Selection of restorers and varieties for stalk sugar traits in sorghum

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In India, sorghum (*Sorghum bicolor*) is an important staple food crop for a large population and ranks fifth in area and production next to rice (*Oryza sativa*), wheat (*Triticum aestivum*), maize (*Zea mays*) and barley (*Hordeum vulgare*). Sorghums that have 10–25% sugar in stalk juice at grain maturity are called sweet sorghums (Harlan and deWet 1972). Sweet sorghums are characterized by their wider adaptability, rapid growth and sugar accumulation associated with high biomass in the semi-arid tropics (Smith et al. 1987). The sugars presented in the stalk juice of sweet sorghum can be fermented and converted to ethanol using relatively simple techniques (Smith and Reeves 1981, Hill et al. 1987, Smith et al. 1987). Sorghum stalks are ideal for ethanol production as the ethanol is significantly cleaner (low sulfur), and potable alcohol produced from sorghum grains has superior quality. The feasibility of converting stalk sugars to ethanol/syrup/jaggery on or near farms, and the adaptability of sorghum to a wide range of environments prompted researchers to evaluate the potential of sweet sorghum as an alternative crop for ethanol production (Daniel et al. 1991).

Research work on sweet sorghum was initiated in 1980s at the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) to develop lines with high fodder value. Later as strategies changed to develop trait specific hybrid seed parents the research on sweet sorghums was discontinued. On realizing the potential benefits of sweet sorghum as feedstock for ethanol production, ICRISAT renewed its sweet sorghum research in 2000 to identify the potential sweet sorghum lines from existing restorer lines and varieties developed for grain at ICRISAT.

Materials and methods

A trial (set 1) was conducted at ICRISAT, Patancheru, India in 2004 postrainy season with 42 varieties/restorers developed at ICRISAT (Reddy et al. 2005) with two controls in a randomized complete block design (RCBD) in two replications to test the sugar contents. A basal dose fertilizer at 40N:40P was applied at planting time, followed by another dose of 40N as top dressing at 25 days after emergence. The data were collected on agronomic traits such as time to 50% flowering (days), plant height (m), grain yield (t ha^{-1}), grain size (g 100^{-1} seeds) and agronomic score, and Brix (%) for sugar contents was estimated with a hand refractometer using the juice sample obtained from the third node of stalks.

Table 1. Performance of selected sorghum varieties/restorers for agronomic traits and Brix content in 2004 postrainy season.

R-line/ Variety	Time to 50% flowering (days)	Plant height (m)	Grain yield (t ha^{-1})	Brix (%)
ICSR 17	84	1.3	2.46	14.0
ICSR 36	77	1.6	2.94	21.5
ICSR 43	80	1.6	4.29	16.3
ICSR 49	79	1.5	3.51	18.3
ICSR 57	78	1.5	3.96	17.3
ICSR 66	81	1.8	4.27	12.2
ICSR 86	83	1.3	3.50	16.7
ICSR 160	73	1.5	2.21	16.3
ICSR 165	85	2.0	6.45	20.0
ICSR 24007	74	1.4	2.66	9.5
ICSR 89001	82	1.5	3.49	14.3
ICSR 89008	79	1.5	3.16	16.7
ICSR 89015	85	1.7	3.76	20.2
ICSR 89068	71	1.4	1.93	9.5
ICSR 91005	75	1.5	2.58	19.0
ICSR 93031	74	2.4	3.56	16.8
ICSR 93034	77	2.1	4.63	13.5
ICSR 94489	75	2.2	2.34	15.2
ICSV 574	84	2.2	5.34	17.7
ICSV 700	78	2.3	2.76	11.2
E 36-1	82	1.5	4.98	14.3
Ent 64 DTN	75	1.7	4.30	15.2
NTJ 2	75	2.0	5.01	11.2
S 35	79	1.8	2.63	15.5
Seredo	74	1.6	3.59	14.4
SPV 1411	76	2.5	2.90	21.0
ICSV 93046	77	2.3	2.61	14.2
Controls				
SSV 74	75	2.5	2.75	14.7
SSV 84	76	2.2	3.15	18.5
Mean	77	1.68	3.28	15.12
SE±	1.92	0.07	0.59	2.59
CV (%)	3.51	5.68	25.75	24.21
CD (5%)	5.47	0.19	1.69	7.38

The data were analyzed using GENSTAT package version 9.1. Significant differences were observed among genotypes for time to 50% flowering, plant height, plant aspect score, grain yield and grain size. A total of 27 entries were selected (Table 1) from 2004 postrainy season evaluation and further tested in 2005 rainy season as set 2. Data were recorded for time to 50% flowering, plant height, plant aspect score and grain yield in addition to sweet stalk traits such as cane yield, juice volume and Brix (%) to estimate sugar yield based on Brix (%) and juice volume.

Results and discussion

In set 1 (Table 1), the genotypes differed significantly for time to 50% flowering. The genotypes that flowered early (<76 days) were ICSR 89068, ICSR 160, ICSR 93031, ICSR 91005 and ICSR 94489 among the restorer lines and Seredo, Ent 64 DTN and NTJ 2 among the varieties including the sweet sorghum control SSV 74. The restorers ICSR 165 and ICSR 89015 were late flowering (85 days). However, the genotypes that flowered early fall under medium duration as per the classification in sorghum. On the other hand, SPV 1411, ICSR 93031, ICSV 700 and ICSV 93046 had plant height similar to the controls indicating their potential to produce high biomass. The grain yield was significantly high (>5.0 t ha^{-1}) in ICSR 165, ICSV 574 and NTJ 2. The Brix content of ICSR 36, SPV 1411, ICSR 89015, ICSR 165, ICSR 91005 and ICSR 49 was similar to that of the best control SSV 84 (18.5%) indicating their superiority for ethanol production. All the late flowering genotypes were superior for Brix (%). The late flowering and tall genotype ICSR 165 recorded higher grain yield and Brix content.

Table 2. Performance of selected sorghum varieties/restorers in 2005 rainy season at ICRISAT, Patancheru, India.

Genotype	Time to 50% flowering (days)	Plant height (m)	Plant aspect score[1]	Grain yield (t ha^{-1})	Brix (%)	Cane yield (t ha^{-1})	Juice volume (kl ha^{-1})	Sugar yield[2] (t ha^{-1})
ICSR 165	91	2.8	3.0	1.9	17.7	72.8	27.1	4.8
ICSV 700	92	3.1	2.3	0.6	17.3	56.0	22.8	3.9
ICSV 574	92	2.8	4.0	1.1	18.7	59.5	19.6	3.7
NTJ 2	90	2.7	3.7	1.8	15.7	44.6	21.7	3.4
ICSR 93034	91	2.7	3.3	2.3	17.3	46.8	19.4	3.3
E 36-1	90	2.4	4.0	0.7	20.0	41.9	16.5	3.3
Controls								
SSV 74	87	2.8	3.7	2.5	17.2	72.4	32.1	5.5
SSV 84	93	2.7	4.0	1.5	18.3	49.8	16.7	3.1
Mean	81	2.21	2.64	4.58	13.25	35.82	15.28	2.18
SE±	1.75	0.11	0.37	0.53	0.81	4.30	2.15	0.39
CV (%)	3.73	8.55	24.49	20.15	10.55	20.78	24.39	30.73
CD (5%)	4.95	0.34	1.06	1.51	2.29	12.18	6.10	1.10

1. Scored on 1–5 scale where 1 = agronomically more desirable and 5 = least desirable.
2. Based on Brix's reading and juice yield.

Table 3. Correlation coefficiencies of sweet sorghum restorers among the traits in rainy season[1].

Trait	Time to 50% flowering (days)	Plant height (m)	Brix (%)	Grain yield (t ha^{-1})	Cane yield (t ha^{-1})	Juice volume (kl ha^{-1})	Sugar yield (t ha^{-1})
Time to 50% flowering (days)	1.000						
Plant height (m)	0.696**	1.000					
Brix (%)	0.887**	0.644**	1.000				
Grain yield (t ha^{-1})	–0.836**	–0.625**	–0.770**	1.000			
Cane yield (t ha^{-1})	0.810**	0.871**	0.786**	–0.678**	1.000		
Juice volume (kl ha^{-1})	0.675**	0.823**	0.652**	–0.539**	0.929**	1.000	
Sugar yield (t ha^{-1})	0.827**	0.798**	0.839**	–0.706**	0.963**	0.942**	1.000

1. ** = Significant at 1% level.

Evaluation of the selected genotypes as set 2 showed significant differences among the genotypes for all the traits in 2005 rainy season (Table 2). In the selected lines, the values for Brix (%) ranged from 16.0% to 20.0%; cane yield from 41.9 t ha^{-1} to 72.8 t ha^{-1}; juice volume from 16.5 kl ha^{-1} to 27.1 kl ha^{-1}; sugar yield (based on juice volume and Brix) from 3.3 t ha^{-1} to 4.8 t ha^{-1}; time to 50% flowering from 90 to 92 days; plant height from 2.4 m to 3.1 m; grain yield from 0.7 t ha^{-1} to 2.3 t ha^{-1}; plant aspect score from 2.3 to 4.0. The controls SSV 74 and SSV 84 produced 5.5 t ha^{-1} and 3.1 t ha^{-1} sugar yield, respectively. The sugar yield of ICSR 165 (4.8 t ha^{-1}) was similar to the best control SSV 74 (5.5 t ha^{-1}) while that of other genotypes ICSV 700, ICSV 574, NTJ 2, ICSR 93034 and E 36-1 (>3.0 t ha^{-1}) was similar to the control SSV 84. Similar results were obtained for juice volume and cane yield. Brix (%) was more than 15% in all the genotypes and similar to both the controls SSV 74 and SSV 84. Brix was highest (20%) in E 36-1. Grain yield of the genotypes ICSR 165, ICSV 574, NTJ 2 and ICSR 93034 were similar to the best control SSV 74 (2.5 t ha^{-1}); ICSR 165 and ICSV 574 are more stable for Brix (%).

Correlation studies (Table 3) indicated that cane yield, juice volume and sugar yield showed significantly positive correlation with time to 50% flowering, plant height and Brix (%) and significantly negative correlation with grain yield. Tall and long-duration genotypes tend to produce more cane yield and juice volume with high Brix value (like ICSR 165). Grain yield had significantly negative correlation with time to 50% flowering, plant height and Brix (%). Genotypes with high grain yield were early in flowering and dwarf for plant height with low Brix values.

The results clearly indicated that all the six entries selected are similar to the best controls for grain yield and sweet stalk traits and mature at the same time. They can be used directly as sweet sorghum varieties and/or in hybrid development. They can increase the diversity of sweet sorghum hybrids without compromising the grain or sugar yields.

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