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Cultivar Differences for Gel Consistency in Sorghum

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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.

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.

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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
Patcha 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.

	1979		1980	
Sources	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

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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; Maxon 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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Properties of Sorghum Grain and their Relationship to *Roti* Quality

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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.*

orghum 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.

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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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Table 1. Grain characteristics of 45 sorghum cultivars.

Cultivar	Grain color	Corneousness[a]	Grain hardness (kg cm^2)	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
imila	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
S-12611	Dull white	3	11.8	4.24
E-12-5	Creamy white	2	11.8	3.36
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 100g)[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.

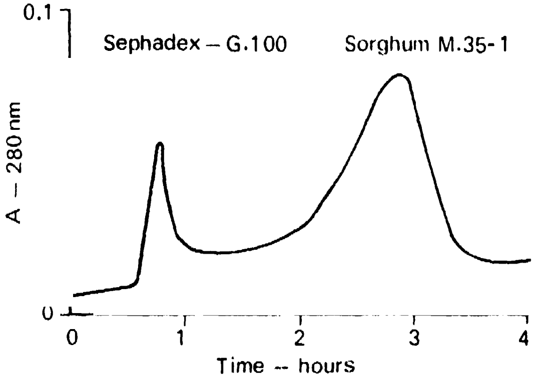

Figure 1. Gel filtration elution profile of water-soluble proteins.

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/100g protein).

	Cultivars	
Amino acids	PJ. 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	3.06
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