

RESEARCH ARTICLE

Physio-biochemical assessment of sweet sorghum genotypes during post rainy season

M.S. Shinde, S.S. Repe, A.R. Gaikwad^{*}, U.S. Dalvi and S.R. Gadakh

All India Coordinated Sorghum Improvement Project, MPKV, Rahuri District, Ahmednagar-413722, Maharashtra, India
atul_sorghum@rediffmail.com ; +91 9404980436

Abstract

The investigation entitled "Physio-biochemical assessment of sweet sorghum genotypes" was undertaken during post rainy season 2010. Twenty sweet sorghum genotypes were evaluated for physiological and biochemical parameters. The genotypes RSSV-275, RSSV-280, RSSV-194 and RSSV-268 were found superior for biomass in terms of green cane yield and its components coupled with better physio-biochemical traits. It is therefore, suggested that these genotypes could be exploited commercially during post rainy season. Simultaneously these genotypes could be utilized in breeding programme for the photoperiod insensitive point of view. The dynamics of sugar content in stalk revealed that the maximum sugar was observed at physiological maturity. Therefore it is suggested that harvesting of sweet sorghum during post rainy season could be done at physiological maturity. Sweet sorghum improvement should be aim for simultaneous improvement of stalk sugar traits viz., brix, green cane yield, juice quality, stem girth, the physiological processes (photosynthesis, transpiration, stomatal conductance, PAR and stomatal resistance) and biochemical traits (reducing, non reducing and total sugars) could be taken into consideration for development of high yielding sweet sorghum variety for ethanol production.

Keywords: Sweet sorghum, post rainy season, green cane yield, ethanol, juice quality, stomatal resistance.

Introduction

Productivity and profitability are essential issue for keeping *kharif* sorghum competitive. Alternate uses may create market demand for raw material and make sorghum production remunerative. There are good options available now for value addition. Ethanol is widely used industrial raw material. It can be produced both from the juice of sweet stalked sorghum as well as from grain and thus whole plant utilization can be promoted. Demand for renewable energy sources and bio-fuel which would minimize pollution are expected to rise rapidly in coming years. Sorghum, by virtue of its C₄ photosynthetic system and rapid dry matter accumulation is an excellent bio-energy crop. Therefore, sorghum is expected to gain importance in the coming years in bio-energy farming. Ethanol is a clean burning fuel with high octane rating and it can be blended easily with petrol to the extent of 15-20%.

Juice from sweet sorghum stalks can be competitive raw materials to molasses for producing ethanol. At present, there has not any one technique which can be needed to meet the demand of the energy in world. Green plant sweet sorghum is the chief collector of solar energy. The accumulation of sugar in stalk of sweet sorghum begins after vegetative growth stage turning to reproduction growth stage. The sugar accumulation in stalk increases with maturity of the plant (Li, 1997). Bio-fuels are gaining importance ever since fossil fuel prices began sky rocketing due to geopolitical issues and also the growing corner all over about environmental pollution.

Considering these issues, various developed and developing countries are formulating policies for mandatory blending of ethanol, resulting in a huge demand for raw material for producing bio-fuels. Sweet sorghum is rich in stalk sucrose and sugars. Sweet sorghum is the only crop that provides grain and stem that can be used as produce sugar, ethanol, syrup, jaggery, feed and fodder. Sweet sorghum is a wonder crop from physiological point of view. The genotypes that perform well in the *kharif* season are not necessarily the top performer in the *rabi* season and vice versa. The post rainy (*rabi*) season grown crops recorded 30-35% less green cane yield with reduced sugar content than rainy (*kharif*) season because of short day length, low night temperature and radiation (Anonymous, 2009).

The sweet sorghum has been so far carried out mainly for *kharif* season. Sweet sorghum being relatively photoperiod sensitive grows very tall in *kharif* but adapts poorly in *rabi* season with low cane yield and quality. Many bio-fuel companies and sugarcane distilleries are interested to plant the sweet sorghum in *rabi* season besides *kharif* season. In order to meet the industrial demand for raw materials, there is need to develop or screen the sweet sorghum genotypes for photo-thermo-insensitive adapted to post rainy season (*rabi*) with high green cane and ethanol yield. Against these backdrops, the physio-biochemical assessment of sweet sorghum genotypes during post rainy season was carried out in this study.

Materials and methods

Study location: The study was undertaken during the post rainy season of 2010-11 at All India Coordinated Sorghum Improvement Project, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist., Ahmednagar (Maharashtra).

Experimental design: The experiment was carried out in Randomized Block Design with two replications. The gross and net plot size were 5.0 x 3.6 m² and 4.6 x 2.4 m², respectively. The sowing was done on 6th Oct 2010. The sweet sorghum genotypes comprised of four rows each of 5.0 m length spaced at 60 cm in each replication. The plants were spaced at 20 cm within a row guard rows were also provided to avoid border effect. The fertilizer dose was applied to the soil as per recommended dose 100:50:50 NPK kg/ha. The half dose of nitrogen and full dose of phosphorous and potash was given at the time of sowing. The remaining half dose of nitrogen was applied at 35 d after sowing. The crop was given three irrigations during the growing period of crop. The five plants in each plot were randomly selected in a net plot area and tagged for recording the various growth characters, yield and other morpho-physiological parameters. The observations on green cane yield, and its attributes were recorded at physiological maturity.

Parameters studied: The physiological processes viz., photosynthetic rate, transpiration rate, photo-synthetically active radiation (PAR), stomatal conductance and stomatal resistance were measured with help of IRGA instrument in bright sunshine at flowering stage. The green cane yield was recorded after stripping the leaves, sheath and panicle in kg/net plot. Cane harvest index (CHI) was computed by the following formula (Anonymous, 2007):

$$\text{CHI (\%)} = \frac{\text{Fresh green cane weight}}{\text{Total fresh biomass}} \times 100$$

At physiological maturity leaf, stem and panicle were separated and dried in hot air oven at 90°C initially for one hrs and then at 60°C till the constant weight. The dry weights (g) were added together to obtain the total dry weight (g). Heat unit efficiency was computed for green cane yield and dry matter at maturity as per the formula given by Rajput (1980).

Brix at boot, flowering, dough and physiological maturity was measured by hand refractometer/brix meter. The juice from stripped stalk was extracted at physiological maturity by using mini crusher. The juice from the cane at physiological maturity analyzed for juice quality parameters viz., non reducing sugars, reducing sugars and total sugars. The Randomized Block Design was used for analysis for all the parameters for the data, as per the procedure given by Panse and Sukhatme (1985).

Statistical analysis: The correlations were worked out between green cane yield and morpho-physiological and bio-chemical characters and ethanol with bio-chemical parameters formula suggested by Snedecor and Chochran (1967). The significance of correlation coefficient was tested against 'r' values given by Fisher and Yates (1963) at (n-2) degrees of freedom at 5 and 1% level of significance.

Result s and discussion

Physiological processes

In the present investigation, the physiological processes like photosynthesis, transpiration, stomatal conductance, stomatal resistance and photosynthetic active radiation differed significantly among the genotypes (Table 1). The photosynthetic rate ranged from 38.95 to 53.45 μ moles CO₂ m⁻²s⁻¹. The genotypes RSSV-202 (53.45 μ moles CO₂ m⁻²s⁻¹), RSSV-275 (50.65 μ moles CO₂ m⁻²s⁻¹) and RSSV-280 (49.20 μ moles CO₂ m⁻²s⁻¹) showed higher photosynthetic rate reflected in high dry matter and green cane yield in these genotypes. The low yielding genotypes possess the relatively lower photosynthetic rates as compared to the high yielding genotypes. These results were in line with those obtained earlier by Ashwathama *et al.* (1997), Channappagoudar *et al.* (2007) and Mutkule (2010). Transpiration is an important bio-physical trait which helps gas exchange. It showed significant variations among the genotypes. The genotypes RSSV-280 (1.75 moles H₂O m⁻²s⁻¹) and RSSV-275 (1.53 moles H₂O m⁻²s⁻¹) showed higher transpiration rate reflected in high of dry matter and green cane yield in these genotypes. The genotype RSSV-216 (0.70 moles H₂O m⁻²s⁻¹) showed lower transpiration rate reflected in relatively lower dry matter (104 g/plant). Similar results are also obtained by Channappagoudar *et al.* (2007). Total dry matter is the product of intercepted photosynthetically active radiation (PAR). The genotypes RSSV-275 (1521 μ mole m⁻²s⁻¹) and RSSV-280 (1493 μ mole m⁻²s⁻¹) showed higher PAR reflected in high dry matter and green cane yield in these genotypes. The low yielding genotypes possess the lower PAR as compared to the high yielding genotypes. Similar report of wide variations in the PAR was made by Channappagoudar *et al.* (2007). Stomatal resistance differed significantly among the genotypes (Table 1) and it was ranged from 0.57 to 1.42 μ mole m⁻²s⁻¹. There is inverse relationship between stomatal resistance and stomatal conductance. Hence, lower resistance increase stomatal conductance and thereby it facilitates easy entry of CO₂ into leaf tissue through stomata. In high yielding genotypes RSSV-280 (0.57 μ mole m⁻²s⁻¹), RSSV-268 (0.65 μ mole m⁻²s⁻¹) and RSSV-275 (0.65 μ mole m⁻²s⁻¹) stomatal resistance was lower with higher transpiration rate and higher accumulation of total dry matter indicating importance of these traits in governing productivity. Similar report was made by Channappagoudar *et al.* (2007).

Table 1. Genotypic variations in physiological processes at flowering stage of sweet sorghum genotypes during Rabi 2010.

Genotypes	Photosynthetic rate (μ mole CO ₂ m ⁻² s ⁻¹)	Transpiration rate (mole H ₂ O m ⁻² s ⁻¹)	Photo-synthetically active radiation (μ mole m ⁻² s ⁻¹)	Stomatal resistance (μ mole m ⁻² s ⁻¹)	Stomatal conductance (mole m ⁻² s ⁻¹)
RSSV-190	44.45	1.17	1181.0	0.85	22.15
RSSV-194	44.60	1.00	1196.0	1.00	18.80
RSSV-196	42.00	0.96	1239.5	1.04	19.06
RSSV-198	40.55	0.96	1371.0	1.04	19.65
RSSV-202	53.45	1.12	1442.0	0.89	22.00
RSSV-216	42.65	0.70	1420.0	1.42	20.85
RSSV-220	45.00	1.42	1409.0	0.70	28.45
RSSV-238	44.40	1.37	1186.5	0.72	24.95
RSSV-242	42.85	1.05	1265.0	0.95	19.85
RSSV-243	44.30	1.17	1384.0	0.85	24.60
RSSV-244	39.15	0.82	1188.0	1.21	21.95
RSSV-249	41.35	1.14	1384.0	0.87	34.05
RSSV-261	46.60	1.12	1358.0	0.89	22.15
RSSV-266	42.45	1.29	1156.5	0.77	25.70
RSSV-267	45.20	1.12	1384.5	0.89	19.85
RSSV-268	41.30	1.53	1134.5	0.65	29.05
RSSV-270	38.95	1.13	1064.0	0.88	19.70
RSSV-271	46.55	0.88	1466.0	1.13	16.30
RSSV-275	50.65	1.53	1521.0	0.65	13.45
RSSV-280	49.20	1.75	1493.0	0.57	15.80
Range	38.95-53.45	0.70-1.75	1064.0-1521.0	0.57-1.42	13.45-34.05
Mean	43.28	1.11	1302.0	0.90	21.91
S.E ±	1.225	0.036	57.20	0.034	0.583
CD at 5%	3.626	0.106	169.31	0.104	1.724

In high yielding genotypes RSSV-202, RSSV-249 and RSSV-220 had relatively higher conductance with high transpiration rate and higher dry matter accumulation. Similar results were also reported by Channappagoudar *et al.* (2007).

Cane yield and its component traits

The green cane weight, plant height, number of internodes, stalk girth, CHI, total sugars, HI and HUE were differed significantly among the genotypes (Table 2). The genotypes RSSV-275 (32.1 t/ha), RSSV-280 (31.5 t/ha), RSSV-194 (28.7 t/ha) and RSSV-268 (26.7 t/ha) recorded significantly higher green cane yields where as lowest cane yield was recorded in RSSV-266 (9.6 t/ha) and RSSV-267 (10.3 t/ha) (Fig.1). The higher green cane yield of RSSV-275, RSSV-280, RSSV-194 and RSSV-268 was mainly due to high photosynthetic rate, transpiration rate, PAR, higher plant height, leaf area, stalk girth, number of internodes and cane harvest index and lower harvest index and stomatal conductance. Diverse sweet sorghum genotypes varied significantly in their plant height. The genotypes RSSV-275 (247.5 cm) and RSSV-280 (241 cm) recorded higher plant height. Higher plant height has an advantage of higher accumulation of total dry matter which has been reflected in higher cane yield into these genotypes.

Besides being tall the plant stature of these genotypes maintained better leaf senescence and poor translocation of photosynthesis from leaf (source) to sink (panicle), resulted in to higher green cane yield. Fresh cane yield had shown high positive correlation with fresh biomass indicating that a very high fresh stalk yield is pre-requisite for higher biomass production in sweet sorghum. Thus, the result was in conformity with Patil *et al.* (2005), Channappagoudar *et al.* (2007) and Mutkule (2010).

Fig. 1. Green cane yield of various sweet sorghum genotypes.

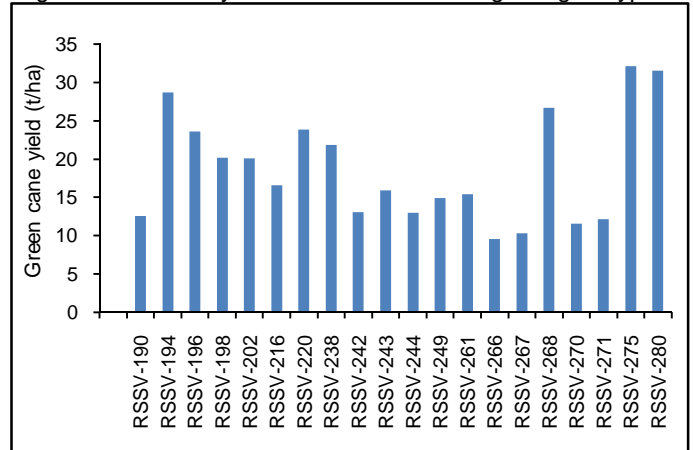


Table 2. Genotypic variations in Green cane yield and its components of sweet sorghum genotypes.

Genotypes	Cane yield (t/ha)	Plant height (cm)	No of inter nodes	Stalk girth (cm)	Cane harvest index (%)	Mean total dry matter (g)	Harvest index (%)	Heat unit efficiency (HUE)	
								Cane yield	Dry matter
RSSV-190	12.6	212.5	7.5	7.15	52.3	128.25	18.00	0.380	0.118
RSSV-194	28.7	209.0	8.9	7.35	73.2	161.55	19.10	0.952	0.112
RSSV-196	23.6	201.0	9.0	8.54	65.0	125.80	19.65	0.695	0.080
RSSV-198	20.2	211.5	9.0	8.28	63.10	149.90	27.00	0.537	0.104
RSSV-202	20.1	232.0	9.0	8.28	55.3	208.25	29.00	0.690	0.145
RSSV-216	16.6	217.0	8.0	7.46	62.80	104.00	23.70	0.547	0.069
RSSV-220	23.8	236.0	9.0	7.03	60.30	180.35	28.30	0.794	0.125
RSSV-238	21.8	197.0	7.5	6.95	57.60	116.55	27.35	0.885	0.075
RSSV-242	13.1	200.5	8.5	7.56	58.20	182.40	20.00	0.549	0.124
RSSV-243	15.9	210.5	8.5	7.62	63.80	162.40	21.35	0.696	0.112
RSSV-244	13.0	192.0	7.5	7.63	54.4	131.70	24.50	0.547	0.085
RSSV-249	14.9	224.0	8.0	7.47	56.00	202.65	28.00	0.392	0.139
RSSV-261	15.4	224.5	6.0	6.86	57.8	85.70	21.65	0.383	0.055
RSSV-266	9.6	184.5	6.5	5.62	51.40	125.70	24.20	0.235	0.080
RSSV-267	10.3	189.5	7.0	7.08	61.4	133.20	24.70	0.382	0.085
RSSV-268	26.7	208.0	7.5	7.13	70.90	174.55	21.65	0.636	0.119
RSSV-270	11.6	238.0	8.0	7.48	47.60	172.55	22.40	0.421	0.119
RSSV-271	12.2	204.5	6.5	6.47	53.7	140.10	21.04	0.467	0.097
RSSV-275	32.1	247.5	9.6	8.94	72.6	196.55	17.75	0.968	0.135
RSSV-280	31.5	241.0	9.5	8.55	72.9	232.40	16.55	0.945	0.158
Range	9.6-32.1	184.5-247.5	6.0-9.6	6.47-8.94	47.60-73.20	85.70-232.4	16.55-29.00	0.235-0.968	0.055-0.158
Mean	18.7	214.0	8.05	7.39	60.5	160.30	22.79	0.604	0.107
S.E ±	1.60	9.17	0.363	0.502	1.48	13.362	1.688	0.033	0.007
CD at 5 %	4.74	27.15	1.074	1.480	4.38	39.547	4.995	0.099	0.021

The genotypes RSSV-275 (9.6), RSSV-280 (9.5) and RSSV 194 (8.9) recorded significantly higher number of internodes which has been reflected in higher green cane yield. The findings are fully supported by the results of Quinby (1967) and Mutkule (2010). The sweet sorghum genotypes viz., RSSV-275 (8.94 cm), RSSV-280 (8.55 cm) and RSSV-196 (8.54 cm) recorded high stalk girth at maturity which has been reflected in higher green cane yield. These results corroborate with the findings of Makanda *et al.* (2009) and Mutkule (2010). They reported that there was positive and highly significant correlation of stalk girth with biomass. The cane harvest index is the proportion of cane yield realized in relation to total fresh biomass. The cane harvest index (CHI) differed significantly among the genotypes. The genotypes RSSV-194 (73.2%), RSSV-280 (72.9%), RSSV-275 (72.6%) and RSSV-268 (70.9%) recorded significantly higher CHI which in turn resulted in higher green cane yield. Whereas, lowest CHI was recorded in RSSV-270 (47.6%) and RSSV-266 (51.4%) which resulted in low green cane yield. Mutkule (2010) reported significant variations in CHI in sweet sorghum genotypes. The genotypes RSSV-280 (232.4 g/plant), RSSV-275 (196.55 g/plant) recorded significantly higher total dry matter. The higher total dry matter in these genotypes mainly due to poor translocation of assimilates towards the sink as indicated by lower harvest index (16.55). These results are in agreement with the results reported by Hiremath *et al.* (1985) and Mutkule (2010).

The variations in efficiency of heat unit due to various sweet sorghum genotypes were significant for green cane yield and dry matter. The genotypes RSSV-275 (0.968) and RSSV-280 (0.945) were observed to be most efficient in converting the heat into cane production owing to efficient utilization of solar radiation. The genotypes RSSV-280 (0.158), RSSV-202 (0.145), RSSV-249 (0.139) and RSSV-275 (0.135) were found to be most efficient in converting the heat into dry matter production. Similar results were earlier reported by Shinde *et al.* (2008) and Mutkule *et al.* (2012). At maturity reducing sugar ranged from 0.865 (RSSV-194) to 2.14% (RSSV-216). The genotype RSSV-194 (0.86%) exhibited significantly the lowest reducing sugar. This is because reducing sugars are utilized for various metabolic reactions and as an energy source. The content of non-reducing sugar differed significantly at maturity. It ranged from 8.27 to 13.25%. The highest non-reducing sugar was recorded in RSSV-198 (13.25%) followed by RSSV-196 (12.50%), whereas it was lowest in RSSV-242 (8.27%). In general high yielding genotypes had higher non-reducing sugars whereas; low yielding genotypes had lesser non-reducing sugar content. This is attributed to decrease in the invertase enzyme activity. Jadhav *et al.* (1994) observed significant differences for non reducing sugar. The total sugar in juice was ranged from 9.51 to 14.74% at physiological maturity. The total sugar content was higher in RSSV-198 (14.74%) while lowest in RSSV-242 (9.51%).

Table 3. Genotypic differences in brix, juice yield, extraction, reducing sugars, non-reducing sugars, total sugars and ethanol at physiological maturity stage.

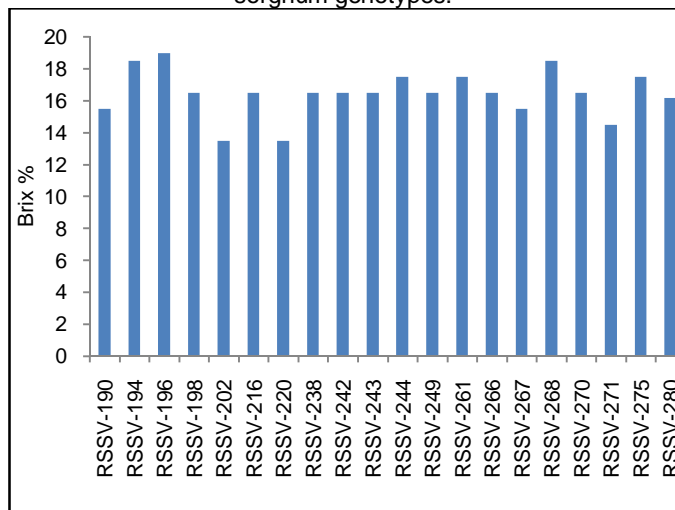
Genotypes	Brix (%) at				Juice yield (L/ha)	Extraction (%)	Reducing sugars (%)	Non reducing sugars (%)	Total sugar (%)	Ethanol yield (L/ha)
	Boot	Flowering	Dough	Physiological maturity						
RSSV-190	9.5	12.5	13.5	15.5	2763	21.95	0.99	9.50	10.49	154
RSSV-194	7.5	9.5	16.5	18.5	9555	33.30	0.86	11.13	12.00	609
RSSV-196	7.5	8.5	12.5	19.0	8015	34.00	1.16	12.50	13.67	582
RSSV-198	7.5	10.5	13.0	16.5	6384	31.60	1.49	13.25	14.74	502
RSSV-202	5.5	7.5	11.0	13.5	6973	34.75	1.38	12.49	13.88	518
RSSV-216	7.5	11.5	14.5	16.5	3849	23.45	2.14	9.58	11.72	240
RSSV-220	4.5	5.5	12.5	13.5	7426	31.30	1.34	10.66	12.00	415
RSSV-238	4.5	6.5	12.5	16.5	6430	29.30	1.55	9.25	10.80	367
RSSV-242	4.5	5.5	13.5	16.5	3396	25.90	1.24	8.27	9.51	169
RSSV-243	7.5	9.5	14.5	16.5	3758	24.40	1.11	9.57	10.69	213
RSSV-244	6.5	8.5	16.5	17.5	2400	18.05	1.35	9.62	10.97	140
RSSV-249	8.5	10.5	11.5	16.5	3351	22.50	1.40	11.56	12.96	230
RSSV-261	5.5	6.5	11.5	17.5	3622	23.40	1.57	9.31	10.88	212
RSSV-266	7.5	11.5	13.5	16.5	1675	17.55	1.30	9.58	10.89	95
RSSV-267	6.5	11.0	13.5	15.5	2083	20.10	1.43	10.62	12.05	135
RSSV-268	7.5	9.5	14.5	18.5	7426	30.85	1.47	10.91	12.38	538
RSSV-270	7.5	9.5	13.5	16.5	1358	11.75	1.11	11.06	12.18	87
RSSV-271	4.5	6.5	12.5	14.5	3305	27.10	1.77	9.94	11.71	206
RSSV-275	6.5	7.5	14.5	17.5	9645	31.50	1.04	11.36	12.40	556
RSSV-280	7.5	10.5	12.5	16.2	8286	32.50	1.62	9.66	11.28	574
Range	4.5-9.5	5.5-12.5	11.0-16.5	13.5-19.0	1358-9645	11.75-34.75	0.86-2.14	8.27-13.25	9.51-14.74	87-609
Mean	6.70	8.9	13.4	16.5	5095	26.26	1.36	10.49	11.86	330
S.E +	0.503	0.472	0.618	0.515	537	1.703	0.065	0.291	0.251	27
CD at 5 %	1.488	1.398	1.828	1.524	1588	5.047	0.193	0.831	0.743	80

This is attributed to decrease in the activity of amylase. This is due to aging and increase in temperature on the crop advances towards maturity. Chavan *et al.* (2009) and Dalvi *et al.* (2011) observed significant variation in total sugar in juice. Sweet sorghum is one of the potential materials for production of ethanol. Computed ethanol yield differed significantly among the genotypes. The genotypes RSSV-194 (609 L/ha), RSSV-196 (582 L/ha) and RSSV-280 (574 L/ha) recorded higher ethanol yields. Thus, it was inferred that high yield of ethanol in these genotypes was mainly attributed due to higher cane yield, juice yield, NRS and total sugar. Positive and significant correlation of cane yield, juice yield, NRS and total sugar with ethanol were reported by Dalvi *et al.* (2011).

Biochemical traits

The brix was found to be increased with the advancement of phenological stages of sweet sorghum (Table 3). The brix (TSS) of juice was increased from 6.70% (boot stage) to 16.5% (Physiological maturity). The brix value increased from flowering to maturity may be attributed to reduce water content in the stem. These results were in line with those obtained by Bapat *et al.* (1986). Physiological maturity is the stage at which higher brix (Fig. 2) was recorded (16.5%). The higher brix value at physiological maturity indicates more accumulation of TSS in the stalk which has been reflected in total sugars. The results were in accordance to LiuGuifeng (1997) and Mutkule (2010).

Fig. 2. Brix % at physiological maturity of various sweet sorghum genotypes.



In the present investigation, the significantly higher brix was recorded in the genotypes RSSV-190 (9.5%) and RSSV-249 (8.5%) at boot stage, RSSV-190 (12.5%) at flowering, RSSV-194 (16.5%) and RSSV-244 (16.5%) at dough stage and RSSV-196 (19%), RSSV-268 (18.5%) at physiological maturity. Sweet sorghum genotypes exhibit wide variability in juice yield, extraction, reducing sugar, non-reducing sugar and total sugars. The maximum juice was obtained in RSSV-275 (9645 L/ha) followed by RSSV-194 (9555 L/ha) when canes are harvested at physiological maturity stage.

Fig. 3. Ethanol yield of various sweet sorghum genotypes.

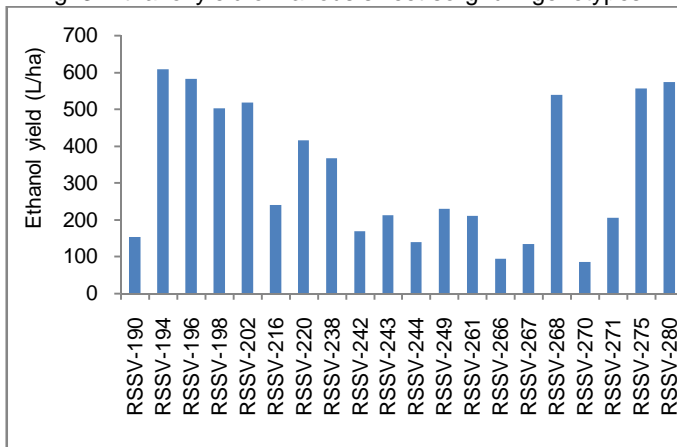


Table 4. Correlation coefficient of green cane yield with morpho-physiological traits.

Green cane yield Vs	Correlation coefficient(r)
No. of internodes	0.4648**
Stalk girth	0.6896**
Plant height	0.4744*
Cane harvest index	0.8459**
Total dry matter	0.4493*
Photosynthesis	0.4806*
Photosynthetic active radiation	0.1364
Transpiration	0.1533
Heat unit efficiency	0.8226**
Harvest index	-0.5323*

Table 5. Correlation coefficient of green cane yield with bio-chemical traits.

Green cane yield Vs	Correlation coefficient(r)
Juice yield	0.9646**
Extraction	0.7988**
Brix	0.4924*
Reducing sugar	- 0.1285
Non-reducing sugar	0.4470*
Total sugar	0.4627*
Ethanol	0.9163**

Table 6. Correlation coefficient of computed ethanol with physio-biochemical traits.

Computed ethanol Vs	Correlation coefficient (r)
Green cane yield	0.9300**
Cane harvest index	0.7700**
Stalk girth	0.0874
Plant height	0.4790*
Leaf area	0.1500
Juice yield	0.9765**
Brix	0.5650**
Reducing sugar	-0.1119
Non-reducing sugar	0.5662**
Total sugar	0.5606**

* = Significant at P≤ 0.05; ** = Significant at P≤ 0.01; Significant levels 0.05, 0.01; If correlation r: 0.4438, 0.5614.

At physiological maturity the high cane yielding genotypes RSSV-275, RSSV-280 and RSSV-194 recorded higher juice extractability percentage. Similar results were reported by Channappagoaudar *et al.* (2007). At maturity reducing sugar ranged from 0.865 (RSSV-194) to 2.14% (RSSV-216). The genotype RSSV-194 (0.86%) exhibited significantly the lowest reducing sugar. This is because reducing sugars are utilized for various metabolic reactions and as an energy source. The content of non-reducing sugar differed significantly at maturity. It ranged from 8.27 to 13.25%. The highest non-reducing sugar was recorded in RSSV-198 (13.25%) followed by RSSV-196 (12.50%), whereas it was lowest in RSSV-242 (8.27%). In general, high yielding genotypes had higher non-reducing sugars where as low yielding genotypes had lesser non-reducing sugar content. This is attributed to decrease in the invertase enzyme activity. Jadhav *et al.* (1994) observed significant differences for non-reducing sugar. The total sugar in juice was ranged from 9.51 to 14.74% at physiological maturity. The total sugar content was higher in RSSV-198 (14.74%) while lowest in RSSV-242 (9.51%). This is attributed to decrease in the activity of amylase. This is due to aging and increase in temperature on the crop advances towards maturity. Chavan *et al.* (2009) and Dalvi *et al.* (2011) observed significant variation in total sugar in juice. The sweet sorghum is one of the potential materials for production of ethanol. Computed ethanol yield differed significantly among the genotypes (Fig. 3).

The genotypes, RSSV-194 (609 L/ha), RSSV-196 (582 L/ha) and RSSV-280 (574 L/ha) recorded higher ethanol yields. Thus, it was inferred that high yield of ethanol in these genotypes was mainly attributed due to higher cane yield, juice yield, NRS and total sugar. Positive and significant correlation of cane yield, juice yield, NRS and total sugar with ethanol were reported by Dalvi *et al.* (2011).

Correlation studies

The correlation studies (Table 4) revealed that green cane yield showed significant and positive correlation with morpho-physiological parameters viz., number of internodes, stalk girth, plant height, CHI, total dry matter, photosynthesis, PAR, transpiration, HUE and negative with harvest index indicating that a very high green cane yield pre-requisite for high biomass in sweet sorghum. These results were accordance to Ganesh *et al.* (1995). The relationship of green cane yield with biochemical traits (Table 5) revealed that the juice yield, extraction, brix, non reducing sugar, total sugars and ethanol were significantly positive. Hence, these traits could be utilized in the sweet sorghum breeding programme. The correlation between ethanol and biochemical traits (Table 6) indicated that the green cane yield, plant height, CHI, stalk girth, juice yield, brix, non reducing sugar, total sugars were significant and positive. Total sugars and calculated ethanol were positively related indicating that the high total sugars are essential to realize high ethanol yield in sweet sorghum. These studies indicated that high green cane yield with total sugar content is a pre-requisite for high ethanol recovery. Similar observations were reported by Ganesh *et al.* (1995).

Conclusion

As per the findings of the present investigation on physio-biochemical assessment of sweet sorghum during *rabi* season, the genotypes viz., RSSV-275, RSSV-280, RSSV-194 and 268 were found superior for green cane yield which could be exploited commercially for high biomass production in terms of green cane yield in *rabi* season. Simultaneously these genotypes could be utilized in further breeding programme for the photoperiod insensitive point of view. Sugars and computed ethanol showed positive correlation indicated that higher total sugars are essential to realize high ethanol yield in sweet sorghum. Hence, the green cane yield with high sugar content is pre-requisite for ethanol recovery. Therefore these traits could be considered for further breeding programme from the high ethanol yield point of view. The genotypes RSSV-275, RSSV-280, RSSV-194 and RSSV-202 were found to be efficient for producing high biomass, coupled with high better juice quality parameters. Further, future research can be directed towards production of high energy sorghum as hopeful attempts to overcome the present day energy crisis to some extent.

References

1. Anonymous. 2007. Sweet sorghum and physiology. All India /009/j4313 e htm. Food and Agricultural Organization of the United Nations, Rome, Italy. Coordinated Sorghum Improvement Project, Annual Progress Report for 2006-07. AICSIP Tech. Pub. No. 3/Sweet sorghum and Physiology (Book 3 of 3 agm-07 prement):102. Director of Sorghum Research Hyderabad, A.P. (India).
2. Anonymous. 2009. Sweet Sorghum for Biofuel and strategies for its improvement. Information bulletin No. 77 of ICRISAT, Patancheru, Hyderabad (India).
3. Ashwathama, V.H., Channappagoudar, B.B., Chetti, M.B. and Hiremath, S.M. 1997. Interrelationship of morphophysiological and biophysical characters in sweet sorghum genotypes during summer. Proceeding of National Seminar on Plant Physiology for sustainable Agriculture, 19-21 March, 1997. IARI, New Delhi. p.11.
4. Bapat, D.R., Jadhav, H.D., Gour, S.L. and Salunkhe, C.B. 1986. Screening of sweet sorghum cultivars for production of quality syrup and jaggary. *Curr. Res. Rep. (M.P.K.V.)*. 2: 65-71.
5. Channappagoudar, B.B., Biradar, N.R., Patil, J.B. and Hiremath, S.M. 2007. Assessment of sweet sorghum genotypes for cane yield, juice characters and sugar levels. *Karnataka J. Agri. Sci.* 20(2): 294-296.
6. Chavan, U.D., Patil, J.V. and Shinde, M.S. 2009. An assessment of sweet sorghum cultivars for ethanol production. *Sugar Tech.* 11(4): 319-323.
7. Dalvi, U.S, Chavan, U.D. and Shinde M.S. 2011. Assessment of sweet Sorghum cultivars for efficient ethanol production. *Sugar Tech.* 13(3): 186-190.
8. Fisher, R.A. and Yates, F. 1963. Statistical tables for biological, agricultural and medical research. 6th edn. Oliver and Boyd: London. p.63.
9. Ganesh, S., Fazlullah Khan A.K., Suresh, M. and Senthil, N. 1995. Characters association for alcohol yields in sweet sorghum. *Madras Agri. J.* 82(5): 361-363.
10. Hiremath, S.M. and Pravatkar, S.R. 1985. Growth and yield analysis in sorghum identification of genotypes with low leaf area and high dry matter production. *Sorghum Newslett.* 28: 108-109.
11. Jadhav, M.M., Chougule, B.A., Chavan, U.D. and Adsule, R.N. 1994. Assessment of juice quality in the improved sweet sorghum varieties. *J. Maharashtra agri. Univ.* 19(2): 233-235.
12. Li, D. 1997. Developing sweet sorghum to accept the challenge problem on food, energy and environment in 21st century. Proceeding of the first International Sweet Sorghum conference, 14-19 sept, 1997, Beijing, China: Institute of Botany, Chinese Academy Sciences. pp.20-34.
13. Makanda, I., Tongoona and Derera. 2009. Quantification of genotypic variability for stem sugar accumulation and associated traits in new sweet sorghum varieties. Proceeding of African Crop Science, Pietermaritzburg, South Africa. pp.39-398.
14. Mutkule, B.R. 2010. Physiological studies on sweet stalk sorghum genotypes in relation to phenology as influenced by temperature and photoperiod. M.Sc. (Agri). Thesis. MPKV. Rahuri (India).
15. Mutkule, B.R., Shinde, M.S, Gaikwad, A.R, Patil, V.R. and Gadakh S.R. 2012. Heat unit efficiency in Sweet Sorghum. *Crop Research.* 43(3):28-30.
16. Panse, V.G. and Sukhatme, P.V. 1985. Statistical methods for agricultural workers. ICAR Publication, New Delhi.
17. Patil, J.V., Chaudhari, S.B., Shinde, M.S. and Kachole, U.G. 2005. Evaluation of sweet sorghum genotypes for green cane yield, grain yield and juice quality parameters. *Plant Arch.* 5(2): 633-635.
18. Quinby, J.R. 1967. The maturity genes of sorghum. *Adv. Agron.* 19: 267-305.
19. Snedecor, G.W. and Cochran, D.S. 1967. Statistical methods. 6th edn. Asia Pub. House, Bombay. p.534.