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On-farm Evaluation of Elite Sweet Sorghum Genotypes for Grain and Stover Yields and Fodder Quality

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ABSTRACT

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Sweet sorghum is a multipurpose crop that comes up well under rainfed conditions in semi-arid tropics. While the stalk juice from sweet sorghum used for ethanol production, its grain is used for food and the bagasse as animal feed. The investigation had four objectives: 1) to popularize sweet sorghum as food, feed and fuel crop; 2) to identify promising sweet sorghum cultivars under on-farm conditions for use as animal feed; 3) to study the associationships between cane yield and stalk sugar traits; and 4) to assess the options for utilizing stover and fresh/dried bagasse as livestock feed. Sweet sorghum cultivation is feasible and profitable under rainfed conditions in the study area with the hybrid CSH 22 SS. Results from on-farm evaluation of elite sweet sorghum hybrids and varieties and correlation studies indicated that dryland farmers gain from whole plant use of sweet sorghum as there is no significant tradeoff between grain yield and sugar/stover yields. The genetic enhancement of sweet sorghum is justifiable as the food and fodder value of the crop is not compromised by its improvement for bio-fuel value. The effective rumen degradable dry matter (ERDDM) for sweet sorghum bagasse (SSB) was 40.60 per cent and effective rumen degradable protein (ERDP) value was 55.30 per cent. The nutritive value of SSB in terms of the digestible crude protein (DCP) and total digestible nutrients (TDN) in sheep was 1.02, 50.67 per cent where as in buffaloes DCP was 0.98 and TDN 51.78 percent. Results from the limited on-farm animal experiments in milch buffaloes and sheep indicate that the potential of sweet sorghum stalks in the form of stover and bagasse in fresh or ensiled form as a source of roughage is good and further long term experiments are required to confirm the same.

Key words: Animal feed quality, Grain and stover yields, On-farm testing, Sweet sorghum.

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INTRODUCTION

Sweet sorghum [*Sorghum bicolor* (L) Moench] is well adapted to the Semi-Arid Tropics (SAT) and one of the most efficient dry land crops to convert atmospheric CO_2 into sugar (Schaffert and Gourley, 1982). The crop is gaining importance as an alternative feedstock for bioethanol production (Reddy *et al.,* 2005; Lau *et al.,* 2006). The sugar rich stalk juice from sweet sorghums is used for ethanol production while grain has multiple uses. Much of the earlier work in sweet sorghum was focused on improving open-pollinated varieties but recent work has been targeted for development of high sugar yielding hybrids that are less photoperiod-sensitive (Reddy *et al.,* 2008). Despite the increasing industrial usage, farmers still consider sweet sorghum as a dual purpose crop as grain is used for human consumption and the stover for livestock feeding (Rao *et al.,* 2008; Shukla *et al.*, 2006). While the industrial usage of sweet sorghum stalks for ethanol production would provide additional income for the farmers, it also diverts biomass away from livestock thus potentially worsening problem of feed scarcity. Recycling of the bagasse residue remaining after juice extraction from stems for ethanol together with leaf stripping could partly compensate for the fodder loss. The work presented here had four objectives: 1) to popularize sweet sorghum as food, feed and fuel crop; 2) to identify promising sweet sorghum genotypes under on-farm conditions for future use; 3) to study the association between cane yield and stalk sugar traits; and 4) to assess the nutritive value of bagasse and options for utilizing stover and fresh/dried bagasse as livestock feed.

MATERIALS AND METHODS

Agronomical experiments

To demonstrate the multiple benefits of sweet sorghum, the released sweet sorghum hybrid CSH 22SS was grown in 106 acres in farmers' fields in the Ibrahimbad village in Medak district, Andhra Pradesh (AP), India during the 2008 rainy season. All the inputs and technical help were provided to raise a good crop. At physiological maturity, the grain was harvested for food and the stalks were crushed to extract the sweet juice for syrup production in the decentralized crushing-cum-syrup unit (DCU) located in the Ibrahimbad village. Part (30%) of the bagasse obtained in the process was used for firing chulas for syrup production and the rest was supplied to farmers for use as animal feed. Data were recorded on the fresh stalk yield (t ha^{-1}), grain yield (t ha^{-1}), soluble solids concentration (°Bx), juice yield (t ha^{-1}), syrup yield (kg t^{-1} of juice) and bagasse yield (t ha^{-1}) from the bulk crop.

To identify the promising sweet sorghum lines, an on-farm trial was conducted during the 2008 rainy season at Ibrahimbad village in Medak District, Andhra Pradesh, India to evaluate a set of 13 elite sweet sorghum entries that include newly developed sweet sorghum hybrids (7) and varieties (4) along with two controls CSH 22SS (hybrid check) and SSV 84 (varietal check). The trial was planted in a Randomized Complete Block Design (RCBD) with three replications in 39 farmers fields (each field 0.5 acres in area). Data were recorded on the fresh stalk yield (t ha^{-1}), grain yield (t ha^{-1}), soluble solids concentration (°Bx), juice yield (t ha^{-1}), juice volume (kL ha^{-1}) sugar yield (t ha-

[1]) and bagasse yield (t ha^{-1}). The data were analyzed using GENSTAT (Edition 10) to test the significant differences among the genotypes, for mean performance to select the high stalk and grain yielding genotypes with high sugar yields and to estimate correlations among the traits.

Feed quality experiments

Studies were undertaken to elucidate the dry matter intake, rumen degradability characteristics, nutrient digestibility and nutritive value of dry sweet sorghum bagasse (SSB). The rumen dry matter and protein degradable characteristics of SSB were determined by nylon bag technique (Kempton, 1980) using four rumen fistulated male Murrah buffaloes. The effective rumen degradable dry matter (ERDDM) and effective rumen degradable protein (ERDP) was calculated using standard model (McDonald, 1981). The nutrient digestibility and nutritive value of sweet sorghum bagasse was determined in sheep (Deccani rams) and buffalo (Murrah Buffalo bulls) through a digestion cum metabolism trial by difference technique. A seven day adaptation period, 14 day preliminary period and 7 day collection period was followed during the trial. Each of four Murrah buffalo bulls (344.25±5.99) and adult Deccani rams (43.25±1.31) were offered sweet sorghum bagasse *ad lib* besides supplementing 720 g and 190 g sunflower cake daily, respectively. During the collection period representative samples of feed offered, leftover, faeces and urine were collected, processed and analyzed (AOAC, 1997; Van Soest *et al.*, 1991).

The sweet sorghum fresh bagasse with leaf residues (BLR) obtained at the DCU has a moisture content of around (50%) and consequently of low keeping quality. In view of this, options for utilizing the BLR in fresh and silage forms were explored by conducting two experiments. In the first experiment, fresh BLR from the crushing unit was collected daily and offered to seven milch buffaloes (local non descript breed with 2-4 liters milk production) *ad lib* and supplemented with 500 g cotton cake/day/animal. The trial lasted for 30 days and three parameters per cent voluntary feed intake, milk production and changes in the body condition of the milch animal were assessed. Farmer's perceptions on use of BLR were also recorded. In the second experiment, the feasibility of preserving fresh BLR by ensiling whole and chopped BLR in air tight plastic drums were explored. Whole and chopped BLR were ensiled by spreading the material in small layers and compaction by trampling the material using manual labour. This process was repeated till the drums were completely filled and then sealed with the lid. The drums were left undisturbed for 30 days after which the quality of silage was assessed by conducting a feeding trial in sheep by assessing voluntary feed intake, digestibility and nitrogen balance.

In instances where the sweet sorghum stalks cannot be crushed due to lack of facilities, the stover *per se* can be used for feeding livestock. An on-farm trial for ten days was conducted in a commercial urban dairy farm having ten milch buffaloes in Hyderabad to assess the sorghum trader and farmers perception and production response to sweet sorghum stover by replacing the conventional sorghum stover that is regularly fed in commercial dairies. Dried sweet sorghum stover was supplied to an urban dairy farmer through the sorghum trader and the perceptions and production response were recorded.

RESULTS

The sweet sorghum hybrid CSH 22SS gave an average stalk yield of 22 t ha^{-1} with a soluble solids concentration (°Bx) of 15% under large scale cultivation in farmers' fields in the Ibrahimbad village in Medak district, Andhra Pradesh (AP), India during the 2008 rainy season. It recorded average grain yield of 1.5 t ha^{-1}. The farmers benefited both from the grain and stalks as stalks were procured by the decentralized crushing unit (DCU) in the village (@INR 600 t^{-1}). A total of 557 tons of green stalks were crushed at DCU and 23 tons of syrup was produced during the 2008 rainy season. The syrup was supplied to M/s. Rusni Distilleries Pvt. Ltd. for ethanol production.

From the on-farm experimentation to identify the promising sweet sorghum genotypes, the ANOVA (data not shown) indicated significant differences among the sweet sorghum cultivars tested for grain yield, stalk yield and other stalk sugar related traits. Comparison of mean values indicated that, among seven hybrids tested, four hybrids (ICSA 724 × SSV 74, ICSA 675 × SSV 74, ICSA 474 × SSV 74 and ICSA 324 × SSV 74) recorded higher sugar yield ranging from 1.3 to 1.7 t ha^{-1} than the control CSH 22SS (sugar yield 1.2 t ha^{-1}) (Table 1). The °Bx in these hybrids ranged from 14 to 15 (CSH 22 SS : 13.3). The grain yield in these hybrids ranging between 1.4 to 3.0 t ha^{-1} was low compared to CSH 22 SS (3.9 t ha^{-1}). Among the four varieties tested, two (SP 4484-2 and SP 4511-2) showed higher sugar yield (1.7 and 1.8 t ha^{-1}) than the control SSV 84 (1.4 t ha^{-1}) with °Bx ranging from 15 to 16 (SSV 84: 16.6). The varieties recorded significantly higher grain yields (1.4 to 2.3 t ha^{-1}) compared to SSV 84 (1.0 t ha^{-1}). The hybrid ICSA 724 × SSV 74 performed better among the hybrids tested with higher °Bx (15%), higher sugar yield (1.7 t ha^{-1}) and grain yield (3.0 t ha^{-1}) and SP 4484-2 recorded high °Bx (15%), higher sugar yield (1.8 t ha^{-1}) and grain yield (2.2 t ha^{-1}) among the varieties (Table 1).

The studies on correlations among 11 sweet sorghum genotypes indicated that there was no significant correlation between grain yield and sweet stalk traits like " °Bx, cane yield, juice yield and sugar yield. Among the sweet stalk traits, fresh stalk yield (stem and leaves without panicle), cane yield, juice yield, juice volume, bagasse yield and sugar yield showed significant positive correlation ($P \leq 0.05$) with each other, where as °Bx showed significant positive correlation only with sugar yield indicating that higher °Bx contributes to higher sugar yield and as expected all other fodder/sweet stalk traits are independent of °Bx (Table 2).

Studies on rumen degradability characteristics of sweet sorghum bagasse (SSB) revealed that the dry matter and protein degradability values ranged from 36.13 to 56.61 per cent and 23.8 to 67.98 per cent, respectively, when ground (2 mm sieve) SSB was incubated from 12 to 72 and 3 to 24 h in the rumen of buffaloes (Table 3). The soluble (a) and degradable fractions (b) of dry matter and protein in SSB were 30.80, 9.84 and 61.51 and 69.91 per cent, respectively. Effective rumen degradable dry matter (ERDDM) and protein (ERDP) values for SSB was 40.60 and 55.30 per cent, respectively.

The dry matter intake (% body weight) from sweet sorghum bagasse was 1.43 and 1.60, respectively in buffaloes and sheep (Table 4). The digestibility (%) values of

Table 1. Performance of elite sweet sorghum genotypes under on-farm conditions during 2008 rainy season.

Pedigree	Soluble solids concentration (°Bx) at maturity	Fresh stalk yield (t ha^{-1})	Cane yield (t ha^{-1})	Bagasse yield (t ha^{-1})	Juice yield (t ha^{-1})	Juice volume (kL ha^{-1})	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
Hybrids								
ICSA 724 × SSV 74	15.1	32.3	24.5	10.3	11.0	10.2	1.7	3.0
ICSA 675 × SSV 74	13.8	29.0	23.5	10.8	10.6	10.1	1.5	2.0
ICSA 474 × SSV 74	15.1	26.6	19.5	8.9	9.5	9.0	1.4	2.0
ICSA 324 × SSV 74	14.8	23.3	19.7	8.5	8.5	8.6	1.3	1.4
ICSA 702 × SSV 74	13.0	27.2	21.1	9.7	9.5	9.1	1.2	3.6
ICSA 731 × ICSV 93046	12.3	23.8	19.8	6.8	10.0	9.5	1.2	2.8
ICSA 38 × NTJ 2	12.3	21.9	17.4	7.8	7.3	6.9	0.9	2.3
CSH 22 SS (control)	13.3	24.3	18.6	7.8	8.8	8.6	1.2	3.9
Varieties								
SP 4484-2	14.7	35.3	29.1	12.9	12.4	11.8	1.8	2.2
SP 4511-2	15.7	29.8	25.0	11.1	11.0	10.2	1.7	2.3
SS 2016	14.4	28.3	22.4	11.0	8.7	8.3	1.3	4.8
SP 4487-3	14.5	23.7	18.8	8.1	8.6	8.1	1.2	1.4
SSV 84 (control)	16.6	27.2	20.4	9.1	8.1	7.4	1.4	1.0
Overall mean	14.27	27.12	21.51	9.45	9.56	9.05	1.37	2.52
SE ±	0.22	0.86	0.68	0.37	0.33	0.32	0.05	0.16

Table 2. Correlation estimations in sweet sorghum genotypes under on-farm conditions during 2008 rainy season

	Soluble solids concentration (^{0}Bx) at maturity	Fresh stalk yield	Cane yield	Juice yield	Juice volume	Sugar yield	Bagasse yield
Fresh stalk yield	0.452	1.000					
Cane yield	0.372	0.953**	1.000				
Juice yield	0.184	0.846**	0.891**	1.000			
Juice volume	0.130	0.793**	0.862**	0.985**	1.000		
Sugar yield	0.613*	0.901**	0.900**	0.886**	0.847**	1.000	
Bagasse yield	0.431	0.904**	0.915**	0.697**	0.670*	0.785**	1.000
Grain yield	-0.417	0.128	0.080	0.059	0.079	-0.124	0.137

* Significant at 5% and ** Significant at 1% level.

proximate principles and fiber fractions of sweet sorghum bagasse calculated by difference method in sheep and buffaloes are presented in Table 5. The digestible crude protein (DCP) and total digestible nutrients (TDN) value of sweet sorghum bagasse in sheep and buffaloes was 1.02, 50.67 and 0.98 and 51.78 per cent, respectively.

In another animal experiment, fresh unchopped bagasse and leaf residue (BLR) when supplemented with 500 g cotton cake in milch buffaloes resulted in feed intake of around 22-26 kg (fresh matter basis) corresponding to 3.3% intake when expressed as percentage of body weight indicating that BLR is quite palatable and well accepted by the milch buffaloes. The level of milk production was around 3 liters/day and during the

Table 3. Rumen degradable characteristics of sweet sorghum bagasse in fistulated graded Murrah buffalo bulls

Incubation interval (h)	DM disappearance (%)	Incubation interval (h)	Protein disappearance (%)
12	36.13	3	23.80
24	41.00	6	34.96
36	45.45	9	43.90
48	49.51	15	56.79
72	56.61	24	67.98
Degradation kinetics			
Soluble fraction	30.80		9.84
Degradable fraction	61.51		69.91
Degradation rate (h^{-1})	0.008		0.071
ED	40.60		55.30

Each value is an average of four observations.

one month feeding period the body condition of the animals also improved as indicated by the heart girth measurements and the condition of the body coat. Animals after the experiment were allowed to be fed as per the farmers feeding practice – grazing supplemented with paddy straw and limited rice bran and it was observed that animals on an average lost around 20 kg within the first fifteen days. Farmers appreciated that fresh SSBLR was well accepted by the buffaloes but pointed out that chopping would have further improved the intake and reduce the refusal of thick stalk pieces. Interestingly farmers observed that the milk of the fresh BLR fed animals were creamier than on their previous grass diets due to increase in fat content.

Generally, for silage preparation the recommended moisture level is 60% and the fodder is chopped for better compaction and anaerobic fermentation leading to better quality silage. In case of fresh BLR, it was observed that the moisture content was around 48-52% and an attempt was made to ensile the fresh material–whole and chopped, without any further processing–moisture addition or silage additives to make it cost effective and as practicable as possible. Ensiling of whole and chopped BLR without any additives for 30 days period resulted in good quality silage as assessed by the appearance and smell of the silage. Further the quality of silage was assessed by feeding experiments in sheep, where the silage was supplemented with 150 g concentrate/animal/day. Intake and nitrogen

Table 4. Effect of supplementing cotton cake to sweet sorghum bagasse (SSB) on dry matter intake in graded Murrah buffalo bulls and Deccani rams.

Parameter	Species	
	Buffalo	Sheep
Body weight (kg)	344.25±5.99	43.25±1.31
Metabolic body weight (kgW$^{0.75}$)	79.89±2.09	16.86±0.38
DMI (kg/d)		
Roughage	4.91±0.13	0.69±0.03
Concentrate	0.72±0.00	0.19±0.00
Total	5.63±0.13	0.88±0.03
DMI (g/kg w$^{0.75}$)		
Roughage	61.53±1.21	40.93±1.25
Concentrate	9.03±0.24	11.41±0.25
Total	70.56±1.32	52.33±1.25
DMI (% B. wt.)		
Roughage	1.43±0.03	1.60±0.05
Concentrate	0.21±0.01	0.45±0.01
Total	1.64±0.04	2.04±0.05

Each value is an average of four observations.

Table 5. Nutrient digestibility and nutritive value of sweet sorghum bagasse in graded Murrah buffalo bulls and Deccani rams

Nutrient	Digestibility (%)	
	Buffalo bulls	Deccani rams
Dry matter	52.47±1.39	50.75±1.84
Organic matter	58.96±0.26	58.82±0.69
Crude protein	40.19±0.83	41.61±0.80
Ether extract	60.97±1.61	58.14±0.31
Crude fiber	51.54±0.40	52.23±0.83
Nitrogen free extract	58.40±0.84	55.72±1.02
Nutritive value (%)		
DCP	0.98±0.02	1.02±0.02
TDN	51.78±0.43	50.67±0.42

Each value is an average of four observations.

balance of chopped SSBLR was similar to the silage prepared from whole BLR and the intake on dry matter basis as per cent body weight was 2.5 per cent (Table 6).

The feedback from the trader and urban dairy farmer on use of sweet sorghum stover was positive. Trader was able to sell the sweet sorghum stover (dried stalks and leaves after harvesting the ear heads) to the farmer at the prevailing rates for the conventional sorghum stover and the farmer was happy with the quality of the stover. The dairy farmer reported an increase of half to one liter in the milk production per animal by the buffaloes and also the quantity of daily stover requirement decreased by 15% (100 vs 120 kg d^{-1}) by replacing the traditional sorghum stover by sweet sorghum stover. Animals in early lactation had a higher increase in milk yield of around one liter while those in late lactation had an increase of half liter per day.

DISCUSSION

Quantitative relationships between productive traits

In the SAT, sweet sorghum is grown as a multipurpose crop that is expected to provide grain for human consumption and fodder for feeding the livestock. Experiences from this large scale cultivation in farmers' fields showed that dryland farmers benefit from sweet sorghum cultivation owing to its multipurpose use provided they have market tie-up for the stalks.

Results from on-farm evaluation of sweet sorghum hybrids and varieties and correlation estimations in this study indicated that no significant tradeoff between grain yield and sugar yields (Tables 2 and 3). Our previous (Reddy *et al.,* 2005 and 2008) findings also suggest that high grain yield for human consumption and high residual biomass in form of stover for livestock feed are basically unrelated owing to non-significant correlation, and cultivars bred for high grain yield will not put penalty for high fodder production. Therefore, farmers can optimize benefits from both the traits

Table 6. Performance of sheep fed SSBLR – whole and chopped silage.

	DMI g/d	DMI (% BW)	DM dig %	OM % dig	N balance g/d
Chopped	415.4	2.5	59.3[a]	60.2[a]	5.7
Whole	414.0	2.5	63.1[b]	64.3[b]	4.8

($P<0.05$).

(grain and stover yields) by choice of appropriate cultivar. The genetic enhancement of sweet sorghum is justifiable as the food and fodder value of the crop is not compromised by its improvement for biofuel use.

High moisture content of around 50-55% and the sweetness from residual juice in the fresh BLR probably contributed to high palatability resulting in high feed intake. High feed intake in buffaloes coupled with reasonably good milk production, better milk quality due to higher fat and improved body condition as perceived by the farmers implies that fresh BLR could be potentially good roughage for milch animals.

In situ evaluation of sweet sorghum bagasse (SSB) revealed that the effective degradable dry matter content of SSB was similar to that of maize stover and maize cobs (Krishna and Prasad, 1990). Similarly, *in vivo* evaluation in sheep and buffaloes showed sorghum and maize stover were at par and slightly superior to that of maize cobs and sugarcane (Raghavan, 1990). Nutritive value expressed in terms of DCP and TDN was similar for sorghum straw and cottonseed hulls indicating that SSB is a good animal feed.

Whole and chopped silage had light brown colour and the typical lactic acid smell of good quality silage suggesting that the moisture content and the sugars from residual juice in the BLR was sufficient enough to promote good ensiling without any need for additives. Similar intake of chopped and whole silage indicated that there was no special advantage in chopping the BLR before ensiling and whole BLR can directly be ensiled without wasting energy and labour in chopping. The digestibility of dry matter and organic matter in group fed on whole silage was significantly ($P<0.05$) higher than the chopped silage fed group.

Preliminary results with use of sweet sorghum stover in urban dairy have been encouraging. Trader was happy with the feedback of the farmer with regard to the increase in the milk yield and reduction in the stover requirement as compared to the traditional grain sorghum stover. Trader was of the opinion that if regular supply of sweet sorghum stover is ensured there would be higher demand for the sweet sorghum stover due to its better quality as reflected by the production response in milch buffaloes.

Results from the limited on-farm animal experiments indicate that the potential of sweet sorghum stalks in the form of stover and bagasse either in fresh or ensiled form as a source of roughage is good and further long term experiments are required to confirm the same.

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