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RESEARCH ARTICLE

Performance of Sweet Sorghum Varieties and Hybrids During Post Rainy Season (*maghi*) in Vertisols of Scarce Rainfall Zone in Andhra Pradesh

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Abstract Sweet sorghum is a new generation bioenergy crop with considerable tolerance to drought and salinity, water logging and amenable for multiple uses. A total of 6 improves sweet sorghum varieties and 8 hybrids were evaluated during 2009–2010 at Nandyal, the centre of scare rainfall zone in the state of Andra Pradesh, India. Genotypic differences for various agronomic and sugar yield related traits was significant across all the three phenological stages i.e. flowering, dough and physiological maturity, while season has little influence on cultivar performance. This study conclude that the varieties urja and ICSV 25274 and the hybrids ICSSH 25, ICSSH 30 and ICSSH 31 are best adapted to scarce rainfall region of Andhra Pradesh for cultivation in early postrainy season (*maghi*).

Keywords Sweet sorghum · Genotypes · Varieties · Hybrids · GxE · Sugar yield · Brix % · Phenology

Introduction

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is similar to grain sorghum with an advantage of producing high biomass while accumulating easily fermentable sugars (glucose, fructose and sucrose). The efficient C_4 photosynthetic pathway, tolerance to drought, water logging, salinity and acidic soils, makes it a preferred crop for cultivation on marginal areas lying between 40° south and north latitudes of the equator (Rao et al. 2009). This crop is considered a new generation bioenergy crop owing to its multiple uses like and wider adaptability to varied agro-climatic conditions. Sweet sorghum is a potential raw material for production of ethanol, which on blending with gasoline is expected to contribute to energy security there by addressing socio-environmental issues in semi-arid tropics (SAT) (FAO-STAT 2013). This novel feedstock can be employed for diverse ethanol conversion systems i.e. grain starch, simple stalk sugars, and biomass/bagasse (Rao et al. 2009, 2010; Zhang et al. 2010), which makes it a choice feedstock in diverse scenarios. Soluble sugars produced from sweet sorghum have the potential to yield up to 5,000 l of ethanol ha^{-1} or twice the ethanol yield potential of maize grain. Approximately 50–85 tons/ha of sweet sorghum stalks with juice extraction of 39.7 to 42.5 t ha^{-1} led to and 3450 to 4132 L ha^{-1} ethanol production (Serna-Saldívar et al. 2012). Further, low water requirement, high biomass and alcohol production and greater income potential, makes it a preferred bioenergy crop (Zegada-Lizarazu et al. 2012; Curt et al. 1995). In addition to sweet-stalk, it yields about 2.0–6.0 t ha^{-1} grain that can be used as food or feed.

Sweet sorghum improvement should aim for simultaneous improvement of stalk sugar traits such as total soluble sugar or Brix %, green stalk yield, juice quantity, girth of the stalk, grain yield and its components. Ganesh et al. (1995) showed a significant positive correlation between girth of the stem, cane yield, juice yield, Brix %, total sugars, sucrose % and alcohol yield. The wide range of variability for Brix % (3–25 %); (Sankarapandian et al. 1994; Almodares et al. 1997; Rao et al. 2011), sucrose (7.2–15.5 %) (Almodares et al. 1997; Rao et al. 2013) and

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fresh stalk yield (24–150 t ha^{-1}) (Elangovan et al. 2007; Rao et al. 2013) in sorghum indicates high potential for genetic improvement to produce high sweet stalk yield coupled with high sucrose and fermentable sugars (glucose and fructose). The genotype × environment (GxE) interaction influences greatly the success of breeding strategy as it has been demonstrated earlier by several researchers on the significant interaction of location (environment) with the cultivars (Wortmann et al., 2010; Rao et al. 2011). Hence, the present investigation was taken up to identify the best adapted sweet sorghum improved varieties and hybrids in the scarce rainfall zone (<500 mm per annum) of Andhra Pradesh, India.

Materials and Methods

Location and Materials

The field experiment was carried out at Regional Agricultural Research Station (RARS), Nandyal, Andhra Pradesh, India, (15°29^{1}N latitude and 78°32^{1}E longitude with an altitude 211.3 m above mean sea level) during post rainy (*maghi*) seasons of 2009 and 2010. RARS Nandyal is the head quarter of scarce rainfall zone comprising the districts of Kurnool, part of Ananthapur and Cuddapah districts in Andhra Pradesh. The experimental materials consists of 6 varieties (urja, ICSV 25274, ICSV 25280, PA 27, NTJ 2 and SPV 422) and 8 hybrids (ICSSH 25, ICSSH 29, ICSSH 30, ICSSH 31, ICSSH 39, JK Recova, PAC 52093 and CSH 22 SS).

Treatments

The experiment was conducted in a split plot design consisting of 6 varieties and 8 hybrids as main plots with three stages of harvesting stalks (flowering, dough and physiological maturity) as sub-plot treatments and was replicated thrice. A spacing of 60 cm between rows and 15 cm within a row was adopted. N, P and K were supplied as urea, single super phosphate (SSP) and murate of potash (MOP). Half the dose of N (45 kg ha^{-1}) and full dose of P_2O_5 (40 kg ha^{-1}) and K_2O (20 kg ha^{-1}) were applied as basal

Table 1 Combined analysis of variance of sweet sorghum varieties evaluated in post-rainy season in 2009 and 2010 for stalk yield, juice yield, Brix and sugar yield

Source of variation	*df*	Stalk yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix (%)	Sugar yield (t ha^{-1})
Replication	2	11.67	2.91	9.70	0.04
Season	1	3,473.70**	128.81**	47.44	0.37
Residual	2	43.20	0.20	14.56	0.03
Stage	2	1,078.08**	176.55**	15.01**	7.84**
Season × stage	2	530.99**	104.98**	1.48	1.25 **
Residual	8	27.82	6.31	7.74	0.13
Genotype	5	155.31**	18.17**	20.75**	0.39**
Genotype × season	5	26.64	5.60	6.34	0.04
Genotype × stage	10	78.42**	10.45**	8.80*	0.16*
Genotype × stage × season	10	44.77**	12.22**	5.80	0.12*
Residual	60	17.86	4.05	4.19	0.06

df degrees of freedom

* Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$

Table 2 Combined analysis of variance (ANOVA) of sweet sorghum hybrids evaluated in post-rainy season in 2009 and 2010 for stalk yield, juice yield, Brix and sugar yield

Source of variation	*df*	Stalk yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix (%)	Sugar yield (t ha^{-1})
Replication	2	27.44	3.11	1.22	0.09
Season	1	783.43	226.92**	259.34	1.28*
Residual	2	71.89	1.27	20.62	0.07
Stage	2	2,571.19**	286.90**	80.55**	1.93*
Season × stage	2	173.53	58.87	36.82**	1.47*
Residual	8	168.24	27.77	2.70	0.34
Genotype	7	330.82**	26.72**	22.48**	0.19
Genotype × season	7	288.92**	32.01**	27.81**	0.59**
Genotype × stage	14	70.01*	11.30	11.29*	0.20*
Genotype × stage × season	14	81.27	10.83	13.63*	0.09
Residual	84	48.68	8.10	6.01	0.11

df degrees of freedom

* Significant at $P \leq 0.05$; ** Significant at $P \leq 0.01$

and remaining half dose of N (45 kg ha^{-1}) was applied as top dressing after interculturing at 35 days after sowing (DAS). One life saving irrigation was given at 30 DAS. Data was recorded for the traits viz, days to 50 % flowering, plant height (m), stalk yield (g), juice yield (g), Brix (%), [recorded using a hand refractometer (Atago, Japan)] and sugar yield was calculated as described by Wortmann et al. 2010. Harvesting of the plots was done at 50 % flowering at dough stage i.e. 18–22 days after flowering and also at physiological maturity.

Data Analyses

The SAS software (SAS Institute Inc. 1991) was employed for the analysis of variance (ANOVA) and to calculate the significant differences among the varieties and hybrids. The statistical significance of the differences between the means was estimated by the least significant difference and all significant results were reported at the $P \leq 0.05$ and $P \leq 0.01$ levels.

Results and Discussion

Analysis of Variance (ANOVA)

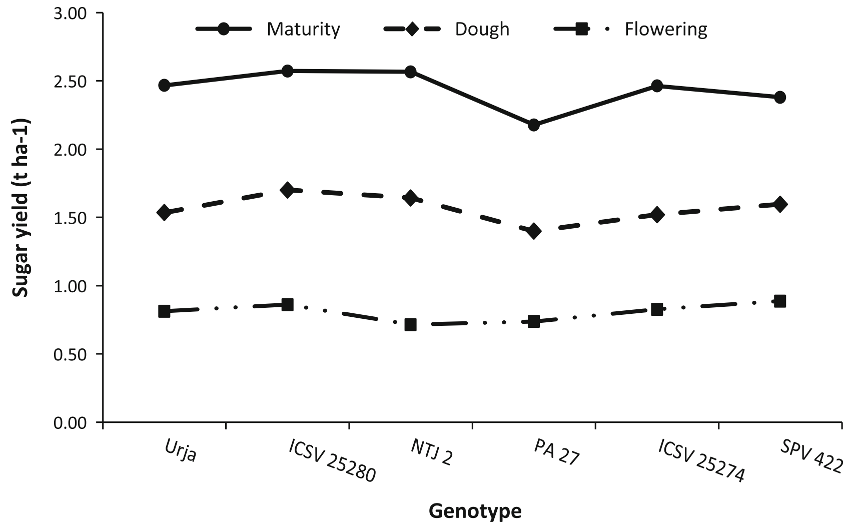
The ANOVA for candidate sugar traits in varieties showed that there was a significant difference among the entries for the sugar yield and its related traits, among the 3 stages of harvest while season has bearing on stalk yield and juice yield only (Table 1). The genotype x stage x season interaction is significant for stalk yield, juice yield and sugar yield while it is non-significant for brix. This is expected as the genotype X stage interaction and stage has lesser influence on sugars accumulation.

The ANOVA for hybrids showed that there was a significant GxE interaction (Table 2). This is vindicated by the fact that the mean squares due to stage, genotype x season and genotype × stage interaction for the sugar yield and related traits are significantly different. Different phenological stages of plant cycle affect Brix % and sugar content (Broadhead 1969, 1972). The mean squares for all candidate sugar traits are found to be significant in both the varieties and hybrids (Tables 1, 2). This is due to the reason that the phenological stage has significant bearing on sugar concentration in both varieties and hybrids as Brix in the stem's juice increases from flowering to ripening (Broadhead 1969; Rao et al. 2009, 2010). Similar reports of increase in total soluble sugars with time and crop cycle length was observed (Zhao et al. 2009). The genotype x stage x season interaction is non-significant for

Table 3 Performance of sweet sorghum varieties for agronomic and candidate sugar traits during postrainy season 2009–10

Genotype	Plant height (m)	Days to 50 % flowering	Stalk yield (t ha^{-1})			Juice yield (t ha^{-1})			Brix (%)			Sugar yield (t ha^{-1})		
			Flowering	Dough	Maturity	Flowering	Dough	Maturity	Flowering	Dough	Maturity	Flowering	Dough	Maturity
Urja	2.25	60	28.06	29.43	26.95	9.03	7.41	7.76	12	13	16	0.81	0.72	0.93
ICSV 25280	1.97	64	32.09	25.07	23.89	8.83	7.46	6.96	13	15	16.7	0.86	0.84	0.87
NTJ 2	1.87	54	32.61	24.97	20.01	7.06	8.53	6.88	13.5	14.5	17.9	0.71	0.93	0.92
PA 27	1.81	54	26	23.39	18.99	7.03	6.78	6.65	14	13	15.6	0.74	0.66	0.78
ICSV 25274	2.17	56	30.54	28.04	24.57	9.19	6.24	7.62	12	14.8	16.5	0.83	0.69	0.94
SPV 422	1.84	60	39.22	26.51	22.55	9.86	7.38	6.97	12	12.8	15	0.89	0.71	0.78
Mean	1.99	58	31.42	26.24	22.83	8.50	7.30	7.14	12.75	13.85	16.28	0.81	0.76	0.87
LSD ($P < 0.005$)	0.07	1.3	7.39			3.29			3.74			0.43		
CV %	3.9	1.4	16.4			31.1			15.8			35.5		

Fig. 1 Dynamics of Sugar yield of improved sweet sorghum varieties in three phenological stages (flowering, dough and maturity)



stalk yield, juice yield and sugar yield while it is significant for Brix content.

Phenology and Varieties Performance

The mean performance of improved sweet sorghum varieties for various agronomic and candidate sugar traits is presented in Table 3. The plant height ranged from 1.81 m to 2.25 (SPV422: 1.84 m) while days to 50 % flowering varied between 54 and 64 days (SPV422: 60 days). The varieties PA27 and NTJ 2 are early to flower (54 days) while ICSV 25280 is relatively late. A wider window of flowering period helps to supply feedstock for longer duration to the sweet sorghum distillery (Rao et al. 2009, 2013). A comparision of stalk yield at three phenological stages i.e. flowering, dough and physiological maturity reveals that the average stalk yield is highest during flowering (32.41 t ha^{-1}) and declines gradually till maturity (22.83 t ha^{-1}). It translates into 16.5 % reduction from flowering to dough and 13 % reduction from dough stage to physiological maturity. This is probably due to drying of leaves and decline in juice content, consequence of stoppage of irrigation post-flowering. This can be noticed as juice yield was highest at flowering (8.5 t ha^{-1}) followed by 7.3 t ha^{-1} at dough stage while it was lowest at physiological maturity (7.14 t ha^{-1}). It translates into 14.1 % reduction in juice yield from flowering to dough and 2.2 % reduction from dough stage to physiological maturity. As expected the brix content an indicator of total soluble sugars gradually increased across the varieties from flowering (12.75 %) to dough (13.85 %). This corroborates previously published literature (Reddy et al. 2005; Rao et al. 2009, 2010, 2011, 2012). The mean sugar yield also increased marginally from flowering stage by 7.5 % (0.81 t ha^{-1}) to physiological maturity (0.87 t ha^{-1}) There is a slight reduction in sugar yield at dough stage i.e. by 6 % (0.76 t ha^{-1}), which is probably due decline in juice content could not be compensated by increase in Brix % content. This forms the basis for recommendation of harvesting of the crop at different stages of maturity (dough to physiological maturity) (Rao et al. 2011). Among the varieties studied, ICSV 25274 and urja have recorded highest sugar yield 0.94 and 0.93 t ha^{-1} respectively (Fig. 1). A practical method to determine the optimum harvest time is based on Brix percent after anthesis until a peak period is reached (Tsuchihashi and Goto 2004). Sweet sorghum produces best when adequate moisture is available, but its real potential appears when it is grown under suboptimal conditions where the combination of its high radiation use efficiency and water and nutrient use efficiencies allows it to continue to produce when other energy crops would struggle (Woods 2001). Though there was significant interaction of stage with genotype, the interaction was insignificant with season due to same season of screening in both the years of study (2009–2010).

Phenology and Hybrids Performance

The mean performance of improved sweet sorghum hybrids for various agronomic and candidate sugar traits is presented in Table 4. Plant height in the tested hybrids ranged from 1.8 to 2.6 m (CSH 22 SS: 2.1 m). Highest plant height was recorded by the hybrid PAC 52093 (2.6 m). The days to 50 % flowering in the tested hybrids ranged from 53 to 60 days (CSH 22 SS: 55 days). There is not much variation in the days to 50 % flowering in the hybrids tested in the trial as evidenced by narrow window of flowering (7 days in hybrids compared to that of 10 days in varieties). The varieties JK recova and ICSSH 25 are

Table 4 Performance of sweet sorghum hybrids for agronomic and candidate sugar traits during postrainy season 2009–10

Genotype	Plant height (m)	Days to 50 % flowering	Stalk yield (t ha^{-1})			Juice yield (t ha^{-1})			Brix (%)			Sugar yield (t ha^{-1})		
			Flowering	Dough	Maturity	Flowering	Dough	Maturity	Flowering	Dough	Maturity	Flowering	Dough	Maturity
PAC 52093	2.61	55	32.04	24.1	22.87	11.26	8.27	7.4	11	12	17	0.93	0.74	0.94
JK Recova	2.25	53	30.49	25.84	23.45	9.18	7.42	6.56	8	14.3	17.3	0.55	0.80	0.85
ICSSH 29	2.35	55	35.48	27.77	26.18	11.61	9.4	8.91	13	16.3	17.8	1.13	1.15	1.19
ICSSH 25	1.87	53	40.49	38.45	35.46	15.33	13	11.88	10.3	14	15.6	1.18	1.37	1.39
CSH 22SS	2.16	60	24.52	21.38	19.84	8.13	7.7	6.4	11	13	15.9	0.67	0.75	0.76
ICSSH 31	1.84	53	40.9	34.36	30.87	12.09	11.04	10.41	11	12.2	15.5	1.00	1.01	1.21
ICSSH 30	1.97	55	34.72	29.31	30.15	12.82	9.96	9.75	12	13	16.8	1.15	0.97	1.23
ICSSH 39	2.17	54	33.88	26.49	26.89	10.58	8.42	8.16	10	12.6	15	0.79	0.80	0.92
Mean	2.15	55	34.07	28.46	26.96	11.38	9.40	8.68	10.79	13.43	16.36	0.93	0.95	1.06
LSD ($P < 0.005$)	0.05	1.72	12.57			5.01			4.12			0.57		
CV %	3.2	2	26			44.3			20.2			49.7		

early to flower (53 days) while CSH 22SS is relatively late (60 days). A comparison of stalk yield at 3 phenological stages i.e. flowering, dough and physiological maturity reveals that the average stalk yield is highest during flowering (34.07 t ha^{-1}) and declines gradually till maturity (26.96 t ha^{-1}). It translates into 16 % reduction from flowering to dough and 5 % reduction from dough stage to physiological maturity. The decline in stalk yield is not sharp from dough stage to physiological maturity probably due to stay green nature and early flowering of hybrids inspite of stoppage of irrigation post-flowering (Miller and Ottman 2010). This is further corroborated by the fact that the juice yield showed sharp decline from flowering to dough stage by 17.3 % while the reduction from dough to physiological maturity is 7 %. The hybrids in contrast to varieties exhibited sharp rise in Brix by 24 % from flowering (10.79 %) to dough stage (13.43 %) while it was 21 % from dough (13.43 %) to physiological maturity (16.36 %). This has significant bearing on the final sugar yield levels at physiological maturity (Rao et al. 2009, 2010, 2011). As a result of increased Brix % content, the mean sugar yield increased gradually from flowering stage by 2.3 % (0.93 t ha^{-1}) to dough (0.95 t ha^{-1}) and by 12 % from dough to physiological maturity (1.06 t ha^{-1}). These observations up hold the earlier published results (Reddy et al. 2008; Rao et al. 2009, 2011). All the screened hybrids exhibited superiority by 15–78 % for stalk yield over the check CSH 22SS (19.84 t ha^{-1}) at physiological maturity. The highest stalk yield at maturity was recorded by ICSSH 25 (35.46 t ha^{-1}). The hybrid ICSSH 25 seems to be the best adapted hybrid to the tested agro-climatic conditions as it recorded highest juice yield (11.88 t ha^{-1}) and sugar yield (1.39 t ha^{-1}). ICSSH 25 recoded standard heterosis for stalk yield by 79 and 86 % for juice yield and 82 % for sugar yield. Similar research was reported (Rebecca 2009). The hybrids ICSSH 29, ICSSH 30 and ICSSH 31 had significant superiority over the check for sugar yield at maturity. The hybrids ICSSH 29 (17.8 %), JK Recova (17.3 %) and PAC 52093 (17 %) are best for Brix (CSH 22 SS: 15.9). Similarly, the hybrids ICSSH 25 and ICSSH31 are found to be superior for juice yield as they recorded 85 and 62 % standard heterosis over the check CSH 22SS respectively. The above observations leads to the conclusion that harvesting the crop at physiological maturity yields sugar higher while the hybrids ICSSH 25, ICSSH 29, ICSSH30 and ICSSH 30 are best adapted to the scarce rainfall zone of Andhra Pradesh (Fig. 2).

Conclusion

The performance of the varieties and hybrids differed in the three stages tested. The major outcome of this study is that

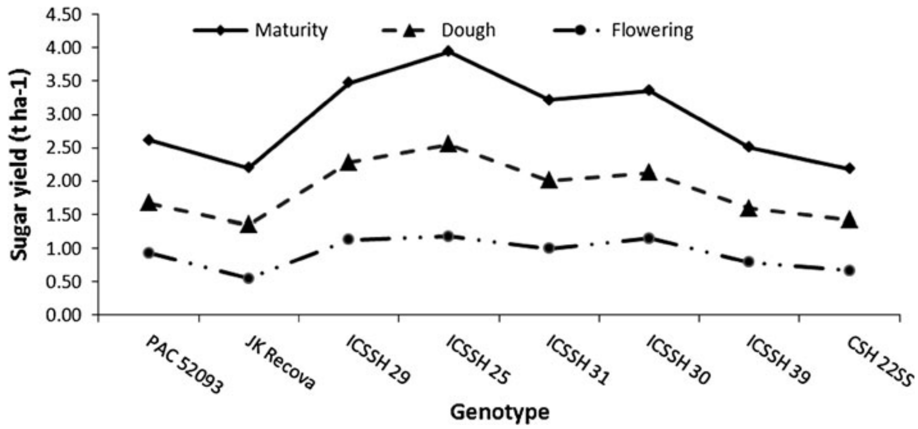


Fig. 2 Dynamics of sugar yield of improved sweet sorghum hybrids in three phenological stages (flowering, dough and maturity)

all the sweet sorghum genotypes showed a increase in sugar yield from flowering stage to physiological maturity. Season had non-significant effects on the genotype stalk and sugar yields in the varieties and hybrids. The significant interactions of genotype on stage and their interactions with each other on stalk yield showed that a large variation exists between cultivars for sugar yield traits could be exploitation suitably by the breeding program aiming for selecting location and season specific cultivars with higher sugar yield. Hybrids are relatively early for flowering i.e. has shorter duration than that of varieties and had exhibited significant exploitable heterosis for stalk yield (15–78 %), juice yield (6–82 %) and sugar yield (11–82 %). The tested hybrids did not record good level of heterosis for sugar yield. This study conclude that the varieties urja and ICSV 25274 and the hybrids ICSSH25, ICSSH 30 and ICSSH31 are best adapted to scarce rainfall region of Andhra Pradesh.

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