

Bio-ethanol production potential of sweet sorghum (*Sorghum bicolor*) cultivars under different spacing and harvest stages

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ABSTRACT

In a field experiment conducted at Kathalagere, Karnataka during *kharif* 2007 and 2008, three sweet sorghum [*Sorghum bicolor* (L.) Monech] cultivars ('Madhura', 'SSV-84' and 'RSSV-9') were evaluated for ethanol production potential under two spacing (45 cm X 10 cm) and two stages of harvest (50% flowering and at physiological maturity). Among the cultivars tested 'Madhura' produced significantly higher ethanol yield (556.7 l/ha and 571.7 l/ha) when compared with 'SSV-84' (378.5 l/ha and 405.2 l/ha) and 'RSSV-9' (368.4 l/ha and 425.9 l/ha). 'Madhura' harvested at physiological maturity showed significantly higher ethanol yield 929.7 l/ha and 958.3 l/ha when compared with that harvested at 50% flowering (183.7 l/ha and 185.2 l/ha). Similarly 'Madhura' cultivar recorded significantly higher brix (degrees) (13.6 and 14.0), pol percent in juice (7.3 and 6.4%) and reducing sugar per cent (3.1 and 3.7%), when compared with 'SSV-84' and 'RSSV-9'. The highest benefit cost ratio was recorded with 'Madhura' (1.88 and 1.73) when sown at spacing of 45 cm X 15 cm and 45 cm X 10 cm and harvested at physiological maturity.

Key words : Cultivars, Ethanol, Harvest stages, Juice quality, Millable stalk yield, Sweet sorghum, Spacing

The sweet sorghum or more appropriately called sweet stalk sorghum is a biofuel crop that accumulates sugars (10 to 15%). It is similar to sugarcane, but it also produces grains like normal food or feed types of sorghum. Ethanol is produced from stalk juice as similar to molasses based ethanol production process. It is an important crop grown around the world for syrup, ethanol, power, food, forage, etc., (Ratnavathi *et al* 2004). India is the largest producer of sorghum in the world with an area of 7.15 mt production occupying 8.47 mha (DES, 2007).

New-a-days the sugarcane molasses rates have become highly fluctuating, varying from ₹3000/t to ₹7000/t, which results in instability of the price of alcohol. This condition not only makes sweet sorghum as sustainable substrate for ethanol production but also can act as supplements to sugarcane molasses. However, due to recent hike in the cost of molasses, it has become necessary to search for cheaper substrate for ethanol production in India. There are various factors that influence the sweet sorghum yield and quality. Among them, selection of suitable variety, adoption of suitable spacing and identification of ap-

propriate harvesting stages have important role on biomass yield and quality of the crop and ultimately ethanol production. The stage of harvest plays an important role on biomass yield, quality of the juice and stubble sprouting. There is scarcity of information on the agro-techniques for sweet sorghum production in Bhadra command area, where sugarcane is the major substrate for sugar and alcohol production. The experiment was conducted keeping in view above said problem.

MATERIALS AND METHODS

A field experiments was conducted at Agricultural Research Station, Kathalagere (latitude of 13°02' North, longitude of 76°15' East with an altitude of 561.6 meters above mean sea level) under Bhadra command area in Davanagere district, Karnataka during *kharif* 2007 and 2008. The total rainfall received during the crop growth periods (*kharif* 2007 and 2008) was 561.8 mm and 499.8 mm, respectively. The rainfall was uniformly distributed throughout the crop growth period. The soil was red clay laom, medium in available N (286.6 kg/ha) and available potassium (233.9 kg K₂O/ha) and low in available phosphorus (17.2 kg P/ha) with neutral pH (6.8) and EC (0.18 dS/m). The twelve treatment combinations consisting of three cultivars 'Madhura', 'SSV-84' and 'RSSV-9', two spacing 45 cm X 10 cm, and 45 cm X 15 cm and two har-

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vesting stages at 50% flowering, and at physiological maturity were replicated thrice in RCBD design. The plant height, millable stalk yield, grain yield and juice quality parameters were recorded at 50% flowering and at physiological maturity. The millable stalk yield / hectare was computed based on the weight of 15 plants harvested at random at the respective stages of harvest. The juice was extracted from the stalks using two-roller crusher and collected in a beaker. It was filtered through the muslin cloth and then analyzed for various juice quality parameters.

Brix (degrees), pol percent of juice, reducing sugars (RS) and ethanol were analyzed / calculated as per the procedure outlined by Verma, (1988); Iswaran, (1981); Lane and Eynon (1970) and Caputi *et al.*, (1968), respectively.

RESULTS AND DISCUSSION

Plant height, millable stalk yield and grain yield

Plant height and millable stalk yield were significantly influenced by the cultivars, sorghum cultivar ‘Madhura’ recorded significantly higher plant height (255 cm and 281 cm) and millable stalk yield (33.0 t/ha and 35.9 t/ha) during 2007 and 2008, respectively when compared with ‘SSV’-84 (229 cm and 237 cm) and (28.3 t/ha and 30.7 t/ha) and ‘RSSV-9’ (229 cm and 244 cm) and (26.3 t/ha and 29.2 t/ha).

The higher millable stalk yield in ‘Madhura’ cv. of sorghum was mainly attributed to higher total dry matter production, which represents efficient utilization of the resources due to higher leaf area. The ‘Madhura’ cv. of sor-

ghum crop remained green even at physiological maturity when compared with other cultivars in which leaves dried early. Channappagoudar *et al.* (2007) also noticed significant variations in millable stalk yield in different sweet sorghum cultivars. Planting geometry of 45 cm X 15 cm recorded significantly higher tonnage (29.9 t/ha and 32.2 t/ha) over 45 cm X 10 cm (28.5 t/ha and 31.6 t/ha) (Table 1). The wider intra-row spacing between the plants enhanced the uptake of nutrients, moisture and ultimately resulted in production of thicker stalks.

Interaction between cultivars and harvest stages

Interaction between cultivars and harvest stages was found significant (Table 2). Sorghum cv. ‘Madhura’ at physiological maturity gave significantly higher millable stalk yield (37.0 t/ha and 41.1 t/ha) during 2007 and 2008, respectively when compared with ‘SSV -84’ (30.0 t/ha and 33.5 t/ha) and ‘RSSV-9’ (28.0 t/ha and 32.1 t/ha). Similar trend was observed for juice yield also. The higher millable stalk and juice yield at physiological maturity was mainly attributed to the prolonged growth period, higher accumulation of dry matter in stem, leaves, and ear head. Jadhav *et al.* (1994) reported that juice quality parameters like brix, purity, reducing sugar, starch and commercial cane sugar at maturity stage were superior over milky stage and Sanjeev Reddy (2006) endorsed the above findings.

Juice yield and quality parameters

The juice quality parameters viz., brix, pol per cent of

Table 1. Plant height (cm), millable stalk yield (t/ha) and grain yield (kg/ha) and juice yield (l/ha) of sweet sorghum as influenced by the cultivars, spacings and stages of harvest during *kharif* 2007 and 2008.

Treatment	Plant height (cm/plant)		Millable stalk yield (t/ha)		Grain yield (kg/t)		Juice yield (l/ha)	
	2007	2008	2007	2008	2007	2008	2007	2008
<i>Sorghum cultivars</i>								
Madhura	255	281	33.0	35.9	1.41	1.40	14,118	13,217
SSV – 84	229	237	28.3	30.7	1.33	1.29	10,906	10,425
RSSV – 9	229	244	26.3	29.2	1.25	1.23	10,568	10,410
SEm ±	2.4	2.6	0.44	0.66	0.16	0.16	318	444
CD (P=0.05)	7.0	7.6	1.27	1.94	NS	NS	934	1,302
<i>Spacing</i>								
45 cm x 15 cm	237	251	28.5	31.6	1.28	1.27	11,344	11,172
45 cm x 10 cm	239	257	29.9	32.2	1.37	1.36	12,384	11,529
SEm ±	1.9	2.1	0.36	0.54	0.13	0.13	260	363
CD (P=0.05)	NS	NS	1.05	NS	NS	NS	762	NS
<i>Harvesting stages</i>								
Harvesting at 50 % flowering	226	238	26.7	28.3	0.0	0.0	11,098	9,078
Harvesting at physiological maturity	250	270	31.7	35.6	1.31	1.33	12,630	13,622
SEm ±	1.9	2.1	0.35	0.54	NA	NA	260	362
CD (P=0.05)	5.7	6.2	1.05	1.58	NA	NA	762	1,064

NS: Non significant; NA: Not analyzed

juice (sucrose %) and reducing sugar were significantly influenced by the cultivars. The sorghum cultivar 'Madhura' recorded significantly higher juice yield (14,118 l/ha and 13,217 l/ha) Table 1; Brix (13.6° and 14.0°), Pol (7.3% and 6.4%) and reducing sugar (3.1% and 3.7%) during 2007 and 2008, respectively when compared with sorghum cultivar 'SSV-84' and 'RSSV-9' (Table 3). Channappagoudar *et al.* (2007) also observed the difference in quality parameters of different sweet sorghum genotypes. Sorghum 'Madhura' harvested at physiological maturity recorded significantly higher juice yield (15,655 l/ha and 16,442 l/ha), Brix (15.4° and 16.0°), pol per cent juice (9.1% and 8.6%) and significantly lower reducing sugar of juice (2.7% and 3.2%) during 2007 and 2008, respectively (Table 4). Better juice quality parameters at physiological maturity might be attributed to the regulation of sugar accumulation in the plant by two enzymes,

viz., acid invertase and neutral invertase. At early stage of the growth the activity of acid invertase was more which disintegrates disaccharide into monosaccharide sugars that is utilized for growth process of the crop. However, at the later part of the crop growth period, neutral invertase enzyme dominates and favours accumulation of sugars resulting in better quality (Alexander, 1973). These findings corroborate with Jadhav *et al.* (1994) and Sanjeev Reddy (2006).

Ethanol yield

The data of two year indicated that sorghum 'Madhura' yielded significantly higher ethanol yield (556.7 l/ha and 571.7 l/ha) during both the years when compared with 'SSV-84' and 'RSSV-9' (Table 3). The sorghum 'Madhura' harvested at physiological maturity gave significantly higher ethanol yield (929.7 l/ha and 958.3 l/ha)

Table 2. Interactive effects of cultivars and stages of harvest on plant height (cm) millable stalk yield (t/ha) and juice yield (l/ha) during *kharif* 2007 and 2008.

Sorghum cultivars	Plant height (cm/plant)				Millable stalk yield (t/ha)				Juice yield (l/ha)			
	2007		2008		2007		2008		2007		2008	
	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂
'Madhura'	244	266	259	304	29.0	37.0	30.6	41.1	12,582	15,655	9,992	16,442
'SSV – 84'	217	242	224	251	26.6	30.0	27.9	33.5	10,574	11,237	8,988	11,861
'RSSV – 9'	217	241	231	256	24.5	28.0	26.3	32.1	10,137	10,999	8,255	12,565
SEm ±	5.7		3.7		0.6		0.9		450		628	
CD (P=0.05)	NS		10.9		1.8		2.7		1,320		1,842	

H₁: Harvesting at 50 % flowering; H₂: Harvesting at physiological maturity; NS, Non-significant

Table 3. Brix (Degrees), Pol % juice, reducing sugar (%) and ethanol yield (l/ha) of sweet sorghum as influenced by the cultivars, spacings and stages of harvest during *kharif* 2007 and 2008

Treatment	Brix (Degrees)		Pol (%) juice		RS (%)		Ethanol yield (l/ha)	
	2007	2008	2007	2008	2007	2008	2007	2008
<i>Sorghum cultivars</i>								
'Madhura'	13.6	14.0	7.3	6.4	3.1	3.7	556.7	571.7
'SSV – 84'	12.7	13.1	6.6	5.3	3.2	3.5	378.5	405.2
'RSSV – 9'	12.6	13.3	6.5	5.3	2.9	3.1	368.4	425.9
SEm ±	0.22	0.21	0.06	0.11	0.10	0.24	16.2	23.2
CD (P=0.05)	0.63	0.61	0.19	0.34	NS	0.06	47.6	68.0
<i>Spacings</i>								
45 cm x 15 cm	12.9	13.4	6.7	5.6	3.0	3.4	424.1	465.5
45 cm x 10 cm	13.1	13.5	6.9	5.6	3.2	3.4	444.9	469.7
SEm ±	0.18	0.17	0.05	0.09	0.08	0.07	13.3	18.9
CD (P=0.05)	NS	NS	1.05	NS	NS	NS	NS	NS
<i>Harvesting stages</i>								
Harvesting at 50% flowering	11.7	12.3	4.0	4.0	3.4	3.8	148.0	159.2
Harvesting at physiological maturity	14.3	14.7	7.3	7.3	2.8	3.0	721.0	776.0
SEm ±	0.17	0.17	0.09	0.09	0.08	0.06	13.0	19.0
CD (P=0.05)	0.51	0.51	0.27	0.27	0.24	0.19	39.0	56.0

NA: Not analysed; NS, Non-significant

Table 4. Interactive effects of sorghum cultivars and stages of harvest on brix (degrees), pol(%) juice, reducing sugar(%) and ethanol yield (l/ha) during *kharif* 2007 and 2008.

Sorghum cultivars	Brix (degrees)				Pol(%)				RS(%)				Ethanol (l/ha)			
	2007		2008		2007		2008		2007		2008		2007		2008	
	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂	H ₁	H ₂
Madhura	11.9	15.4	12.1	16.0	5.5	9.1	4.1	8.6	3.6	2.7	4.2	3.2	183.7	929.7	185.2	958.3
SSV – 84	11.7	13.8	12.3	13.8	5.3	7.9	3.9	6.6	3.4	3.0	3.9	3.1	132.9	624.2	148.3	662.1
RSSV – 9	11.7	13.6	12.4	14.2	5.5	7.5	3.9	6.6	3.0	2.9	3.3	2.9	127.6	609.3	144.1	707.8
SEm ±	0.26		0.28		0.30		0.16		0.15		0.11		23		32.8	
CD (P=0.05)	0.81		0.87		0.91		0.48		0.43		0.33		67		92.2	

H₁ : Harvesting at 50 % flowering; H₂: Harvesting at physiological maturity

over harvesting at 50% flowering (183.7 l/ha and 185.2 l/ha). Similar observations were made with respect to ‘SSV-84’ and ‘RSSV-9’, (Table 4).

For ethanol production it is ideal to have higher sugar content, juice yield and extractable juice percent which, intern dictates the ethanol production.

Multiple linear regression (MLR) model between ethanol vs other quality parameters.

$$\text{Ethanol yield (Y)} = -5028 + 0.0325 X_1 + 320 X_2 - 504 X_3 - 82.96 X_4 \quad (R^2=0.96)$$

where,

X₁=Juice yield

X₂=Brix

X₃=Sucrose per cent

X₄=Reducing sugar per cent

The multiple linear regression model clearly explains the functional relationship between ethanol yield and other quality parameters to the extent of 96%. Sanjeev Reddy (2006) also established the functional association of ethanol yield vs juice yield (0.68**), Brix (0.69**), Pol per cent (0.53**) and reducing sugar (0.78**).

Economics

The sorghum ‘Madhura’ with a spacing of 45 cm × 15 cm and harvesting at physiological maturity recorded higher net returns (₹26,700) and B:C ratio (1.88) when compared with other two cultivars (Table 5).

The investigations showed that in Bhadra Command area of Karnataka, sorghum cultivar ‘Madhura’ can be grown with a spacing of 45 cm × 15 cm and harvested at physiological maturity to get higher monetary benefits and ethanol yield in addition to higher grain yield.

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Table 5. Cost of cultivation, net returns and cost: benefit ratio for grain and millable stalk yield of sweet sorghum, as influenced by cultivars, spacings and stages of harvest.

Treatment	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C ratio (₹/ha)
V ₁ S ₁ H ₁	13,800	3,240	0.23
V ₁ S ₁ H ₂	14,500	25,040	1.73
V ₁ S ₂ H ₁	13,500	5,220	0.39
V ₁ S ₂ H ₂	14,200	26,700	1.88
V ₂ S ₁ H ₁	13,700	2,440	0.18
V ₂ S ₁ H ₂	14,400	19,740	1.37
V ₂ S ₂ H ₁	13,400	3,160	0.24
V ₂ S ₂ H ₂	14,400	21,120	1.52
V ₃ S ₁ H ₁	13,700	1,480	0.11
V ₃ S ₁ H ₂	14,400	17,580	1.22
V ₃ S ₂ H ₁	13,400	1,960	0.15
V ₃ S ₂ H ₂	14,100	19,740	1.40

V₁: ‘Madhura’ V₂: ‘SSV-84’ V₃: ‘RSSV-9’ S₁: 45 cm X 10 cm S₂: 45 cm X 15 cm H₁: Harvesting at 50% flowering H₂: Harvesting physiological maturity. Produce cost: Grain ₹ 12/kg; Biomass: ₹600/tones.

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