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Sweet Sorghum – A Potential Alternate Raw Material for Bio-ethanol and Bio-energy

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Introduction

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a special purpose sorghum with a sugar-rich stalk, almost like sugarcane. Besides having rapid growth, high sugar accumulation, and biomass production potential, sweet sorghum has wider adaptability (Reddy and Sanjana 2003). Given that water availability is poised to become a major constraint to agricultural production in coming years (Ryan and Spencer 2001), cultivation of sugarcane becomes difficult. Sweet sorghum would be a logical crop option in lieu of sugarcane in such situations. 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. 2004a). The stillage after extraction of juice from sweet sorghum can be used for co-generation of power.

Need for alternate raw material

The Supreme Court of India informed the Government of India (GOI) to use Compressed Natural Gas (CNG) as an alternative to petrol and diesel for fuelling automobiles to reduce environmental pollution. However, considering the reduced output by the Oil and Natural Gas Corporation (ONGC), and thereby likely shortage of CNG in future (Anonymous 2001), the GOI has made it mandatory to blend petrol and diesel with ethanol (to reduce carbon monoxide emission in automobiles) initially up to 5% and gradually hiking it to 10% in the second phase. There are two objectives in this strategy, reducing both the environmental pollution and the fuel-import bill for the country. According to the Federation of Indian Chambers of Commerce and Industry (FICCI), India could save nearly 80 million L of petrol annually if petrol is blended with alcohol by 10%. Burning quality of alcohol-blended petrol is more eco-friendly than that of CNG (Arbatti 2001). These environment and cost considerations have triggered a debate on the availability of adequate raw material to meet the possible increased demand for ethanol production. Molasses (a by-product of sugarcane after the extraction of sugar), the traditional source of raw material for ethanol production, is unlikely to meet the actual demand in the long run (Ratnavathi et al. 2004b). The requirement of ethanol in India to blend with petrol (10%) is about 1000 million L, and for blending with diesel (5%) another 3000 million L per annum. Total ethanol requirement including other purposes is 5000 million L per annum. The possible ethanol production from available sugarcane molasses (8.2 million t) and other sources is 2000 million L per annum. This leaves a deficit of 3000 million L of ethanol per annum. Further, the molasses-based ethanol distilleries operate only for 180 days (during sugarcane crushing season) because of the limited availability of the molasses to run the distillery throughout the year as well as the problems associated with the spent wash to comply with pollution control standards [Personal communication from Patil, Vasanthadada Sugar Institute (VSI), Pune, India]. The existing distilleries therefore, operate at 50% efficiency and needs alternate raw material(s) to operate at their full efficiency (Anonymous 2004). The underutilization of the existing molasses-based ethanol distilleries and the deficit in ethanol requirement can be made good if sweet sorghum cultivation is promoted for ethanol production.

Comparative advantages of sweet sorghum

In recent years, there has been increased interest in the utilization of sweet sorghum for ethanol production in India as its growing period (about 4 months) and water requirement (8000 m^3 over two crops) (Soltani and Almodares 1994) are 4 times lower than those of sugarcane (12–16 months and 36,000 m^3 $crop^{-1}$, respectively). The cost of cultivation of sweet sorghum is three times lower than that of sugarcane (Dayakar Rao et al. 2004) (Table 1). Further, sweet sorghum is best suited for ethanol production because of its higher total reducing sugar content and poor sugar content compared to sugarcane juice (Huligol et al. 2004). The presence of reducing sugars in sweet sorghum prevents crystallization and sweet sorghum cultivars have 90% fermentation efficiency (Ratnavathi et al. 2004a). These along with its suitability for mechanized crop production, seed propagation and higher ethanol production capacity of sweet sorghum (2800 L ha^{-1} yr^{-1} over two crops; 70 t ha^{-1} of millable stalk per two crops @ 40 L t^{-1}) *vis-a-vis* sugarcane molasses (850 L ha^{-1} yr^{-1}; 3.4 t ha^{-1} @ 250 L t^{-1}) (as per the pilot study by VSI, Pune, India) (Table 1) makes sweet sorghum the best alternative source of raw material that can be used as a supplementary raw material rather than as a substitute to ethanol production in India.

Comparative economics of ethanol production by sweet sorghum and sugarcane

A techno-economic feasibility study undertaken by the National Research Center for Sorghum (NRCS), Hyderabad, Andhra Pradesh, with active collaboration with M/s Renuka Sugars Ltd, Belgaum, Karnataka, indicated that the per liter cost of production of ethanol from sweet sorghum (Rs. 13.11) is slightly lower than that from sugarcane molasses (Rs. 14.98) (Table 2). In addition to sweet-stalk, grain yield of 2 to 6.0 t ha^{-1} (which can be used as food or feed) could be harvested from sweet sorghum. Further, the stillage from sweet sorghum after the extraction of juice has a higher biological value than the bagasse from sugarcane when used as forage for animals, as it is rich in micronutrients and minerals (Seetharama et al. 2002). It could also be processed as a feed for ruminant animals (Sumantri and Edi Purnomo 1997). The stillage contains similar levels of cellulose as sugarcane bagasse, and therefore has a good prospect as a raw material for pulp product. According to a pilot study by Shree Renuka Sugars Ltd., Karnataka, India, blending sweet sorghum juice up to 10% in sugarcane juice does not affect crystallization; hence it is compatible with the sugarcane industry (Huligol et al. 2004). Apart from these, the pollution level in sweet sorghum-based ethanol production has 1/4th of the biological oxygen demand (BOD, 19,500 mg L^{-1}) and lower chemical oxygen demand (COD, 38,640 mg L^{-1}) compared to molasses-based ethanol production (Personal communication from Patil, VSI, Pune, India). Further, ethanol is a "clean burning fuel" with a high octane rating because of its low sulphates and aldehydes and existing automobile engines can be operated with Gasohol (petrol blended with

Table 1. Comparative advantages of sweet sorghum *vs.* sugarcane/sugarcane molasses for ethanol production.

Crop	Cost of cultivation (Rs. ha^{-1})[1]	Crop duration[2]	Water requirement[2]	Ethanol productivity (L ha^{-1})[3]
Sweet sorghum	17820	4 months	8000 m^3 over two crops	2800 $year^{-1}$ over two crops [(4)]
Sugarcane	49250	12-16 months	36,000 m^3 $crop^{-1}$	6500 $crop^{-1}$ [(5)]
Sugarcane- molasses	-	-	-	850 $year^{-1}$ [(6)]

1. Source: Dayakar Rao et al. (2004);
2. Source: Soltani and Almodares (1994)
3. Personal communication from Patil, Vasanthadada Sugar Institute, Pune, India
4. 70 t ha^{-1} millable stalk over two crops @ 40 L t^{-1};
5. 85-90 t ha^{-1} millable cane $crop^{-1}$@ 75 L t^{-1};
6. 3.4 t ha^{-1}@ 250 L t^{-1}.

Table 2. Comparative per liter cost of ethanol production from sweet sorghum and sugarcane molasses.

Particulars	Sweet sorghum[1] (Rs. L^{-1})	Sugarcane molasses[2] (Rs. L^{-1})
Manpower	0.50	0.25
Steam	1.00	1.00
Electricity	1.00	1.00
Yeast	0.10	0.10
Management/Administration	0.10	0.25
Pollution control	Nil	0.25
Raw material	10.41	12.13
Total	13.11	14.98

1. Sweet sorghum stalk @ Rs. 500 t^{-1};
2. Sugarcane molasses @ Rs. 2000 t^{-1}

Source: Dayakar Rao et al. 2004

ethanol) without any need for engine modification (Ratnavathi et al. 2004a). Thus, from both economics and environment protection point of view, sweet sorghum offers good prospects for ethanol production as an additional feed stock to existing distilleries.

Prospects of enhancing genetic potential of sweet sorghum

The wide range of variability for Brix reading (from 13 to 24%), sucrose% (from 7.2 to 15.5), stalk yield (from 24 to 120 t ha^{-1}) and biomass yield (from 36 to 140 t ha^{-1}) in sweet sorghum (Almodares et al. 1997) under long growing seasons in Iran; and Brix readings (from 14.1 to 19.2%) and millable stalk yield (27.1 to 47.6 t ha^{-1}) under Indian conditions (AICSIP 2004–2005) indicates the high potential for genetic improvement to produce high sweet-stalk yield coupled with high sucrose% sweet sorghum lines. Genotypic differences for extractable juice, total sugar content, and fermentation efficiency and alcohol production have also been reported (Ratnavathi et al. 2003). The predominant role of non-additive gene action for plant height, stem girth, total soluble solids, millable sweet-stalk yield and extractable juice yield (Sankarapandian et al. 1994) indicates the importance of breeding for heterosis for improving these traits. The substantial magnitude of standard heterosis for all the traits related to ethanol production (plant height: up to 46.9%, stem girth: up to 5.3%, total soluble solids (%): up to 7.4%, millable stalk yield: up to 1.5% and extractable juice yield: up to 122.6%) (Sankarapandian et al. 1994) further supports breeding for heterosis for genetic enhancement of sweet sorghum.

Sweet sorghum research at ICRISAT

Hybrid parents. Sweet sorghum research at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was initiated in 1980 to identify lines with high stalk-sugar content in part of the sorghum world germplasm collection maintained at ICRISAT's gene bank initially by chewing the stalks at maturity. Seventy accessions that tasted sweet were evaluated during the rainy season of 1980 and nine accessions with high sugar content were planted in the 1981 rainy season. Two cultivars, IS 6872 and IS 6896, were selected. The mean stalk-sugar content of the nine accessions grown in 1980 and 1981 varied by roughly 3% between the two seasons, indicating that differences between growing seasons had little influence on the stalk-sugar content. The density of juice did not show appreciable variation among the accessions (Subramanian et al. 1987). Apart from this, several sweet sorghum lines with high Brix values were identified among Nigerian and Zimbabwe lines and within advanced breeding progenies at ICRISAT-Patancheru.

Due to changed focus driven by donor perceptions and the needs of national agricultural research systems (NARS), sweet sorghum research at ICRISAT was discontinued in the late 1990s. However, ICRISAT renewed its sweet sorghum research in 2002 to meet the possible increased demand created for ethanol following the Indian Government's policy to blend petrol and diesel with ethanol. As a short-term strategy for immediate utilization for hybrid cultivar development, a set of 92 hybrid parents (among the existing diverse set of grain sorghum hybrid parents) with high Brix values were identified based on field evaluations during the 2002 rainy, 2002–03 postrainy and 2004 rainy seasons. Promising among these are ICSB 264, ICSB 401, ICSB 405, ICSB 472, ICSB 474 among the seed parents (B-lines), and ICSR 93034, S 35, ICSV 700, ICSV 93046, Entry# 64 DTN among the varieties/R-lines (Table 3). Four of these lines, S 35, ICSV 700, ICSR 93034 and Entry# 64 DTN, were tested in the All India Coordinated Sorghum Improvement Project (AICSIP) during 2004 rainy season and two of these, ICSV 700 and ICSR 93034, have been promoted for advanced testing.

Table 3. Promising sweet sorghum hybrid parents identified at ICRISAT, Patancheru, India.

Year / season of evaluation	Promising lines	Stalk Brix (%)	Sweet-stalk yield (t ha^{-1})
Hybrid seed parents			
2002 rainy and 2002-03 postrainy seasons	ICSB 472, ICSB 401, ICSB 405, ICSB 731	15.9 to 17.9	17 to 35
2004 Rainy season	ICSB 264, ICSB 293, ICSB 213, ICSB 654, ICSB 474	13.3 to 16.8	14 to 24
Varietal/Restorer lines			
2002 rainy and 2002-03 postrainy seasons	GD 65003, Entry#64 DTN, GD 65080, ICSV 96143, ICSV 93046	13 to 20	26 to 46
2004 Rainy season	ICSR 93034, ICSR 91005, S 35, ICSV 574, ICSR 93026-2, ICSV 700	16.8 to 20.3	30 to 45

Further, five other varieties, ICSV 574 (SPV 422), SPV 1411, ICSV 93046, Seredo and NTJ 2, were sent to the NRCS, Hyderabad, India, for preliminary testing under AICSIP during the 2005 *kharif* season.

A set of 48 varieties/restorers selected based on high Brix reading and sweet-stalk yield from a set of 92 entries were evaluated during 2003 rainy season at ICRISAT-Patancheru, Andhra Pradesh. The sugar% in the entries ranged from 11.5 to 20.6 (trial mean 17.3) and sweet-stalk yield from 14.6 to 62.5 t ha^{-1} (Trial mean 36.2; SE ± 4.3). Two varieties (NTJ 2 and Seredo) and one restorer line (ICSR 93034) were on par with SSV 74 and SSV 84 for sugar% and sweet-stalk yield. They showed 10% superiority for sugar% and sweet-stalk yield over S 35. In another trial consisting of 28 sweet stalk B-lines, the sugar% in the B-lines ranged from 10.9 to 21.8 (trial mean 16.4) and fresh fodder yield ranged from 9.6 to 53.9 t ha^{-1} (trial mean 26.6) with sugar% being on par with sweet stalk check varieties, SSV 53, SSV 74 and SSV 84. Among these, ICSB 293 and SP 20656 B produced 46% higher grain yield than 296 B (widely used grain sorghum seed parent).

Hybrids. Research experience at ICRISAT and elsewhere, shows that hybrids are known to be relatively more tolerant and produce higher biomass, besides being early and photo- insensitive than the pure-line varieties. The requirement of photoperiod- and thermo-insensitiveness is essential to facilitate plantings at different dates to ensure a year-round supply of sweet sorghum stalks for ethanol production. Therefore, at ICRISAT hybrid parents' research is being given strategic importance for enhancing genetic potential of sweet sorghum. As mentioned in the previous section, several promising sweet-stalk hybrid parents have been identified at ICRISAT. To strengthen the hybrid parents' research and to delineate method(s) of developing sugar-rich high stalk yielding hybrids, 144 hybrids synthesized by crossing nine male sterile lines (five with low Brix and four with high Brix values) with 16 restorer lines (eight with low Brix and eight with high Brix values) were evaluated under protective irrigation at ICRISAT, Patancheru, India, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, and at the University of Agricultural Sciences (UAS), Dharwad, under the Indian Council of Agricultural Research (ICAR)-ICRISAT partnership project and as a part of the research work of a PhD scholar from the UAS, Dharwad, during the 2004 *kharif* season. Results indicated that the hybrids were 15 days earlier in maturity than their parents. Some of the hybrids produced higher milleable cane yield (t ha^{-1}), juice yield (kL ha^{-1}), sugar yield (t ha^{-1}) on juice yield basis than the check variety SSV 84 (Table 4). Further, it was found that the probability of producing high-yielding sugar-rich hybrids is significantly higher if both the hybrid parents or at least the male parent are sugar-rich. A Special/Sweet Sorghum Hybrid, CSH 23 (NSSH-104) developed by the NRCS from ICSA 38, an ICRISAT-bred male-sterile (seed) parent and SSV 84 (the sweet-stalk sorghum variety bred and released for general cultivation by the national program in India through extensive testing in AICSIP in 1992/93) is being recommended for release for commercial cultivation. Several new hybrids were developed during 2004 *kharif* season and promising hybrids were identified. A total of 15 promising hybrids (ICSA 56 × SPV 1411, ICSA 293 × SPV 1411, ICSA 474 × SPV 1411, ICSA 52 × SSV 84, ICSA 293 × SSV 84, ICSA 686 × SSV 84, ICSA 264 × SSV 74, ICSA 293 × SSV 74, ICSA 560 × NTJ 2, ICSA 675 × NTJ 2, ICSA 293 × ICSV 700, ICSA 474 × ICSV 700, ICSA 502 × ICSV 574, ICSA 561 × ICSV 574 and ICSA 502 × Seredo) were sent to NRCS, Hyderabad, India, for

Table 4. Performance of selected sweet-stalk hybrids at ICRISAT-Patancheru, India- 2004 *kharif* season.

Hybrid	Days to 50% flowering	Brixreading at maturity	Millable cane yield (t ha^{-1})	Juice yield (kl ha^{-1})	Sugar yield[1] (t ha^{-1})	Grain Yield (t ha^{-1})
ICSA 264 × ICSV 93046	70	16.0	43.6	18.5	2.6	6.5
ICSA 213 × S 35	72	17.0	48.6	17.6	2.6	5.3
ICSA 474 × ICSV 574	75	19.0	52.2	17.2	2.9	3.8
ICSA 474 × SSV 74	74	17.7	50.7	17.1	2.7	4.4
ICSA 657 × SSV 84	74	17.7	48.8	16.8	2.6	4.7
ICSA 474 × SSV 84	74	19.7	50.0	16.7	2.9	3.9
SSV 84 (control)	88	22.7	41.0	12.1	2.4	0.2
Mean	69	15.7	32.9	10.8	1.5	4.6
CV (%)	1.7	8.1	15.0	21.6	24.3	22.0
LSD (5%)	1.9	2.1	7.9	3.8	0.6	1.6

1. Sugar% based on formula (Brix at maturity × 0.8746) + 0.1516.
2. Sugar yield= (sugar%/100) × juice yield (kl ha^{-1}) (Source: Corleto et al. 1986).

preliminary evaluation under AICSIP during the 2005 *kharif* season.

Sweet sorghum research in Indian national programs

Sweet sorghum research in India is carried out at NRCS, Hyderabad, and at six AICSIP centers, Rahuri, Parbhani, Akola, Surat, Coimbatore and Dharwad. The NRCS has been engaged in sweet sorghum research since 1989. The sweet sorghum varieties and hybrids bred at NRCS, Hyderabad, have the ability to produce extremely high stalk yields of up to 50 t ha^{-1}, with juice Brix reading between 18% and 22% and 1.5 to 2.5 t ha^{-1} grain (Table 5).

Concerted research efforts at AICSIP centers have resulted in the identification of several promising sweet sorghum varieties such as SSV 96, GSSV 148, SR 350-3, SSV 74, HES 13, HES 4, SSV 119 and SSV 12611 for TSS% and juice yield (AICSIP 1991–92), GSSV 148 for cane sugar (AICSIP 1993–94), NSS 104 and HES 4 for green cane yield, juice yield, juice extraction and total sugar content (AICSIP 1999–2000), and RSSV 48 for better alcohol yield during 2001–02 (AICSIP 2001–2002). An evaluation of 12 sweet sorghum varieties bred at different AICSIP centers in Advanced Sweet Sorghum Varietal Trial at four locations in India-Parbhani, Akola, Rahuri, S-wadi and NRCS, Hyderabad, indicated the significant superiority of one hybrid, NSSH 104, and two varieties, RSSV 56 and PAC 52093 for millable cane yield and juice yield by 31% and 18%, 17% and 4% and 17% and 18%, respectively, over the check, SSV 84 (AICSIP 2004–2005). The Brix reading of the test hybrid, NSSH 104 (20%), was comparable to the check, SSV 84 (19.2%).

A National Agricultural Technology Project (NATP) on sweet sorghum for bio-energy (RNPS 24) ran from 2000–2005 at NRCS, Hyderabad. A strong network with AICSIP program is currently underway to identify high biomass and bio-energy sweet sorghums from multi-environment trials.

Opportunities for ICRISAT–public and private sector collaboration

Genetic enhancement

ICRISAT–public sector. Recognizing that NRCS, Hyderabad, is the leader in sweet sorghum research in India, ICRISAT desires active collaboration with the NRCS in the following areas of genetic enhancement of sweet sorghum:

- Study the relationship between stem sugar% and agronomic traits
- Study the inheritance of sugar% and related traits
- Identify/develop sorghum hybrid parents with high sugar% and traits related to high sugar% and their further improvement

Table 5. Promising sweet sorghum varieties identified for ethanol production in Indian national programs.

Sl. No.	Variety	Stalk yield (t ha^{-1})	Grain yield (t ha^{-1})	Juice extract-ability (%)	Brix (%)	TSS (%)	RSS (%)	Sucrose (%)
1	RSSV 59	48.4	2.2	50.1	17.7	15.1	1.5	13.6
2	RSSV 46	47.6	2.8	42.5	16.2	13.1	1.7	11.3
3	RSSV 24	45.7	1.5	46.7	16.1	13.1	1.4	11.2
4	RSSV 45	45.5	2.0	39.1	16.8	14.1	1.8	11.9
5	RSSV 57	44.3	2.5	45.7	16.6	13.7	1.3	12.0
6	RSSV 44	44.5	2.6	43.1	15.9	13.2	1.3	12.3
7	RSSV 58	42.4	2.2	46.1	17.2	13.3	1.4	11.9
8	NSS 219	40.5	2.1	42.3	16.6	14.1	2.0	12.0
9	NSS 216	39.2	2.7	41.3	16.2	13.8	1.9	11.7
10	NSS 218	38.6	2.2	39.4	16.9	13.0	2.2	10.6
11	NSS 209	38.1	1.8	46.3	16.9	13.6	1.5	11.6
12	NARISS 41	34.5	1.9	48.8	14.2	12.9	1.3	9.5
13	AKSS 01-03	28.7	2.9	44.8	14.9	11.6	1.9	9.6
14	NARISS 83	27.9	2.3	41.1	16.2	14.4	1.9	12.3
15	SSV 84 (C)	43.6	1.8	47.1	16.5	14.1	2.1	11.8

TSS: Total soluble solids; RSS: Reducing sugar
Source: Ratnavathi et al. 2003

- Develop and identify sorghum hybrids suitable for use in bio-ethanol and bio-energy production

ICRISAT–private sector. Identification of several promising hybrid parents (Table 3) within a short span of two years since ICRISAT renewed sweet sorghum research during 2002 stands testimony to ICRISAT's strength in sweet sorghum research. It is expected that private seed companies in India would complement the efforts of the national programs in the development and marketing of location-specific, high yielding, sweet-stalk hybrids (using hybrid parents developed at ICRISAT and the national programs) in a business approach through the well-established ICRISAT–Private Sector Sorghum Hybrid Parents Research Consortium.

Technology Collaborations

ICRISAT-Industry. Research on sweet sorghum for ethanol production involves two distinct but simultaneous phases: (1) genetic enhancement of sweet sorghum for quantity and quality of juice for ethanol production and (2) development of cost-effective economy-scale ethanol production technology. While the former requires crop improvement research expertise, the latter requires industrial expertise. Therefore, "ICRISAT's strategy is two-pronged." ICRISAT, besides developing sweet sorghum hybrid parents and varieties suitable for ethanol production, facilitates private sector involvement in ethanol production technology from sweet sorghum. Ever since the establishment of Agri-Business Incubator (ABI)-ICRISAT, there have been perspective proposals for sweet sorghum-based ethanol production from major industries. These industries could be classified into two types: (1) start-up and stand-alone industries and (2) sugarcane-based industries.

Start-up and stand-alone industries. These encompass proposals from start-up entrepreneurs and stand-alone units mainly based on sweet sorghum as raw material for ethanol production. These firms require ABI-ICRISAT and NARS program (NRCS and AICSIP) support for providing sweet sorghum cultivars suitable to their command areas and agricultural extension consultancy. Some of them even need backstopping in terms of project consultancy and business facilitation support. The ABI at ICRISAT signed a memorandum of agreement (MoA) with Rusni Distilleries Pvt. Ltd., a private sector industry based in Hyderabad, which obtained licence to establish 40 KLPD distillery at Sanga Reddy Mandal in Andhra Pradesh for supply chain management, seed development, supply and procurement of raw materials. ABI-ICRISAT offers technical back-stopping on suitable sweet sorghum cultivars and sweet sorghum production technology besides laboratory and land facilities. Several other private firms such as M/s XL Telecom, M/s Minerva Industries, M/s Matrix Power Pvt. Ltd., M/s Shriba Agro and M/s Morita Biotech Pvt. Ltd., all based at Hyderabad have shown interest in incubating ethanol production technology at ABI-ICRISAT.

Sugarcane-based industries. These encompass proposals from major sugar industries. Sugar industries are looking to complement their existing molasses-based ethanol production capacities with alternative raw material to fill-in the lean sugarcane crushing periods for year-round operation. They are interested in research and development support on sweet sorghum seed-based and production technologies from ABI-ICRISAT. An MoA was signed by ICRISAT and VSI, Pune, Maharashtra, for identification/development of improved sweet sorghum varieties and characterization of juice and ethanol quality and quantity. VSI has well-equipped alcohol production and quality testing laboratories and also has connections with the distilleries in the state of Maharashtra. Several other industries such as Bannari Amman Sugars India Ltd, EID Parry India Ltd and Thiruarooran Sugars India Ltd, have expressed interest in incubating ethanol production technology at ABI-ICRISAT.

Public sector industry. Shree Renuka Sugars Ltd, located at Manoli village in Belgaum district, Karnataka, India commissioned an ethanol plant recently in 2003 and initiated a pilot project with the need for finding new substrates for producing ethanol for the National Fuel Ethanol program in collaboration with the United States Agency for International Development (USAID) and NRCS, Hyderabad (Huligol et al. 2004). Three varieties – SSV 74 from the University of Agricultural Sciences, Dharwad; cv. Madhura from Nimbakar Agricultural Research Institute, Maharashtra; and cv. SSV 84 from NRCS, Hyderabad; were supplied to farmers for evaluation. These varieties gave an average sweet-stalk yield of 10–12 t $acre^{-1}$ and grain yield of 0.8–1.0 t $acre^{-1}$ under normal conditions in farmers' fields. For grain yield, Madhura and for stalk yield, SSV 84, were found better. The laboratory analysis indicated that sweet sorghum juice is very rich in total reducing sugars (TRS) and comparatively poor in sugar content and hence suitable for making alcohol. From a trial at the distillery, it was reported that 112 t of sorghum stalk (25 t ha^{-1}) has 23.47% juice with 8.5% TRS, Brix of 12 and pH 5. Alcohol yield was about 16.38 L t^{-1} of stalk. The study also indicated that sweet sorghum could be cultivated in the lean period of sugarcane (as crushing period of sugarcane varies from state to state), thus extending the crushing period before and after sugarcane crushing (Ratnavathi et al. 2003).

The NRCS is also interacting with industries like Praj Industries at Pune, Maharashtra, GMR sugar industries at Sankili, Andhra Pradesh, and Mohan breweries and distilleries at Chennai, Tamil Nadu and Sagar Sugars and Allied Products, Chittor district, Andhra Pradesh, India. These industries have expressed an interest in conducting large-scale trials and big mill tests on sweet sorghum as an alternative source of raw material for ethanol production to supplement sugarcane molasses. The NRCS intends continued collaboration with these industries in the coming seasons to popularize sweet sorghum for ethanol production.

Future outlook

The promising sweet-stalk sorghum varieties identified at ICRISAT and NARS (NRCS and AICSIP) programs need to be re-evaluated in a more systematic manner. Also, basic research aspects such as inheritance of sweet-stalk yield and juice quality-evident traits and inter-relationships among juice quality-evident traits and with ethanol quality and yield and strategic research aspects such as method(s) of developing shoot fly, stem borer and shoot bug resistant high yielding sweet sorghum varieties and hybrids and the effects of stalk-sugar content on stalk yield, juice quantity and quality and reaction to insect pests and diseases will be delineated in partnerships with NRCS and AICSIP programs. Formation of an ICRISAT-led consortia (similar to the existing and highly successful ICRISAT-Private sector Hybrid parents Research Consortia and NRCS-led NRCS-AICSIP-Alcohol industry collaborative project) comprising of NRCS, private seed companies, alcohol distilleries and sugar industries for comprehensive research and development of sweet sorghum hybrid parents and hybrids, integrated sweet sorghum production packages, and ethanol production technology would help enhance the demand for sorghum, which ultimately benefit the poor farmers of the semi-arid tropics. The existing collaboration with the private sector for developing cost-effective economy-scale ethanol production technology will be strengthened further. The partnership technologies developed, improved breeding products and ethanol production processes will be scaled-up and transferred to farmers and entrepreneurs by involving private seed companies and distilleries.

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Socioeconomics

Evaluation of Farmer-Grown Improved Sorghum Cultivars for Stover Quality Traits

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Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important staple food crop in semi-arid tropical tracts of India where mixed crop and livestock farming systems are mostly prevalent. Sorghum not only provides grains for human consumption, but also provides fodder for livestock. For farmers, both grain and stover (crop residue) are of equal importance and they consider harvested stover as almost equal in market value to harvested grain. However, the feeding/nutritive value of sorghum crop residue is generally poor and it provides sub-maintenance levels of nutrients. The limited adoption of improved sorghum varieties has been mainly attributed to the lower nutritional value of their crop residue (Kelley and Rao 1994). The farmers feel that the stover yield and stover quality of improved cultivars in terms of nutrition and digestibility is lower than that of the local cultivars. This study attempts to examine the validity of farmers' perceptions about stover yield and stover quality traits of improved cultivars *vis-à-vis* local cultivars. The study was conducted as one of the activities of the Department For International Development (DFID)-funded project on *Exploring marketing opportunities through a research, industry and users coalition: sorghum poultry feed* aimed at enhancing the access to and availability of rainy-season sorghum for poultry feed rations.

Materials and Methods

Selection of villages and farmers. The Mahabubnagar and Ranga Reddy districts of Andhra Pradesh, India, where rainy season sorghum cultivation is predominant were selected for farmer participatory evaluation of improved and local cultivars for stover yield and stover