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SCREENING FOR SWEET STALK SORGHUMS, AND ENVIRONMENTAL EFFECT ON STALK SUGAR CONCENTRATIONS*

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*Two sets of sorghum (***Sorghum bicolor** *(L.) Moench) germplasm accessions were screened for sweet stalks during rainy (n = 9,000) and postrainy (n = 102) seasons by chewing and tasting, and for sugar percentage in the juice by using brix-refractometer. Sets of 96 and 25 lines were selected during the two respective seasons. Stalk juice from a few selected lines were further characterized for sugar concentration, recovery of sugar, etc. A few lines were found to be stable in sugar percentage across environments. Water stress increased the stalk sugar percentage, while nitrogen fertilizer application had little effect. Stalk rot incidence decreased stalk sugar concentrations. Suggestions are made for the use of sweet and juicy stalk characteristic in crop improvement program to produce multipurpose sorghum.*

The traditional farmers in India and African countries grow sorghum [**Sorghum bicolor** (L) Moench] for multiple uses. Besides grain, the stem is used for fodder, fuel, roofing, and fencing[1], and in some places in Africa even for chewing[2]. Even in some developed countries there is a growing recongnition that conventional production of sorghum solely for grain is an antiquated practice. It has been estimated, for example in Texas, U.S A., that fresh biomass yields in excess of 60 tonnes ha^{-1}, and ethanol yields in excess of 5600 Lha^{-1} are possible from use of improved cultivars[3].

The scope for sorghum production exclusively for use other than grain in the semi-arid tropical regions is restricted to certain pockets. The area under sorghum in countries such as India is decreasing because of its poor demand compared to other food crops such as rice and wheat[4], and, with growing urbanization and changing market demands both the area under cultivation, and the proportion of sorghum for special uses in mixed cultures, are dwindling. Hence alternate uses of sorghums should be examined. Juicy stalks with ability to accumulate sugars is undoubtedly one of the useful charac-

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ters enhancing the use of crop residue, either as fodder[4] or fuel[6], and for improving crop health by preventing or delaying incidence of root and stalk rots[7]. The rich diversity in the sorghum germplasm can be exploited for production of such multipurpose sorghum. We also need to know the effects of environmental factors on sugar percentage in sorghum stalk especially during the later stages of development. This knowledge is useful for effective screening of germplasm, and to predict the scope for multiple uses under different target regions and management practices.

As our major thrust at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is mainly on grain sorghums, we have done only a limited amount of work on stalk quality. We have screened germplasm by rapid methods, so as to select some lines likely to be useful for programs elsewhere exclusively dealing with sweet sorghum. We have also studied some of the environmental factors influencing sugar accumulation in sorghum stalks, especially in the grain type sorghums as a prelude for examining the prospects for multipurpose sorghum with increased tolerance to environmental stress. The objective of this paper is to bring together all our findings to date on these & related aspects. We will further discuss other possible applications for the study of sweet stalk sorghums in a sorghum improvement program.

Materials and methods

During 1980 rainy season over 9,000 accessions planted in our germplasm evaluation nursery were screened. A team of two cut and chewed the basal internodes (second to fourth visible internodes from below) of the plants between hard-dough to physiological maturity. In this first round of selection 983 lines were identified; the juice from the stalks of these selections were sweeter than that of the systematic grain sorghum check SC 108, planted in every ninth row. Next, the sugar concentrations in the stalks of all the 983 selections were measured using a brix-refractometer. Between 1000-1500 hours, the second or third internode (from below) was pressed using a nose-player to extract juice for measuring the sugar percentage. Two plants per entry were sampled. This procedure was also used to evaluate sorghums planted during the postrainy season of 1976.

For soluble sugar analysis, two plants were cut at ground level around maturity. Samples of basal internodes were collected, oven dried, and weighed. The soluble sugar percentages in both the dried samples and the fresh juice were determined by phenol sulphuric acid method[8].

Results and discussion

The distribution of soluble sugar percentages (brix-readings) in the two different sets of lines studied during 1980 rainy, and 1976 postrainy seasons are shown in Figure 1. It is difficult to compare these two heterogeneous sets of data, as there were no common lines; however, it is clear that the mean sugar percentage was higher, and the range was wider in the rainy season than during postrainy season. In Appendix I, data on sugar percentage (brix reading), race, and origin of selected lines are listed. The majority of the lines selected during the rainy

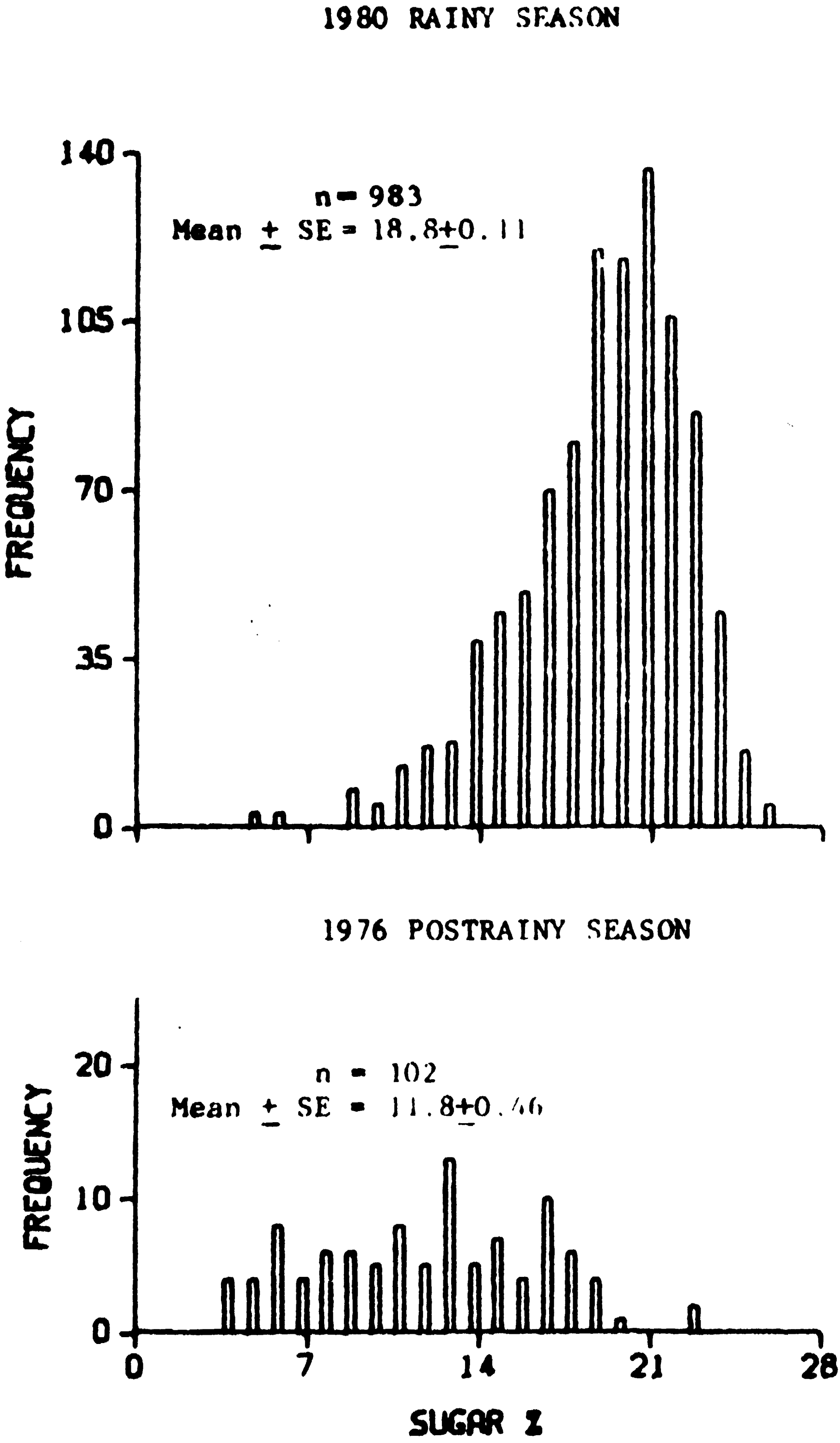

Figure 1: Distribution of sugar percentage (brix-reading) in the two sets of sorghum lines screened during rainy (A), and postrainy (B) seasons.

season belonged to the race Caudatum (42 out of 96) followed by Durra (16) (Appendix IA). Forty two lines originated from Sudan, and 10 each from Kenya, Camoroon, and India, while 9 were from Ethiopia. Out of the 25 lines selected during postrainy season (Appendix 1B) 8 of them belonged to Durra, and 5 to Caudatum. Most of them originated in Ethiopia (7 out of 25), followed by India and Lebanon (5 each). During both seasons, sugar percentages were not related to time to flower (days).

The correlation between brix-readings and the sugar percentage estimated by a chemical method during the 1980 rainy season was of low magnitude ($r = 0.22$; not significant). This may be due to the fact that dried samples rather than fresh juice were used for chemical analysis. However, subsequent studies revealed that brix-readings were highly correlated with total sugars in the juice ($r = 0.95$; $P < 0.001$). The correlations between sugar percentages in the stalk juice and the grain were not significant, indicating that sugary grain and sweet stalk characteristics in sorghum are not related; however two accessions from kenya - IS 20963 and IS 20984 - had both high sugar percentage in grain ($\geq 22\%$) and stalks ($\geq 32\%$).

Selected genotypes were further characterized for the volume and quality of their stalk juice. Sweet sorghum differ considerably in juiciness. Two genotypes, IS 12135 and IS 9890 have nearly the same stalk sugar percentages (table 1), but the latter yielded almost twice as much juice (and recovery percentage of juice) than the former. However, the juice from IS 9890 had the lowest specific gravity and least (amount of) solids; it also yielded the least amount of sugar. Such information on these characteristics of sweet sorghums is important for making final selections for commercial exploitation.

TABLE . TOTAL SUGAR CONTENT, EXTRACTABILITY AND JUICE CHARACTERISTICS OF SORGHUM STALKS AT PHYSIOLOGICAL MATURITY

Pedigree	Country of Origin	Total sugar in stalks (%)a	Juice volume in stalks (ml kg^{-1})	Juice recovery (%)	Juice characteristics: Specific gravity (g ml^{-1})	Total solids (g ml^{-1} x 10^{-2})	Total sugar (g ml x 10^{-2})
IS 12135	Kenya	34.8	266	28.5	1.07	24.8	15.0
IS 9639	Sudan	37.2	292	31.3	1.07	19.9	12.1
IS 9890	Sudan	35.8	464	48.1	1.04	11.9	7.0
IS 9901	Sudan	42.7	410	44.5	1.08	26.1	15.9
IS 19674	Zimbabwe	38.5	407	43.3	1.07	20.7	12.2
Mean		37.8	368	39.1	1.07	20.7	12.4
SE ±		1.37	37.8	3.87	0.001	2.49	1.55

aOn oven-dry weight basis.
(1981 rainy season), ICRISAT Center

In general, sugar percentages of sorghums grown during postrainy season (Fig. 1) were less than those grown during rainy season, as also reported by Chowdhari[*]. The reasons for these shifts in concentrations across seasons need to be understood. However, sweet stalk sorghums with fairly stable sugar percentage across seasons can be selected. Four of the selected lines tested for stability in sugar percentages across season can be selected. Four of the selected lines tested for stability in sugar percentages in three environments maintained their ranking for brix-readings satisfactorily (table 2). IS 19674, followed by IS 9901 showed high sugar percentages, and IS 3940 the lowest. SPV 352, with a low reading showed some increase during summer over the rainy season value; the reverse was noted in case of IS 9901.

Several environmental factors affect the stalk sugar percentage. Water stress increased sugar percentage (table 3) although the grain and biomass yields were reduced under the stress. Stalk rot incidence decreased the sugar percentage. The effects of irrigation, nitrogen, and growth stage are show in table 4. The sugar levels in the stalks of sweet sorgum increase from flowering to maturity; however, this need not be so in grain or dual purpose sorgums, and in crops under water stress[*]. As seen from table 4, the sugar percentage and amount was higher at flowering than at maturity; the higher percentages of sugar in stems of dryland crops may be either due to lack of large grain sinks, or response to water stress (as also evident from table 4). Soil fertility effects on sugar concentration were not significant.

TABLE 2. SUGAR CONCENTRATIONS (STALK % ± SE; OVEN-DRY WEIGHT BASIS) IN FOUR GENOTYPES OF SORGHUM GROWN IN THREE ENVIRONMENTS (ENV)

Genotype	Env 1	Env 2	Env. 3	Mean
IS 9901	17.5±0.70	17.9±0.45	14.6±0.48	16.7±1.04
IS 3940	7.9±0.70	7.5±0.98	9.8±0.76	8.4±0.71
IS 19674	17.3±0.39	17.8±0.63	19.0±0.61	18.0±0.51
SPV 352	9.6±1.20	12.3±0.77	13.1±1.09	11.7±0.92
Mean	13.1±2.52	13.9±2.50	14.1±1.91	13.7±2.23

Env. 1. 1984 Postrainy, Patancheru Vertisol, 3 Irrigations.

Env. 2. 1985 Rainy, Patancheru Vertisol rainfed.

Env. 3. 1986 Summer, Bhavanisagar, Alfisol, irrigated approximatly at 10 days interval

TABLE 3. EFFECT OF TERMINAL WATER SHORTAGE ON STALK SUGAR PERCENTAGES AT PHYSIOLOGICAL MATURITY, BIOMASS AND GRAIN YIELDS

Irrigation treatment (Stress level)	Stalk sugar (percentage)		Biomass ($g\ m^{-2}$)		Grain yield ($g\ m^{-2}$)	
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Control	4.10	1.79	978	791	481	353
Water stress	6.73	2.74	853	720	401	320
Mean	5.42	2.26	916	755	441	336
SE ±	0.85	0.47	34	37	20	18

Sorghum hybrid CSH 6, crop grown during 1979 postrainy season at the ICRISAT Centre. The two soil water levels correspond to the two extreme ends of an irrigation gradient imposed by using four line-source irrigations 44 days from sowing. Diseased (charcoal rot) plants were identified on the basis of soft stalks. For other details, see Leetharama et al. (in press)

TABLE 4. EFFECT OF NITROGEN FERTILIZER, IRRIGATION LEVELS AND GROWTH STAGES ON SUGAR PERCENTAGE, CULM, AND GRAIN WEIGHT

Applied N (kg ha^{-1})	Treatment	Sugar %		Culm dry weight ($g\ m^{-2}$)		Grain yield ($g\ m^{-2}$)
		Flowering	Maturity	Flowering	Maturity	
0	Irrigated	10.0	6.5	174	200	550
	Rainfed	13.4	5.6	183	181	497
80	Irrigated	9.4	6.8	179	195	440
	Rainfed	13.5	6.6	196	181	376
Mean a		11.6	6.4	183	189	466
SE ±		1.08	1.54	21.9	5.0	1.4
Mean b		9.00		18.6		
SE ± – Fertility		0.47		15.5		
SE ± – Irrigation		0.45		38.3		
SE ± – Stage		2.22		32.6		

a : Split plot analysis : nitrogen as main, and irrigation as subplots

b : Split-split plot analysis : The two growth stages formed the sub-sub plots

Two irrigations were given at 4 and 7 weeks after sowing. 1985–86 postrainy season, sorghum hybrid CSH 8R, ICRISAT Center.

Further research on alternate uses of sorghum should consider (i) upper limits of biomass productivity and sugar percentages in the culm in different regions under the existing constraints in each of these regions, and (ii) the dry matter production and distribution within the plant. Study of growth and functioning of the sorghum stems is a neglected area of research; this should be remedied as the stem is the sink for sugars envisaged for alternate uses. Some selected breeding materials contain as high sugar percentages as in sweet stalk sorghums*. Hence incorporation of sweet and juicy character of the stalk into the dual-purpose stocks seems practical. Preliminary results from inheritance studies on F_1, B_1 and B_2 populations of high x low sugar parents showed that high stalk sugar percentage (measured as brix-readings) exhibited dominance, and additive x dominance effects (unpublished data).

Increase in the availability of culm carbohydrate reserves may result in reduced sensitivity of grain development to drought during seed set and filling as in maize", and such a possibility in case of sorghum should be examined. Delayed leaf senescence, continued root activity even during grain filling, & resistance to root & stalk rots can all be expected to ensure that the alternate sink, viz., the culm also stores enough sugars before during, and after grain maturation. Thus, emphasis on higher biomass production rather than mere increase in harvest index (HI) in sorghum improvement programs is important. Attention has already been paid to this as seen by the simultaneous increase in (seasonal and per day) grain and biomass yields with decrease in HI in the recently released hybrids in India such as CSH 9, as compared to the first released hybrid, CSH 1. Such an increase in biomass also calls for higher availability of nutrients, mainly nitrogen, especially during the later part of the season. It would be worthwhile to test whether sorghum with sweet stalk and juicy stems exhibit greater non-symbiotic N_2 fixation. Thus the prospects for using sweet stalk sorghum germplasm identified in this study to breed multipurpose sorghum are bright.

APPENDIX IA. STALK SUGAR PERCENTAGE (BRIX-READING), GEOGRAPHIC AND TAXONOMIC DISTRIBUTION, AND TIME TO FLOWER IN THE SELECTED GERMPLASM ACCESSIONS DURING 1980 RAINY SEASON

Pedigree	Sugar %	Ranks	Race	Country	Time to 50% Flower (d)
1	2	3	4	5	6
IS- 1098	26.6	1	D	India	78
IS- 7073	25.8	2	C	Sudan	82
IS- 21410	25.6	3	—	——	81
IS- 14904	25.5	4	DC	Camoroon	94
IS- 12639	25.2	5	D	Ethiopia	92
IS- 21991	25.0	6	D	India	85
IS- 20962	25.0	6	C	Kenya	90
IS- 14529	25.0	6	C	Uganda	85

1	2	3	4	5	6
IS- 14548	25.0	6	C	Ethiopia	76
IS- 10050	25.0	6	D	India	77
IS- 14465	25.0	6	B	Sudan	75
IS- 11496	24.6	7	D	Ethiopia	74
IS- 6962	24.5	8	C	Sudan	87
IS- 9889	24.5	8	GC	Sudan	75
IS- 9767	24.3	9	C	Sudan	89
IS- 6973	24.3	9	C	Sudan	91
IS- 4751	24.2	10	D	India	78
IS 9699	24.2	10	C	Sudan	83
IS- 7077	24.2	10	C	Sudan	80
IS- 20503	24.2	10	DC	Sudan	73
IS- 9890	24.1	11	C	Sudan	76
IS- 9638	24.0	12	C	Sudan	90
IS- 21005	24.0	12	C	Kenya	90
IS- 6936	24.0	12	C	Sudan	80
IS- 9911	24.0	12	C	Sudan	82
IS- 15448	24.0	12	C	Camoroon	75
IS- 19616	24.0	12	GC	Sudan	75
IS- 14861	24.0	12	D	Camoroon	103
IS- 9901	23.8	13	C	Sudan	87
IS- 20984	23.8	13	—	Kenya	82
IS- 19626	23.8	13	C	Sudan	83
IS- 131	23.8	13	CK	USA	74
IS- 8218	23.8	13	DB	Uganda	84
IS- 10690	23.8	13	CB	Nigeria	80
IS- 21023	23.8	13	C	Kenya	90
IS- 14594	23.6	14	D	Ethiopia	84
IS- 3556	23.5	15	GC	Sudan	83
IS- 19587	23.5	15	C	Sudan	80
IS- 24419	23.5	15	DB	India	76
IS- 3552	23.5	15	C	Sudan	87
IS- 18603	23.5	15	—	Nigeria	86
IS- 16054	23.5	15	C	Ethiopia	82
IS- 20583	23.5	15	GC	Sudan	78
IS- 8157	23.5	15	CK	Uganda	80
IS- 2130	23.5	15	D	USA	80
IS- 11093	23.5	15	CB	Ethiopia	82
IS- 20557	23.5	15	DC	Sudan	77
IS- 18431	23.4	16	DB	India	89
IS- 14446	23.4	16	GC	Sudan	98
IS- 19107	23.3	17	CB	Sudan	81
IS- 14960	23.3	17	CB	Camoroon	103
IS- 14790	23.2	18	D	Camoroon	100
IS- 3524	23.2	18	GC	Sudan	72
IS- 21036	23.2	18	DC	Kenya	111
IS- 9775	23.2	18	C	Sudan	100
IS- 3569	23.2	18	GC	Sudan	92
IS- 6928	23.2	18	C	Sudan	87

1	2	3	4	5	6
IS- 9734	23.2	18	C	Sudan	75
IS- 2135	23.2	18	D	USA	72
IS- 2325	23.2	18	CK	Sudan	84
IS- 4755	23.2	18	D	India	86
IS- 19214	23.2	18	GC	Sudan	75
IS- 271	23.2	18	C	——	75
IS- 9705	23.2	18	C	Sudan	92
IS- 15428	23.1	18	GC	Camoroon	80
IS- 4617	23.0	19	D	India	84
IS- 19261	23.0	20	D	Sudan	72
IS- 14942	23.0	20	DC	Camoroon	77
IS- 15102	23.0	20	C	Camoroon	82
IS- 20974	23.0	20	C	Kenya	98
IS- 10954	23.0	20	D	——	75
IS- 2331	23.0	20	CB	Sudan	84
IS- 19130	23.0	20	CB	Sudan	66
IS- 12292	23.0	20	C	Zimbabwe	80
IS- 19273	23.0	20	—	Sudan	68
IS- 18461	23.0	20	—	India	66
IS- 21235	23.0	20	C	Kneya	98
IS- 22001	23.0	20	C	India	64
IS- 20888	23.0	20	—	——	—
IS- 15455	23.0	20	C	Camoroon	75
IS- 21229	23.0	20	C	Kenya	92
IS- 21100	23.0	20	C	Kenya	94
IS- 9639	22.8	21	C	Sudan	80
IS- 21813	22.8	21	—	Sudan	78
IS- 7080	22.8	21	C	Sudan	87
IS- 10282	22.8	21	D	Sudan	78
IS- 14463	22.8	21	B	Sudan	75
IS- 21260	22.8	21	C	Kenya	84
IS- 21218	22.8	21	C	Kenya	99
IS- 14722	22.8	21	C	Ethiopia	—
IS- 14831	22.8	21	DC	Camoroon	90
IS- 776	22.8	21	C	——	75
IS- 9645	22.8	21	C	Sudan	85
IS- 2541	22.8	21	CK	USA	49
IS- 21460	22.8	21	G	Malawi	86
IS- 3572	22.8	21	C	Sudan	84

Total number of lines tested for sugar percentage = 983

Total number of selected lines (listed above) = 96

		All entries	Selected entries only
Range	=	26.0-4.8	26.0-22.8
Mean ± SE	=	18.8±0.11	23.6±0.08
Mode	=	17.7	24.0
Median	=	19.3	23.4

B = Bicolor; G = Guinea; DC = Durra-caudatum

C = Caudatum; GC = Guinea-caudatum; CB = Caudatum-bicolor

D = Durra; CK = Caudatum-kafir; DB = Durra-bicolor

APPENDIX IB. STALK SUGAR PERCENTAGE (BRIX-READING), GEOGRAPHIC AND TAXONOMIC DISTRIBUTION, AND TIME TO FLOWER IN THE SELECTED GERMPLASM ACCESSIONS DURING 1976 POSTRAINY SEASON

Pedigree	Sugar %	Ranks	Race	Country	Time to 50% Flower (d)
IS- 18162	23.0	1		Lebanon	73
IS- 4831	22.4	2	D	India	58
IS- 18150	19.2	3		Lebanon	75
IS- 18163	19.0	4		Lebanon	70
IS- 3951	18.8	5	D	India	58
IS- 4835	18.7	6	D	India	51
IS- 8553	18.3	7	C	Uganda	79
IS- 11161	18.0	8	D	Ethiopia	79
IS- 11162	17.8	9	D	Ethiopia	77
E- 410	17.5	10		Ethiopia	83
IS- 18174	17.5	10		Lebanon	68
IS- 9609	17.2	11	C	India	68
IS- 1333	17.2	11	DB	India	67
IS- 10007	17.0	12	C	Ethiopia	74
IS- 11022	16.8	13	D	Ethiopia	77
IS- 18164	16.8	13		Lebanon	68
IS- 6780	16.8	13	CB	Burkina Faso	68
IS- 642	16.8	13	GK	USA	61
IS- 686	16.5	14	B	USA	60
IS- 7044	16.4	15	C	Sudan	60
IS- 7484	16.4	15	C	Nigeria	[illegible]0
IS- 12038	16.2	16	D	Ethiopia	73
IS- 669	16.1	17	B	S. Africa	72
IS- 633	16.0	18	B	USA	72
IS- 18554	16.0	18	D	Ethiopia	99

Total number of lines tested for sugar percentage 102
Total number of selected lines (listed above) = 25

		All entries	Selected entries only
Range	=	23.0-3.2	23.0-16.0
Mean ± SE	=	11.8±0.46	17.7±0.36
Mode	=	11.0	18.7
Median	=	12.2	17.2

B = Bicolor
C = Caudatum
D = Durra
DB = Durra-bicolor
CB = Caudatum-bicolor
GK = Guinea-kafir

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