Relationship of Sorghum Grain Hardness to Selected Physical and Chemical Measurements of Grain Quality[1]

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ABSTRACT

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Selected physical and chemical measurements were used to determine grain quality of 15 sorghum cultivars differing widely in degree of grain hardness (endosperm texture). All assays were done on pearled grains. Results of the modified adhesion test, Instron back-extrusion test, alkali gel stiffness test, and weight ratio of cooked to uncooked grain were strongly correlated with grain vitreousness. The alkali disintegration test and microamylograph viscosities (peak and hot paste) were significantly but weakly correlated with grain vitreousness. Fats, ash, total sugars, soluble and kafirin proteins, and amylose content had some association with grain vitreousness.

Sorghum (*Sorghum bicolor* L. Moench) competes with wheat, rice, and maize as a food crop in the developing world. Little is known about the physical and chemical properties that affect the processing and food-making properties of sorghum grain (Deyoe and Robinson 1979, Hulse et al 1980). The consumption of sorghum, as opposed to rice and wheat, as a staple food in arid regions of Africa and Asia is so diverse that no single criterion of quality can be identified. These factors have hindered the progress of plant breeders in selecting agronomically improved sorghum cultivars with acceptable grain quality.

The influence of certain physical characteristics of the grain, such as hardness or vitreousness, on the quality of traditional sorghum food products has been well demonstrated (Murty and House 1980, Scheuring 1980, Rooney et al 1980, Scheuring et al 1982). Recently, grain hardness was shown to be strongly associated with the texture of cooked sorghum porridges (Cagampang et al 1982). Sorghum grain with a high proportion of corneous endosperm produced stiffer gels than did floury type grain. Accordingly, techniques that directly measure differences in the textural characteristics of the cooked product, such as texture of the cooked paste, should be useful tools in a breeding program in which sorghum lines are screened for food quality.

The functional food-making properties of the major chemical constituents in rice and wheat have been well characterized. For instance, in rice the ratio of the starch fractions (amylose to amylopectin), along with protein, was established to be the major influence on the cooking and eating quality of the grain (IRRI 1979, Juliano et al 1972, 1981). Other rice grain components (lipids and hemicelluloses) have a minor effect on grain food quality (Juliano 1980). Because wheat is a staple food in many parts of the developed world, utilization of the grain as a food is well understood (Pomeranz 1971, 1980). Some factors still need to be resolved, however. The functional properties of sorghum grain components are not as well understood as those of rice and wheat.

To elucidate some of the physicochemical factors affecting sorghum grain quality, we have modified several simple rice quality techniques and used them to evaluate and characterize a number of sorghum cultivars varying widely in grain hardness. Thus, our study was designed to demonstrate the association between sorghum grain hardness and each of the indices examined.

MATERIALS AND METHODS

Fifteen sorghum cultivars varying in grain hardness were used in this study. Twelve of the cultivars were grown at the Purdue University Agronomy Farm, West Lafayette, IN, during the 1980 crop year, and the remaining three were grown at Halfway, TX, during the 1979 or 1980 crop year (Table I). All grain samples were uniformly pearled in a barley pearler to obtain approximately a 70% pearled grain yield as described by Cagampang et al (1982). Subsamples of the pearled grain were ground into flour in a Udy cyclone mill (Boulder, CO) to pass through a 0.4-mm round-hole screen.

Proximate analyses (moisture, protein, fat, and ash) of the flour were determined by AACC (1983) approved methods 44-10, 46-12, 30-25, and 08-01, respectively.

A modification of the method described by Esen (1980) was used to determine kafirin content of the flour. Two hundred milligrams of ground pearled grain were extracted with 10 ml of 60% (v/v) tertiary butanol by agitating for 2 hr on a reciprocal shaker at 60 cycles per minute. The extracted protein was separated from the residue by centrifugation at $1{,}000 \times g$ for 20 min and was dried for nitrogen analysis. 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 by a factor of 6.25.

Water-soluble proteins were extracted from the flour by shaking 200 mg of the flour with 10 ml of water in a 15-ml screw-capped centrifuge tube for 2 hr at 4°C. The suspension was centrifuged at $1{,}500 \times g$ at 0°C for 10 min, and the clear supernatant was assayed

TABLE I
Grain Hardness and Minor Chemical Components of Pearled Sorghum Cultivars Used in the Grain Quality Study[a]

Cultivar[b]	Vitreousness[c] (%)	Ash (%)	Fat (%)	Total Sugar (mg/100 g)
SC-283-14*	88 a	0.60 d	0.22 g	160 h
954062	62 b	0.56 e	1.14 cd	471 de
954114	61 bc	0.48 f	1.05 de	344 f
CS-3541*	61 bc	0.71 c	1.30 cd	460 e
IS0469	58 bcd	0.56 e	1.38 c	371 f
P721N	56 bcd	0.64 d	1.31 cd	165 h
954063	55 bcd	0.55 e	0.86 ef	290 g
IS0452	55 bcd	0.64 d	1.90 b	503 d
IS4225	52 bcd	0.37 g	0.71 f	172 h
954100	49 cd	0.45 f	1.29 cd	353 f
M35-1*	47 d	0.43 f	0.51 fg	298 g
954130	47 d	0.57 e	1.43 c	720 b
IS1461	26 e	0.63 d	1.30 cd	549 c
P7210	12 f	1.02 a	2.28 a	810 a
850649	10 f	0.85 b	1.93 b	702 b
CV (%)[d]	20.2	2.01	7.07	5.32

[a]All values reported are on dry basis and are mean of two determinations except grain hardness data, which is the mean of 30 determinations. Means followed by the same letter are not significantly different at $P = 0.01$.
[b]Unmarked samples grown at West Lafayette, IN, in the 1980 crop year. * indicates samples grown at Halfway, TX, in the 1979 crop year except CS-3541, which was grown in the 1980 crop year.
[c]Percent vitreousness values supplied by Kirleis and Crosby (1982).
[d]CV (%) = coefficient of variation for the replicates.

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for protein content by the method described by Lowry et al (1951). Crystalline bovine serum albumin was used in the preparation of the standard protein curve.

The soluble sugars were extracted from 100 mg of flour with 10 ml of boiling 80% (v/v) ethanol for 10 min with a Tekmar Tissumizer (Tekmar Company, Cincinnati, OH). The ethanol extract was clarified by centrifugation at 1,500 × *g* for 15 min. The clear supernatant was assayed for total sugar content with anthrone reagent as suggested by McCready et al (1950). The standard sugar curve was prepared with anhydrous glucose.

Total and hot-water-soluble amylose were determined colorimetrically by the method of Williams et al (1958) as modified by Juliano (1971).

Stickiness of cooked sorghum porridge was determined with an Instron model 1132 food-testing machine by the adhesion method described by Cagampang et al (1982).

The texture of cooked pearled grain was determined with an Instron model 1132 food-testing machine by employing the micro back-extrusion method of Cagampang et al (1983). It is a measure of the percentage of water absorbed by the grain during cooking.

The ratio of cooked to uncooked grain weight was calculated with data obtained from the cooked-grain texture test described by Cagampang et al (1983).

Alkali gel stiffness measurements were performed by modifying a method described by Cagampang et al (1973). The modified procedure consisted of combining 200 mg of flour with 3 ml of 0.2*N* KOH in a 16 × 150-mm culture tube, placing the tubes in a vigorously boiling water bath for 8 min, and allowing the thickened mixture to stand upright at room temperature for 30 min to form a stiff gel. After cooling, the gel tubes were laid flat over ruled paper for 1 hr at room temperature, and the gel front migration was read to the nearest millimeter.

The alkali digestibility of pearled unbroken grain was determined by modifying the procedure developed by Little et al (1958) for rice. Six pearled kernels were placed in a 60 × 15-mm petri dish and covered with 10 ml of a 1.75% (w/v) KOH solution. The covered petri dishes were placed in a 30°C incubator for 18 hr and then scored on a six-point scale on which 1 = kernel not affected; 2 = kernel swollen; 3 = kernel much enlarged, corroded, or rough on edges; 4 = kernel elongated (split or segmented); 5 = kernel dispersed (chalky, milky, or cottony center); and 6 = kernel completely digested. The reported alkali digestibility scores are the mean scores of six kernels.

The micro-Brabender Visco/Amylograph was used to compare the pasting viscosities of a flour–water solution. The curves were obtained on a mixture of 20 g of flour and 100 ml of water heated at a rate of 1.5°C per minute from 30 to 93°C and then holding the temperature at 93°C for 20 min. From the heating curves, the peak viscosity and the viscosity at the end of the 93°C holding period were recorded in Brabender units (BU).

Birefringence endpoint temperatures of flour samples were determined microscopically by Watson's (1964) method.

Grain hardness of the sorghum samples was measured by the vitreousness test described by Kirleis and Crosby (1982).

The results of the various physical and chemical measurements for grain quality were analyzed by a one-way analysis of variance (ANOVA) and tested for level of significance by the Newman-Keul method of multiple comparison (Nie et al 1975). The various measured properties were compared for relationships by the coefficient of linear correlation.

RESULTS AND DISCUSSION

Most of the world's sorghum-consuming population have long recognized the close association between grain hardness and the textural characteristic of the corresponding cooked sorghum food product. For this reason, in recent studies dealing with sorghum grain food quality, much emphasis has been placed on the relationship between grain hardness and food texture. In this article, we examine the relationships between grain hardness and selected physicochemcial grain characteristics related to grain quality.

In sorghum, endosperm texture refers to the proportion of the corneous (hard) fraction of the endosperm with respect to the floury (soft) endosperm fraction. In this study, endosperm texture is expressed as percent vitreousness. Because endosperm texture determines grain hardness in sorghum, the terms *grain hardness* and *percent vitreousness* will be used interchangeably.

The vitreousness values of the 15 sorghum cultivars ranged from 88% for the most corneous samples (SC-283-14) to 10% for the nearly completely floury sample (850649) (Table I).

Minor Chemical Components

Table I shows the ash, lipid, and total sugar content of the sorghum cultivars that were pearled to yield approximately 70% pearled grain. The values ranged from 0.37–1.02% ash, 0.22–2.28% lipid, and 160–810 mg/100 g of free sugars (d.b.). The outer parts of the sorghum seed and the germ have been reported to contain high levels of ash, fats, and sugars (Hubbard et al 1950).

Consequently, the differences in the amounts of these components in the pearled grain may in part reflect differences in the pearling characteristics of the grain. In this study, although degree of pearling was made as comparable as possible (about

TABLE II
Major Chemical Components of 15 Pearled Sorghum Cultivars

Cultivar	Protein[a] Total[b] (% N × 6.25)	Fractions Soluble[b,c] (%)	Fractions Kafirin[b,c] (%)	Amylose[a,b] Total (%)	Amylose[a,b] Hot-Water-Soluble (%)
SC-283-14	9.80 h	0.072 e	6.55 ab	29.0 a	16.2 c
954062	12.6 c	0.121 de	6.88 ab	26.2 d	11.2 k
954114	11.3 f	0.074 e	5.84 d	27.0 c	15.1 d
CS-3541	11.7 e	0.153 cd	6.20 c	25.1 e	10.1 c
IS0469	14.0 a	0.076 e	8.75 a	25.5 e	14.9 e
P721N	11.9 de	0.191 bc	5.54 e	26.9 cd	16.3 b
954063	10.7 gh	0.074 e	5.51 e	25.0 e	14.7 f
IS0452	12.8 b	0.109 de	7.45 b	24.9 e	14.3 g
IS4225	10.9 g	0.098 de	6.11 c	28.7 a	16.9 a
954100	12.8 c	0.109 de	6.80 c	28.1 b	15.1 e
M35-1	10.6 gh	0.073 e	7.46 b	26.6 cd	12.9 j
954130	12.8 c	0.124 de	6.46 ab	26.4 cd	14.2 g
IS1461	10.9 g	0.174 bc	5.95 d	25.3 e	14.0 h
P7210	12.2 d	0.398 a	4.59 f	25.2 e	13.1 i
850649	10.3 h	0.207 b	3.98 f	24.8 e	9.0 m
CV (%)[d]	1.07	13.0	4.14	1.83	0.60

[a]Means followed by the same letter are not significantly different at $P = 0.01$.
[b]Means of two values, dry basis.
[c]Soluble protein is expressed as milligrams per 100 g of sample. Kafirin is in grams per 100 g of protein, or percent of total protein.
[d]CV (%) = coefficient of variation for the replicate.

TABLE III
Correlations Between Percent Vitreousness and Some Chemical Parameters for Grain Quality

Grain Chemical Components	Percent Vitreousness[a]
Minor	
Total sugars	−0.73**
Fats (%)	−0.70**
Ash (%)	−0.58*
Major	
Protein	
Total	0.01
Water-Soluble	−0.72**
Kafirin	0.67**
Amylose	
Total	0.52*
Hot-water-soluble	0.46*

[a]** and * indicate significance at $P = 0.01$ and $P = 0.05$, respectively.

70%), cultivars vary in the amount of brokens obtained during pearling.

Major Chemical Components

Proteins. Protein content of the 15 pearled sorghum cultivars ranged from 9.80 to 14.0% (Table II). In this study, the correlation between percent vitreousness and total protein was not significant (Table III). When the pearled grain water-soluble and kafirin protein content were related to grain hardness, significant correlations were obtained. The water-soluble protein content ranged from 0.072 to 0.398%, whereas kafirin protein content ranged from 3.98 to 8.75% for the 15 samples (Table II). Both soluble protein ($r = 0.72$**) and kafirin protein ($r = 0.67$**) content were found to be highly significantly correlated with grain percent vitreousness (Table III). Accordingly, vitreous cultivars tended to have fewer of the soluble proteins but more of the kafirin proteins in the endosperm, implicating the involvement of these protein fractions with endosperm texture. This trend was reflected in the data obtained by Guiragossian et al (1978) that showed that the level of kafirin in germless undecorticated seeds of P721 N, a corneous cultivar, was almost twice that of its isogenic soft-endosperm counterpart (P721 O). In this study, we found a ratio of 1.21 between the kafirin protein level of P721 N and P721 O pearled grains.

TABLE IV
Stickiness of Cooked Paste, Texture of Cooked Grain, Cooked to Uncooked Grain Weight Ratio, and Alkali Gel Stiffness of Some Pearled Sorghum Cultivars

Cultivar	Adhesion (stickiness) Value[a,b] (g)	Alkali Gel Stiffness[a,b] (mm)	Cooked Grain Texture[a,b] (cm-kgf)	Cooked to Uncooked Grain Weight Ratio[a,b]
SC-283-14	453 g	83 a	13.2 a	3.05 f
954062	610 f	46 f	7.86 cd	3.71 bc
954114	1,100 cde	47 f	8.67 bc	3.66 bcd
CS-3541	1,015 de	58 c	9.28 b	3.54 cde
IS0469	1,185 cd	50 de	7.87 cd	3.60 bcde
P721N	1,145 cd	46 f	8.70 bc	3.44 e
954063	1,245 c	41 g	8.50 bc	3.71 bc
IS0452	945 e	49 ef	7.07 de	3.48 de
IS4225	1,015 de	51 de	6.85 e	3.63 bcde
954100	1,275 c	52 d	7.53 de	3.54 cde
M35-1	1,040 de	75 b	8.68 bc	3.06 f
954130	1,145 cd	47 f	9.12 b	3.49 de
IS1461	1,480 b	41 g	4.58 g	3.75 b
P7210	1,530 b	29 i	5.41 f	3.74 bc
850649	1,755 a	34 h	3.26 h	4.49 a
CV (%)[c]	4.82	2.35	18.74	1.56

[a] Means followed by the same letter are not significantly different at $P = 0.01$.
[b] Means of two values.
[c] CV (%) = coefficient of variability for the replicates.

TABLE V
Correlations Between Percent Vitreousness and Some Physical Parameters for Grain Quality for 15 Sorghum Cultivars

Quality Indices	Percent Vitreousness[a]
Adhesion (stickiness) value	−0.89**
Alkali gel stiffness value	0.71**
Cooked grain texture	
Energy	0.90**
Cooked to uncooked grain weight ratio	−0.68**
Amylograph viscosities	
Peak	−0.67**
Hot paste	−0.65**
Alkali digestibility score	0.59*
Birefringence endpoint temperatures	
Initial	−0.07
Final	−0.31

[a] ** and * indicate significance at $P = 0.01$ and $P = 0.05$, respectively.

Amylose. The total amylose content for the pearled sorghum grains ranged from 24.8 to 29.0% (d.b.) (Table II). When related to the percent vitreousness data, total amylose was highly significantly correlated ($r = 0.52$**) (Table III). However, only 27% of the variation in the amylose content can be accounted for by grain hardness.

As shown in Table II, hot water-soluble amylose showed a wider range of values among the 15 sorghum cultivars (9.0–16.9). However, the amount of amylose that solubilized in the cooking water indicated a low correlation with grain hardness ($r = 0.46$*) (Table III).

Physical Measurements

Adhesion test. A previous report showed that the stickiness of sorghum porridges was influenced by grain hardness (Cagampang et al 1982). The adhesion values obtained for pearled grain ranged from 435 to 1,755 g (Table IV). When related to the percent vitreousness data, a highly significant correlation ($r = -0.89$**) between adhesion value and vitreousness was found (Table V). This result supports our earlier observation concerning the usefulness of the adhesion test as a method for objectively evaluating the texture of cooked sorghum paste.

Alkali gel stiffness. Gel-stiffness values for the 15 sorghum cultivars varied from 34.0 mm for the soft cultivar (850649) to 83.0 mm for the highly corneous grain (SC-282-14) (Table IV). A fairly strong, highly significant correlation ($r = 0.71$**) between gel stiffness value and percent vitreousness was found (Table VI). Thus, grain from the most vitreous cultivars produced the most runny gel. Our finding confirms results reported by Murty et al (1982a), who found a correlation coefficient of 0.54 (significant at $P = 0.01$) between KOH gel consistency and grain hardness. In another study, Murty et al (1982b) reported a gel flow range of 49–115 mm for 25 cultivars, using dehulled grain, and a positive association with the texture of several traditional sorghum preparations (*roti, soru,* and *sankati*). Apparently, the simplicity of the test, the small sample size, and the close association of the sample size with grain hardness makes the test well suited for use in a breeding program for evaluating the textural properties of cooked sorghum gruels.

Cooked grain texture. Because decorticated sorghum is boiled as whole grain (as rice is) and consumed as whole grain in some parts of the semiarid tropics (Subramanian et al 1982), an Instron back-extrusion technique was used to measure the texture of boiled sorghum grain. The results obtained on pearled grain showed that the samples had a wide range of cooked grain texture (Table IV). The soft cultivar (850649) required the least energy (3.26 cm-kgf), while the most vitreous cultivar (SC-283-14) required the greatest amount of energy (13.2 cm-kgf) for back extrusion. As indicated by the highly significant correlation coefficient ($r = 0.90$**) between percent vitreousness and energy value (cooked grain texture (Table V) these two parameters are strongly related. In fact, the linear trend accounts for 81% of the variation in cooked grain texture among the sorghum cultivars examined.

This result demonstrates that the Instron cooked grain texture test is as good as the adhesion test for predicting texture of sorghum cooked product, although the cooked grain texture procedure measurements are made on boiled decorticated grain instead of a cooked paste. The test may also be a useful screening test in a breeding program, as only a 5.0 g grain sample is required. Thus, the method could replace or supplement the assessment of cooked product texture by the traditional panel evaluation, which generally requires a large quantity of sample and trained panel members. The reliability of instrumental texture measurements has been previously demonstrated by Sterling (1978), Blackney (1979), and Juliano et al (1981) for assessing the texture of cooked rice.

Cooked to uncooked grain weight ratio. An obvious consumer consideration in addition to palatability and texture for boiled rice is expansion of the grain during cooking (Juliano 1980). As pearled sorghum has been suggested as a rice substitute, data on the weight ratio of cooked to uncooked pearled grain were collected in conjunction with the test on cooked grain texture. The ratios ranged from 3.05 for the highly vitreous cultivar (SC-283-14) to 4.49

TABLE VI
Amylograph Viscosities, Alkali Digestibility of Birefringence Endpoint Temperature of Some Sorghum Cultivars[a]

Cultivar	Amylograph Peak (BU)	Viscosities[b] Hot Paste (BU)	Alkali Digestibility (score)	Birefringence Endpoint Temperature[a,c]	
				Initial (°C)	Final (°C)
SC-283-14	180 k	180 i	5.3 a	56.2 fg	66.0 e
954062	180 k	178 i	2.8 c	55.1 g	60.5 g
954114	260 g	265 e	4.4 b	59.8 bc	66.9 e
CS-3541	248 h	245 f	4.4 b	56.0 g	66.5 e
IS0469	290 e	250 f	5.2 a	60.2 bc	70.2 c
P721N	235 i	223 g	2.3 c	57.5 ef	68.5 d
954063	298 e	283 d	2.6 c	61.0 ab	69.9 c
IS0452	293 e	255 f	4.0 b	58.1 de	68.9 d
IS4225	338 c	328 c	4.0 b	62.0 a	71.6 ab
954100	278 f	273 e	3.9 b	55.3 g	60.2 g
M35-1	235 j	225 g	2.6 c	55.1 g	66.2 f
954130	218 j	203 h	2.2 cd	50.9 h	55.7 h
IS1461	318 j	270 e	4.6 b	59.7 bc	70.0 c
P7210	368 b	355 b	1.7 d	58.9 cd	72.2 a
850649	438 a	438 a	1.6 d	56.5 fg	71.0 b
CV (%)[d]	1.51	7.25	5.54	1.58	0.99

[a] Means followed by the same letter are not significantly different ($P = 0.01$).
[b] Means of two values in Brabender units (BU).
[c] Means of three values.
[d] CV (%) = coefficient of variability for the replicates or triplicates.

for the floury sample (850649) (Table IV). A significant correlation ($r = -0.68$**) was found between the cooked to uncooked grain weight ratio and percent vitreousness (Table V).

Amylography. As shown in Table VI, most of the 15 cultivars exhibited similar values of peak and hot paste viscosities. Values for both peak viscosity and hot paste viscosity ranged from 180 to 438 BU. The soft grain sample (850649) exhibited the most viscous paste, which was more than twice the viscosity of the most vitreous cultivar (SC283-14).

A highly significant correlation was observed between Brabender viscosities and percent vitreousness (Table V), with $r = -0.67$** and $r = -0.65$** for peak and hot paste viscosity, respectively. The low magnitude of the r^2 values, however, indicates that factors other than grain hardness influence the viscosity of a sorghum paste.

Alkali test. In rice, the pattern of disintegration of the grain in a 1.70% KOH solution is regarded as an important measure for varietal differentiation because the test is significantly correlated with gelatinization temperature (Juliano et al 1982, Maningat and Juliano 1978). The usefulness of this method as a sorghum screening technique was examined. Digestibility scores ranged from 1.6 for the most floury sample (850649) to 5.3 for the most vitreous grain (SC-283-14) (Table VI). Thus, grains with hard endosperms are corroded to a greater extent by the alkali than grains with soft endosperms. This trend is confirmed by the significant correlation found between percent vitreousness and alkali digestibility score ($r = 0.59$*) (Table V).

Birefringence endpoint temperature (BEPT). The temperature range at which the birefringence of an aqueous flour suspension is lost is regarded as a good measurement of starch gelatinization temperature (Leach 1965). In sorghum, high gelatinization temperature has been considered an undesirable property because it prolongs the cooking time of sorghum during food processing (Desikachar 1975, Ali and Wills 1980).

In this study, the pearled grain samples exhibited BEPT values ranging from 50.9 to 62.0°C for the initial and from 55.7 to 72.2°C for the final temperature (Table VI). Correlations between BEPT values and percent vitreousness for the 15 sorghum cultivars studied were not significant (Table V) and it appears that this parameter is not related to the hardness of the grain.

Relationships between physical and chemical grain quality measurements. The relationships between the various physical and chemical parameters studied are shown in Table VII. Adhesion value of sorghum paste was highly significantly correlated with kafirin protein content ($r = -0.67$**), but not with hot water-soluble amylose ($r = -0.31$). Also, the adhesion value of cooked sorghum paste was significantly related to total amylose ($r = -0.53$*) and water-soluble protein ($r = -0.55$*). However, only 45, 28, and 30% of the variation in the adhesion value of cooked sorghum paste can be accounted for by the level of kafirin protein, total amylose, and water-soluble protein, respectively.

TABLE VII
Correlations Between the Major Grain Components and Some Physical Parameters for Grain Quality of 15 Sorghum Cultivars

Quality Indices	Grain Components[a]: Protein Fractions: Water-Soluble	Protein Fractions: Kafirin	Amylose: Total	Amylose: Hot-Water-Soluble
Adhesion (stickiness) value	0.55*	−0.67**	−0.53*	−0.31
Cooked grain texture energy	−0.53*	0.59*	0.55*	0.42
Alkali gel stiffness value	−0.61**	0.85**	0.59**	0.24
Alkali digestibility score	−0.53*	0.62**	0.34	0.38
Cooked to uncooked grain weight ratio	0.40	−0.75**	−0.52*	−0.52*
Amylograph viscosities				
Peak	0.41	−0.36	−0.21	−0.23
Hot paste	0.43	−0.44	−0.14	−0.29
Birefringence endpoint				
Initial	0.02	−0.05	−0.07	0.37
Final	−0.35	−0.28	−0.30	0.05

[a] ** and * indicate significance at $P = 0.01$ and $P = 0.05$, respectively.

The cooked grain texture energy was significantly related to soluble proteins ($r = -0.53$*), kafirin proteins ($r = 0.59$*), and total amylose ($r = 0.55$*) content of the pearled grain (Table VII). However, hot water-soluble amylose did not correlate with cooked sorghum grain texture. This finding conflicts with reports on rice (Juliano et al 1972) in which hot water-soluble amylose was observed to be significantly related to the texture of cooked rice.

The gel stiffness value is strongly influenced by soluble proteins ($r = -0.61$**), kafirin protein ($r = 0.85$**), and total amylose ($r = 0.59$**) (Table VII). No significant relation was exhibited with the hot water-soluble amylose ($r = 0.24$) (Table VII).

The disintegration of the pearled grain in alkali was highly significantly correlated with kafirin proteins ($r = -0.62$*) and significantly with soluble proteins ($r = -0.53^*$) (Table VII). Nonsignificant relationships, however, were found between alkali digestibility and total protein, and total and hot water-soluble amylose.

The weight gained by the grain during cooking (cooked to uncooked grain weight ratio) was highly significantly correlated with kafirin proteins ($r = -0.75^{**}$), but correlations with total amylose ($r = -0.52^*$) and hot water-soluble amylose ($r = -0.52^*$) were lower (Table VII). Water-soluble protein did not influence weight increase of the grain during cooking.

Amylograph paste viscosities were unaffected by any of the grain components examined (Table VII). Thus, the viscosity of sorghum flour as measured by the Brabender amylogram is not affected by differences in the chemical components of the grain examined in this study. Similarly, BEPT was unaffected by any of the grain chemical components examined. On this basis, BEPT is another sorghum grain characteristic not influenced by the above grain components.

CONCLUSION

Fifteen sorghum cultivars differing widely in grain hardness (percent vitreousness) were subjected to some selected physical and chemical techniques to determine the relationship of grain hardness to the texture of the cooked sorghum. The percent vitreousness or grain hardness data were significantly related to adhesion value, cooked grain texture, alkali gel stiffness value, weight ratio of cooked to uncooked grain, and amylograph viscosities. BEPT and alkali digestibility scores were not related to percent vitreousness. The content of total amylose and hot water-soluble amylose, soluble and kafirin proteins in the endosperm were significantly related to grain hardness.

In terms of their potential value in the sorghum-breeding program as screening tests for predicting the texture of cooked sorghum cultivars, the following tests could be recommended: adhesion, cooked-grain texture, alkali-gel stiffness, and cooked to uncooked grain weight ratio.

Results obtained in this study show that the ratio of the corneous to the floury endosperm apparently affects the interaction between the chemical components of the endosperm that ultimately influence the textural behavior of the sorghum paste. Consequently, more work is needed on the properties of the major grain constituents (starch and protein) for further elucidation of the distinct differences in textural characteristics of sorghum cultivar cooked paste. Research in these areas is in progress.

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