Factors Affecting Quality of Sorghum *Tô*, a Thick Porridge[1]

A. B. BELLO, L. W. ROONEY, and R. D. WANISKA[2]

ABSTRACT

Cereal Chem. 67(1):20–25

Sorghum cultivars typical of West African and Honduran sorghums were evaluated for physical and chemical properties and quality of *tô* (textural and solubility properties). Endosperm hardness, amount of pericarp remaining after decortication, flour particle size distribution, pH of the cooking water, and presence of nonstarch flour components affected *tô* quality. *Tô* prepared from SC265 with corneous endosperm had the firmest texture (low penetrometer reading). *Tô* prepared from NSA740 with floury endosperm had the softest texture (high penetrometer reading). *Tô* prepared from ground, decorticated grain was firmer than *tô* prepared from ground, whole grain. Thus, the pericarp adversely affected *tô* texture, regardless of grain hardness. In general, acidic *tô* (pH 4.6) was the most firm, whereas alkaline *tô* (pH 8.6) had the softest texture. The amount of soluble solids in *tô* ranged from 30 to 57%. Firmer *tô* contained less soluble solids. Higher pH of the cooking water increased soluble solids in *tô* from 32–34% for acidic *tô* to 39–47% for alkaline *tô*. *Tô* prepared from isolated sorghum starch (<45 μm) was of equal or better quality and contained less soluble solids than *tô* prepared from sorghum flours containing particles <250 μm or < 425 μm. *Tô* prepared from flours containing more ash was of poor quality and contained higher amounts of soluble solids. Thus, kernel and flour characteristics, the chemical constituents in sorghum, and the amounts of soluble and insoluble solids in *tô* affected sorghum *tô* quality.

Porridges prepared from wheat (semolina, cream of wheat, farina, etc.), corn (grits or hominy grits) and rolled or flaked oatmeal are popular in the United States and many European countries. These porridges require cooking before serving (Hoseney 1986). In many African and Asian countries, porridges prepared from sorghum, pearl millet, rice, and corn are popular. Traditional African thick porridges are generally prepared by cooking a slurry of unfermented or fermented flour in boiling water (acidic, neutral, or alkaline) with continous stirring; the resulting thick porridge after cooling is known by different names such as *tô, tuwo, aseda, ugali, mudde,* etc., depending on geographical region (Rooney et al 1986). Sorghum and pearl millet porridges are common in semiarid regions because those crops are drought resistant and heat tolerant. Sorghum thick porridges provide a major portion of the total caloric intake in the semiarid regions of Africa (Scheuring et al 1982). Sorghum thick porridge is consumed with a sauce using the fingers; the sauce contains vegetables, meat or fish, oil, spices, etc., which provide additional nutrients (Rooney et al 1986).

The textural quality of traditional sorghum porridges determines their acceptability to consumers (Cagampang et al 1982). For example, sorghum *tô* that is too soft and sticky cannot be molded between the fingers, sticks to the teeth and palate during consumption (Da et al 1982), and sticks to the cooking utensils. Thus, sorghum cultivars that consistently produce relatively firm and nonsticky *tô* are preferred by consumers. Although consumers select firmer, nonsticky thick porridge primarily because of better texture and mouthfeel, the scarcity of water in areas (semiarid) where thick porridges are consumed is an important additional factor for their selection. Consumers often cannot afford to wash their hands and the cooking utensils with excess water.

The textural quality of sorghum *tô* differs significantly among different cultivars (Da et al 1982, Chandrashekar and Desikachar 1986, Kante 1987). Grain hardness is the most important and consistent grain characteristic that affects *tô* quality (Rooney et al 1986). Sorghums with corneous (hard) endosperm generally produce good quality *tô*, whereas very hard and very soft endosperm sorghums produce poor quality *tô*. The intermediate and soft sorghums are generally used for preparation of thin porridges and fermented or unfermented breads (e.g., *roti*), and very corneous sorghums are used for ricelike products (Chandrashekar and Desikachar 1986, Rooney et al 1986).

The physical and chemical bases for the observed differences in sorghum food quality are not well understood. The objectives of this study were to determine the relationships between *tô* quality and the physical and chemical properties of sorghum.

MATERIALS AND METHODS

Kernel and Milling Characteristics

Ten sorghum cultivars with different kernel characteristics (Table I) were grown at College Station, TX, in 1987. SC265, SC283, and SC605 are typical of West African sorghums; Tortillero, Dorado, and Sureno are improved sorghums released from Honduras; NSA740 and BTx3197 are kafir lines; whereas ATx623 × CS3541 and A155 × SC1207 are hybrids. Cultivars SC265, SC283, and NSA 740 were selected for more detailed studies because they had significantly different *tô* qualities and endosperm textures.

Endosperm texture was evaluated by subjectively rating the proportion of corneous to floury endosperm on a scale of 1 to 5. The smaller the number, the harder the texture (Rooney and Miller 1982).

Pericarp thickness was rated as thin, intermediate, or thick by visually observing a cross section of the pericarp that was scraped from 10 kernels with a razor blade. The amount of pericarp remaining on decorticated grain was determined by visually comparing the color of decorticated grains stained with the May-Grunwald dye (Scheuring and Rooney 1979). The amount of pericarp remaining was rated on a scale of 1 to 5; the higher the number, the greater the amount of pericarp remaining.

Grain (20 g) was decorticated for 4 min using the Tangential Abrasive Dehulling Device (TADD) (Reichert et al 1986) except for NSA740. Because NSA740 disintegrated into flour particles due to its soft, floury endosperm texture, it was decorticated to remove about 25% of its kernel weight by using a Strong Scott Barley Pearler equipped with a carborundum wheel from a Satake rice mill. Milling yield was calculated as the percentage of decorticated grain remaining after pericarp removal (Galiba et al 1987).

Whole or decorticated grains were ground into flours using an attrition mill (Kitchenetics model D, Campbell, CA) at its finest setting.

Particle size index (PSI) of flour was determined according to Galiba et al (1987) with slight modification. U.S. Standard sieve no. 100 was used in place of a no. 80 sieve; and particle size index (PSI) was calculated as $\Sigma a_i b_i$ divided by flour weight; where a is the weight of overs and b is the U.S. Standard sieve number. A fine flour (<250 μm) and coarse semolina (<250 μm) were prepared by sieving sorghum flour through U.S. Standard sieve no. 60. A medium flour (<425 μm) was prepared by sieving through U.S. Standard sieve no. 40.

---

[1] Contribution TA No. 24628 from the Texas Agricultural Experiment Station.

[2] Graduate research assistant, professor, and associate professor, respectively, Cereal Quality Laboratory, Soil and Crop Sciences Department, Texas A&M University, College Station 77843-2474.

TABLE I
Kernel and Milling Characteristics of 10 Sorghum Cultivars

Sorghum Cultivar	Pericarp/Plant Color	Pericarp Thickness	Endosperm Texture[a]	Milling Yield[b] (%)	Pericarp Remaining[c]
SC265	white/tan	thick	1.7	70.7	1.0
Dorado	white/tan	thick	2.9	75.4	2.0
Tortillero	white/tan	thin	2.9	74.4	2.0
BTx3197	white/purple	intermediate	3.2	67.5	2.5
SC283	white/purple	thin	1.1	82.5	3.0
Sureno	white/tan	thin	1.8	83.3	3.0
A155 × SC1207	white/purple	thick	2.9	72.5	3.5
ATx623 × CS3541	white/red	intermediate	2.8	73.0	4.0
SC605	red/purple	thin	1.1	82.0	5.0
NSA740	white/purple	thick	5.0	75.6[c]	5.0
LSD ($\alpha = 0.05$)	···	···	0.50	2.51	0.65
CV (%)	···	···	8.74	1.21	7.42

[a] Smaller number indicates harder texture.
[b] Milling yield using the Tangential Abrasive Dehuling Device.
[c] Determined by May-Grunwald staining of kernels; larger number indicates more pericarp remaining.
[d] Milling yield using the Strong Scott barley pearler equipped with a carborundum wheel from a Satake rice mill.

Tô Preparation and Quality Evaluation

Tô was prepared according to the method of Da et al (1982) from attrition-milled whole and decorticated sorghums and from the fine and medium flour fractions. Flour (9.6 g, dry basis) was slurried in 25 ml of distilled water and cooked with continous stirring in 20 ml of boiling 0.04*M* KOH solution (alkaline *tô*, pH 8.6) or 20 ml of boiling distilled water containing 1 ml of lemon juice (acidic *tô*, pH 4.6) or 20 ml of boiling water (neutral *tô*, pH 7.0). The freshly prepared *tô* was transferred into a beaker and allowed to cool for 1 hr at 23°C.

Tô was also prepared from isolated starch by cooking a starch slurry in 20 ml of boiling water (starch *tô*, pH 6.8). Sorghum starches were prepared by laboratory wet milling (Norris and Rooney 1970). Starch yields were 77% for NSA740 and 67% for SC265 and SC283 based on weight of starch. The starches contained $<$0.4% protein. The higher starch yield for NSA740 indicates that floury endosperm starch granules separate more easily from the protein matrix than the corneous endosperm starch granules during wet milling.

Textural quality (softness) of fresh *tô* (i.e., *tô* cooled for 1 hr at 23°C) was evaluated using the penetrometer test (Da et al 1982). *Tô* quality was rated as good ($\leq$7.00 mm), intermediate (7.10–8.00 mm) and poor ($>$8.10 mm) based on penetrometer readings.

Fractionation of *Tô* into Soluble and Insoluble Solids

Soluble and insoluble solids of fresh *tô* were prepared using the masa wet-fractionation procedure of Gomez et al (1988) with modifications. *Tô* was dispersed in water by mixing with a Waring Blendor at medium speed for 30 sec and at high speed for 90 sec (Fig. 1). Unlike masa, it was necessary to blend *tô* in water to uniformly disperse the agglomerated to particles. The dispersed *tô* was centrifuged at 5,000 × *g* for 15 min to obtain extract I and residue (Fig. 1). The residue was washed by dispersing it in water with a glass rod, vigorously hand-shaken for 30 sec, and then centrifuged again. Unlike the agglomerated *tô* particles, it was not necessary to blend the residual particles during washing of the *tô* residue because the components that agglomerated the *tô* were removed with the soluble solids component.

Extracts I and II (Fig. 1) were pooled and thoroughly mixed. The percentage of soluble solids in *tô* was calculated after drying a 25-ml aliquot of the pooled supernatant in a forced-air oven at 100°C for 24 hr.

Insoluble solids from *tô* were wet-sieved on a stack of 8-cm diameter U.S. Standard sieves, nos. 60, 100, and 325. The insoluble particles were classified into a fine fraction of $<$45 μm (throughs of sieve no. 325), a medium fraction of 45–250 μm (overs of sieve nos. 100 and 325), and a coarse fraction of $>$250 μm (overs of sieve no. 60).

Chemical Analyses

Moisture and ash contents were determined according to standard procedures (AACC 1983) except that moisture content of fresh *tô* (80–82%) was determined by drying at 100°C for 24 hr.

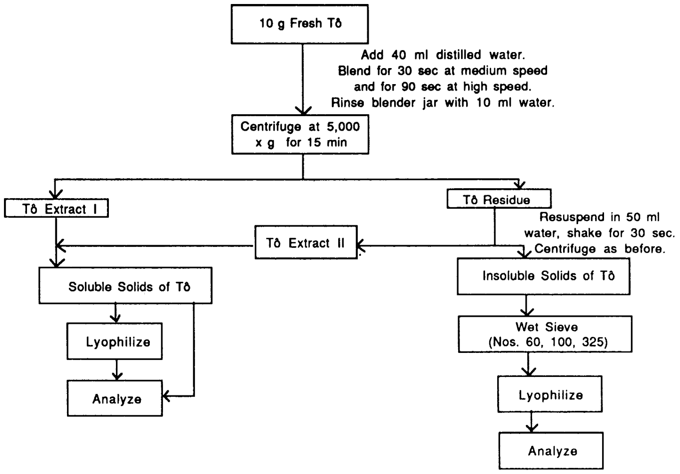

Fig. 1. Fractionation of *tô* into soluble and insoluble solids.

Protein (%N × 6.25) was determined by micro-Kjeldahl digestion (AACC 1983) followed by automated analysis of ammonia nitrogen (Technicon 1976).

Determinations were conducted in duplicate, and each determination was replicated; averaged results were expressed on a dry matter basis.

Analysis of variance and linear correlation coefficients were computed (SAS 1985). Differences between treatment means and the relationships between the physical, chemical, and *tô* properties were tested at the 5% level of significance using the least significant difference (LSD) and the Pearson product-moment correlation, respectively.

RESULTS AND DISCUSSION

Kernel and Milling Characteristics

The pericarp was white in all cultivars except SC605, which was red (Table I). The secondary plant color varied from tan to red to purple. Endosperm texture varied from soft to hard; SC283 and SC605 were very corneous (hard), SC265 and Sureno were corneous, NSA740 was completely floury (soft), and the other cultivars were intermediate.

Endosperm texture affected milling yield. Corneous sorghums had good milling quality compared to floury sorghums. SC283 and SC605 had a milling yield of 82–83%. NSA740 disintegrated into flour particles when it was decorticated with the TADD for only 1 min. This resulted in very poor milling yield ($<$5%); therefore, NSA740 was specially milled to obtain about 75% milling yield. Traditional milling of sorghum with a mortar and pestle generally yields 75–85% of decorticated grain (Scheuring et al 1982). In addition to endosperm texture, milling yield is affected by pericarp thickness and kernel size, shape, and density (Rooney and Miller 1982, Kante 1987). Kernels with a thick pericarp and intermediate to corneous endosperm are easier to decorticate during traditional milling. Weathered (deteriorated) and insect infested grains have poor milling yields.

The amount of pericarp removed during decortication was highest for SC265 and lowest for NSA740 and SC605 (Table I). Because NSA740 was decorticated gently, only the outer layers of its thick pericarp were removed. Consequently, the inner pericarp layers stained green. The red pericarp color of SC605 may have interfered with the ability of the exposed endosperm cells to stain pink. The amount of pericarp remaining after decortication was significantly related to softer endosperm texture ($r = 0.87$).

During traditional preparation of *tô*, sorghum is decorticated by hand pounding in a wooden mortar and pestle. Rural women spend about one-third of their daily working time milling cereals (Galiba et al 1987). Apparently, they recognize the adverse effect of large amounts of pericarp in traditional sorghum foods. Chandrashekar and Desikachar (1986) reported that polishing (pearling) of sorghum improved the quality of *mudde* (a *tô*-like thick porridge) by increasing retrogradation and decreasing α-amylase activity.

Flour Characteristics

The PSI of ground, whole grains of SC265 (59.6), SC283 (59.2), and NSA740 (58.8) did not differ significantly ($LSD_{0.05} = 0.85$). However, the PSI of ground, decorticated grains of SC265 (54.7), SC283 (49.9), and NSA740 (60.3) were significantly different ($LSD_{0.05} = 0.64$). Thus, whole ground grain contained more fine pericarp particles than decorticated ground grain.

Flour from whole and decorticated SC265 (corneous) and SC283 (very corneous) sorghums contained 40–52% fine flour fraction (<250 μm) and 48–60% coarse semolina (250–610 μm) (Fig. 2), whereas flour from NSA740 (floury) contained 60–63% fine flour fraction and 37–40% coarse semolina particles (Fig. 2). Kirleis and Crosby (1982) reported that the vitreous (hard) endosperm portion of sorghum forms larger particles, whereas the floury (soft) endosperm forms smaller particles. Flours from hard grains were also coarser, contained less damaged starch, and swelled less during cooking (Chandrashekar and Desikachar 1986).

Flour Composition

Flour from SC265 and SC283 whole grain contained higher amounts of protein than their corresponding decorticated grains (Table II). Obviously, decortication to remove the pericarp (bran) of the grain also results in partial removal of the aleurone layer, peripheral endosperm, and the germ, which have higher protein concentrations than the endosperm. Cultivars SC265 (good quality *tô*) and SC283 (intermediate quality *tô*) with corneous endosperm texture contained lower amounts of protein than NSA740 (poor quality *tô*) with a floury endosperm texture (Table II). NSA740 had a lower plant density and thus a higher protein content.

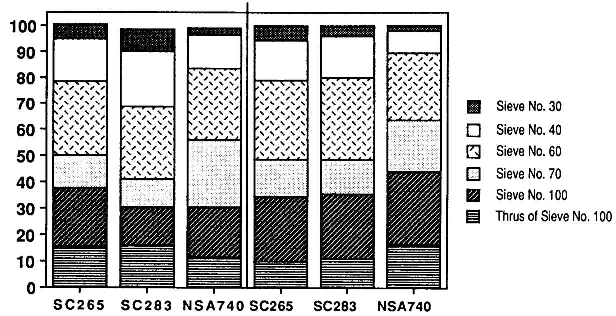

Fig. 2. Particle size distributions of flours from sorghums with different *tô* properties. $LSD_{0.05} = 2.66$; CV (%) = 7.57.

The protein contents of the fine, medium, and coarse flour fractions increased with increasing particle size, i.e., coarse > medium > fine (Table II). The higher protein content of the coarse semolina indicates that this fraction is composed mainly of corneous endosperm and peripheral endosperm cells. Sorghum grain decreases in protein concentration from the outer portion of the kernel towards the center (Rooney and Miller 1982).

The amount of flour protein was significantly correlated with softer endosperm texture ($r = 0.77$) and flour ash content ($r = 0.90$). Preliminary studies showed that flour protein content was significantly correlated with fat, starch, and pentosan contents (data not shown).

Whole grain flours contained more ash than the decorticated grain flours (Table II). This was expected because the germ and pericarp tissues of the kernel are partially removed during decortication.

The ash content of the fine flour fraction was higher than that of the medium fraction and the coarse semolina (Table II). Thus, the fine flour fraction also contains some germ and pericarp cells in addition to the floury endosperm particles. The germ, endosperm, and pericarp, respectively, account for about 62, 19, and 10% of total ash in whole sorghum flour (Watson 1984).

The amount of ash in decorticated grain flour was correlated positively with softer endosperm texture ($r = 0.97$) and with the amount of pericarp remaining on decorticated grains ($r = 0.96$). Thus, the efficiency of decortication may be determined by comparing the ash contents of different sorghum flours or flour fractions. Preliminary studies indicate that flour ash was correlated positively with protein, fat, and total pentosans of decorticated grain flour and correlated negatively with starch (data not shown).

Relationship Between Physicochemical Properties of Sorghums and *Tô* Quality

SC265 produced good quality firm *tô* (low penetrometer readings) at all cooking conditions, whereas cultivars NSA740, BTx3197, and SC605 produced poor quality, soft *tô* (Table III).

TABLE II
Protein and Ash Contents of Whole and Decorticated Sorghums and of Flour Fractions Prepared from Decorticated Sorghums[a]

Sorghum Sample	Protein (%N × 6.25)	Ash (%)
Whole grain		
SC265	13.2	1.4
SC283	13.5	1.4
NSA740	14.3	2.1
Decorticated grain		
SC265	12.1	0.92
SC283	12.5	1.00
NSA740	13.9	1.90
Fine fraction[b]		
SC265 (49.5%)	11.0	1.38
SC283 (41.0%)	11.3	1.67
NSA740 (57.0%)	9.84	2.11
Medium fraction[b]		
SC265 (78.4%)	11.6	0.94
SC283 (70.2%)	12.4	1.17
NSA740 (84.7%)	13.1	1.97
Coarse semolina[b]		
SC265 (50.5%)	13.1	0.48
SC283 (59.0%)	13.4	0.54
NSA740 (43.0%)	19.2	1.62
LSD ($\alpha = 0.05$)	0.59	0.06
CV (%)	1.77	2.23

[a] Values are means of replicate determinations in duplicate.

[b] Numbers in parenthesis = yield of fraction expressed as percentage of flour weight.

Other cultivars produced intermediate quality *tô*. Generally, corneous endosperm sorghum (e.g., SC265) produced acceptable quality *tô*; extremely corneous (e.g., SC283 and SC605) and extremely soft endosperm sorghums (e.g., NSA740) produced unacceptable quality *tô* (Table III). Softer endosperm texture significantly correlated with *tô* softness ($r = 0.89$).

Efficiency of pericarp removal during decortication appears to correspond to good *tô* quality of sorghums with similar endosperm texture. SC265 (good quality *tô*) and Sureno (intermediate quality *tô*) have similar corneous endosperm texture but different *tô* quality and extent of pericarp removal (Table I). *Tô* softness significantly correlated ($r = 0.92$) with the extent of pericarp remaining after decortication.

Tô prepared from ground decorticated grain was firmer in texture than *tô* from ground whole grain (Table III). The presence of more bran (pericarp) in the whole flour contributed to this difference in texture; presumably, the bran competes with starch for moisture, thus limiting starch solubilization and retrogradation. In addition, the bran physically disrupts the gelled *tô* structure. Increased amounts of solubilized and retrograded amylose in *tô* result in increased tô firmness (*unpublished*).

Tô prepared from whole grain flour had a darker color than that from decorticated grain flour. Sorghum pericarp contains phenolic compounds that cause undesirable dark *tô* color, especially for alkaline *tô*.

Tô prepared from different particle size fractions had different textures (Fig. 3). *Tô* of poor quality resulted from fine flour particles <250 μm), and medium size flour particles (< 425 μm) produced intermediate quality *tô*. However, *tô* of good (SC265) and intermediate (SC283) qualities resulted from unsieved flour particles. The protein and ash contents of the sorghum flours and flour fractions were significantly different, as shown in Table II.

Preliminary studies indicated that *tô* softness is significantly positively correlated with the protein, ash, fat, and pentosan contents of decorticated sorghum grain irrespective of the *tô* pH. Starch content was negatively correlated with *tô* softness (data not shown). Because the firmness of sorghum *tô* is related to endosperm texture, and endosperm starch constitutes about 92% of the total kernel starch, it has been suggested that starch influences *tô* quality to a large extent. It appears that the amount, origin (corneous vs. floury endosperm), and interaction of starch with other sorghum flour components affects *tô* firmness.

Starch Functionality in Relation to *Tô* Quality

Isolated sorghum starch (<45 μm, throughs of sieve no. 325) produced firmer *tô* (Fig. 3) than the flour counterparts. However, the ranking of *tô* quality prepared from isolated starch and from flour was identical. This observation supports the view that other flour components (i.e., protein, fiber, lipids, and minerals) adversely affect the functionality of starch during *tô* preparation. Apparently, this is why improvement in food quality of traditional porridges prepared from isolated cereal starches (e.g., *ogi* and *agidi*) is possible in most African countries.

TABLE III
Evaluation of Textural Quality of *Tô* Prepared at Three pH Levels from Ground Decorticated Sorghums Using a Penetrometer[a]

Sorghum Cultivar	Acidic (pH 4.6)	Neutral (pH 7.0)	Alkaline (pH 8.6) Decorticated	Alkaline (pH 8.6) Whole
SC265	6.20	6.65	6.81	7.25
Dorado	7.58	7.98	7.88	8.43
Tortillero	7.80	7.90	8.08	8.90
BTx3197	8.50	8.90	8.80	8.85
SC283	7.80	7.88	7.83	8.65
Sureno	7.60	7.80	7.90	8.70
A155 × SC1207	7.90	8.05	8.63	9.17
ATx623 × CS3541	7.70	7.78	7.98	8.53
SC605	9.08	8.85	9.08	9.65
NSA740	10.0	10.0	10.0	10.0
LSD ($\alpha = 0.05$)	0.14	0.13	0.17	0.25
CV (%)	1.20	1.12	1.14	3.90

[a] Data are millimeters penetrated; lower number indicates firmer (better) texture.

Fine flour particles (<250 μm) produced poorer quality *tô* than isolated starch (<45 μm) (Fig. 3). Apparently, the presence of other flour components inhibited starch functionality of the fine flour fraction. Also, the starch in the fine flour fractions was probably from the floury endosperm fraction. Cagampang and Kirleis (1985) reported that firmer alkali gels resulted from corneous endosperm starch than from floury endosperm starch.

Relationship Between *Tô* Quality and pH

Tô quality was affected by the pH of the cooking media. Generally, acidic *tô* was firmer in texture than neutral and alkaline *tô* (Table III). Mild acid hydrolysis of starch increases the retrogradation of starches (Whistler and Johnson 1948) and probably

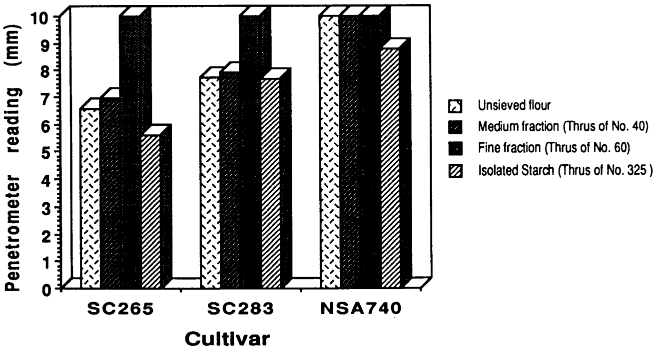

Fig. 3. Texture of *tô* (pH 8.6) prepared from selected sorghum flour fractions and from isolated starch (pH 6.8). $LSD_{0.05} = 0.20$; CV (%) = 1.06.

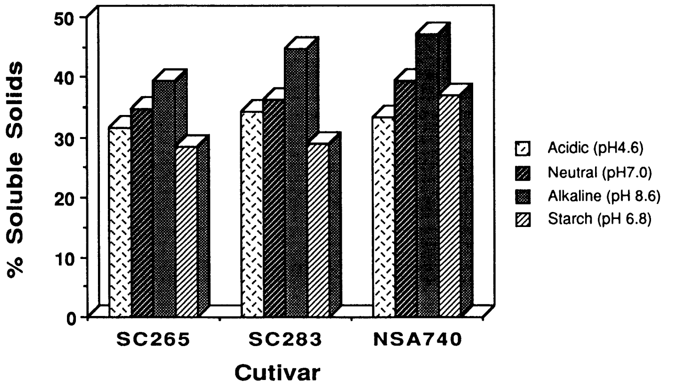

Fig. 4. Soluble solids in *tô* prepared at three pHs from ground decorticated sorghum and at pH 6.8 from isolated sorghum starch. $LSD_{0.05} = 2.76$; CV (%) = 7.54.

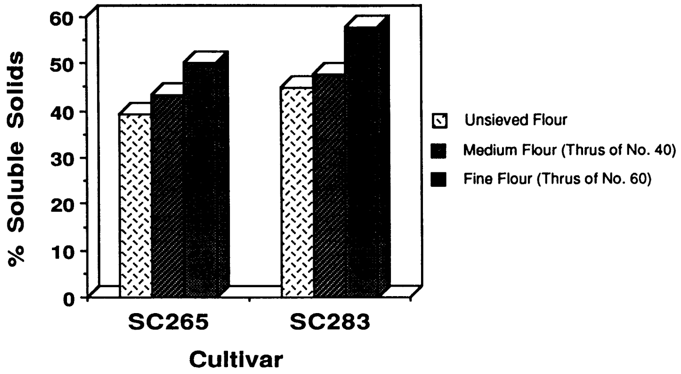

Fig. 5. Soluble solids in alkaline *tô* prepared from selected flour fractions. $LSD_{0.05} = 1.50$; CV (%) = 7.44.

caused the firmer texture of acidic tô. Alkaline *tô* is a more sensitive index of *tô* quality, however, because sorghum with good alkaline *tô* properties definitely has good acidic *tô* properties, but the reverse is not always true.

Soluble Solids in *Tô*

The amount of soluble solids in *tô* was affected by pH, flour particle size, and *tô* quality. Soluble solids content was 32–35% of acidic *tô*, 35–40% of neutral *tô*, and 40–47% of alkaline *tô* (Fig. 4). Apparently, more gelatinized starch, protein, and other flour components were dissolved under alkaline conditions than under acidic and neutral conditions. Isolated starches produced *tô* with the lowest amounts of soluble solids (29-37%) (Fig. 4). Fine and medium flour fractions produced *tô*s with 10–13% and 2–10% higher soluble solids, respectively, than *tô* from unsieved flour (Fig. 5).

Good quality, firm *tô* had less soluble solids than poor quality, soft *tô*. Hence, higher pH, smaller flour particle size, and poor *tô* quality correspond to increased soluble solids (Figs. 4 and 5). The amount of soluble solids of alkaline *tô* correlated with softer *tô* texture ($r = 0.81$) and could thus be used as an index of sorghum *tô* quality.

Preliminary characterization of *tô* (using high-performance size-exclusion chromatography) indicated that more total amylopectin than amylose was solubilized during *tô* preparation. The apparent amylose contents of SC265, SC283, and NSA740 decreased in that order (data not shown). Jackson et al (1988) reported that the water solubility of amylopectin and amylose need not conform to the ratio of these components in native starch.

Particle Size Distribution of Insoluble Solids of *Tô*

The insoluble solids in *tô* from SC265 (good quality *tô*) and SC283 (intermediate quality *tô*) contained a similar distribution of fine, medium, and coarse fractions (Fig. 6). The fine fraction of NSA740 (poor quality *tô*) was 10% higher and the coarse fraction was 10% lower than those of SC265 and SC283. During *tô* preparation, the flour slurry was continously stirred to prevent the formation of undesirable lumps in the cooked product. Good quality *tô* appears to contain a certain proportion of coarse semolina particles.

CONCLUSION

Sorghum cultivars with different kernel characteristics had different *tô* qualities. Endosperm texture, amount of pericarp remaining on decorticated grain, flour particle size distribution, and the amount of soluble solids in *tô* were related to *tô* quality and can help predict sorghum porridge quality.

Corneous textured sorghums generally produced good quality *tô*. *Tô* prepared from decorticated ground sorghum was firmer than *tô* from whole ground sorghum presumably due to the adverse effect of the pericarp on starch functionality. The pericarp probably competes with starch for moisture, thus limiting starch solubilization and retrogradation. Isolated sorghum starches (<45 μm) produced the firmest *tô*, indicating that starch plays a major role in the determination of *tô* quality. The presence of other flour components (protein, fiber, lipid, and ash) adversely affected the functionality of starch during *tô* preparation from sorghum flour.

Generally, acidic *tô* was firmer than neutral and alkaline *tô*. However, alkaline conditions provided the most sensitive index of *tô* quality evaluation in breeding programs.

The firmer the *tô*, the lower the amount of soluble solids. Further research is in progress to characterize the dissolved starch, pentosan, and protein in *tô*.

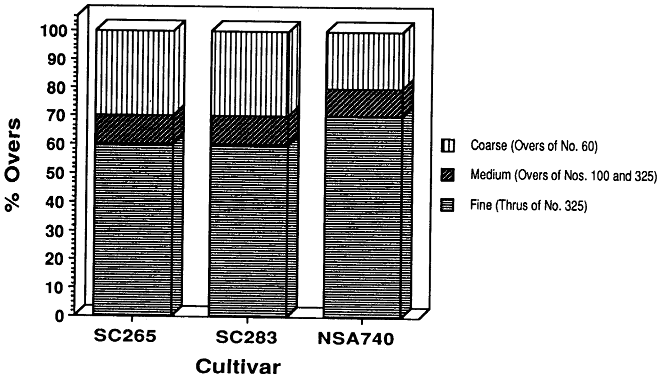

Fig. 6. Particle size distribution of insoluble solids in *tô*. $\text{LSD}_{0.05} = 2.55$; CV (%) = 7.54.

ACKNOWLEDGMENTS

The authors wish to thank members of the Cereal Quality Laboratory at Texas A&M University for their technical assistance. Financial support for this research was provided partially by the INTSORMIL Title XII Sorghum and Millet Research Program and by Grant AID/DSAN/XII/G-0149 from the Agency of International Development, Washington, DC 20253.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC. Methods 08-01 and 44-15a, revised October 1981; Method 46-09, reviewed October 1982. The Association: St. Paul, MN.

CAGAMPANG, G. B., and KIRLEIS, A. W. 1985. Properties of starches isolated from sorghum floury and corneous endosperm. Starch/Staerke 8:253.

CAGAMPANG, G. B., GRIFFITH, J. E., and KIRLEIS, A. W. 1982. Modified adhesion test for measuring stickiness of sorghum porridges. Cereal Chem. 59:234.

CHANDRASHEKAR, A., and DESIKACHAR, H. S. R. 1986. Studies in sorghum quality part II. Suitability for making dumpling (*mudde*). J. Food Sci. Technol. 23:7.

DA, S., AKINGBALA, J. O., ROONEY, L. W., and MILLER, F. R. 1982. Evaluation of *tô* quality in a sorghum breeding program. Pages 11–23 in: Proc. Int. Symp. Sorghum Grain Quality. L. W. Rooney, D. S. Murty, and J. V. Mertin. eds. International Crop Research Institute for the Semi-Arid Tropics (ICRISTAT): Patancheru, India, October 28-31, 1981.

GALIBA, M., ROONEY, L. W., WANISKA, R. D., and MILLER, F. R. 1987. The preparation of sorghum and millet couscous in West Africa. Cereal Foods World 32:878.

GOMEZ, M. H., WANISKA, R. D., and ROONEY, L. W. 1988. Masa fractionation: A method for control of nixtamalization process. Cereal Foods World 33:674.

HOSENEY, R. C. 1986. Pages 293-296 in: Principles of Cereal Science and Technology. Am. Assoc. Cereal Chem.: St Paul, MN.

JACKSON, D. S., CHOTO-OWEN, C., WANISKA, R. D., and ROONEY, L.W. 1988. Characterization of starch cooked in alkali by aqueous high-performance size-exclusion chromatography. Cereal Chem. 65:493.

KANTE, A. 1987. Factors Affecting the Porridge Quality of Sorghum and Pearl Millet. M.S. thesis. Texas A&M University, College Station, TX.

KIRLEIS, A. W., and CROSBY, K. O. 1982. Sorghum hardness: Comparison of methods for its evaluation. Pages 231-241 in: Proc. Int. Symp. Sorghum Grain Quality. L. W. Rooney, D. S. Murty, and J. V. Mertin, eds. International Crop Research Institute for the Semi-Arid Tropics (ICRISTAT): Patancheru, India, October 28-31, 1981.

NORRIS, J. W., and ROONEY, L. W. 1970. Wet milling properties of four sorghum parents and their hybrids. Cereal Chem. 47:64.

REICHERT, R. D., TYLER, R. T., YORK, A. E., SCHWAB, D. J., TATARRYNIWICH, J. E., and MWASARU, M. A. 1986. Description of a model of the Tangential Abrasive Dehulling Device (TADD) and its application to breeders' samples. Cereal Chem. 63:201.

ROONEY, L. W., and MILLER, F. R. 1982. Variation in the structure and kernel characteristics of sorghum. Pages 143-162 in: Proc. Int. Symp. Sorghum Grain Quality. L. W. Rooney, D. S. Murty, and J. V. Mertin, eds. International Crop Research Institute for the Semi-Arid Tropics (ICRISTAT): Patancheru, India, October 28-31, 1981.

ROONEY, L. W., KIRLEIS, A. W., and MURTY, D. S. 1986. Traditional foods from sorghum: Their production evaluation and nutritional value. Adv. Cereal Sci. Technol. 8:317-353.

SCHEURING, J. F., and ROONEY L. W. 1979. A staining procedure to determine the extent of bran removal in pearled sorghum. Cereal Chem. 56:545.

SCHEURING, J. F., SIDIBE, S., and KANTE, A. 1982. Sorghum alkali *tô*: Quality considerations. Page 24-31 in: Proc. Int. Symp. Sorghum Grain Quality. L. W. Rodney, D. S. Murty, and J. V. Mertin. eds. International Crop Research Institute for the Semi-Arid Tropics (ICRISTAT): Patancheru, India, October 28-31, 1981.

STATISTICAL ANALYSIS SYSTEM (SAS). 1985. SAS Users guide. Statistics, Version 6. SAS Institute, Cary, NC.

TECHNICON. 1976. Autoanalyzer II Industrial Method No. 334-74A/A. Technicon Instrument Corp.: Tarrytown, NY.

WATSON, S.A. 1984. Corn and Sorghum Starches: Production. Pages 417-464 in: Starch Chemistry and Technology, 2nd ed. R. L. Whistler, J. N. BeMiller, and E. F. Paschall, eds. Academic Press: Orlando, FL.

WHISTLER, R. L., and JOHNSON, C. 1948. Effect of acid hydrolysis on the retrogradation of amylose. Cereal Chem. 25:418.

[Received March 6, 1989. Accepted July 10, 1989.]