Grain Quality and Biochemistry
Progress Report 10/88

Sorghum

Report of Work

January 1986 - December 1987

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

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FOREWORD

This report describes the various research activities carried out on biochemical, processing and food quality aspects of sorghum from January 1986 to December 1987. This work was carried out by Grain Quality and Biochemistry unit in collaboration with Sorghum Breeding and Genetic Resources Units.

This is not an official publication of ICRISAT and should not be cited

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SORGHUM - PROGRESS REPORT

1986-1987

Project No. : S-106 (85) IC

Project title : Evaluation of Food and Nutritional Quality of Sorghum

Project Scientist: V. Subr ian

Objecti

a) To assist national and regional programs in determining the characteristics of sorghum grain that contribute to the quality of specific foods in SAT.

b) To relate physicochemical, structural and processing characters of sorghum grain to product quality.

c) To establish simple, rapid and reliable physicochemical tests useful to breeders in national program.

d) To evaluate elite breeding and standard cultivars originating from ICRISAT center as well as other national programs for food and nutritional quality.

e) Study the variability in protein and lysine content in germplasm and breeding accessions (1985-1986).

1. Assisting the national programs in grain and food quality

Three trainees from Africa (Ethiopia, Kenya, and Sudan) were given intensive training for 5 months on grain and food quality of sorghum. The traditional foods like injera, and ugali were evaluated using the grains brought by the trainees. Various chemical analyses of grain and foods were determined and the results were reported in individual reports prepared by the trainees. Out of the six cultivars tested, M 35-1 (India) and Gambella

1107 (Ethiopia) were comparable for their good _injera_ quality.

Mr. J.H. Mushonga, Scientist, Ministry of Agriculture, Zimbabwe spent three months in our laboratory. We assisted him in standardizing the methods for estimating diastatic activity in malted sorghum. We have modified the malting method and compared with the diastatic activity values obtained by the earlier method. It is necessary to obtain more information about the method of sorghum diastatic units (SDU) estimation from the local beer industry. A wide range of diastatic activity was observed among the genotypes that were analysed. The tannin content in ungerminated grains and SDU values in malted sorghum were not correlated.

We have worked on _tortilla_ quality of sorghum with the help of a trainee from Mexico. _Tortilla_ prepared from sorghum variety M 35-1 was found to be comparable to maize in quality.

2. Processing quality

Dehulling and milling are important processes for making acceptable foods from sorghum. As per the recommendation of the International Association of Cereal Chemistry (Study Group of Sorghum and Millet) meeting in 1984, bulk samples of 7 cultivars of diverse grain quality characters were supplied to cooperators located at Institut de Recherches Agronomiques Tropicales (IRAT), France; Overseas Development Natural Resources Institute (ODNRI), United Kingdom and Carlsberg Research Center, Denmark. Physical characters and dehulling quality of these grain samples were studied. The grains of 7 cultivars showed variation for 1000-grain mass, endosperm texture, grain hardness, pericarp content and floaters percent (Table 1). Hard grain type (SPV 472) had the least floaters percent while soft-grain types (WS 1297, Dobbs) had 100% floaters. The pericarp content of Dobbs

Table 1. Physical characteristics of sorghum grains

Cultivar	Origin	1000-grain mass (g)	Endosperm texture[1]	Grain hardness[2] (kg sq cm^{-1})	Pericarp content (%)	Floaters (%)
SPV 472	ICRISAT	39.2	4.0	9.1	6.9	28.5
CO 4	(India)	30.5	1.0	4.0	4.5	54.5
ET 3491	Ethiopia	39.9	1.5	3.5	5.0	82.0
Lulu dwarf	Tanzania	21.5	2.5	4.5	8.3	84.0
WS 1297	Ethiopia	37.5	1.0	4.4	6.8	100.0
Dobbs	Uganda	21.2	1.0	4.9	13.0	100.0
<u>Control</u>						
M 35-1	India	39.5	2.0	5.3	3.4	56.0
Mean		32.8	1.9	5.1	6.8	72.1
SE		±3.18	±0.42	±0.70	±1.20	±10.08

[1]Endosperm texture was scored on a 1-5 scale, where 1 is floury and 5 is corneous.

[2]Grain hardness was measured using a Kiya hardness tester.

was the highest among the cultivars studied.

A comparative statement of dehulling quality of grains using three methods is give in Table 2. The dehulling quality of M 35-1 (control) was exceptionally good when the traditional method was used. It required less time to dehull with fewer strokes and the recovery of dehulled grain was higher as compared to other cultivars (Table 2). Soft grain types Dobbs and WS 1297 recorded lower dehulled grain recovery, and yielded higher quantities of husk and fines. The brokens percent was also higher for them as compared to other cultivars. Lulu dwarf also had more brokens due to dehulling by traditional method. Dobbs and WS 1297 grains also had high percent floaters. It was very difficult to dehull Dobbs satisfactorily. This data confirms that soft grain types are not suitable for traditional dehulling.

When the grains were dehulled using a Scott barley pearler, the recovery of dehulled grain increased considerably for all the cultivars as compared to the traditional method (Table 2). Again M 35-1 gave better dehulling recovery than other cultivars. The cultivars having low percent floaters (CO 4, SPV 472, and M 35-1) yielded higher dehulled grain recoveries by the barley pearler method. A similar trend was observed for the dehulled grain recovery using a Tangential Abrasive Dehulling Device (TADD). Our data clearly indicated that even soft grains can be dehulled comparatively better using mechanical methods as compared to the traditional method.

Barley pearler method is based on vertical rotation of the hard or rough surface to come into contact with grains. TADD method is based on horizontal rotation of the hard surface. Though these two are different

Table 2. Comparison of dehulling by traditional, barley pearler, and Tangential Abrasive Dehulling Device (TADD) Methods[1]

Cultivar	Water used (ml kg^{-1})	Number of strokes to dehull 1 kg	Time for dehulling (min kg^{-1})	Traditional dehulling Recovery (%)			Barley pearler Recovery (%)			TADD Recovery (%)	
				Dehulled grains	Brokens	Husk and fines	Dehulled grains	Brokens	Husk and fines	Dehulled grains	Brokens
SPV 472	90.8	1880	40.5	66.7	9.6	20.0	81.9	4.0	13.5	82.6	2.5
CO 4	81.2	1600	37.8	60.7	13.5	21.5	81.2	3.2	15.3	77.9	2.3
ET 3491	76.0	1624	28.7	50.1	19.0	25.9	72.1	6.7	20.6	72.6	2.5
Lulu Dwarf	88.0	2076	43.5	47.9	25.0	21.7	67.2	15.8	17.0	59.8	5.8
WS 1297	76.0	1328	29.5	34.1	24.1	37.1	52.2	15.1	31.1	50.4	6.7
Dobbs	118.8	2592	57.0	25.3	21.3	48.4	70.6	3.9	25.2	60.0	1.9
Control											
M 35-1	57.2	1504	30.7	82.4	4.0	10.8	84.0	4.0	13.0	84.6	0.8
Mean	84.0	1800	38.2	52.5	16.6	26.5	72.8	7.3	19.4	69.7	3.2
SE	±7.12	±161.2	±3.80	±7.34	±2.97	±4.70	±4.19	±2.09	±2.53	±4.94	±0.82

laboratory models, and work on different principles, the results obtained by both these methods are similar for the cultivars tested (Table 2). This observation may be useful in developing future prototype model of dehullers.

Dehulled grain recovery using the three methods of dehulling was negatively associated with floaters percent. But the husk recovery showed positive correlation with floaters percent, suggesting that floaters percent give an indirect assessment of dehulling recovery. The magnitude of correlation was strong between the two mechanical methods of dehulling, indicating that either of the methods can be used for evaluating dehulling quality of sorghum grains in the laboratory.

3. Malting studies

Grain samples of 15 cultivars comprising of soft and hard endosperm, red pericarp, and high tannin lines were germinated in an incubator, for 16, 48, 96, and 144 h. In order to assess the potential of the cultivars for diastase enzyme production by malting, a relative humidity of 90% at 30°C during while germination was chosen. Changes in one-hundred grain mass, protein, starch, soluble sugars, tannin, total phenols contents and sorghum diastatic units (SDU) were determined. The 100-grain mass ranged from 1.9 to 4.0 (Table 3). Obviously the weight decreased progressively as germination time increased. However, the rate of decrease varied considerably among the cultivars.

Germination resulted in loss in weight, as explained. It is to be noted that the rate of loss from one stage to the other is highly variable among for the cultivars. The decrease in weight was more pronounced between 48 and 96 h periods of germination. At the 144 h germination

Table 3. 100-grain mass (g) at different stages of germination in sorghum

Cultivar	Ungerminated (Control)	Germination period (h) 16	48	96	144
ET 3491	4.0	3.7	3.3	2.6	1.5
Lulu dwarf	2.1	1.9	1.5	1.1	0.8
M 35-1	3.9	3.8	3.2	2.4	1.6
WS 1297	3.9	3.6	3.0	2.3	1.6
SAR 1	2.8	2.6	2.2	2.1	1.0
SPV 351	1.9	1.7	1.4	0.9	0.5
SPV 386	3.3	3.0	2.9	1.7	-
SPV 475	2.9	2.6	2.3	1.6	1.4
Safra	3.1	2.7	2.4	1.8	-
SPV 472	3.8	3.5	3.1	2.2	-
Dobbs	2.2	2.0	1.5	1.0	0.9
IS 7055	2.8	2.5	2.3	1.5	-
IS 14384	2.0	1.9	1.6	1.2	-
Framida	3.1	3.0	2.9	2.0	-
CO 4	3.1	2.9	2.4	1.6	1.1
Mean	3.0	2.8	2.4	1.7	1.1
SE	±0.18	±0.18	±0.17	±0.13	±0.09

nearly one-third to half the original weight of grain was lost indicating that metabolic activity in terms of respiration and thus loss in seed mass showed variation among the cultivars. The germination percent reached normal after 96 h and the percent germination was low only for the grains of WS 1297, and SPV 386.

Starch content varied from 59.8 to 72.3% in the sorghum cultivars (Table 4). Starch is important in malting as it undergoes modification during malting. Starch is converted to maltose, maltodextrins and other sugars although all the starch present in the grains is not modified. Reduction in starch content was not observed in all the cultivars at 16 and 48 h germination. The quantity of starch was reduced only at 96 h in most of the cultivars and in certain cultivars there was an increase in starch quantity as compared to ungerminated grain. This may be due to preferential depletion of other nutrients like proteins and fat in the grain and thus on an unit weight of malted grain, starch % was higher. The data also indicate that starch convertion may take place only beyond 48 h germination. However, in all the cultivars, reduction in starch content was observed in 144 h germinated grains from that present in the ungerminated grains.

The soluble sugars content showed a variation from 1.1 to 2.5% in the cultivars (Table 5). In contrast to starch, the soluble sugars showed appreciable changes in their quantity due to germination. The content decreased in all the cultivars at 16 h germination. The sugars increased at 48 and 96 h germination period, in all the cultivars. At 144 h period, although the quantity decreased from that of 96 h in several cultivars, in five cultivars the contents increased further. The increase in sugar may

Table 4. Starch content (%) in sorghum grains at different stages of germination

Cultivar	Control	Germination period (h)			
		16	48	96	144
ET 3491	67.5	67.3	69.0	64.3	56.5
Lulu dwarf	72.3	69.9	71.7	65.4	62.0
WS 1297	68.3	69.2	70.4	67.0	59.4
Safra	70.2	70.3	70.8	70.6	64.7
Dobbs	65.3	67.3	66.7	59.9	50.8
IS 7055	65.9	66.2	63.1	63.6	55.5
IS 14384	68.8	65.4	63.6	68.7	50.6
Framida	59.8	62.8	60.7	62.0	48.5
SAR 1	72.3	73.8	73.6	74.6	67.3
SPV 351	67.3	68.7	70.8	64.9	53.3
SPV 386	66.3	67.0	68.7	63.8	52.2
SPV 475	69.4	68.7	68.8	67.7	62.8
SPV 472	70.1	67.9	66.7	68.8	58.5
M 35-1	70.9	72.1	70.3	67.7	63.2
CO-4	69.4	70.9	70.6	64.3	56.7
Mean	68.3	68.5	68.4	66.2	57.5
SE	±0.82	±0.71	±0.92	±0.94	±1.48

Table 5. Soluble sugars content (%) in sorghum grains at different stages of germination.

Cultivar	Control	Germination period (h)			
		16	48	96	144
ET 3491	1.4	0.9	4.9	11.1	12.8
Lulu dwarf	1.4	1.0	4.6	6.6	5.9
Safra	1.4	1.1	4.6	7.0	5.9
WS 1297	1.3	1.0	4.8	7.8	5.8
Dobbs	1.8	1.4	6.2	11.4	10.0
IS 7055	1.7	1.4	5.1	11.8	9.9
IS 14384	1.5	1.3	5.6	10.7	13.7
Framida	2.5	1.5	4.1	10.5	10.4
SAR 1	1.2	1.0	5.9	6.7	5.6
SPV 351	1.1	0.8	6.3	10.9	9.0
SPV 386	1.6	1.2	2.8	9.8	3.7
SPV 475	1.3	0.8	3.5	5.6	4.8
SPV 472	1.2	1.1	4.3	9.0	5.2
M 35-1	1.4	1.3	3.6	7.8	10.8
CO 4	1.8	1.4	6.8	13.1	16.2
Mean	1.5	1.1	4.9	9.3	8.7
SE	±0.09	±0.06	±0.29	±0.59	±0.96

be due to metabolic pathways other than starch degradative pathway at different incubation periods. However, at 144 h, the increase may be from starch degradation, as starch content appreciably decreased in these grains.

Among fifteen cultivars only four had tannin in the grains and the tannin content (C.E.%) varied from 0.9 to 2.7 (Table 6). Germination decreased the tannin (catechin equivalents) at 16 h germination period, followed by an increase up to 96 h. The increase was remarkable in Dobbs due to germination, which needs further study. Total phenols in ungerminated grains of 3 cultivars (Dobbs, IS 7055, and Framida) were high (Table 7). These lines have subcoat in their grains. Other cultivars had comparatively low quantities of phenols. A decrease was observed at 16 h germination in the grains followed by a progressive increase. The quantities were high in the three cultivars indicated above. The significance of the variation needs further study.

Protein content decreased in general, except in SPV-475 at 16 h germination. At later periods of germination, either it remained same or a decrease was observed for most of the cultivars (Table 8). Although the protein content <u>per se</u> did not change appreciably, the enzyme level in the malted samples varied as indicated below.

Diastatic activity (called as sorghum diastatic units, SDU) is reported as an important factor in the quality of grain for making traditional opaque beer in Africa. The SDU was very low in ungerminated grain. It progressively increased from 16 h to 96 h of germination, and showed either decrease or increase in some of the cultivars at 144 h germination. Appreciable variation among the cultivars was found only from

Table 6. Tannin content (C.E. %) in sorghum grain at different stages of germination

Cultivar	Control	Germination period (h)			
		16	48	96	144
WS 1297	0.9	0.4	0.3	0.6	0.5
Dobbs	2.7	2.0	2.6	4.5	5.7
IS 7055	2.1	1.4	1.3	2.1	2.4
Framida	1.9	1.4	1.2	1.8	2.0

C.E. : Catechin equivalents

Table 7. Total phenols content (A_{560} g^{-1}) in sorghum grain at different stages of germination.

Cultivar	Control	Germination period (h)			
		16	48	96	144
ET 3491	1.7	0.9	2.4	5.2	8.9
Lulu dwarf	1.2	1.3	2.4	5.0	6.7
WS 1297	1.5	1.2	2.3	3.1	6.3
Safra	2.0	1.0	2.5	2.3	5.1
Dobbs	15.0	11.6	16.1	27.6	34.8
IS 7055	12.7	9.5	10.4	19.8	21.4
IS 14384	3.8	2.7	4.1	3.2	8.0
Framida	14.6	9.8	12.3	17.9	26.8
SAR 1	1.5	1.0	1.7	2.6	4.9
SPV 351	1.2	1.1	1.6	3.1	5.2
SPV 386	1.6	1.0	1.5	3.3	5.0
SPV 472	1.7	1.4	2.3	2.4	8.7
SPV 475	1.3	1.4	1.9	3.6	5.4
M 35 1	1.0	0.7	1.7	3.3	4.8
CO 4	3.1	2.6	3.8	7.0	10.2
Mean	4.3	3.2	4.5	7.3	10.8
SE	±1.34	±0.97	±1.18	±2.02	±2.39

Table 8. Protein content (%) in sorghum at different stages of germination

Cultivar	Control	Germination period (hrs)			
		16	48	96	144
ET 3491	12.4	12.3	11.2	11.1	11.3
Lulu dwarf	9.6	9.3	7.5	7.2	7.4
Safra	9.7	9.0	8.4	7.4	8.2
WS 1297	10.1	10.0	9.0	8.3	9.0
Dobbs	9.0	9.4	6.5	5.3	5.0
IS 7055	11.1	10.9	10.9	7.3	8.2
IS 14384	10.7	11.2	11.2	8.5	11.1
Framida	14.3	14.3	14.6	11.2	14.9
SAR 1	7.2	6.6	6.2	6.3	7.4
SPV 351	10.7	10.7	9.2	8.7	10.3
SPV 386	11.5	10.2	10.3	9.7	11.7
SPV 475	10.2	11.6	10.8	11.4	11.5
SPV 472	9.5	9.2	9.6	7.6	9.6
M 35-1	9.9	9.5	8.3	8.7	9.2
CO-4	10.6	10.5	8.6	8.5	8.8
Mean	10.4	10.3	9.5	8.5	9.6
SE	±0.41	±0.45	±0.55	±0.46	±0.68

48 h onwards and the SDU ranged from 10.0 to 85.9 (Table 9). The cultivars SAR 1 and M 35-1 had low values even at 96 h period. Cultivars IS 7055, WS 1297, SPV 386, Dobbs, Framida and IS 14384 had higher values compared to other cultivars. IS 14384 had the highest values among the cultivars. Although the values decreased at 144 h period for most of the cultivars, an increase was observed for WS 1297 and ET 3491. The decrease was appreciable for SAR 1. It is interesting to note that though variation for protein content due to germination was not appreciable and even a reduction was observed for a few cultivars, SDU increased appreciably due to germiantion, particularly up to 96 h. This study suggest that grains of IS 14384, IS 7055, WS 1297, SPV 386, Dobbs and Framida have good potential for malting as they showed an increase in SDU values with the increase in period of germination.

3.1 Studies on malting conditions to improve the enzyme activity

We compared the malting quality in terms of seedling yield, malting loss, total loss and SDU using 8 cultivars. Grains were germinated under three different conditions. Germination was done for 48 and 96 h. The details of germination conditions are:

Method I. 5 g grains soaked in water for 16 h at 30oC. Drained the excess of water and germinated by keeping the grains in polyethylene cover (10 x 7.8 cm) with big holes. They were incubated at 30^{o}C and the incubator had a circulating fan. The approximate relative humidity in the incubator was 35% during germination.

Method II. All conditions were similar to that described in method I, but the size of polyethylene cover was 6.5 x 5.8 cm with small

Table 9. Diastatic ativity (SDU g^{-1}) in sorghum grain at different stages of germination.

Cultivar	Control	Germination period (h)			
		16	48	96	144
ET 3491	0.1	3.8	37.7	79.5	80.7
Lulu dwarf	0.2	2.5	39.5	73.5	25.9
WS 1297	0.3	3.4	48.8	95.3	97.9
Safra	0.2	2.3	44.7	68.7	55.2
Dobbs	0.2	1.9	49.0	89.5	71.7
IS 7055	0.3	3.0	83.2	114.0	81.8
IS 14384	0.2	4.5	85.9	150.4	147.4
Framida	0.1	1.5	57.0	87.0	65.3
SAR 1	0.2	2.7	16.5	20.0	3.4
SPV 351	0.2	2.1	35.5	61.2	58.2
SPV 386	0.2	2.7	54.4	85.2	52.9
SPV 472	0.1	3.0	32.7	37.2	11.7
SPV 475	0.3	3.0	44.7	70.5	45.8
M 35-1	0.3	3.0	10.0	26.3	14.3
CO-4	0.2	2.1	38.7	74.5	69.4
Mean	0.2	2.8	45.2	75.5	58.8
SE	±0.02	±0.52	±5.26	±8.51	±9.58

holes. The approximate relative humidity in the incubator was 50%.

Method III 5 g grains were spread over a bed of cotton taken in a petridish (9.0 cm diameter). Enough water was added such that the grains are wetted well and germinated at 30°C for 48 and 96 h. The approximate relative humidity inside the incubator was 90%.

The grains after germination by the methods I, II and III were dried at 50°C for 24 h. The malted and dried grains were ground in an Udy mill to pass through 0.4 mm screen and analysed for SDU.

It is obvious that due to increased relative humidity, metabolic activity in the grain may be increased. Seedling yield increased with more humidity %. The differences between 48 and 96 h was only little except for SPV 386 and Framida using the method I (Table 10). But higher seedling yield was obtained by method II and III. The sorghum cultivars differed markedly in producing seedling yield. An increase of several-folds from 48 to 96 h period was observed for the method III (high RH). The cultivars Red Swazi A, IS 14384, Dobbs and IS 7055 had higher seedling yield than others (Table 10).

Malting loss at 48 h did not vary much among the three methods of germination (Table 11). At 96 h, malting loss increased as RH increased during germination. Red Swazi A, IS 14384 and Dobbs had comparatively high malting loss. Loss in grain weight which comprised of malting and seedling loss increased with increased RH conditions. The loss was very high at 96 h germination, particularly in cultivars like Red Swazi A, Dobbs, WS 1297, IS 14384 and IS 7055 (Table 12). Though higher SDU is desirable, it is

Table 10. Seedling yeild at 48h and 96 h germination in sorghum.

Cultivar	Seedling yield (%)					
	48 h			96 h		
	Method			Method		
	I	II	III	I	II	III
Red Swazi A	0.8	3.4	15.5	0.7	6.1	31.1
Dobbs	2.1	3.4	7.0	2.7	3.8	27.9
WS 1297	0.7	3.4	5.1	1.0	5.3	19.6
SAR 1	---	1.7	4.4	---	4.9	9.0
SPV 386	0.8	3.3	6.9	1.6	6.1	12.5
IS 7055	1.9	4.3	8.2	2.2	10.1	21.7
IS 14384	---	3.0	9.8	0.6	8.0	29.3
Framida	0.9	3.4	3.5	2.3	7.7	15.1
Mean	1.2	3.2	7.5	1.5	6.5	20.8
SE	±0.26	±0.25	±1.35	±0.31	±0.71	±2.90

Method I : 35 % Relative humidity

Method II : 50 % Relative humidity

Method III : 90 % Relative humidity

Table 11. Malting loss at 48 h and 96 h of germination in sorghum

	Malting loss (%)					
	48 h			96 h		
	Method			Method		
Cultivar	I	II	III	I	II	III
Red Swazi A	10.5	11.1	12.8	11.1	14.4	23.2
Dobbs	10.4	10.6	10.0	10.9	11.7	20.3
WS 1297	9.6	10.6	8.0	10.0	14.5	17.0
Sar 1	8.1	8.7	8.1	8.5	14.5	15.9
SPV 386	7.7	8.6	8.3	9.6	13.9	12.9
IS 7055	8.0	8.2	8.7	9.3	12.0	15.3
IS 14384	7.1	7.1	8.5	8.5	12.0	19.4
Framida	10.8	10.6	8.4	12.5	15.0	15.5
Mean	9.0	9.4	9.1	10.1	13.5	17.4
SE	±0.52	±0.51	±0.57	±0.49	±0.48	±1.18

Method I : 35 % Relative humidity

Method II : 50 % Relative humidity

Method III : 90 % Relative humidity

Table 12. Loss in grain weight at 48 h and 96 h of germination in sorghum

	Total loss (%)					
	48 h			96 h		
	Method			Method		
	I	II	III	I	II	III
Red Swazi A	11.2	14.1	26.2	11.8	19.6	47.0
Dobbs	12.3	13.6	16.3	13.2	15.1	42.5
WS 1297	10.3	13.6	12.6	10.9	19.1	33.3
SAR 1	8.1	10.3	12.1	8.5	18.7	23.5
SPV 386	8.5	11.6	14.6	11.0	19.1	23.8
IS 7055	9.8	12.2	16.2	11.3	20.1	33.6
IS 14384	7.1	9.9	17.5	9.0	19.0	43.0
Framida	11.6	13.6	11.6	14.6	21.5	28.2
Mean	9.9	12.4	15.9	11.3	19.1	34.4
SE	±0.61	±0.54	±1.58	±0.66	±0.63	±2.99

Method I : 35 % Relative humidity

Method II : 50 % Relative humidity

Method III : 90 % Relative humidity

advantageous to have lower loss.

In general, SDU increased with increased RH. Wide variation among the cultivars was observed for SDU at 48 and 96 h by the three methods of germination. By the methods I and II, an increase in SDU was observed for Red Swazi A (Table 13). But an increase in values was observed from 48 to 96 h by the method III. The values increased progressively due to time as well as RH in IS 14384, Dobbs, WS 1297 and Framida. The SDU did not improve appreciably for SAR 1 with increase of RH during germination and with time. This study suggest that the potential for high SDU can be realized in cultivars like IS 14384, WS 1297, Dobbs, Red Swazi A, Framida and IS 7055 at relatively high humidity conditions.

4. *In vitro* protein digestibility (IVPD)

Protein digetibility (*in vitro*) was carried out in grains, *ugali*, and *tortilla* using 5 sorghum cultivars and one maize cultivar. The IVPD of sorghum was comparatively higher than maize, but only one maize cultivar was used in this experiment. IVPD was lower in *ugali* made from sorghum. Although the reduction was low for maize *ugali*, the percent decrease was higher for all sorghum cultivars except M 35-1 (Table 14). IVPD of *tortillas* also was low for sorghum as well as maize. Protein content increased due to cooking in *ugali* or *tortilla* made from sorghum.

IVPD was estimated in whole grain and malted sorghum. Protein content decreased due to germination for 96 h (Table 15). An appreciable increase in IVPD was observed due to malting, particularly for cultivars like Dobbs and IS 7055.

Table 13. Diastatic power (SDU g^{-1}) at 48h and 96h of germination in sorghum

	SDU					
	48 h			96 h		
	Method			Method		
Cultivar	I	II	III	I	II	III
Red Swazi A	37.2	59.7	103.5	30.0	42.8	120.4
Dobbs	35.7	45.0	58.5	53.3	50.3	123.0
WS 1297	27.4	54.8	55.0	52.5	70.9	135.8
SAR 1	8.3	13.2	16.2	13.2	16.9	18.1
SPV 386	27.5	46.6	39.4	36.0	46.5	80.7
IS 7055	46.6	59.3	63.4	44.3	78.4	130.6
IS 14384	20.7	43.3	55.9	35.3	65.7	173.3
Framida	31.9	52.5	33.8	41.7	63.4	105.6
Mean	29.4	46.8	53.2	38.3	54.4	110.3
SE	±4.07	±5.30	±9.07	±4.61	±6.92	±16.72

Method I : 35 % Relative humidity

Method II : 50 % Relative humidity

Method III : 90 % Relative humidity

Table 14. *In Vitro* Protein Digestibility (IVPD) of grain, *ugali* and *tortilla* of sorghum and maize.

Cultivars	Whole grain		*Ugali*		*Tortilla*	
	Protein %	IVPD %	Protein %	IVPD %	Protein %	IVPD %
Sorghum						
SPV 351	8.3	86	10.6	71	9.0	70
CSH 11	8.1	85	8.5	74	8.9	73
Hageen durra 1	8.2	85	8.5	73	8.6	74
SAR 1	9.7	85	8.9	74	10.3	71
M 35-1	10.2	82	10.4	79	10.8	76
Maize	9.3	80	7.9	77	9.5	70
Mean	9.0	84	9.1	75	9.5	72
SE	±0.36	±1.0	±0.93	±1.0	±0.35	±1.0

Table 15. Changes in *in vitro* protein digestibility (IVPD) of sorghum grain due to malting

Cultivar	Whole grain		Malted grain[1]	
	Protein %	IVPD %	Protein %	IVPD %
CO 4	10.4	83	8.5	90
Dobbs	9.1	49	5.3	71
ET 3491	12.6	79	11.1	91
Lulu dwarf	9.7	82	7.2	ND
M 35-1	10.0	81	8.7	86
WS 1297	10.0	82	8.3	91
SAR 1	7.2	81	6.3	91
SPV 351	10.8	82	8.7	90
SPV 386	11.1	82	9.7	88
Safra	9.4	85	7.4	86
IS 7055	11.4	59	7.3	73
IS 14384	10.8	75	8.5	90
SPV 472	9.6	85	7.6	90
Mean	10.4	77	8.3	85
SE	±0.41	±3.0	±0.44	±2.2
M 35-1 (Check)	13.5	63	11.2	70

1 : Grains were malted (germinated) for 96 h at 30°C.

ND : not determined

5. Nutritional quality

5.1 Tannin/polyphenols in relation to bird resistance

A set of eight cultivars reported to be bird-resistant sorghums were chosen. These sorghums were grown during the 1985 postrainy season at ICRISAT Center for studying the tannins and polyphenols in developing grains at 10, 20, 30, 40 and 50 days after flowering. The same lines were grown by Dr. L.G. Butler, Purdue University in Indiana, USA for evaluating bird attack. This is a collaborative research between ICRISAT and Purdue University, USA.

Tannin, flavan-4-ols, total phenols and protein precipitable phenols contents were determined in the developing grains. The data for the eight cultivars are given in Tables 16-19. Tannin content of developing grain was high at 10 days after flowering in five cultivars (Table 16) and cvs IS 2849, IS 3149 and IS 8765 did not have tannin at any stage of grain maturity. Out of the eight cultivars, only five had tannin, although all of them had red/brown colored grain. The reduction was appreciable in cultivars IS 8748 and IS 10301. Total phenols, flavan-4-ols and protein precitable phenols contents also followed similar trend for the above cultivars (Table 17, 18 and 19). Total phenols content of IS 724 was low in methanol extract. Flavan-4-ols extractable in acidic methanol, had a high concentration at early stages of grain, which decreased at later stages in IS 8748, IS 3031 and IS 10301. The relevance of the data will be known after comparing the data on bird resistance evaluated by Dr. Butler.

5.2 Chemical composition

Chemical composition of 7 elite cultivars of ICRISAT was determined and all of them had acceptable quantities of various consituents (Table 20).

Table 16. Tannin content (C.E.%) of Bird resistant sorghum cultivars

Cultivar/ Extract	Days after flowering				
	10	20	30	40	50
IS 10301 Me	22.8	11.5	4.0	1.6	1.3
H^+/Me	1.8	1.0	1.2	0.6	0.6
Total	**24.6**	**12.5**	**5.2**	**2.2**	**1.8**
IS 8748 Me	30.7	11.3	6.4	1.5	1.9
H^+/Me	2.[illegible]	0.9	1.3	0.8	0.7
Total	**32.8**	**12.2**	**7.7**	**2.3**	**2.6**
IS 724 Me	28.0	15.4	8.6	2.8	2.0
H^+/Me	4.41	1.4	1.8	1.1	0.9
Total	**32.41**	**16.8**	**10.4**	**3.8**	**2.9**
IS 2880 Me	38.5	26.1	9.2	8.8	8.4
H^+/Me	3.9	1.9	2.3	2.2	1.7
Total	**42.4**	**28.0**	**11.5**	**11.0**	**10.1**
IS 3031 Me	18.0	10.8	4.	4.1	3.7
H^+/Me	2.9	1.8	2.9	1.8	1.8
Total	**20.9**	**12.6**	**7.1**	**5.9**	**5.5**

ME : Methanol extract; H^+/ME : Acidic-methanol extract

Table 6 Total phenols content (%) of bird resistant sorghum cultivars

Cultivar Extract	Days after flowering					
	10	20	30	40	50	60
IS 10301 Me	11.0	1.9	1.2	0.6	0.5	0.3
H^+/Me	2.0	0.7	0.6	0.7	0.5	0.4
Total	13.0	2.6	1.8	1.3	1.0	0.7
IS 8748 Me	12.7	2.3	1.7	0.6	0.8	0.7
H^+/Me	2.5	0.8	0.6	0.7	0.6	0.4
Total	15.2	3.1	2.3	1.4	1.4	1.1
IS 724 Me	7.0	2.8	2.3	0.9	0.8	0.7
H^+/Me	1.7	1.0	0.7	0.8	0.7	0.6
Total	8.7	3.8	3.0	1.7	1.5	1.3
IS 2880 Me	8.8	4.0	1.8	2.2	2.5	-
H^+/Me	1.9	1.4	1.3	1.3	1.4	-
Total	10.7	5.4	3.1	3.5	3.9	-
IS 3031 Me	4.7	3.0	1.6	1.2	1.3	-
H^+/Me	4.4	1.1	1.5	1.2	1.5	-
Total	9.1	4.1	3.1	2.4	2.8	-
IS 2849 Me	0.6	0.4	0.3	0.3	0.2	0.2
H^+/Me	0.3	0.2	0.1	0.2	0.4	0.2
Total	0.9	0.6	0.4	0.5	0.6	0.4
IS 3149 Me	1.6	0.6	0.5	0.4	0.2	0.3
H^+/Me	0.2	0.2	0.2	0.2	0.4	0.4
Total	1.8	0.8	0.7	0.6	0.6	0.7
IS 8765 Me	1.5	0.5	0.2	0.2	0.3	0.3
H^+/Me	0.4	0.2	0.2	0.2	0.4	0.4
Total	1.9	0.7	0.4	0.4	0.7	0.7

Table 18. Flavan-4-ols content ($A_{550}\ g^{-1}$) of bird resistant sorghum cultivars

Cultivar Extract	Days after flowering					
	10	20	30	40	50	60
IS 10301 Me	79.8	24.7	26.3	12.0	9.0	1.3
H^+/Me	2.0	6.5	3.0	3.6	2.5	nd
Total	**81.8**	**31.2**	**29.3**	**15.6**	**11.5**	**1.3**
IS 8748 Me	62.0	21.3	34.4	8.5	9.0	3.3
H^+/Me	1.3	3.3	8.5	6.6	3.8	3.7
Total	**63.3**	**24.6**	**42.9**	**15.1**	**12.8**	**7.0**
IS 724 Me	92.2	31.3	40.1	14.3	12.0	3.0
H^+/Me	16.5	4.0	8.5	5.7	5.0	4.0
Total	**108.7**	**35.3**	**48.6**	**20.0**	**17.0**	**7.0**
IS 2880 Me	78.4	40.7	36.3	20.3	24.3	-
H^+/Me	14.8	8.8	9.0	8.8	9.1	-
Total	**93.2**	**49.5**	**45.3**	**29.1**	**33.4**	-
IS 3031 Me	108.8	62.5	31.3	17.5	17.5	-
H^+/Me	20.3	22.5	24.0	8.8	10.0	-
Total	**129.1**	**85.0**	**55.3**	**26.3**	**27.5**	-
IS 2849 Me	23.5	12.3	3.0	1.5	nd	-
H^+/Me	0.5	0.3	nd	nd	nd	-
Total	**24.0**	**12.6**	**3.0**	**1.5**	**nd**	-
IS 3149 Me	82.0	26.5	15.0	4.8	nd	nd
H^+/Me	1.5	nd	nd	nd	nd	nd
Total	**83.5**	**26.5**	**15.0**	**4.8**	**nd**	**nd**
IS 8765 Me	70.3	25.0	6.3	nd	nd	nd
H^+/Me	1.7	0.9	1.5	nd	nd	nd
Total	**72.0**	**25.9**	**7.8**	**nd**	**nd**	**nd**

nd : not detected

Table 19. Protein precipitable phenols content (A_{510} g^{-1}) of Bird resistant sorghum cultivars

Cultivar	Days after flowering					
	10	20	30	40	50	60
IS 10301 Me	22.8	11.5	8.4	0.9	1.5	nd
H^+/Me	1.8	1.0	1.3	0.8	1.5	nd
Total	24.6	12.5	9.7	1.7	3.0	nd
IS 8748 Me	30.7	11.3	12.0	8.5	3.8	1.9
H^+/Me	2.07	1.4	1.4	1.6	1.3	1.2
Total	32.8	12.7	13.4	10.1	5.1	3.1
IS 724 Me	92.2	15.4	15.6	3.8	3.6	1.7
H^+/Me	16.5	1.4	1.5	2.4	2.4	1.0
Total	108.7	16.8	17.1	6.2	6.0	2.7
IS 2880 Me	54.8	26.0	14.8	18.2	20.0	-
H^+/Me	3.9	1.9	7.3	3.9	4.5	-
Total	58.7	27.9	22.1	22.1	24.5	-
IS 3031 Me	18.0	10.8	8.5	4.6	8.3	-
H^+/Me	2.9	1.8	6.7	4.1	5.0	-
Total	20.9	12.6	15.2	8.7	13.3	-

Protein precitable phenols were not detected in cultivars IS 2849, IS 3149, and IS 8765

nd : not detected

Table 20. Chemical composition of elite sorghum cultivars[1]

Cultivar	Protein	Total soluble sugars	Starch	Fat	Ash	Crude fiber
	(%)					
SPV 351	10.2	1.1	80.4	3.8	1.3	2.3
SPV 386	11.8	1.5	79.2	4.0	1.5	2.6
SPV 475	9.0	1.4	81.6	4.0	1.4	1.8
SPH 221	9.8	1.2	80.7	3.9	1.2	1.8
SAR 1	12.2	1.8	78.5	4.4	1.7	1.9
PM 11344	12.3	1.8	79.2	4.0	1.1	2.1
Hegeen Durra 1	10.2	1.7	82.9	4.4	1.3	2.0
Mean	10.8	1.5	80.4	4.1	1.4	2.1
SE	±0.49	±0.11	±0.58	±0.09	±0.08	±0.11

1. Expressed on moisture free basis; mean of three independent determinations

Changes in amino acid composition in whole grain and 96 h germinated grains of 13 cultivars were compared. Lysine content increased in certain cultivars and dereased in others (Table 21). Leucine, cystine and methionine, glutamic acid contents decreased due to malting.

A total of 13,000 germplasm lines grown during the 1985 post-rainy season at ICRISAT center were screened for protein and lysine contents. Grain protein content ranged from 3.7 to 21.6 % and lysine content from 0.9 to 5.1 %. We have identified 77 promising lines having grain protein content from 9.4 to 21.6% and lysine content from 1.1 to 3.3%.

Roti quality was evaluated in 112 samples comprising of Asian Regional sorghum variety/hybrid adaptation trial and advance varietal trial. Cultivars SPV 819, SPV 821, SPV 475 ICSV 214, ICSV 219, ICSV 225 and CSH 9 were rated high by the taste panelists in comparision with the control (M 35-1).

6. Stalk rot complex studies S-113 (85) IC collaborative project involving Pathology, Physiology, Microbiology and Biochemistry units

Total sugar content in stalks of cultivars showing variation for stalk rot incidence was determined and a wide difference was observed among the cultivars. The stalk strength was also measured using an Instron machine. The chemial composition of grains between the resistant E 36-1 and susceptible CSH 6 did not show appreciable variation.

7. Summary and Conclusions

To strengthen the capabilities of national programs (NARS) in Africa, intensive training on food quality was given to three trainees from Ethiopia, Kenya, and Sudan. We also assisted the trainees from Zimbabwe and Mexico on SDU analysis and tortilla quality respectively.

Table 21. Amino acid composition [g (100 g)$^{-1}$] composition in whole and malted sorghum grains

Cultivar	Trt.	Pro	Lys	His	Arg	Asp	Thr	Ser	Glu	Pro	Gly	Ala	Cys	Val	Met	Ileu	Leu	Tyr	Phe
Dabbe	WF	9.0	2.44	2.46	4.43	6.54	2.56	3.73	19.87	8.31	3.16	8.41	1.37	4.97	1.52	3.71	11.25	4.07	5.07
	MF	5.3	3.67	2.56	4.38	6.65	2.90	3.76	15.39	6.92	4.06	6.79	1.40	5.43	1.44	3.71	8.49	4.15	5.25
Lulu dwarf	WF	9.6	2.27	2.00	3.92	7.03	2.59	3.66	20.31	8.90	2.87	9.02	1.35	4.92	1.60	3.87	11.02	3.98	5.19
	MF	7.2	2.89	1.95	3.68	6.91	2.87	3.70	15.89	8.52	3.30	7.06	1.25	4.86	1.44	3.63	9.52	3.84	4.85
M 35-1	WF	9.9	2.43	2.04	4.03	6.83	2.73	3.92	20.26	10.79	3.18	8.92	1.36	4.92	1.55	3.67	11.31	3.79	5.25
	MF	8.7	2.12	1.54	2.79	6.39	2.72	3.89	18.55	8.00	2.85	7.97	0.81	4.65	1.43	3.51	11.67	3.39	5.26
SAR 1	WF	7.2	2.28	2.34	4.42	6.95	2.94	3.86	19.70	9.78	3.44	8.56	1.32	5.07	1.45	4.11	12.00	4.01	5.32
	MF	6.3	2.45	2.31	3.60	6.59	2.92	3.71	17.20	8.26	3.37	7.73	1.36	4.91	1.43	3.81	10.85	3.69	5.02
SPV 351	WF	10.7	2.28	2.15	4.01	6.41	2.77	4.00	20.55	10.14	3.00	9.02	1.41	5.06	1.28	3.65	12.35	4.29	5.47
	MF	8.7	2.26	2.14	3.50	7.02	2.95	3.91	17.12	7.38	3.26	7.72	1.29	4.95	1.50	3.49	11.02	3.31	5.25
SPV 475	WF	10.2	2.29	2.12	3.86	7.33	2.84	3.79	20.45	9.85	2.97	9.21	1.35	5.00	1.49	3.69	12.32	4.30	5.47
	MF	11.4	2.06	2.00	3.73	6.66	2.54	3.58	17.58	7.54	2.71	7.73	1.16	4.63	1.32	3.72	11.20	3.81	5.00
Safra	WF	9.5	2.34	1.90	3.73	6.25	2.62	3.92	19.47	9.02	2.81	8.75	1.43	4.70	1.59	3.40	12.19	3.44	5.42
	MF	7.4	1.47	2.00	3.11	6.63	2.70	3.94	18.43	7.77	2.94	7.66	1.46	4.53	1.26	3.99	11.06	3.74	5.22
WS1297	WF	10.9	2.39	2.31	3.89	6.74	2.17	3.58	19.51	7.85	2.91	8.17	1.25	4.58	1.49	3.80	11.61	3.98	4.92
	MF	7.6	2.75	2.51	3.94	7.43	2.28	3.76	19.88	7.09	3.03	8.26	1.25	4.59	1.54	3.76	11.63	4.00	5.07
Feniida	WF	10.9	2.04	2.26	3.89	6.54	2.41	4.20	19.21	8.77	2.83	8.92	1.31	4.79	1.40	3.80	11.65	4.20	4.24
	MF	11.2	2.29	2.53	3.85	7.01	2.63	4.28	19.38	7.32	3.21	7.84	1.09	4.89	1.34	3.84	10.94	4.51	5.15
IS7055	WF	11.6	2.27	2.37	4.25	6.92	2.69	4.15	18.61	7.25	3.03	8.12	1.14	4.84	1.43	3.28	11.26	3.91	4.72
	MF	7.5	2.61	2.22	3.79	7.06	2.44	3.67	18.97	7.07	3.18	7.27	1.13	4.64	1.40	3.37	10.87	4.17	4.92
IS 14384	WF	10.7	2.37	2.39	3.71	7.35	2.29	3.39	19.90	7.96	2.81	8.08	1.19	4.58	1.28	3.32	12.21	3.71	4.65
	MF	8.8	2.47	2.49	3.92	7.05	2.28	3.58	19.95	7.87	2.78	7.84	1.19	4.80	1.27	3.61	12.00	3.94	4.94
ET3491	WF	13.3	2.05	2.35	3.88	7.29	2.49	3.68	19.60	7.09	2.79	8.19	1.21	4.79	1.32	3.25	11.50	3.90	4.75
	MF	11.4	2.44	2.40	3.86	7.53	2.50	3.69	19.66	7.31	2.91	7.95	1.17	4.74	1.33	3.28	11.55	3.98	4.69
CO 4	WF	10.8	2.15	2.37	3.97	7.39	2.37	3.59	20.09	7.91	2.85	8.03	1.18	4.53	1.20	3.32	11.85	3.69	4.73
	MF	8.6	2.37	2.29	3.74	7.37	2.44	3.62	19.72	7.34	3.29	7.89	1.14	4.80	1.27	3.45	11.61	3.91	4.75
Mean	WF	10.8	2.32	2.24	4.00	6.80	2.58	3.81	19.81	8.59	2.97	8.57	1.30	4.85	1.43	3.58	11.75	3.94	5.01
SE±	WF	0.51	0.006	0.005	0.06	0.11	0.06	0.07	0.15	0.27	0.05	0.12	0.03	0.05	0.04	0.07	0.13	0.70	0.11
Mean	MF	8.5	2.45	2.25	3.68	6.95	2.63	3.78	18.28	7.57	3.15	7.67	1.21	4.80	1.38	3.66	10.98	3.88	5.05
SE±	MF	0.53	0.14	0.08	0.11	0.10	0.07	0.05	0.42	0.13	0.10	0.11	0.05	0.06	0.03	0.05	0.27	0.09	0.55

WF: Whole flour MF: Malted flour - (96 h germinated grain)

Dehulling is the most important grain processing method for utilization of sorghum for food. Dehulling quality of hard grain is better than soft grain. Soft grain is suitable for dehulling using traditional method of hand pounding. But such grain can be dehulled using mechanical dehullers, as evaluated by laboratory models.

Grains of 15 sorghum cultivars representing different geographic origin were germinated for 16, 48, 96, and 144 h. Changes in diastatic activity, protein, starch, soluble sugars, tannin and total phenols contents were studied. The diastatic activity increased upto 96 h of germination and decreased at 144 h. Diastatic activity showed significant variation among cultivars. A few cultivars showed high diastatic activity suggesting that sorghum has the potential for use in malting and brewing. Starch and protein contents decreased during germination, while soluble sugars increased. Variation in protein content during germination was not appreciable among the cultivars. Our study suggest that diastatic activity increased in some cultivars irrespective of the changes in quantities of protein or starch. It appears that changes in proximate composition is independent of diastatic activity. Such information will be useful in a breeding program to incorporate the above traits in high yielding cultivars.

In general, SDU increased with increased relative humidity during germination at 30°C, in several sorghum cultivars. However, in cultivar like SAR 1, increased relative humidity did not result in high SDU.

IVPD of sorghum Ugali was lower than maize Ugali. IVPD of sorghum and maize tortillas was lower as compared to the whole grain indicating that cooking (processing) reducing the IVPD. Malting sorghum grain improved IVPD.

We observed that a few sorghum cultivars had high tannin/flavanols contents at early maturity which reduced at full maturity of grains. These cultivars may have relevance in bird depredation.

Elite sorghum cultivars of ICRISAT were evaluated for chemical composition, including amino acids. A total of 13,000 germplasm lines were screened for protein and lysine contents and 77 promising lines with high protein/lysine contents are indicated. Roti quality was evlauated in advanced breeding lines.

8. Publications

1. Subramanian, V., Prasada Rao, K.E., Mengesha, M.H., and Jambunathan, R. 1987. Total sugar content in sorghum stalks and grains of selected cultivars from the world germplasm collection. Journal of the Science of Food and Agriculture 39(4):289-295 (JA # 279).

2. Subramanian, V., Jambuanthan, R., and Prasada Rao, K.E. 1987. Dry milling characteristics of sorghum grains and their relationship to product quality. Pages 45-54 In Technology and applications for alternate uses of sorghum: proceedings of the National Seminar, 2-3 Feb 1987, Parbhani, India. Parbhani (CP # 346).

3. Seetharama, N., Prasada Rao, K.E., Subramanian, V., and Murty, D.S. 1987. Screening for sweet stalk sorghums, and environmental effect on stalk sugar concentrations. Pages 169-179 In Technology and applications for alternate uses of sorghum: proceedings of the National Seminar, 2-3 Feb 1987, Parbhani, India. Parbhani,

Maharashtra 431 402, India: Marathwada Agricultural University (CP # 308).

4. Jambunathan, R., and Subramanian, V. 1987. Grain quality and utilization of sorghum and pearl millet. Proceedings of the International Symposium on Biotechnology, ICRISAT, 12-15 January 1987, Patancheru, A.P., India (CP # 394).

5. Subramanian, V., and Jambunathan, R. 1987. Utilization of sorghum for alternative uses. Paper presented at the 17th Annual Sorghum Workshop of the AICSIP, 25-27 May 1987, Parbhani, India.

6. Subramanian, V., and Jambunathan, R. 1987. Grain quality of sorghum, pearl millet, maize and minor millets. Proceeding of the Symposium on "Present Status and Future Perspectives in Technology of Food Grains", Central Food Technological Research Institute, 28 February - 1 March 1987, Mysore, India (CP # 352).