CP - 89

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

1756

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

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 Anantharaman (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

---

* Murty is Sorghum Breeder; Patil is Research Technician; House is Program Leader, Sorghum Improvement Program, ICRISAT.

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]	5.0	1.0
	(2.5 0.05)[b]	(4.0)	(1.0)
Grain weight (g 100)	3.49 ± 0.043	7.63	2.04
	(3.43 0.048)	(5.27)	(2.04)
Breaking strength (kg)	8.4 ± 0.09	14.6	0.8
	(8.9 0.15)	(14.6)	(5.5)
Density	1.26 ± 0.002	1.38	1.002
	(1.23 0.002)	(1.32)	(1.119)
Water absorption (%)	25.3 ± 0.23	43.1	12.4
	(26.3 0.38)	(42.1)	(14.4)
Dough:			
Water for dough (ml)	27.9 ± 0.12	38.9	20.9
	(27.2 0.17)	(37.5)	(20.9)
Kneading quality	1.2 ± 0.02	3.0	0.5
	(1.1 0.02)	(3.0)	(0.5)
Rolling quality (cm)	22.0 ± 0.06	27.8	15.2
	(22.3 0.08)	(25.4)	(16.2)
Roti:			
Taste	2.3 ± 0.03	5.0	1.0
	(2.0 0.04)	(3.5)	(1.0)
Texture	2.2 ± 0.02	4.5	1.0
	(2.2 0.04)	(4.0)	(1.0)
Aroma	1.4 ± 0.02	3.0	1.0
	(1.4 0.03)	(3.0)	(1.0)
Keeping quality	2.8 ± 0.03	5.0	1.0
	(2.6 0.04)	(4.5)	(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	2.95	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	29.2	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 ± 0.04	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.

	Quality parameters									
	Grain			Flour	Dough		*Roti*			
Source of variation	Weight (g/100)	Breaking strength	Water absorption (%)	PSI	Water for dough (ml)	Rolling quality	Taste	Texture	Aroma	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.

		Quality parameters											
		Grain				Flour	Dough			*Roti*			
Source	df	Corneous-ness	Weight (g/100)	Breaking strength (kg)	Water absorption (%)	PSI	Water required (ml)	Kneading quality	Rolling/ spread-ing	Taste	Texture	Aroma	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**	0.25**	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]	Endosperm texture	Weight (g 100)	Breaking strength (kg)	Water absorption (%)	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	Corneous-ness	Weight (g/100)	Breaking strength	Water absorp-tion (%)	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.

Acknowledgment

We thank Dr. N. Seetharama, Sorghum Physiologist, ICRISAT for the supply of grain samples from his moisture stress experiment and Dr. K. L. Sahrawat for analysis of soil samples.

References

ANANTHARAMAN, P. V. 1968. Grain quality studies in sorghum. Sorghum Newsletter 11: 49–53.

DESIKACHAR, H. S. R. 1977. Processing of sorghum and millets for versatile food used in India. *In* Proceedings, Symposium on Sorghum and Millets for Human Food. London, UK: Tropical Products Institute.

GOVERNMENT OF INDIA. 1969, 1980. Agricultural situation in India. Published by the Directorate of Economics and Statistics, Ministry of Agriculture. (1969) 24: 690–691; (1980) 35: 738-739.

MADHAVA RAO. 1965. Bread or *roti* making quality in sorghum hybrids. Sorghum Newsletter 8: 27–30.

MUNSELL SOIL COLOR CHARTS. 1975 ed. Evanston, Illinois, USA: Soil Test Inc.

MURTY, D. S., and SUBRAMANIAN, V. 1981. Sorghum *roti* I. Traditional methods for consumption and standard procedures for evaluation. These Proceedings.

MURTY, D. S., PATIL, H. D., and HOUSE, L. R. 1981. Sorghum *roti* quality tests at ICRISAT. Paper presented at the All India Sorghum Improvement Project Workshop, Navsari, India, 11-14 May 1981.

PARTHASARATHY, P., and GHODAKE, R. D. 1981. Personal communication.

RAO, S. B. P., BHATIA, H. P., and DABIR, V. N. 1964. Quality tests on grain sorghum hybrids. Sorghum Newsletter 7: 34–45.

RAO, N. G. P., VIDYABHUSHANAM, R. V., RANA, B. S., JAYAMOHAN RAO, V., and VASUDEVA RAO, M. J. 1980. Breeding sorghums for disease resistance in India. Pages 430–433 *in* Proceedings, International Workshop on Sorghum Diseases, 11–15 Dec 1978, Hyderabad, India. Patancheru, A. P., India: ICRISAT.

ROONEY, L. W., BLAKELY, M. E., MILLER, F. R., and ROSENOW, D. T. 1980. Factors affecting the polyphenols of sorghum and their development and location in the sorghum kernel. Pages 25–35 *in* Proceedings of a Symposium on Polyphenols in Cereals and Legumes, 10–13 June 1979. Ottawa, Canada: IDRC.

VIRAKTAMATH, C. S., RAGHAVENDRA, G., and DESIKACHAR, H. S. R. 1972. Varietal differences in chemical composition, physical properties and culinary qualities of some recently developed sorghum. Journal of Food Science Technology (Mysore). 9(2): 73–76.

WANISKA, R. D. 1976. Methods to assess quality of boiled sorghum, gruel and chapatis from sorghum with different kernel characters. M.Sc. thesis, Texas A&M University, Texas, USA.

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 he *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*, du[illegible] 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.

---

* Iruegas is Grain Project Leader, INIA, Mexico; Cejudo is Grain Quality Associate Scientist, INIA, Mexico; Guiragossian is Sorghum Breeder, ICRISAT, Mexico.