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Research Paper

Effect of harvesting stages on juice quality and ethanol yield in sweet sorghum (*Sorghum bicolor*) cultivars during *rabi*

Y.M. RAMESHA[1] AND SHARANAPPA[2]

University of Agricultural Sciences, GKVK, Bengaluru, Karnataka 560 065

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ABSTARCT

A field experiment was conducted during *rabi* 2008 and 2009 in red sandy clay loam soil at Agriculture Research Station, Kathalagere, Karnataka to study the effect of harvesting stages on juice quality and ethanol yield in sweet sorghum {*Sorghum bicolor* (L.) Moench} cultivars. There were four cultivars ('NSSH 1', 'RSSV 9', 'SSV 84' and 'SSV 74') and three harvesting stages (50% flowering, milky stage and maturity). The cultivar 'NSSH 1' recorded significantly higher brix (14.5), pol (8.4), available sugar (4.4%), calculated sugar yield (132.7 kg/ha), millable stalk (29.5 t/ha), green biomass (32.9 t/ha), juice (10,914 l/ha) and ethanol yield (538.4 l/ha) as compared to 'RSSV 9', 'SSV 84' and 'SSV 74'. The crop harvested at maturity recorded significantly higher brix (14.8), pol (8.7), available sugar (4.7%), calculated sugar yield (136.6 kg/ha), millable stalk (29.1 t/ha) and green biomass yield (31.7 t/ha) compared to crop harvested at 50% flowering stage and milky stage. But, juice (9,777 l/ha) and ethanol yield (474.5 l/ha) were significantly higher when the crop harvested at milky stage. The 'NSSH 1' harvested at milky stage recorded significantly higher juice (11,415 l/ ha) and ethanol yield (591.0 l/ha).

***Key words*:** Brix, Ethanol, Harvesting stages, Juice, Pol, Sweet sorghum

Sweet sorghum is special purpose sorghum with a sugar–rich stalk, similar to sugarcane. Besides having rapid growth, high sugar accumulation, and biomass production potential, sweet sorghum has wider adaptability. Sweet sorghum can be grown with less irrigation and rainfall and purchased inputs compared to sugarcane. The sugar content in the juice extracted from sweet sorghum varies from 16–23% brix. It has a great potential for jaggery, syrup and most importantly fuel alcohol production (Ratnavathi *et al.* (2003). The stillage after extraction of juice from sweet sorghum can be used for co-generation of power. Recently high sucrose sweet sorghum cultivars have been developed with potential as a sugar crop. Because of the rapid increase in crude oil prices, sweet sorghum has been investigated as potential source of fermentable sugars for ethanol fuel production. Considering all these aspects, it is clear that sweet sorghum possesses considerable potential as an alternative crop to sugarcane. This is because of the crops high sugar content and biomass production, wide geographic and climatic adoption and relatively low water requirements. The full potential of crop can be exploited by following optimum agronomic practices. Further, this crop has bright prospects and efforts required in developing and identifying the varieties possessing higher sugar content and higher ethanol production potential for different agro ecological conditions. It is also necessary to understand the variations in sugar and biomass yield among sweet sorghum cultivars. Time of harvest is yet another factor. This indirectly influences biomass yield, quality of juice and ultimately ethanol production, because of variation in climatic conditions during pre-harvesting and post harvesting period. Limited information is available on the effect of stage of harvest on sweet sorghum, hence the present investigation was undertaken on sweet sorghum.

MATERIALS AND METHODS

An experiment was conducted during *rabi* 2008 and 2009 at Agriculture Research Station, Kathalagere, Davanagere Dist, Karnataka (India). The centre is situated in the agro-climatic zone VII (Southern transitional zone) of Karnataka. The station is situated at latitude of 13^{o} 2' north, longitude of 76^{o}15' east and at an altitude of 561.6 meters above the mean sea level. The soil of the experimental site was sandy clay loam (coarse sand 20.36%, fine sand 22.11%, silt 20.6% and clay 36.93%) with a bulk density of 1.59 Mg/m^3. The soil was slightly acidic (5.5)

[1]**Corresponding author Email:** rameshyam@gmail.com
[1]Associate Professor, Agronomy; [2]Professor of Agronomy, College of Agriculture

with an electrical conductivity of 0.08 dS/m. The soil was medium in available nitrogen (284.6 kg/ha), phosphorus (23.3 kg/ha), potassium (198.5 kg/ha) and organic carbon (0.5%). The experiment was laid out in a factorial randomized complete block design with four cultivars *viz.,* 'NSSH 1', 'RSSV 9', 'SSV 84' and 'SSV 74' and three harvesting stages *viz*., at 50% flowering stage, milky stage and maturity constituting twelve treatment combinations and replicated three times. The seeds were dibbled with the spacing of 45 cm × 15 cm. The recommended dose of fertilizers (100:75:40 kg NPK/ha) was applied to all the treatments. Half dose of nitrogen and full dose of phosphorus and potassium were applied at the time of sowing by using urea, single super phosphate and muriate of potash, respectively. The remaining 50% of nitrogen was applied at 30 days after sowing. The homogenous mixture of juice samples were drawn from all treatments at different growth stages. Representative juice sample was analyzed in the laboratory for various parameters of juice quality. Pol indicates the sucrose percentage of the juice sample. It was estimated by Horne's dry lead acetate clarification method using polarimeter and expressed in percentage (Ishwaran, 1981). Brix is the percentage of total soluble solids in the sample. Juice brix values were recorded by using hand Refractometer (0-30^0) and values were expressed in degrees. The available sugar per cent was calculated from winter carp-Geerling formula (Spencer and Meade, 1952) as modified by Mathur (1978). Available sugars (%) = [S-0.4(B-S)] × F. Calculated sugar yield per hectare was worked out using the formula and expressed in kg per hectare. Calculated sugar yield (kg/ha) = [S-0.4(B-S)] × F X Y/100. Where, B and S = Brix and Pol per cent, respectively of the juice extracted, F = value of the factor dependent on the fibre per cent of the sample. The fibre percentage in sweet sorghum is 16.1 and corresponding F value is 0.74. Y = weight of the stripped stalk (t/ha). Millable stalk yield was calculated by recording fresh weight of stalk without leaves and ear head in each net plot using spring balance expressed in tonnes/ha. Green biomass yield of sorghum was recorded after harvesting the stalks from each net plot except grain and expressed on per hectare basis. Juice yield was calculated by using formula and expressed in litrers/ha. Juice yield (l/ha) = Extractability (ml/kg) × Millable stalk yield (t//ha). Ethanol yield was calculated from juice from each treatment according to Manke and Kapoor, (2003).

RESULTS AND DISCUSSION

Juice quality, millable stalk and ethanol yield of sweet sorghum cultivars

'NSSH 1' recorded significantly superior quality parameters *viz* brix (14.5), pol (8.4), available sugar (4.4%) and sugar yield (132.7 kg/ha) as compared to 'RSSV 9' (14.0, 8.1, 4.3%, 120.4 kg/ha, respectively) and 'SSV 84' (13.9, 8.0, 4.2%, 110.4 kg/ha, respectively). Cultivar 'SSV 74' recorded significantly lower values of brix, pol, available sugar and sugar yield (13.6, 7.8, 4.0%, 95.3 kg/ha, respectively) (Table 1&2). The differences observed in quality parameters might be due to the activity and content of enzymes involved in sucrose synthesis or may be due to synthesis of sucrose. This was affected by the functioning of sucrose synthesizing enzymes in juice. The variation in the quality characters was reported in different cultivars by Ratnavathi *et al.* (2003). Cultivar 'NSSH 1' recorded significantly higher millable stalk (29.5 t/ha), green biomass (32.9 t/ha), juice (10914 l/ha) and ethanol yield (538.4 l/ha) as compared to 'RSSV 9' and 'SSV 84'. 'SSV 74' recorded significantly lower millable stalk, green biomass, juice and ethanol yield (Table 3&4). The increase in millable stalk yield recorded in 'NSSH 1' was attributed to increase in the length of millable stalk and internodal length. The increase in green biomass yield was attributed to increase in the stem girth, leaf area and total dry matter production and distribution in stem, leaf and ear head. The leaf area was correlated to increased green biomass yield, since leaf area is an indication of the assimilatory surface area providing the synthesis and accumulation of more photosynthates and dry matter production. The increase in juice yield was due to increased extractability. The extent of increase in ethanol yield in 'NSSH 1' was 17.9, 34.4 and 62.5% over 'RSSV 9', 'SSV 84' and 'SSV 74', respectively. For alcohol production, it is desirable to have higher sugar content, juice yield and extraction per cent of juice, which in turn dictates the ethanol production. It is

Table 1. Brix, pol per cent, available sugar and calculated sugar yield of sweet sorghum as influenced by the cultivars and harvesting stages (Pooled data over two years)

Treatment	Brix^0	Pol (%)	Available sugar (%)	Calculated sugar yield (kg/ha)
Cultivars (C)				
'SSV 74'	13.6	7.8	4.0	95.3
'SSV 84'	13.9	8.0	4.2	110.4
'NSSH 1'	14.5	8.4	4.4	132.7
'RSSV 9'	14.0	8.1	4.3	120.4
SEm±	0.3	0.1	0.2	6.2
CD (P=0.05)	0.8	0.3	NS	19.0
Harvesting stages				
At 50% flowering	12.8	7.1	3.6	84.0
At milky stage	14.4	8.4	4.4	123.5
At maturity	14.8	8.7	4.7	136.6
SEm±	0.3	0.1	0.1	5.3
CD (P=0.05)	0.9	0.3	0.4	16.4

evident from the present findings that the cultivar 'NSSH 1' was significantly superior in ethanol production and quality parameters *viz*., sugar yield, brix, pol over 'RSSV 9', 'SSV 84' and 'SSV 74'. The results are also in agreement with those of Sanjeev Raddi (2006).

Effect of harvesting stages on juice quality, millable stalk and ethanol yield

The crop harvested at maturity recorded significantly higher brix (14.8), pol (8.7), available sugar (4.7%) and calculated sugar yield (136.6 kg/ha) as compared to crop harvested at milky stage (14.4, 8.4, 4.4%, 123.5 kg/ha, respectively) but, crop harvested at 50% flowering stage recorded significantly lower quality parameters (Table 1 and 2). Low brix, pol per cent and available sugar content of the juice could be due to high acid invertase enzyme at 50% flowering stage. At physiological maturity, the acidic invertase content decreases while neutral invertase activity increases, as a result brix, pol per cent and available sugar content were increased at this stage. In sweet sorghum assimilate does not mobilize from stem to the grain so that pol of juice increases at physiological maturity. This increase in sugar yield was attributed to significantly higher brix, pol per cent and available sugar of juice over 50% flowering stage. The results are in agreement with the findings of Mallikarjun *et al*. (1997)**.** Crop harvested at maturity recorded significantly higher millable stalk (29.1 t/ha) and green biomass yield (31.7 t/ha) as compared to crop harvested at 50% flowering stage and milky stage (Table 2). Significantly lower green biomass yield was recorded when sweet sorghum was harvested at 50% flowering. This might be due to incomplete development of crop leading to lower dry matter distribution in leaves, stems and ear head. Similar findings were observed by Channa Naik and Jayakumar (1994). Juice (9777 l/ha) and ethanol yield (474.5 l/ha) were significantly higher when crop harvested at milky stage as compared to crop harvested at 50% flowering stage and maturity (Table 2). The increase in juice yield at milky stage might be due to higher millable stalk yield and extractability. This can be attributed to distribution of photosynthates towards formation of structural units and conversion of sugar into more

Table 2. Millable stalk, green biomass, juice and ethanol yield of sweet sorghum as influenced by the cultivars, harvesting stages and their interaction (Pooled data over two years)

Treatment	Millable stalk yield (t/ha)	Green biomass yield (t/ha)	Juice yield (l/ha)	Ethanol yield (l/ha)
Cultivars (C)				
'SSV 74'	23.4	26.5	7831	331.3
'SSV 84'	26.2	29.2	8839	400.4
'NSSH 1'	29.5	32.9	10914	538.4
'RSSV 9'	27.8	30.5	9783	456.6
SEm±	1.0	1.2	252	13.1
CD (P=0.05)	3.2	3.8	775	40.5
Harvesting stages (H)				
At 50% flowering	23.3	26.8	8789	352.7
At milky stage	27.8	30.8	9777	474.5
At maturity	29.1	31.7	9460	467.8
SEm±	0.9	1.1	218	11.4
CD (P=0.05)	2.8	3.3	670	35.0
Interaction (C × H)				
'SSV 74' × at 50% flowering	21.0	24.9	7563	275.7
'SSV 74' × at milky stage	24.0	27.1	8111	359.9
'SSV 74' × at maturity	25.2	27.5	7817	358.4
'SSV 84' × at 50% flowering	22.7	26.0	8303	329.9
'SSV 84' × at milky stage	26.9	30.1	9101	435.6
'SSV 84' × at maturity	29.0	31.5	9113	435.7
'NSSH 1' × at 50% flowering	26.0	29.5	10396	440.4
'NSSH 1' × at milky stage	30.6	33.8	11415	591.0
'NSSH 1' × at maturity	32.0	35.3	10932	583.8
'RSSV 9' × at 50% flowering	23.6	26.7	8893	364.7
'RSSV 9' × at milky stage	29.5	32.1	10478	511.6
'RSSV 9' × at maturity	30.3	32.8	9977	493.6
SEm±	1.8	2.1	436	22.8
CD (P=0.05)	5.3	6.0	1290	70.1

complex starch granules. The increase in ethanol yield at milky stage and physiological maturity stage was to the extent of 34.5 and 32.6% over 50% flowering stage. This was mainly due to significantly higher calculated sugar yield, pol, brix, juice yield and green biomass yield. These results were in conformity with the findings of Gupta *et al.* (2007).

Interaction effect of cultivars and harvesting stages on juice, millable stalk and ethanol yield

'NSSH 1' harvested at maturity recorded significantly higher millable stalk (32.0 t/ha) and green biomass yield (35.3 t/ha) (Table 2). The increase in millable stalk yield was a consequence of increase in length of millable stalk and internodal length. This increase in green biomass yield with 'NSSH 1' harvested at maturity was a result of increase in total dry matter production and its distribution in stem, leaves and ear head. Similar increase in millable stalk and green biomass yield was observed from the studies conducted by Sanjeev Raddi (2006) at Dharwad. Cultivar 'NSSH 1' harvested at milky stage recorded significantly higher juice (11415 l/ha) and ethanol yield (591.0 l/ha) as compared to other treatment combinations (Table 2). This increase in juice and ethanol yield was linked to increase in millable stalk, green biomass, sugar yield as well as brix and pol. These results are conformity with the findings of Latha (2007).

Economics of sweet sorghum as influenced by cultivars and harvesting stages

Pooled data showed that treatment combination of NSSH 1 harvested at maturity recorded higher gross returns, net returns and B:C ratio (Rs. 42103, 32180/ha and 4.24, respectively) followed by 'RSSV 9' harvested at maturity stage, 'SSV 84' harvested at maturity stage and 'SSV 74' harvested at maturity stage over the rest of the treatment combinations. The increase in gross returns, net returns and B:C ratio was mainly due to higher grain and ethanol yield (Table 3). Similar results were reported by Sanjeev Raddi (2006).

Table 3. Economics of sweet sorghum as influenced by the cultivars and harvesting stages (Pooled data over two years)

Treatment	Gross returns ($\times 10^3$ ₹/ha)	Net returns (₹/ha)	B:C ratio
'SSV 74' × at 50% flowering	6.90	-2,705	0.72
'SSV 74' × at milky stage	9.02	-621	0.94
'SSV 74' × at maturity	32.2	22,587	3.34
'SSV 84' × at 50% flowering	8.3	-1332	0.86
'SSV 84' × at milky stage	10.9	1,255	1.13
'SSV 84' × at maturity	35.0	25,379	3.63
'NSSH 1' × at 50% flowering	11.0	1,130	1.11
'NSSH 1' × at milky stage	14.7	4,732	1.48
'NSSH 1' × at maturity	42.1	32,180	4.24
'RSSV 9' × at 50% flowering	9.1	-624	0.94
'RSSV 9' × at milky stage	12.8	3,034	1.32
'RSSV 9' × at maturity	37.2	27,416	3.80

The sweet sorghum cultivar 'NSSH 1' may be grown for higher millable stalk and ethanol yield in Bhandra command area of Karnataka. Harvesting the crop at milky stage is ideal for higher ethanol yield.

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