Sweet sorghum as a biofuel crop: Where are we now?

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Introduction

Agriculture and energy have always been linked closely, but the strength of the relationship has significantly increased in recent years. Agriculture has always been a source of fuels for energy production such as feed for draught animals and, more recently juice for biofuels, e.g., bioethanol (blended with fossil fuels) or biodiesel.Energy supplied by fossil fuels is a major input into modern mechanized crop production. Economic, environmental and energy security concerns resulting from excessive reliance on fossil fuels like petroleum are forcing countries throughout the world over to shift to alternatives like biofuels. Since biofuels can be produced from a diverse set of crops, each country is adopting a strategy that exploits the comparative advantages it holds with respect to such crops. For example, sugarcane and maize are the main feedstock for ethanol in Brazil and US respectively, while rapeseed in Europe, and palm oil in Malaysia are the main feedstocks for biodiesel. The Government of India (GoI) has formulated a national policy on biofuels aiming to achieve a target of 20% blending of petrol and diesel by 2017. Besides reducing the dependence on imported fossil fuels, the policy aims to generate several other benefits like employment for the rural poor, regeneration of wastelands, reduction of emissions resulting from energy use that can lead to positive economic and environmental consequences. Similar, biofuel policies have also been formulated by several countries in Asia, Africa, Europe and the Americas (Parthasarathy and Bantilan 2007).

Sweet sorghum, *Jatropha*, *Pongamia* and sugar beet are among the underexploited crops for biofuel (ethanol and biodiesel) production. Large-scale commercial cultivation of these crops by industries for biofuel production may be economically viable but lack of knowledge and access to seed material besides marketability of the farm produce would potentially deprive the poor dryland farmers from benefitting from the these emerging opportunities. To find ways to em**power** the dryland poor to benefit from, rather than be marginalized by the **bio**energy revolution, ICRISAT has launched a global **BioPower** initiative. The BioPower strategy focuses on feedstock sources and approaches that do not compete with food production; rather produce food as well as fuel, and may even enhance food production by stimulating increased inputs and crop management intensity. As part of its BioPower initiative, ICRISAT has developed a sweet sorghum research and development strategy to be implemented over the next 15−20 years horizon on integrated genetic and natural resources management. The platform encompasses region-specific research activities on the management of natural resources besides developing cultivars through conventional breeding methods and modern molecular tools. The latter targets to improve sugar and grain productivity of sweet sorghums for specific semi-arid tropic regions that may usher sustainable development of drylands.

ICRISAT is currently conducting research on sweet sorghum for use in first generation ethanol technology in all the three major regions in the SAT─Asia, Eastern and Southern Africa (ESA) and Western and Central Africa (WCA)─on the following areas:

- Application of Integrated Genetic and Natural Resource Management (IGNRM) approach to integrate and upscale the research findings in sweet sorghum ethanol value chain including energy and economic issues,
- Assessment of major challenges in sweet sorghum value chain, and identification of key research issues and opportunities, and
- Commercialization of ethanol production technology through an Agri-Business Incubation with the aim of helping poor farmers.

Sweet sorghum as feedstock for first generation ethanol production

Sorghum [*Sorghum bicolor* (L) Moench] is considered to be one of the most important food and fodder crops in arid and semi-arid regions of the world. Globally, it occupies about 45 million hectares with Africa and India accounting for about 80% of the global acreage. Although sorghum is best known as a grain crop, sweet sorghum is similar to the grain sorghum, besides possessing sweet juice in the stalk tissues that is traditionally has been used as livestock fodder due to its ability to form excellent silage (Table 1); the stalk juice is fermented and distilled to produce ethanol. Therefore the juice, grain and bagasse (the fibrous residue that remains after juice extraction) can be used to produce food, fodder, ethanol and electricity. The ability of sweet sorghum to resist drought, saline and alkaline soils, and water logging has been proven by its wide prevalence in various regions of the world. The per day ethanol productivity of sweet sorghum is higher when compared to sugarcane besides a shorter growing period of four months and low water requirements of 8000 cubic meter (over two crops) that are about four times lower than that for sugarcane (12−16 month growing season and 36000 cubic meters of water) (Soltani and Almodares 1994). Its lower cost of cultivation and familiarity with cultivation of sorghum, the ability and willingness of farmers to adopt sweet sorghum is much easier. Sweet sorghum has some inherently pro-poor characteristics compared to other major feedstocks (sugarcane, maize) for ethanol production. Moreover, sweet sorghum-based distilleries require quality feedstock at a predetermined price and in high volumes on continuous basis while small-scale farmers need a fair price for their produce, and technical and credit assistance.

Table 1. Characteristics of sweet sorghum that makes it a viable source for ethanol production.

As crop	As ethanol source	As stillage/bagasse
• Shorter gestation period (3−4 months) • Dryland crop • Greater resilience • Farmer friendly • Meets fodder/food needs • Non-invasive/least invasive species • Low soil NO_2/CO_2 emission • Seed propagated	• Eco-friendly process • Superior quality • Less sulphur • High octane • Automobile friendly (up to 25% of ethanol petrol mixture)	• Higher biological value • Rich in micronutrients • Use as feed/for power cogeneration/ biocompost

(*Modified from Reddy et al., 2005 and 2008*).

Other positive aspects of sweet sorghum include its higher profitability (23% higher)) than the grain sorghum under rainfed conditions in India. Sweet sorghum juice is better suited for ethanol production because of its higher content of reducing sugars as compared to other sources including sugarcane juice. These important characteristics, along with its suitability for seed propagation, mechanized crop production, and comparable ethanol production capacity *vis a vis* sugarcane molasses and sugarcane juice makes sweet sorghum a viable alternative source for ethanol production (Table 2). Additionally, the pollution levels in sweet sorghum-based ethanol production has 25% of the biological oxygen dissolved (BOD), i.e., 19500 mg liter^{-1} and lower chemical oxygen dissolved (COD), i.e., 38640 mg liter^{-1} compared to molasses-based ethanol production [as per pilot study conducted by Vasantdada Sugar Institute (VSI), Pune, India].

Table 2. Sweet sorghum vis-à-vis sugarcane and sugarcane molasses.

Crop	Cost of cultivation (USD ha^{-1})	Crop duration (months)	Fertilizer requirement (N-P-K kg ha^{-1})	Water requirement (m^3)	Ethanol productivity (liters ha^{-1})	Av. stalk yield (t ha^{-1})	Per day productivity (kg ha^{-1})	Cost of ethanol production (USD lit^{-1})
Sweet sorghum	435 over two crops	4	80 - 50 - 40	8000 over two crops	4000 year^{-1} over two crops(a)	50	416.67	0.32(d)
Sugarcane	1079 crop^{-1}	12−16	250 to 400 - 125 -125	36000 crop^{-1}	6500 crop^{-1}(b)	75	205.47	
Sugarcane molasses	-	-	-	-	850 year^{-1}(c)	-	-	0.37(e)

(a) 50 t ha^{-1} millable stalk per crop @ 40 l t^{-1} (b) 85−90 t ha^{-1} millable cane per crop @ 75 l t^{-1} (c) 3.4 t ha^{-1} @ 250 l t^{-1}
(d) Sweet sorghum stalk @ US$ 12.2 t^{-1} (e) Sugarcane molasses @ US$ 39 t^{-1} Source(d,e): Dayakar Rao et al. 2004.

Multiple uses of sweet sorghum crop

As indicated above, in addition to sweet stalks, average grain yield of 2−2.5 t h^{-1} can be obtained from sweet sorghum for use as food or feed. The bagasse (stalks after crushing) remaining afterthe extraction of juice has higher biological value than the bagasse from sugarcane when used as cattle feed, as it is rich in micronutrients and minerals which is also as good as stover in terms of its digestibility. Animal feeding experiments using the sweet sorghum bagasse and stripped leaves-based feed block (BRSLB) by International Livestock Research Institute (ILRI) and ICRISAT showed that no significant differences between BRSLB and commercial sorghum stover-based feed block (CFB) for neutral detergent fiber % (NDF), daily intake (kg d^{-1}) and weight gain per day in animals (Table 3). However for significant differences were observed between BRSLB and CFB for nitrogen content, *in vitro* digestibility and metabolizable energy (ME) contents. As expected, the laboratory quality indices were lowest in the sorghum stover. An important aspect of the present work was to investigate the palatability of feed blocks when sorghum stover was entirely replaced by BRSLB. There was no (statistical) difference in feed intake between the CFB and the BRSLB.

Table 3. Changes in live weight of catle bulls when fed with different types of diets.

Diets	Nitrogen (%)	NDF (%)	*In vitro* diges-tibility (%)	Metabolizable energy (MJ kg^{-1})	Intake (kg d^{-1})	Intake (g/d/kg LW)	Weight changes (kg d^{-1})
CFB	1.81^{a}	56.1^{a}	57.5^{a}	8.21^{a}	7.31^{a}	35^{a}	0.82^{a}
BRSLB	1.65^{b}	56.2^{a}	54.6^{b}	7.77^{b}	7.52^{a}	37^{a}	0.73^{a}
Sorghum stover	0.45^{c}	70.2^{b}	50.5^{b}	7.30^{b}	2.31^{b}	13^{b}	-0.38^{b}

Different superscripts in columns denote significant differences ($P < 0.05$).

NDF = neutral detergent fiber; CFB = commercial sorghum stover-based feed block; BRSLB = experimental sweet sorghum bagasse/stripped leaves-based feed block (Blummel et al. 2009, accepted in Animal Feed Science and Technology).

In summary, sweet sorghum is more accessible to poor farmers because of its low cost of cultivation and its ability to grow in areas that receive a minimum of 700 mm annual rainfall. Secondly, sweet sorghum has a high net energy balance, 3.63 compared to grain sorghum (1.50) and corn (1.53) (Wortmann et al. 2008). Even though the ethanol yield per unit weight of feedstock is lower for sweet sorghum compared to sugarcane, the much lower production costs and water requirement for this crop more than compensates for the difference, and hence, it still returns a competitive cost advantage in the production of ethanol in India (Rao et al. 2004). It produces three valuable products: food, fuel and feed, raising smallholder incomes by about 23% in central India (Rajasekhar 2007), while probably reducing net greenhouse gas emissions compared to fossil fuels.

Sweet sorghum research at ICRISAT

Considerable progress has been made in breeding for improved sweet sorghum lines with higher millable cane and juice yields in India. ICRISAT has developed several improved hybrid parental lines of sweet sorghum with high stalk sugar content that are currently being tested in pilot studies for sweet sorghum-based ethanol production in India, the Philippines, Mali and Mozambique. A few of these cultivars like SSV 84, SSV 74 and CSH 22SS have already been released in India. Trial data over three years (2005, 2006 and 2007) and six seasons (rainy and postrainy) indicated that there is no reduction in grain yield while improving the sugar yield (Table 4). Sugar yield and allied traits have greater genotype × environment interaction, therefore, it is prudent to breed for season-specific hybrids (Table 5).

Table: 4 Tradeoff between sugar yield (t ha^{-1}) and grain yield (t ha^{-1}) in varieties and hybrids, Patancheru during 2005−07.

Season	Variety/ hybrid	Sugar yield (t ha^{-1})			Grain yield (t ha^{-1})		
		Sweet stalks (SS)	Non-sweet stalks	% gain of SS	Sweet stalks (SS)	Non-sweet stalks	% gain/ loss in SS
Rainy season	Varieties	6.0 (6)[1]	3.9 (11)	54	3.0 (6)	3.3 (11)	-9
	Hybrids	6.2 (5)	5.6 (4)	11	6.2 (5)	5.9 (4)	5
Postrainy season	Varieties	1.7 (11)	0.9 (6)	89	4.6 (11)	4.7 (6)	-2
	Hybrids	1.5 (6)	1.0 (3)	50	6.4 (6)	8.5 (3)	-25

[1] The numbers in parenthesis refer to the sample size.

Table 5. Performance of sweet sorghum hybrids in rainy (R) and post-rainy seasons (PR) for sugar yield (t ha-1) and grain yield (t ha-1), Patancheru during 2005-07.

Hybrid	Total soluble solids (%)		Sugar yield (t ha^{-1})				Grain yield (t ha^{-1})			
	R	PR	R	Rank	PR	Rank	R	Rank	PR	Rank
ICSA 675 × SPV 422	17.3	12.9	6.7	1	1.3	6	4.7	9	7.0	7
ICSA 702 × SSV 74	16.6	12.3	6.2	2	1.4	5	6.0	5	6.4	9
ICSA 749 × SSV 74	15.2	11.6	5.6	9	1.6	1	6.3	4	6.9	8
ICSA 474 × ICSR 93034	15.5	12.8	5.9	5	1.6	2	7.3	1	5.5	10
CSH 22SS (check)	18.3	11.6	5.8	6	1.3	7	3.1	10	9.0	2

The performance of some of the varieties in Mozambique is given in Table 6. Since the range of stalk yield seems narrow (14 to 41 t ha^{-1}), fine-tuning the production technology suited the location and farmers participatory breeding will give desired results.

Table 6. Performance of sweet sorghum genotypes in a multi-location trial in Mozambique.

Genotype	Plant height (m)	Days to 50% flowering	Stalk yield (t ha^{-1})	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
IS 2331	3.29	72	41	1.65	2.57
ICSV 93046	2.93	84	37	1.48	1.54
IESV 92001 DL	2.54	75	33	1.25	2.62
SPV 422	2.42	71	30	1.22	2.26
IESV 92008 DL	2.43	75	31	1.16	2.80
IESV 92028 DL	2.38	69	34	1.07	2.98
ICSV 700	2.93	82	29	1.06	0.75
IESV 92021 DL	2.27	71	31	1.05	3.51
IESV 92165 DL	2.52	66	30	0.95	2.97
Local check	2.31	64	23	0.82	1.94
NTJ 2	2.38	72	22	0.73	2.54
Grand mean	2.34	71	27	0.85	2.39
SE	24	5	5		1.13
LSD	46	10	10		2.14

SE: Standard error, LSD: Least significant difference of means

The performance of ICRISAT-bred sweet sorghum material has been more than satisfactory in the Philippines. As the ratooned crop coincides with a large number of rainy days, the stripped stalk yields are impressive but the total soluble solids are relatively low.

Table 7. Performance of sweet sorghum genotypes in the Philippines (plant crop).

Cultivar	Plant height (m)	Unstripped stalk (t ha^{-1})	Stripped stalk (t ha^{-1})	Juice weight (t ha^{-1})	Juice volume (kl ha^{-1})	Stillage weight (t ha^{-1})	°Brix (%)
NTJ 2	2.43	54.4	41.4	25.0	23.6	16.4	13.8
SPV 422	2.51	64.4	44.9	27.8	26.3	17.1	14.8
ICSV 93046	2.45	47.6	33.6	19.9	18.4	13.7	11.5
ICSV 700	3.03	58.8	39.7	22.4	19.4	17.3	15.0
IS 2331	2.93	58.0	40.6	24.4	23.1	16.2	14.6
ICSR 93034	2.46	50.8	35.1	20.3	19.2	14.8	13.1

Table 8. Performance of sweet sorghum genotypes in the Philippines (ratooned crop).

Cultivar	Plant height (m)	Unstripped stalk (t ha^{-1})	Stripped stalk (t ha^{-1})	Juice weight (t ha^{-1})	Juice volume (kl ha^{-1})	Stillage weight (tha^{-1})	°Brix (%)
NTJ 2	2.84	67.5	51.0	32.9	30.6	18.1	13.7
SPV 422	3.14	84.8	66.8	35.0	33.0	31.8	14.0
ICSV 93046	3.20	72.0	54.8	30.9	28.2	23.9	13.7
ICSV 700	3.35	56.3	43.5	22.6	21.9	20.9	13.9
IS 2331	3.81	102.0	79.5	39.1	37.1	40.4	12.2
ICSR 93034	3.19	71.3	50.3	25.7	23.7	24.6	13.9

The experimental data on the relationship between stalk sugar traits and grain yield (Table 9) shows that the regression coefficient of stalk sugar yield on grain yield is not significant, thereby indicating that the grain yield is not affected when we select for stalk sugar yield and therefore the selection programs can aim to improve both the traits simultaneously.

Table 9: β and R^2 of traits on stalk sugar yield.

Trait	Season	Hybrids		Varieties/R-lines		B-lines	
		β	R^2	β	R^2	β	R^2
Days to 50% flowering	Rainy	-0.02	0.01	0.14	0.49	0.02	0.09
	Postrainy	0.03	0.12	0.11	0.51	-0.03	0.19
Grain yield (t ha^{-1})	Rainy	0.26	0.27	-0.07	0.01	-0.13	0.19
	Postrainy	-0.21	0.23	-0.09	0.05	0.08	0.32
Juice yield (t ha^{-1})	Rainy	0.17	0.87	0.19	0.84	0.18	0.84
	Postrainy	0.17	0.85	0.12	0.65	0.09	0.93
Brix %	Rainy	0.22	0.07	0.29	0.23	0.10	0.60
	Postrainy	0.08	0.35	0.18	0.57	0.09	0.65

(β- Coefficient of regression, R^{2-} Coefficient of regression)

Research experience at ICRISAT and elsewhere has showed that hybrids produce relatively higher biomass, besides being earlier and more photo-insensitive when compared to the varieties under normal as well as abiotic stresses including water-limited environments. The requirement of photo- and thermo-insensitiveness is essential to facilitate plantings at different dates for continuous supply of stalks to distilleries for ethanol production. Therefore, the development of sweet sorghum hybrids is receiving high priority to produce more feedstock and grain yield per drop of water and unit of energy invested. Data for ethanol related traits for the selected sweet sorghum hybrids in 2008 are given Table 10.

Table 10. Performance of selected sweet sorghum hybrids in rainy season 2008 at ICRISAT, Patancheru, Andhra Pradesh, India.

Hybrid	**Days to 50% flower**	**Brix (%)**	**Cane yield (t ha^{-1})**	**Juice yield (kl ha^{-1})**	**Sugar yield (t ha^{-1})**	**Grain yield (t ha^{-1})**	**Per day ethanol productivity (l ha^{-1})^{1}**
ICSA 702 x SSV 74	76	14.7	92.0	46.7	6.89	3.71	32.66
ICSA 502 x SSV 74	78	14.7	111.3	45.4	6.69	3.62	31.20
ICSA 749 x SSV 74	76	14.3	95.0	45.0	6.47	3.90	30.73
SSV 84 (Check)	82	16.0	72.9	35.8	5.76	3.36	25.96
CSH 22SS (Check)	82	14.0	64.7	24.8	3.56	3.44	15.69

1. Ethanol productivity estimated at 40 liters ton^{-1} of millable cane yield.

Second generation lingo-cellulosic ethanol production through high biomass and brown midrib (*bmr*) sorghums

a) High biomass sorghums

With the development of biocatalysts including genetically engineered enzymes, yeasts and bacteria, it is possible to produce ethanol from ligno-cellulose biomass including cereal crop residues (stovers). The conversion of lignin and cellulose-rich biomass into ethanol using specific enzymes and/or microbial organisms is collectively referred to as second generation technologies. Currently, a few countries with higher ethanol and fuel prices are producing ethanol from ligno-cellulose feedstocks in pilot plants. The present day sweet sorghum hybrids/varieties on an average yield about 3−5 tons of grain and 50−80 tons of biomass per hectare under proper management conditions. The other biomass crops like bana grass and miscanthus also yield above 50 t ha^{-1}, while a highly invasive species like water hyacinth gives much higher yields (Fig. 1). Sorghum possesses great genetic diversity for high biomass production, and has a high tolerance to abiotic stresses such as drought and heat and is non-invasive. Also sorghum root mass contributes to the build-up of soil organic C after removal of the aerial parts of the plant, and would thus alleviate concerns about depletion of soil organic matter resulting from the removal of stover. Therefore, sorghum stover has an excellent potential as feedstock for ligno-cellulosic ethanol production. Technical and economic analyses have shown that the ethanol production from lignocelluloses results in a net gain of energy, and when compared to gasoline and ethanol derived from starch/sugar, ethanol produced from lignocellulosic biomass is projected to have the smallest contribution to the emission of CO_2 and the largest net energy production (Farrell et al. 2006). Nevertheless, the production of ethanol from lingo-cellulosic biomass will need to be considerably more cost-effective than is possible with the current technologies for the fuel ethanol to be economically competitive (Vermerris et al. 2007). Improvements to make this process economically viable are necessary, including efficient and cost effective pretreatment strategies (Ragauskas et al. 2006). Pretreatment is a process during which the stover is subjected to chemical and/or physical agents with the aim of improving the rate and the extent of cellulose hydrolysis, which is not cost-effective currently.

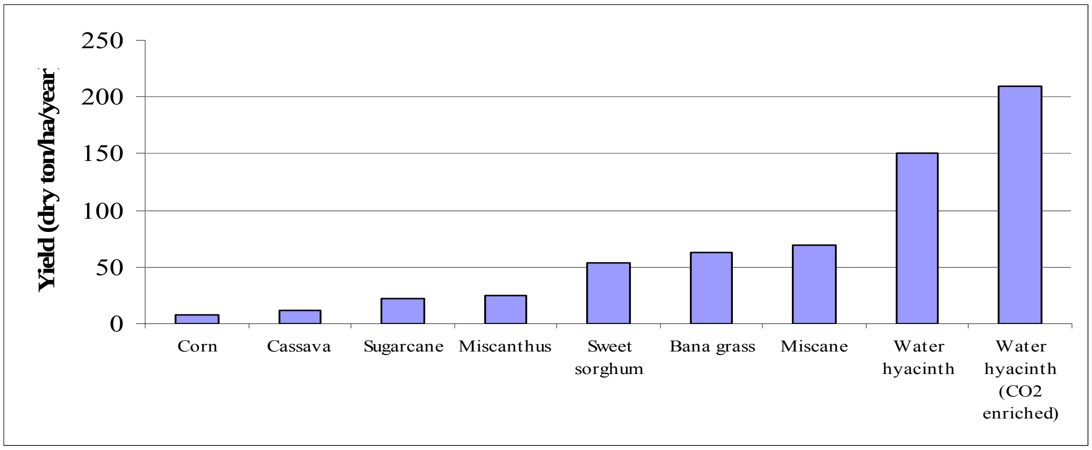

Figure 1. Dry matter production potential of various biomass crops.
(Adopted and modified from Texas A&M University, College Station, USA).

By using different pretreatment techniques followed by fermentation, the expected total ethanol yield is about 19400 l ha^{-1}, which is substantially higher than that of switch grass and *Miscanthus* spp (Table 11).

Table 11. Potential ethanol yield from cellulosic biomass of biofuel crops.

Feedstock	**Biomass yield (t ha^{-1})**	**Ethanol yield (l t^{-1})**	**Grain yield (t ha^{-1})**	**Total ethanol yield (l ha^{-1})**
switch grass	38	450	-	17100
Miscanthus spp.	25	666	-	16650
Sweet sorghum	35	500	5	19400
bmr sorghum	25	600	2	15760

b) *Brown midrib* sorghums

Vascular plants posses a primary cell wall made up of cellulose and hemicellulose with cross linking glucuronoarabinoxylans and a secondary cell wall rich in cellulose (15−30%), hemicellulose (20−40%) and lignin (10−25%). Spontaneous mutations in any one gene of the lignin biosynthetic pathway are associated with a prominent brown color of leaf midrib that has reduced lignin content. Reduced lignin content or altered lignin composition will greatly improve ethanol yield as cellulases used in second generation technologies would convert them to sugar. This will also enhance sorghum forage quality by increasing digestibility when fed to ruminants. *Brown midrib* (*bmr*) mutants of sorghum were first developed at Purdue University via chemical mutagenesis (Porter et al. 1978). Since then, additional spontaneous *bmr* mutants have been identified (Vogler et al. 1994). Both groups of *bmr* mutants, numbered consecutively 1 through 28 show altered cell wall composition, particularly relative to lignin subunit composition, and some have superior forage quality. Current research is focused on introgressing the *bmr* trait in to elite genotypes by repeated cycles of backcrossing and selfing with agronomically promissing *bmr* mutants for enhancement of extraction of cellulosic ethanol besides improving forage quality.

Introgression of *brown midrib* trait using *bmr*-1, -3, -7 and -12 mutants into elite hybrid parents (both B- and R-lines) is in progress at ICRISAT since 2004 (Table 12). Preliminary results indicate that there is considerable reduction in lignin content of hybrid parents *vis a vis* non-*bmr white midrib* lines. The *bmr* parental lines (B/R) will be used to develop elite hybrids (high grain and biomass), which are amenable for lingo-cellulosic ethanol extraction at lower costs.

Table 12. *Brown midrib* sources and improved parental lines.

Source /lines	
bmr mutant sources	IS 21887 (*bmr*-1), IS 21888 (*bmr*-3), IS 21889 (*bmr*-6), IS 21890 (*bmr*-7) and IS 21891 (*bmr*-8), IS 40602 (*bmr*-12)
Number of high biomass *bmr* B-lines	*Bmr*-1: (2), *bmr*-3: (3), *bmr*-7: (6)
Number of high biomass *bmr* R-lines	*Bmr*-1: (10), *bmr*-3: (3), *bmr*-7: (9)

Number of lines developed is shown in parenthesis. (Reddy et al. 2007).

“Atlas *bmr*-12” forage sorghum, developed jointly by the USDA, ARS and the Agricultural Research Division, Institute of Agriculture and Natural Resources, University of Nebraska, was released in January 2005 for cultivation in USA. Though reduced lignin content in the cell walls favors easy fermentation and digestibility, there is a greater possibility of enhanced susceptibility to biotic stresses besides lodging (Pederson et al. 2006). Interestingly, genotypes with *bmr-6* and *bmr-12* have shown increased resistance to *Fusarium* and *Alternaria* spp. (Funnell and Pedersen 2006). This is probably due to accumulation of phenyl proponoids. It is essential to incorporate lignin-reducing genes into numerous genetic backgrounds and combinations to obtain valuable genotypes in the context of economic viability and sustainability of the farming system.

Public-private partnerships

Agri-Business Incubator (ABI) is a pioneering initiative of ICRISAT to foster the commercialization of agricultural technologies through entrepreneurship initiatives. ABI supports perspective entrepreneurs to commercialize agro-technology through business facilitation support. ABI facilitated the establishment of Rusni Distilleries Pvt. Ltd. in the Medak district of Andhra Pradesh for the production of sweet sorghum-based ethanol. This distillery has a capacity of 40 KLPD and capable of using multi-feed stocks for the production of ethanol. It produces fuel ethanol (99.4% alcohol), Extra Neutral Alcohol (ENA) (96%) and pharma alcohol (99.8%) from agro-based raw materials such as sweet sorghum stalks (juice) and molded grains, cassava and rotten frutis. Buoyed with the success more and more farmers are coming forward to take up the cultivation of sweet sorghum crop. This initiative has given us first insights into various aspects related to the commercialization of sweet sorghum-based ethanol technology including the forward and backward integration of farming communities in the value chain.

The ICRISAT-Private Sector Sweet Sorghum-Ethanol Research Consortium (SSERC) has been established to meet the current and future demands of the sweet sorghum-based ethanol distillery that is being facilitated by ABI. This involves collaborative research activities to develop the package of practices and feasibility studies for the commercialization of sweet sorghum-related technologies. These distilleries will not only help widen the marketing opportunities for sweet sorghum farmers to get a higher income, but also help in generating more employment. As of now, four national and international companies are active members of SSERC.

Major challenges in sweet sorghum ethanol value chain

Sweet sorghum ethanol production technology has been steadily gaining momentum in India and elsewhere. However, there is a need to address some core issues to make sweet sorghum a popular choice for biofuel production by entrepreneurs and farmers. Seasonality of the crop, limited harvest window, high labor requirement, quick reduction in stalk sugar content with delay in crushing and supply chain management are some of the major challenges in sweet sorghum to ethanol technology and value chain. Planting the crop in wider geographical areas, staggered sowing, choosing cultivars with different maturity durations, decentralized crushing of stalks, and irrigating the standing crop after harvesting panicles help extending the period of raw material availability to industry. ICRISAT and its partners are working on the development of high sugar and grain yielding sweet sorghum hybrids that are stable across planting dates, mechanization of sowing and weeding operations and overall supply chain management in sweet sorghum. ICRISAT with the help of NAIP-ICAR established the first decentralized crushing-cum-syrup making unit (DCU) at Ibrahimbad village in Medak district of Andhra Pradesh, India, to enable the farmers located away from the industry to participate and gain from sweet sorghum ethanol technology by reducing the volume of raw material for transportation, prevent the losses with delay in crushing and extend the period of raw material availability to industry in the form of syrup. In the 2008 rainy season, a total of 557 tons of green stalks were crushed and to produced 22.5 tons syrup (approx. 80% Brix). The syrup was transported to Rusni Distilleries for ethanol production.

Impact assessment

Impacts of this technology are several-folds. Cultivation of a smart crop like sweet sorghum offers multiple dividends in terms of food, feed, fuel and electricity on environmentally sustainable basis. This could be viable and sustainable alternative fuel source particularly for the developing countries as the year 2008 has witnessed huge fluctuations in international crude oil prices (US $147 in July 2008 to US $33 in December 2008). Resource poor SAT farmer can get additional income from sweet sorghum cultivation (23% or more) when there is a tie up with the industry. If the distillery is distant from the area of sweet sorghum cultivation, decentralized syrup making units would be a better choice, but the details are to be worked out to make viable business models. The results and experience gained so far should pave the way to move forward particularly in breeding photosynthetically efficient, non-photosensitive sweet sorghum hybrids with some degree of tolerance to both biotic and abiotic stresses without compromising the grain yield.

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