypercholesterolemic response of rabbits to casein could be modified by the carbohydrate, fat, or supplementary protein content of the diet. Apparently, ascorbic acid can be added to the list of casein-cholesterogenesis modifiers. Our earlier data (Klopfenstein et al., unpublished) showed that a high level of ascorbic acid (60 mg/day) had a cholesterol-lowering effect in sorghum-fed guinea pigs. In the work reported here, liver cholesterol was lowest in sorghum-fed animals receiving 40 mg of ascorbic acid per day; however, the difference was not significant ($P < 0.05$).

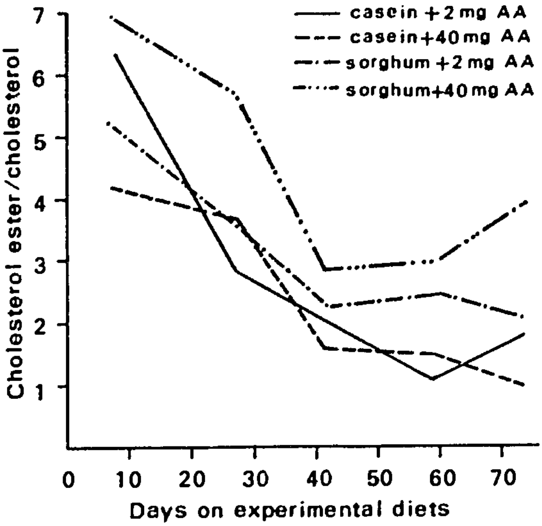

Figure 5. Change in serum cholesterol ester/free cholesterol ratio with time. Values represent LS means for 6–8 observations. After 26 days, ratios were higher in animals fed sorghum + 40 mg AA/day than in those fed sorghum + 2 mg AA/day or casein + 2 mg AA/day (P <0.05). After 71 days, ratios were higher in the sorghum + 40 mg AA/day group than in the casein + 40 mg/day group (P <0.05).

Effects on High Density Lipoprotein Cholesterol (HDLC)

A large increase in HDLC occurred after the animals were fed sorghum diets for 40 days (Fig. 6). Thereafter, HDLC levels declined. In general, ascorbic acid level had no effect on that trend except at 57 days, when animals fed sorghum diets containing 40 mg ascorbic acid per day showed significantly ($P < 0.05$) higher HDLC levels.

Animals fed casein diets showed a gradual

Table 2. Liver cholesterol/ester/free cholesterol ratio, liver total cholesterol, and correlation with serum cholesterol and liver triglycerides.

Diet	Cholesterol esters/free liver cholesterol[1]	Total liver cholesterol[1]	Liver cholesterol/ serum cholesterol corr. (probability)	Liver cholesterol/ liver triglyceride corr. (probability)
		mg/100 g		
Casein + 2 mg ascorbic acid	$1.40^{ab} \pm 0.31$	$671^{ab} \pm 130$	0.908 (0.005)	0.828 (0.011)
Casein + 40 mg ascorbic acid	$1.85^{a} \pm 0.18$	$932^{a} \pm 140$	0.755 (0.030)	0.953 (0.0003)
Sorghum + 2 mg ascorbic acid	$0.99^{ab} \pm 0.37$	$509^{b} \pm 130$	0.601 (0.114)	0.872 (0.005)
Sorghum + 40 mg ascorbic acid	$0.65^{b} \pm 0.25$	$392^{b} \pm 80$	0.915 (0.001)	0.810 (0.015)

1. Values are means ± SEM for 6–8 observations. Means in the same column not followed by the same superscript differ significantly [Duncan's multiple range test (Duncan 1955), $P < 0.05$].

increase in HDLC levels up to 57 days, then a sharp increase in HDLC occurred at 71 days. Again, the level of ascorbic acid in those diets had no effect on HDLC. Our results are in contrast to Bates et al. (1977) who reported a positive association between ascorbic acid status and HDLC.

Sharp increases in HDLC levels were noted in both sorghum- and casein-fed animals at different times during the experiment. An increase occurred at 40 days for the sorghum diets, but not until 71 days with the casein diets.

Effects on Triglycerides

Some workers have found significant reductions in serum triglycerides with high doses of ascorbic acid (Sokoloff et al. 1967; Cerna and Ginter 1978), but others have not (Heine and Norden 1979). We found serum triglycerides to vary with no consistent significant differences attributable to ascorbic acid level or type of diet (Fig. 7). Liver triglyceride concentration was highly correlated with liver cholesterol concentration (Table 2).

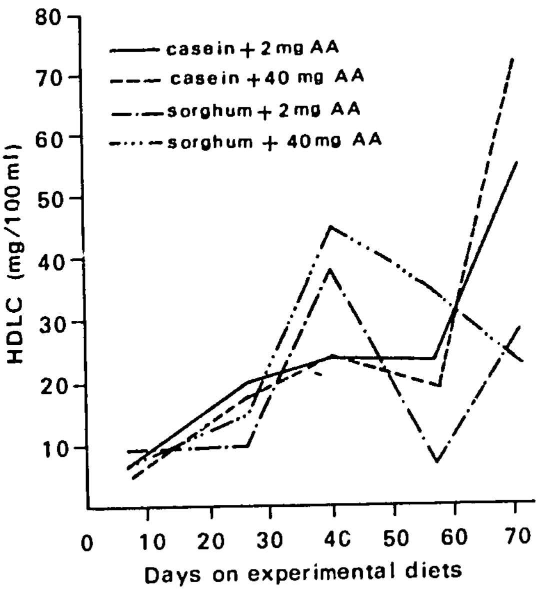

Figure 6. Change in HDLC with time. Values represent LS means for 6–8 observations. After 40 days, HDLC was higher in animals fed sorghum + 40 mg AA/day than in both groups of casein-fed animals (P <0.05). At 57 days, HDLC remained higher in that group than in animals fed casein + 40 mg AA/day or sorghum + 2 mg AA/day, but after 71 days HDLC was higher in the casein + 40 mg AA/day group than in both sorghum-fed groups (P <0.05).

Effects on Copper and Zinc Concentration

High zinc to copper ratios have been associated with increased serum cholesterol levels and coronary heart disease (Klevay 1973; Allen and Klevay 1978). We determined liver and serum zinc to copper ratios (Table 3). In general, the ratios were all quite low and showed no significant correlation with liver and serum cholesterol levels, cholesterol ester-total cholesterol ratios, HDLC, growth rates, or triglyceride levels.

The ascorbic acid supplementation level did influence zinc-copper ratios. Liver ratios (Table 3) were higher in animals fed sorghum plus 40 mg of ascorbic acid per day than those fed sorghum plus 2 mg per day ($P < 0.05$), apparently because of a higher accumulation of copper in the livers of the latter group. As mentioned earlier, sorghum has a high leucine content. Leucine apparently enhances copper absorption (Krishnamachari 1974). This could explain the greater liver copper deposition in the sorghum-fed, low ascorbic acid

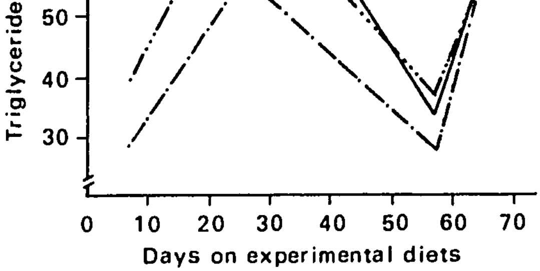

Figure 7. Change in serum triglycerides with time. Values represent LS means for 6–8 observations. The only significant difference among treatments occurred after 57 days when triglycerides were higher in animals fed casein + 40 mg AA/day than in those fed any other diet (P <0.05).

Table 3. Ascorbic acid and diet effects on liver and serum zinc and copper concentrations.

Diet	Liver copper	Liver zinc	Serum copper	Serum zinc	Liver Zn/Cu	Serum Zn/Cu
	μg/g	μg/g	μg/ml	μg/ml	ratio	ratio
Casein +2 mg ascorbic acid	$5.18^{b} \pm 0.66$	$25.0^{ab} \pm 0.8$	$0.61^{a} \pm 0.06$	$1.83^{ab} \pm 0.07$	$5.30^{a} \pm 0.64$	$3.12^{a} \pm 0.31$
Casein +40 mg ascorbic acid	$4.74^{b} \pm 0.28$	$23.4^{b} \pm 0.6$	$0.46^{b} \pm 0.05$	$1.89^{a} \pm 0.08$	$5.03^{a} \pm 0.69$	$4.39^{a} \pm 0.44$
Sorghum +2 mg ascorbic acid	$9.10^{a} \pm 1.59$	$27.2^{a} \pm 1.1$	$0.47^{ab} \pm 0.03$	$1.57^{bc} \pm 0.13$	$3.77^{b} \pm 0.63$	$3.42^{a} \pm 0.45$
Sorghum +40 mg ascorbic acid	$5.02^{b} \pm 0.39$	$25.9^{a} \pm 0.6$	$0.40^{b} \pm 0.06$	$1.47^{c} \pm 0.13$	$5.43^{a} \pm 0.55$	$4.20^{a} \pm 1.74$

Numbers in table are means ± SEM for 6–8 observations. Means not followed by the same superscript differ significantly [Duncan's multiple range test (Duncan 1955), $P < 0.05$].

supplemented animals. Evidently, enhancement of copper deposition is nullified by high ascorbic acid supplementation in the sorghum diet.

Serum copper concentration was lower ($P < 0.05$) and the zinc-copper ratio higher ($P < 0.10$) in the high ascorbic acid casein-fed group than the low ascorbic acid casein-fed group. Our conclusions substantiate those of others who state that large doses of ascorbic acid decrease copper absorption and utilization in guinea pig (Milne and Omaye 1980; Tsai and Evans 1975).

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Nutritional Value of Sorghum in Preschool Children: Digestibility, Utilization, and Plasma Free Amino Acids

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Summary

Digestibility of protein and energy and nitrogen balance were studied in 13 Peruvian children consuming diets in which sorghum (two conventional, two high-protein high-lysine varieties) supplied all of 256 or 300 mg N/100 Kcal. Apparent N absorption during 6-day balance studies was 56%, apparent N retention 37% of casein control. Stool weights and energy losses were excessive. Studies of postprandial changes of plasma-free amino acid concentrations following a sorghum meal demonstrated that lysine was the first limiting amino acid. A comparison of the results from sorghum with similarly obtained data from other major staple foods underscored the importance of digestibility in determining food value, especially as it related to amino acid requirements.

Sorghum is widely consumed in Africa and Asia and is among the world's major cereal crops. The broad range of protein and amino acid contents of different sorghums presents the possibility of improving these aspects as they relate to human nutrient needs. If the world's staples are to help alleviate the problem of malnutrition around the world, they must be suitable for consumption by small children, i.e., the group with the highest nutrient requirements and, consequently, most vulnerable to malnutrition.

These studies were undertaken in conjunction with the group at Purdue University. Four varieties of sorghum, two conventional and two high-protein high-lysine varieties, were evaluated in the controlled setting of a metabolic unit. Protein and energy digestibility, nitrogen balance, and changes in plasma-free amino acids were determined. These results are compared with similarly obtained data from other cereals.

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Materials and Methods

A more detailed description of these studies has been published (MacLean et al. 1981). Consequently, methods will only be summarized here.

Subjects

Thirteen Peruvian children ages 6–30 months, weighing between 4.7 and 9.7 kg, participated in the studies with the consent of their parents. All children were remaining in hospital for long-term recuperation from chronic malnutrition. All were free of infection and gaining weight well at the time of entrance into the study.

Diets

Four varieties of sorghum (Table 1) were evaluated. The sorghums had been ground in an air-impact grinder through an 0.27-inch RHD screen (Quaker Oats, Barrington, IL). Based on the values in Table 1, four sorghum diets were designed so that sorghum provided all of 256 mg N (1.6 g protein, N × 6.25) per 100 Kcal. This was later increased to 300 mg N/100 Kcal. A blend of soybean and cottonseed oil was used to provide 30% of the calories. Sucrose completed the re-

Table 1. Analysis of four sorghums evaluated.

	Sorghum variety			
	954063	954114	P721-0P9	IS11758
Nitrogen (mg/100 g)[a]	1638	1917	1984	2326
Protein (N × 6.25) (g/100 g)	10.24	11.98	12.40	14.54
Lysine (mg/g protein)[b]	21	22	30	29
PER[c]	0.63	0.87	1.39	1.74
Energy (Kcal/100 g)	367	363	360	359

a. N analysis carried out in the Instituto de Investigacion Nutricional.
b. Lysine content is that reported by Purdue University.
c. PER is corrected to a casein value of 2.50.

maining calories. Major minerals were constant in all diets and the intakes of all vitamins and minerals exceeded dietary allowances recommended by the Food and Nutrition Board (1980).

A control diet of casein, oil, sucrose dextrimaltose, and cornstarch paralleled the study diets in calorie distribution and macro- and micro-nutrient contents in all respects, except that the nitrogen content remained 256 mg N/100 Kcal in all studies.

The sorghums were boiled, in early studies for 15–20 min and in later studies for 45 min, and then blended with the other ingredients and sufficient water to produce a liquid formula with an energy density of 0.67 to 0.8 Kcal/ml, similar to an infant formula. The control diet was also prepared as a formula. Children were fed 100 to 150 Kcal/kg body weight per day, divided into four or five feedings, throughout the study.

Protocol

A 9-day control period was followed by two sorghum periods, one of 9 and one of 7 days, and then by a final 9-day control period. One high protein and one conventional sorghum were fed to each child; the sequence alternated in different children. A few children consumed all four sorghums with appropriate intervening control periods.

Complete urine and stool collections were obtained during the last 6 days of each dietary period. Blood for determination of serum total protein (Biuret) and albumin (acetate gel electrophoresis) concentrations was obtained at the beginning and end of each dietary period. Blood for plasma-free amino acids was obtained just before and then 3 and 4 hr after the 8 a.m. feeding on the last day of the second sorghum diet period.

Stools were weighed wet and dry. Nitrogen (Micro-Kjeldahl), fat (method of Van de Kamer et al. 1949) and energy content by bomb calorimetry (Raymond et al. 1957) were determined in 3-day pooled collections. Urinary nitrogen was also determined. Apparent absorptions and retentions of nitrogen were calculated and statistical analysis was carried out using Student's "t" test for paired and unpaired comparisons (Snedecor and Cochran 1968).

Plasma amino acids were analyzed by liquid column chromatography using norleucine as an internal standard (Piez and Morris 1960).

Results

Initial analysis showed no differences among the four sorghum varieties, and consequently further analysis was carried out with the data from all 26 sorghum dietary periods combined. These results are summarized in Table 2. Apparent absorption of nitrogen from sorghum was 57% of that from casein, apparent nitrogen retention, 37% of the initial control and 29% of the final control values. Stool weight increased nearly 2½ fold, fecal energy loss nearly 3 fold, while consuming sorghum. All differences were highly statistically significant. The rate of weight gain during sorghum dietary periods slowed dramatically. Both apparent nitrogen retention and rate of weight gain appeared exaggerated in the second casein period when compared with the initial casein period. Only the difference in the values for nitrogen retention was statistically significant. This compensatory nitrogen retention during the final casein period is commonly seen as a response to a diet previously inadequate in protein. Serum albumin concentrations showed no significant diet-related changes.

Plasma-free amino acid results are presented in Table 3. The fasting values for total amino acids (TAA) and the molar fraction of total essential amino acids to TAA (TEAA/TAA) were low and in the range previously seen after 27 days of wheat protein consumption (MacLean et al. 1977a). Fasting plasma lysine was also low as was the Lys/TEAA ratio. There was a significant fall of the Lys/TEAA ratio 4 hr postprandially, indicating that lysine is the first limiting essential amino acid in sorghum protein (MacLean et al. 1977a; Graham et al. 1981). Threonine would be predicted to be the second limiting amino acid based on the FAO/WHO provisional scoring pattern (FAO/WHO 1973). Fasting and postprandial changes of Thr/TEAA were not remarkable.

Discussion

Whole grain sorghum prepared as in these studies is a poorly digestible source of dietary energy and protein for young children. Consumption of sorghum was associated with poor weight gain and excessive fecal losses of energy and nitrogen. Data from the present studies are compared with similarly obtained data from our unit on other major staple foods in Table 4. Absorption of nitrogen from whole grain sorghum was lower and fecal weight and energy losses higher than from any of the other major staples. The poor absorption of nitrogen from sorghum accounts in part for the poor nitrogen retention from the cereal. In this perspective, the major problem with sorghum appears to be one of digestibility, a problem conceivably solvable by processing.

Although conventional sorghum has the lowest amino acid score relative to the FAO/WHO provisional scoring pattern of the cereals that we have

Table 2. Summary of comparative balance studies with sorghum.

		Apparent N balance		Stool		
	n	Absorption (%)	Retention (%)	Wet wt (g/day)	Energy (% Intake/day)	Wt gain (g/kg body wt per day)
Casein-Pre	14	81 ± 5	38 ± 3	95 ± 35	7.2 ± 1.7	4.9 ± 2.6
Sorghum[a]	26	46 ± 17	14 ± 10	224 ± 66	21.0 ± 13.5	1.0 ± 3.2
Casein-Post	11	81 ± 4	49 ± 11	129 ± 32	7.0 ± 1.5	6.5 ± 3.2

a. All values differ significantly from casein controls ($P < 0.01$).

Table 3. Selected plasma amino acid values—sorghum.

	TAA μmoles/L	TEAA/TAA	Lysine μmoles/L	Lysine/TEAA
Fasting	2364 ±346	0.217 ±0.037	70 ±36	0.136 ±0.044
3 hours postprandial	2814 ±534	0.213[a] ±0.032	71 ±21	0.120 ±0.033
4 hours postprandial	2557 ±512	0.224[a] ±0.029	58 ±22	0.104[b] ±0.033

a. Differs from corresponding fasting value by paired "t" test ($P < 0.05$).
b. Differs from corresponding fasting value by paired "t" test ($P < 0.01$).

studied to date (Column 2, Table 5), its score of 38 is only minimally below the value of 42 for 70% extraction wheat flour. The amino acid score of 55 for P721-OP9 places it above whole wheat, white flour (70% extraction wheat flour) and conventional maize, and near rice.

The importance of the interaction of digestibility and the concentrations of protein and lysine on the amount of lysine actually absorbed relative to lysine requirements is illustrated in columns 3 to 6 of Table 5. Food intake is in large part regulated by a need to meet energy requirements and by the bulk of the diet. All of the cereals in Table 5 provide approximately 360 Kcal/100 g. The protein intake from 100 g of each staple is shown in column 3 and was multiplied by the apparent nitrogen digestibility (corrected to 100% for casein, column 4) and lysine concentration to give an

Table 4. Comparison of sorghum with other staple foods.[a]

	Apparent nitrogen balance		Stool wet weight (g/day)	Stool energy loss (Kcal/day)
	Absorption (%)	Retention (%)		
Sorghum	46	14	224	183
Potato	66	34	165	78
Rice	66	26	67	58
Maize	73	27	133	117
Wheat	81	20	95	60
Casein	81	38	95	63

a. Data for sorghum and casein are from the current studies. Values for other staples are from the following sources: potato (Lopez de Romana et al. 1980), rice (MacLean et al. 1978), maize (Graham et al. 1980), and wheat (MacLean et al. 1979).

Table 5. Lysine contents and amino acid scores of selected staples and the effect of digestibility on meeting the lysine requirement of young children.[a]

	Lysine content (mg/g protein)	Amino acid score	g protein per 100 g consumed	% N digestibility	Lysine (mg) absorbed per 100 g consumed	Lysine absorbed as % lysine requirement, age 1-3 years
Sorghum (whole grain)						
954063	21	38	10.2	58	125	14
P721-OP9	30	55	12.4	58	216	25
Maize hybrids (whole kernel meal)						
Conventional	29	53	8.3	91	219	27
su$_2$-*op*$_2$	43	78	9.0	90	348	40
Wheat flour						
100% Extraction	30	55	13.0	91	355	40
70% Extraction	23	42	11.4	100	262	30
Rice-milled (60% extraction)						
IR480-5-9	37	67	11.4	82	345	39
IR 32	38	69	7.1	82	221	25

a. All values for digestibility have been corrected assuming casein digestibility to be 100%. Values for all staples from references cited in Table 4 except for wheat flour (MacLean et al. 1976). Amino acid scores are based on the FAO/WHO provisional scoring pattern. Lysine requirement for 1-3-year-old children is also based on FAO WHO recommendations (FAO WHO 1973).

estimate of the amount of lysine absorbed for each 100 g of cereal ingested. This value is expressed as a percentage of the lysine requirement of 1-3-year-old children, in column 6. Looked at in this way, because of its poor digestibility, conventional sorghum appears even more limiting in lysine than its amino acid score would suggest. P721-OP9 equals conventional maize and low protein rice, is slightly below 70% extraction wheat flour, and substantially below su_2-op_2 maize, whole wheat flour, and high protein rice.

Other studies have commented on the relatively poor digestibility of sorghum protein. In one, the progressive substitution of sorghum for rice in the predominantly vegetarian diets of 12-14-year-old boys was associated with a progressive decrease of apparent nitrogen absorption from 75% to 55% and of apparent nitrogen retention from 4.5 to 2.1% (Kurien et al. 1960). Studies of Nigerian men comparing cassava, rice, and sorghum to egg protein reached similar conclusions. Of interest in these studies was the finding that home pounded and winnowed sorghum contained 6% less fiber than milled whole grain sorghum and supported better nitrogen balance (Nicol and Phillips 1978). A single previous study, carried out in preschool children, has reached opposite conclusions (Pushpamma et al. 1979). Mixed diets of sorghum and redgram or blackgram, and pulses were fed to six children, ages ⌣ to 6 years. Apparent nitrogen absorptions averaged 90%, apparent retentions 70%. These very high values are unexpected with a mixture of vegetable proteins and are in the ranges reported for rapidly growing infants while consuming high quality milk protein (Shenai et al. 1980). The requirement for and retention of nitrogen by young infants are well above those for older children.

Our previous experience with a heat-extruded blend of 20% dehulled sorghum and 80% wheat-soy blend (Thriposha) suggests that this form of processing may be of value. Apparent absorption of nitrogen averaged 76 ± 5%, apparent retentions 37 ± 11%. Stool weights (105 g/day) were not excessive (MacLean et al. 1977b). With this in mind, studies are currently under way in our unit to evaluate a decorticated heat-extruded sorghum following the same protocol used in the present studies. Results from a single child to date are encouraging and show a marked improvement in apparent nitrogen absorption (75% vs 81% for casein control). Apparent nitrogen retention was about 50% of that from casein. Stool weights were similar on both diets.

The role of processing in improving the digestibility of sorghum underscores the importance of obtaining accurate information on local methods of sorghum preparation in areas of the world where sorghum is commonly consumed. A rapid in vitro assay for the digestibility of sorghum proteins has recently been reported (Axtell et al. 1981) and should prove useful in studying a wide variety of locally prepared sorghum dishes and in selecting those for which human studies would be valuable.

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Discussant's Comments

Session 6: R. Jambunathan*

Of the four papers presented in this session, two were related to consumer acceptance, one was related to the market price, and the fourth was related to digestibility and utilization studies.

The concepts of consumer acceptance and consumer preference were recognized. There is a need to know more about the factors that affect the consumer acceptance of a cultivar. This aspect was stressed especially due to the fact that in Africa and India, the majority of the farmers and consumers prefer local sorghum even when they grow hybrids or high-yielding varieties in their own field. Several factors responsible for the poor status of sorghum in the market and among the consumers were recognized. It is necessary to change the present status of sorghum as "poor man's food" by introducing various processing and technological changes.

The need to study the market channels, pricing, supply and demand was recognized. Although it appears to be possible to predict the market price of a breeder's sample using various grain quality attributes, there appears to be a need to refine and improve the methodologies further.

That a diet of sorghum is poorly utilized (14% nitrogen retained) of all the cereals studied, reveals that in addition to improving the yield of the grain, there are several areas such as nutritional quality, digestibility, bioavailability of nutrients, processing and milling characteristics, etc., where further evaluation should be carried out in order to improve the utilization of sorghum.

A survey carried out in some parts of Maharashtra, India, (Jambunathan, Subramanian and Bapat, Unpublished) showed that most of the consumers preferred to consume local sorghum as compared with hybrid sorghum. According to the consumers, local sorghum lasts longer in their stomachs and is also sweet in taste. A study carried out in cooperation with six families in Rahuri, Maharashtra using ground sorghum samples of a hybrid and a local failed to show any preference for local in the case of four families. It is emphasized that these are preliminary results and further studies using a greater number of subjects are needed to understand the consumer preferences. It is also recognized that much work has to be done to benefit this group of silent consumers of coarse grains who have no political nor economic power to draw the attention of the public or policy makers to their plight.

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Session 6—Factors Affecting Nutrition and Consumer Acceptance

Discussion

Rana:

The price of sorghum is determined on the basis of varietal traits such as taste, color, size, luster, uniformity, and demand and supply as well as the price of the preferred cereal, e.g. rice. Could you please explain the relative role of these factors in fixing sorghum prices?

von Oppen:

As long as it is not fixed by any institution, the market price is determined on the basis of consumers' relative preferences for sorghum and other cereals, and in relation to their budget constraints. Color and luster were not included in the regression because color differences did not really explain price variation; luster could not be measured. There is regional specificity in apparent color preferences, which dissappears when cryptic nutritive qualities are taken into consideration.

Tunde Obilana:

I have been enthused by the interesting papers given this morning. This is because these topics are the end products and success of sorghum breeders in areas where the crop is consumed for food. Is there any information or proposed study to obtain correlations among and between grain quality, market price index, and consumer cultivar acceptance and production?

von Oppen:

Yes, to an extent. A study like that was initiated in IAR, Samaru, Nigeria in 1977 but conclusive results have not yet been reported.

Tunde Obilana:

We have observed in Nigeria that palatability acceptance of grain for food does not necessarily mean acceptability for production. This is due to obvious cultural and economic reasons associated with the cultivation and production of local varieties which are variously used as food and for their extensive by-products. We hope that these situations will change, appropriately with time.

Jaya Mohan Rao:

Dr. MacLean, one of your slides showed that the lysine content of P-721 is 3.00 and IS 11758 is 2.90. How far is this correct? It is very well established through our studies as well as from other studies made elsewhere that the lysine content of IS 11758 is always higher than P-721. From our research of the last 6 years, the lysine content of P-721 stood at 2.70 and that of IS 11758 at 3.20. Your comments on this please.

MacLean:

Dr. Axtell provided the grain for our nutritional studies and he agrees that your general observation is correct. However, there are environmental effects on protein and lysine concentrations from one year to the next. The important point is that there is a consistent and inheritable increase in lysine content of both IS 11758 and P-721 relative to lysine in normal sorghum grains.

Pushpamma:

Some doubts have been expressed about the digestibility of sorghum. In this connection I want to share with you our experience and information from consumer/nutrition surveys. In the areas of Andhra Pradesh where we surveyed, 85% of the population was eating sorghum and will continue to live on sorghum, irrespective of its nutritional status. However, a shift in consumption to other cereals is noted in the urban areas. We have investigated the nutritional status of sorghum and rice-eating populations. The differences between these two groups cannot be attributed to the staple cereal alone. The other supplementary foods taken along with the cereal are grossly inadequate in the sorghum-eating population, due to their poor living conditions.

The other point I would like to make is that the availability of nutrients from a pure laboratory experimental sorghum diet is different from that of sorghum food prepared after a traditional process—e.g., with alkali, acid, etc.

I agree with Dr. MacLean that undernourished children are frequently from sorghum-eating areas. However, I must point out that the supplementary diet taken by these people along with sorghum is much less than that of people eating rice, maize, and wheat. This should be attributed to their poor living condition, hygiene, socioeconomic conditions, etc.

MacLean:

In these areas, people eat sorghum because other cereal crops have failed and therefore they are forced to subsist on sorghum. Also, we should not come away with the feeling that sorghum is something very bad.

Session 7

Potential Grain Quality Standards for Sorghum: A Discussion

Chairman: H. Doggett

Discussants: N. G. P. Rao
D. T. Rosenow

Rapporteur: J. F. Scheuring

Discussant's Comments

Session 7: N. G. P. Rao*

This symposium addressed itself to various quality parameters that influence food preparations in the semi-arid tropics. Attributes such as taste, color, hardness, structural, textural, chemical and storage (keeping quality) properties have been considered. Related to them are the consumer acceptance and pricing.

1. Traditional sorghums have been known to be local in their adaptation and they generally satisfy the needs of the local food properties. In fact, the local food preparations must have developed around existing traditional cultivars. Since our efforts are aimed at transforming the subsistence sorghums to more productive forms, it is logical that we need to pay particular attention to parameters that condition diverse food preparations. We, therefore, need to look into the problem of food quality in the context of the integrated improvement of sorghums.

2. Yield advances of major cereals like wheat and rice were based on altered rather than traditional genotypes. When the first Mexican wheats and IR-8 type rices were grown on a commercial scale in India, there were no questions on yield advantage, but the quality of the *chapati* or cooked rice were certainly not to the satisfaction of the local needs. They were no doubt marketed and consumed in those years when the food situation in the country was not fully satisfactory. Once the yield base was stabilized at higher levels of productivity, addition of quality attributes was a matter of time. Altered varieties of wheat and rice of today combine yield with consumer and market acceptance.

Similarly in sorghum, when the first hybrid, CSH-1, was commercially grown in India during the late 1960s, its yield advantage, particularly under drought, was spectacular. But, consumers did raise questions on its food quality and in the market it fetched a relatively lower price. Yet CSH-1 continues to be grown and consumed on a large scale. Subsequent hybrids like CSH-5, CSH-6, and CSH-9 did reflect both yield and quality advances.

The point I would like to emphasize, therefore, is that yield advance preceded quality advance. Such yield advances involved radical alterations of the genotype, and quality was superimposed on altered genetic backgrounds. Once the yield base is established, quality improvements could follow rapidly.

3. That traditional sorghums are local in their adaptation and generally satisfy the requirements of local food preparations has been pointed out. Consequently, there has been a feeling that unless sorghums are bred to satisfy the needs of diverse food preparations they might not be acceptable. This leads us to the question of adaptation.

Genotype alterations in wheat and rice have not only conferred an yield advantage but also wider adaptability. Even in the case of sorghum, which has been considered to be highly local in adaptation, consequent to recent efforts at its improvement, the entire *kharif* (rainy season) sorghum belt of India constituting nearly two-thirds of the total sorghum area, is now treated as one zone. There is evidence of adaptation of some such sorghums in other continents as well. Thus, high levels of productivity and wide adaptability are not uncorrelated. In fact, they are well correlated in several instances.

This being the case, the problem of food quality may be viewed as an adaptational problem. ICRISAT conducted an International Food Quality Trial in several centers of the semi-arid tropics and diverse local food preparations were made from a common set of sorghums. Surprisingly, M35-1, the traditional *rabi* (winter) Indian sorghum variety known for its food quality in India, and the commercial hybrid CSH-5 generally satisfied the requirements of most of the local food preparations across countries. The endosperm properties of the *guineense* type of sorghums widely grown in West Africa and several other African sorghums are no different from the white-seeded corneous Indian

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sorghums. There are no doubt differences among the white corneous types for various parameters that influence diverse food preparations. However, since the general preference for food use everywhere is for the white corneous grain and in view of the data available on M35-1 and CSH-5 across continents, it is possible to look at the problem of food quality on a wider basis and yet satisfy the local food needs.

Higher levels of yield, yield stability, adaptability, and food quality are compatible and could be combined with altered genetic backgrounds.

4. Having emphasized the role of altered genetic backgrounds in influencing yield and adaptability, the question of food quality needs to be looked more from the nutritional angle. Sorghums will continue to provide the staple for the masses of semi-arid tropics where nutritional problems are known to plague the populace. The white corneous sorghums generally used for food do not pose problems of tannins.

A recent FAO estimate on protein consumption in grams per person per day during 1975-77 placed Africa at 54.9 g and Far East at 49.6 g, whereas for industrial countries it was 98.5 g and for developing countries 57.8 g. It was pointed out that the gap in protein consumption between developed and developing countries has only widened between 1966-68 and 1975-77. These facts lend support to the argument that food quality should embrace nutritional quality.

5. Sorghum is generally grown in combination, in sequence, or in rotation with several grain legumes. Pigeonpea, cowpea, mung bean, soybean, and groundnut are examples of companion, sequence, or rotational crops with sorghum.

The nutritional advantages of blending sorghum with soyflour (after inactivating the trypsin inhibitor) in promoting growth have been brought out in a cooperative study at the Home Science College, Hyderabad. There are several other studies in this direction. More work on blends involving sorghum and grain legumes traditionally grown or those recommended and practiced under productive cropping systems might become a priority area for studies on food quality in sorghum-consuming areas. Diverse new food preparations of such blends could be developed, be more meaningful, and could become acceptable rapidly.

6. The need for nutritional upgrading of sorghum proteins has been debated. Yet, the fact that nature provided the genetic resources for such an upgrading is enough of a challenge to attempt this task and it is for us to find the methods and means.

I would like to reiterate that nutritional quality, food quality, and yield are not uncorrelated and it is a matter of time to incorporate quality attributes without sacrificing yield. I am not inclined to agree with those who argue that nutritional upgrading involves tremendous investment. There are already built-in laboratories, and what is needed is an effort to accomplish the objectives of combining quality with yield. There are indications both from our work and the Purdue laboratory that this is an accomplishable task. It is perhaps a matter of time when all sorghums would provide quality protein as well as improved yields.

Food habits and preferences tend to be conservative, but they are not static. While the efforts to document the methods of traditional food preparations and the attributes that contribute towards the betterment of organoleptic properties are laudable, our endeavors, in the context of sorghum improvement in the semi-arid tropics, should be toward incorporating changes that would contribute towards better bodies and better minds.

Discussant's Comments

Session 7: D. T. Rosenow*

Breeders can make significant contributions to grain quality in sorghum. In fact, the key to improving grain quality, or maintaining acceptable levels of grain quality in new, high-yielding varieties or hybrids, is close cooperation between breeders and food quality specialists.

The breeder's first concern is yield; but I believe that significant progress in grain quality factors can be made by the breeder utilizing proper selection techniques. In the early segregating generations such as the F_2 and F_3, the breeder must concentrate on the major agronomic traits such as plant height, maturity, and yield. At the same time, however, the breeder can select for easily recognized grain traits. Therefore, breeders need some traits that can be evaluated quickly by visual means during the selection process in the field. Later, more refined techniques involving laboratory tests can be used on advanced material. However, some very rapid, inexpensive tests that require only a very small quantity of grain would be useful in some cases on F_2 or F_3 selections.

Breeders will select for yield, height, maturity, and disease and insect resistance. They can also select easily, or at least manipulate, many inherited traits that are associated with grain quality, such as pericarp color, pericarp thickness, presence or absence of testa, endosperm color, plant color, glume color, glume shape and size, kernel size and shape, kernel hardness, and head shape.

This is quite easily done individually or a very few traits at a time, but it becomes very difficult to select for several at one time. Therefore, priorities should be determined for these quality-related traits, depending on the requirements for food use.

While recognizing the usefulness of tan plants, I believe that nonstaining types can be selected from purple or red plant types. There are other glume colors that have not been explained genetically, such as straw colors, which can be very useful in reducing the staining of the grain. More information on the genetics of the sorghum plant and kernel properties that affect grain quality is desired.

The overall grain mold/weathering situation is a complex interaction involving molds and wet weather. It is an extremely important problem, especially as improved, often earlier-maturing, photoperiod-insensitive types are introduced or developed for the tropics. Higher levels of grain mold and weathering resistance will be needed. It is my opinion that the so-called "weathering" phase (grain deterioration at or after maturity) is a more important problem worldwide than the early-season grain molds. Breeders can contribute much to the improvement of overall weathering resistance without sophisticated help simply by visual selection in the field. By manipulation of planting dates, use of sprinkler or mist systems, or leaving plants in the field following maturity, breeders can create a natural environment conducive to grain deterioration, and thus apply heavy pressure for the selection of resistant genotypes.

I believe the role of head bugs in overall field grain deterioration has been underestimated. This area needs entomological research with pathologists and breeders working as a team. The role of loose or open heads on insect damage needs investigation, since in most cases it appears that the long open, pendant *guineense* type heads, typical of many West African varieties, show little if any head bug damage.

In summary, I would like to encourage breeders worldwide to become seriously involved in grain quality improvement. Breeders and quality researchers must become familiar with the genetics and appearance of the major evident grain quality factors. This requires only a little reading, but a lot of careful observation and study in the field. Use that pocket knife to scrape and cut the kernels, so that you know what to select, how to select, and

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what genotypes to intercross to obtain desired segregates. Much of the information is already available and can be adopted for use at the local level.

The grain quality problem is formidable; but quality researchers and breeders working together can make great progress and in many cases without sophisticated equipment.

Session 7—Discussion

Doggett:
I would request scientists representing different regions of the sorghum-consuming world to state briefly what could be considered as quality requirement standards for sorghum for their respective regions.

Pushpamma (India):
I must emphasize that in addition to taste, regional preferences for color of grain vary greatly. Different varieties are grown by people because for several reasons they are conditioned to use a particular variety in a particular region. Breeders could map different pockets of these regions for their preferences. Fodder quality should be considered as very important in addition to grain quality. People eat sorghum irrespective of its nutritional status. As scientists and policy makers we have the responsibility to provide varieties with improved nutritional qualities.

B. Gebrekidan (Ethiopia):
Eighty percent of the sorghum produced in Ethiopia is consumed as *injera* and any sorghum recommended to the farmer should have good *injera*-making quality. White color is preferred, although red color is tolerated. White-colored grain commands a higher price. In fact, in Ethiopia, unlike Kenya, sorghum has a price advantage over maize.

G. Ejeta (Sudan):
All good-looking varieties and hybrids of sorghum do not make good *kisra*. Some elite varieties make good *kisra*; however, the traditionally grown *feterita* varieties in Sudan which have chalky white grains with a soft endosperm make the best *kisra*. Although consumers say that they like white or yellow bold grains, good batter consistency and desirable *kisra* texture are associated with chalky white soft types like *feterita*. A white *kisra* is certainly preferred.

Mukuru (Uganda; Tanzania):
The situation in Uganda is much different. Brown grain types are most commonly grown and when these brown grains are used to prepare *ugali*, the flour is invariably mixed with other flours like cassava to improve the taste. The people prefer brown grains since they give the preferred taste after alkali treatment. In Tanzania,, the situation differs with the regions. In the lowlands, white corneous grains with good storage quality are preferred. In other places red grains are also used.

Tunde Obilana (Nigeria):
The variability among indigenous sorghums is great and regional preferences might be different. The sorghum varieties should be suitable to produce *ogi*, the thin porridge, and *tuwo*, the thick porridge. White and/or cream colored corneous grains are preferred. The grains should have a low tannin content and subcoat types are not preferred. A good gel consistency and high *ogi* recovery are preferred.

Scheuring (Mali; Upper Volta):
After consulting Miss Sidibe and Mr. San San Da, I have to say that white pericarp types are the most preferred, although red pericarp types and thin subcoat types are also grown. Medium thick or thick pericarp types with a corneous endosperm are desired since they save 25% of the processing/pounding time in comparison with thin pericarp types. Grains should be symmetrical in shape. Turtle beaked caudatum types cannot be dehulled properly. A vitreous grain which is stable in vitreousness across poor and good fertility, and moisture situations, is essential.

Guiragossian (Central America):
My experience in Central America and that of other Central American colleagues indicates that the following criteria of grain should be satisfied before recommending a sorghum variety to the farmer: (a) grain mold resistance, (b) a tannin level less than 0.05 C.E., (c) a phenol level less than 0.4 mg, (d) a low color score in alkali test, preferably 1 or 2, (e) white or cream colored corneous grains, (f) a thin pericarp (so that less dry matter is lost in the cooking process), and (g) appropriate cooking time (the cooking time depends on the vitreosity of endosperm; if sor-

ghum is to be used in a mixture with maize, the sorghum kernels should be more vitreous so that their cooking time is close to that of maize).

B. S. Rana (India):
There is a global need for sorghum grains that can produce attractive products to compete with maize and wheat. Since chalky-white soft types lead to grain mold attack, one should try to identify methods of incorporating the desirable nutritional factors in a white corneous grain. My experience in Kenya indicated that white sorghums are liked because they produce an acceptable *ugali* comparable to white maize, which is preferred. Since birds are a problem, high tannin types, whose pericarp can be pearled, should be identified. In the urban areas where wheat and maize are preferred, industrial uses of sorghum through which attractive sorghum products can be made, should be explored.

Doggett:
I would request Dr. H. S. R. Desikachar to comment upon potential sorghum grain quality standards from his food technological experience.

Desikachar (India):
Our objective is to give the consumer what he wants. The consumers want a cheap and best product. Obviously, high yield is important. Consumer preferences vary and so does the desired quality of grain for various products. Breeders can probably provide cultivars suitable for various products. For example, in the case of soft cooked (in water) products, a less sticky dough is desirable whereas for a product like *roti*, a very sticky dough is required. Interaction between food technologists and breeders is desirable. The use of composite flours should be more thoroughly explored. In the case of *dosai*, rice can be substituted by 100% sorghum. The use of 25% sorghum and 75% wheat to make semolina, bread, etc., has been demonstrated. The objective should be to work towards products that can compete with those of rice, wheat, and maize.

Doggett:
Dr. Desikachar's comments are very timely since in countries like Kenya, the prices for sorghum are much less than those of maize.

Plenary Session

Recommendations of the Symposium

Chairman: J. D. Axtell

Recommendations of the Symposium

Studies on Traditional Products as a Basis for Sorghum Improvement

1. The traditional food products of sorghum can be categorized as follows:

Product category	Product name
A. Thick porridges:	
i. Acid and fermented	*tô* (in tamarind or lemon medium)
ii. Neutral pH	*bogobe, ugali, tuwo, sankati*
iii. Alkali	*tô* (with lime ash)
B. Unfermented (unleavened) breads	*tortilla, roti*
C. Fermented (leavened) breads	*kisra, injera, dosai*
D. Steamed foods	*couscous*, noodles
E. Thin porridges	*ugi, ogi, edi, ambali*
F. Boiled sorghums	*soru, annam*
G. Snack foods and special uses	popped sorghum
H. Alcoholic and nonalcoholic beverages	*busaa, burukutu, ajon, abrey*

2. Additional information is required, preferably at the local level to define product quality differences between cultivars possessing similar grain color. A standard procedure should be developed for preparing each of the major products.

3. A list of sorghum kernel characteristics representing the present knowledge should be developed. These characteristics should be patterned after the International Board for Plant Genetic Resources (IBPGR) list of descriptors whenever possible.

4. A set of standard Munsell color plates should be made available to collaborators working on grain quality. Photomicrographs of kernel characteristics and grain samples representing different genotypes for individual kernel characteristics should be made available.

5. Information and assistance in setting up taste panels to evaluate product quality can be obtained from the publication of Vogel and Graham "Sorghum and Millets for Human Food." Standard evaluation scales and procedures that fit local situations need to be developed.

6. Methods of evaluating color, flour particle size, starch damage, hardness, and other flour properties are needed for sorghum cultivars with good and bad quality.

7. The texture of the product is an important trait affecting the acceptability and keeping quality of sorghum foods. Considerable work on measurements of food texture is required; techniques requiring simple equipment should be developed.

8. The following cultivars were identified as good/bad for specific food qualities:

	Good	Bad
Alkali *tô*	S-29, Tiemarifing	E35-1, Feterita
Neutral *tuwo*	L-187, FFBL	SK-5912, HP-3
Acid *tô*	S-29, Kamboinse Local	940, TAM-428
Ogi	FFBL	L-1499
Tortilla	M62588, M62724	TAM-428
Roti	M35-1	P721
Kisra	Tetron, Wad Fehal, Safra	Feterita, Wadiyabis
Injera	Alemaya-70, ETS-2752	Gato-994

Studies on Grain Structure and Deterioration

1. It is noted with satisfaction that a wealth of valuable information has been accumulated over the past 12 years on sorghum grain structure and composition. It is recommended that research in this field be continued, especially as it relates to food quality characteristics.

2. Special efforts should be made to establish closer cooperation between scientists interested in food quality and food technology and those in sorghum breeding and pest control.

3. Food technologists should expedite the development of rapid, simple tests for quality traits

that are correlated with some agronomic characteristics which breeders can use effectively in selection programs.

4. Breeders should develop sets of isogenic lines that possess traits relating to grain quality or product acceptability, such as endosperm texture and type, and grain and plant color, which would facilitate comparative food quality studies.

5. Breeders should establish a standard set of genotypes that can be distributed as examples of the major genes affecting grain color, testa, plant color, endosperm texture and type, pericarp thickness, etc.

6. Breeders should continue to develop higher-yielding varieties and hybrids that are widely adapted. As new information on food quality parameters becomes available, it should be utilized in breeding programs.

7. Grain molds and insects like head bugs significantly affect the food and nutritional quality of sorghum. Research on grain molds and improvement for grain mold resistance should be continued in accordance with the recommendations made during the International Workshop on Sorghum Diseases.

Milling and Laboratory Methods for the Evaluation and Improvement of Food Quality

1. Breeders need methods to predict the dehulling quality of grain for (a) hand decortication and (b) mechanical decortication. Different milling procedures should be compared at a realistic milling yield, e.g., 80%. Tempering should be investigated in relation to kernel morphology and milling properties.

2. To test milling quality, a simple method for measuring the extent of dehulling is needed.

3. Simple methods need to be perfected for measuring rheological properties of sorghum flour and sorghum products that can be used by breeders, i.e., gel consistency tests, etc.

4. Research on tannins should be intensified. It would be helpful if purified sorghum tannin standards could be made commercially available.

5. Methods are required to improve the nutritional quality of high-tannin sorghum varieties for human food and animal feed. This includes mechanical methods for removal of pericarp and testa layers (decortication), and chemical and physiological methods for deactivating tannins.

Studies on Nutrition

1. Information is minimal regarding the human nutritional value of sorghum grain and foods prepared by traditional processing methods. Accurate assessments of protein quality, digestibility of protein and starch, effects of lysine supplementation, nutritional characteristics of high lysine sorghum cultivars, and effects of milling and other traditional forms of processing on sorghum foods and sorghum-grain legume diets are required to guide and evaluate the efforts of plant breeders, food quality experts, food processors, and grain millers. Biochemical studies (e.g., amino acid profile, in vitro digestibility) and animal studies (e.g., protein efficiency ratio, true digestibility, and biological value) are useful for screening and warrant further study. Because of the well documented differences in the digestive capacities and nutritional requirements of lower animals and man, human studies will be required. These nutritional studies should address themselves to the value of sorghum foods in children, the most vulnerable group.

2. Facilities for nutritional evaluations are available at the Instituto de Investigacion Nutricional (IIN, Nutrition Research Institute) in Lima, Peru. The IIN is now recognized throughout the world as a leading institute for the reliable determination of the nutritional value of foods in infants and children. This research facility has had over 15 years of experience in the evaluation of cereal grains and other food products. IIN has already established links with a metabolic ward in the Philippines—similar regional wards are being considered and would constitute a method for nutritive evaluation of food grains and their range of products. It is vitally important that funding for these facilities be continued, since they can provide human nutritional evaluation of the wide variety of locally processed foods currently produced from sorghum, as well as new sorghum foods that are now becoming available.

3. It is recognized that an important opportunity exists to gain more food value from the currently produced sorghum grain by minor modifications in the processing procedure, if we understand the effects of these modifications on human nutritional value. It is further recommended that the Consultative Group on International Agricultural Research (CGIAR) arrange for the Technical Advisory Committee (TAC) to undertake a feasibility study of the need to provide nutritional

evaluation services to all the commodity-oriented International Centers, and also to provide nutritional evaluations that can be used as standards by regional metabolic units being developed throughout the world.

Evaluation of Sorghum Consumption and Marketing

1. We need to know a great deal more about what else is eaten with sorghum and how this affects nutritional quality. More information is needed about the specific impact of sorghum diets on children, when sorghum is eaten with inadequate supplements. This requires detailed nutrition studies, including nutrition surveys, studies of food preparation patterns, and feeding studies.

2. There is need for a study of what actually happens when an improved cultivar is successfully or unsuccessfully introduced to field, market, household, etc.

3. More information is required on how consumers cope with varieties that are considered of poor quality. Do they modify the preparations? Do the modifications compensate for the poorer quality?

4. A need exists for the development of nontraditional sorghum products for urban consumption. Such novel products would help many countries reduce grain imports and stimulate local sorghum markets.

5. Further studies are required on the effect of variety on market prices. This should eventually be linked to identifiable food quality characteristics.

Potential Grain Quality Standards for Sorghum

We still lack the information to describe quality standards for the sorghum grain, but we now know more about how to develop them.

1. The first task of plant breeders is to obtain improved, and more stable yield. Only limited attention can be paid to grain type at this stage, and initially the objective should be a quality of wide acceptability. The white, corneous grain is the most widely acceptable, with the exception of the bird areas. In some areas such grains must be hard for storage and must also have a symmetrical shape for milling. Grain must be clean, which requires mold/weathering resistance in some areas. The endosperm, when ground, must be able to produce good, stable gels under local preparation methods, which may use neutral, acid, or alkaline pH media. The color of the alkali-cooked product is important for *tortillas*, and a pearly grain is desirable. A thicker pericarp is desired in some West African areas, to facilitate traditional dehulling.

2. The criterion for *kisra* and *injera* quality is the excellence of the product. Some white chalky grains with testa make good *kisra* or *injera*. Further information is needed for grain characteristics leading to good *kisra* and *injera* quality.

3. Studies of food and beer preparation with brown grains are needed for the establishment of quality criteria. The quest for the corneous grain with the brown testa that can be pearled off should be continued.

4. It is necessary to develop further the existing simple laboratory tests and to study new laboratory tests that can be used rapidly by plant breeders.

5. The next International Sorghum Food Quality Trials (ISFQT) should include a number of white corneous types to test for wide acceptability: some of these should have a medium or thick pericarp and some should have a hard endosperm. Some white chalky grains, brown grains, and markedly asymmetrical grains (caudatums) should also be included. The main grain and glume colors should be included for demonstration purposes.

6. A set of important grain genotypes should also be included, and sets of these grains should be sent out to breeders and other grain quality workers. These should include the following:

Pericarp colors	Spreader condition
Testa condition	Pericarp thickness
Endosperm texture	Endosperm color
Endosperm type	

7. More studies are needed of high lysine complementary foods in a mixed sorghum diet, but the attempt to develop better quality sorghum protein with a higher lysine content should be continued.

Food Grain Characteristics of Sorghum for Potential Standards

1. White grains with a corneous endosperm (may

need mold resistance in many regions):

A. Endosperm texture / End use

Endosperm texture	End use
Hard	Storage in hard tropics
Hard and symmetrical	Milling
Hard with a thin pericarp	*Tortillas* and other foods
Hard with a medium to thick pericarp	Traditional dehulling and porridges
Medium texture	*Roti*
Medium to soft texture	*Injera* and *kisra*(?)

B. Flour quality / End use

Flour quality	End use
Thick gel at pH 1.0–6.9	*Tô* (N. Mali and Upper Volta)
Thick gel at pH 7.1–14.0	*Tô* (S. Mali)
Thick gel at pH 7	Thick porridges (Nigeria, Botswana, E. Africa, and India)
White color at pH 7.1–14.0	*Tortilla*
Sticky dough	*Roti*
Less sticky dough	Boiled sorghum, thick porridges

2. Chalky white grains with soft endosperm:
   Check for use in *injera* and *kisra* preparation.
3. Brown grains:
   Check tannin content after cooking with tamarind, wood ash, etc.
4. Dark brown grains:
   Germinate in wood ash, malt, and check diastase activity.

Appendix

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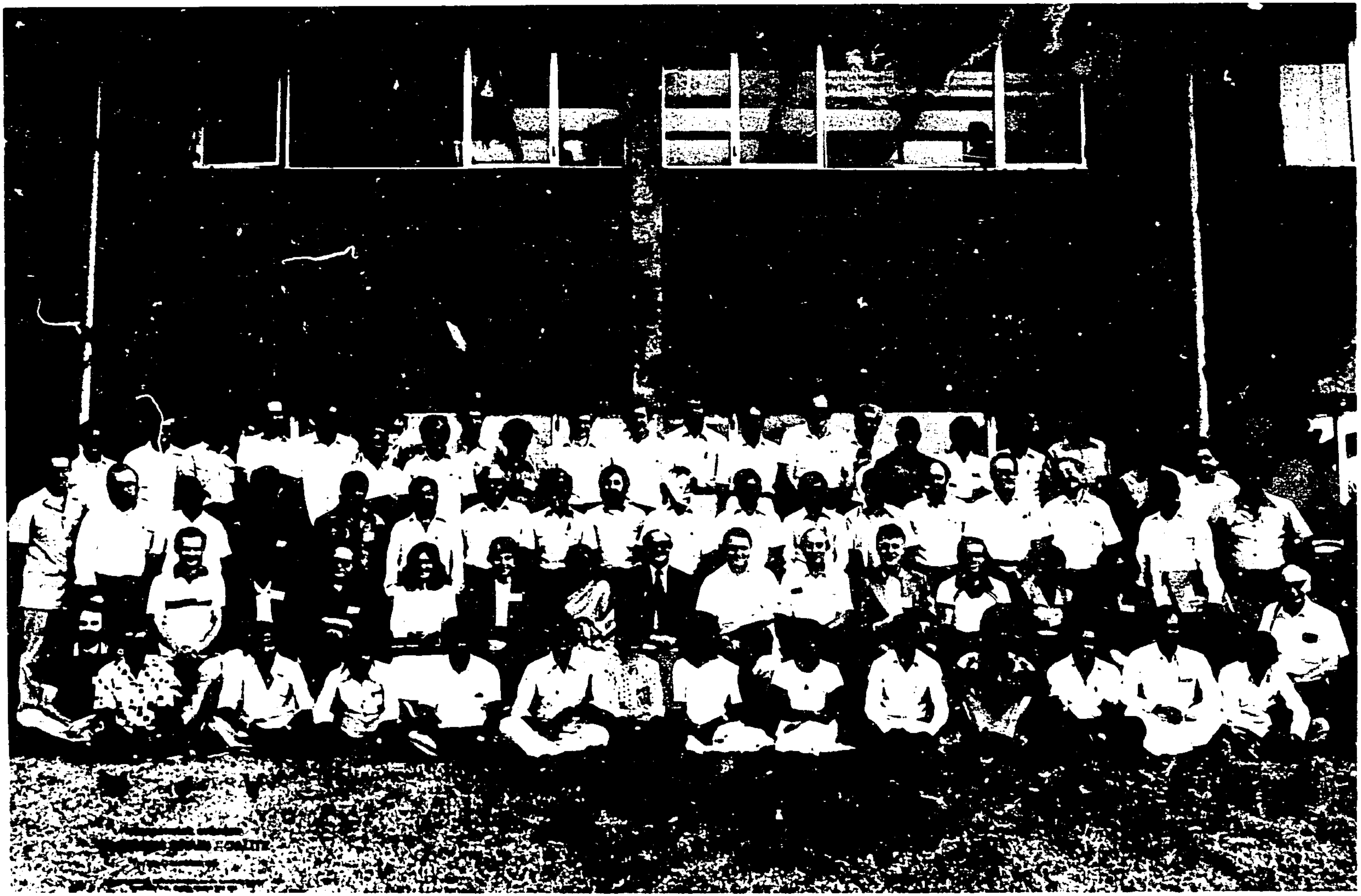

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