

Sweet Sorghum

Food, Feed, Fodder and Fuel Crop



International Crops Research Institute for the Semi-Arid Tropics





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Energy needs and feed stocks

Soaring prices of fossil-fuels and environmental pollution associated with their use, has resulted in increased worldwide interest in the production and use of bio-fuels. Both developed and developing countries have made mix of policies which have triggered public and private investments in bio-fuel crop research and development and bio-fuels production.

- Many developing countries including India, have made it mandatory to blend petrol with ethanol. A large volume of ethanol is needed to meet current and future blending requirements.
- In India, 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 demand in the long run.
- Molasses-based ethanol distilleries operate only for 180 days a year (during the sugarcane crushing season) ie, at 50% efficiency due to lack of supply of feed stock.

Sweet sorghum

Sweet sorghum (*Sorghum bicolor* (L.) Moench) which is similar to grain sorghum with sugar-rich stalks and a water-use efficient crop, has a very good potential as an alternative feed stock for ethanol production.





Sweet sorghum variety NTJ 2 in farmers' fields.



Potential uses: Juice from stalks is used primarily for fuel alcohol production. Juice can also be used for the production of jaggery and syrup. Stillage, the leftover stalks after juice extraction, can be used for cogeneration of power and/or animal feed and/or organic manure.

Comparative advantages of sweet sorghum

- Growing period (about 4 months) and water requirement (8000 m³ over two crops) are 4 times lower than those of sugarcane (12 to 16 months and 36000 m³ crop⁻¹ respectively) (Table 1)
- Cost of cultivation of sweet sorghum is 3 times lower than sugarcane
- Seed propagated
- Suitable for mechanized crop production
- The ethanol production process from sweet sorghum is eco-friendly compared to that from molasses

Ethanol burning quality is superior - less sulphur than from sugarcane and high octane rating (Table 2).

How does the farmer benefit?

Greater income from sweet sorghum cultivation: From sale of stalks to distilleries and sale of grain, stillage and threshed panicles for food and feed (Table 3).





Stalks from sweet sorghum.



Grain from sweet sorghum.



Jaggery made from sweet sorghum juice.



Stillage – a by-product after extraction of juice.



Table 1. Sweet sorghum scores over sugarcane and maize

Parameter	Sweet sorghum ²	Sugarcane ²	Maize ³
Crop duration	4 months	12 months	4 months
Water requirement	4000 m ³	36000 m ³	8000 m ³
Grain yield (t ha ⁻¹)	2.0	-	3.5
Ethanol from grain (l ha ⁻¹)	760	-	1400
Green stalk cane yield (t ha ⁻¹)	35	75	45
Ethanol from stalk cane juice (l ha ⁻¹)	1400	5600	0
Stillage/ stover (t ha ⁻¹)	4	13.3	8
Ethanol from residue (l ha ⁻¹)	1000	3325	1816
Total ethanol (l ha ⁻¹)	3160	8925	3216
Corn oil (l ha ⁻¹) ⁴	-	-	140
Income from corn oil (US\$ ha ⁻¹)	-	-	61
Cost of cultivation (US\$ ha ⁻¹)	220	995	272
Cost of cultivation (ha ⁻¹) after corn oil profit (US\$)	220	-	211
Cost of cultivation with irrigation water cost (US\$) ⁵	238	995	287
Ethanol cost per kilo liter (US\$) ⁶	69.6	111.5	65.6
Ethanol cost per kilo liter (US\$) ⁷	75.3	111.5	89.2

1. Processing costs assumed equal and excluded from the estimates; does not take into account water needs and crop duration

2. Sorghum grain ethanol: 380 l t⁻¹; sorghum stalk juice ethanol: 40 l t⁻¹; sorghum or sugarcane stillage ethanol: 250 l t⁻¹ [Ref. Badger (2002) Trends in New Crops and New Uses];

3. Corn (grain) ethanol: 400 l t⁻¹; maize stover ethanol: 227 l t⁻¹ [Ref. Badger (2002) Trends in New Crops and New Uses];

4. Oil produced from corn: 40 l t⁻¹; oil cost of production: Rs 15 l⁻¹; oil sale price: Rs 35 l⁻¹;

5. Sorghum needs two irrigations and maize four each @ the cost US\$19 ha⁻¹ per irrigation in rainy season

6. Without accounting for water cost; 7. After accounting for water cost



Promising sweet sorghum varieties



ICSV 700 (Brix value: 18).

S 35 (Brix value: 18).



NTJ 2 (Brix value: 18.5).



Table 2: Other advantages of sweet sorghum		
As a crop	As process and product (ethanol)	As by-product (stillage)
<ul style="list-style-type: none"> • Shorter gestation period 	<ul style="list-style-type: none"> • Eco-friendly process 	<ul style="list-style-type: none"> • Higher biological value
<ul style="list-style-type: none"> • Dryland crop 	<ul style="list-style-type: none"> • Superior quality 	<ul style="list-style-type: none"> • Rich in micronutrients
<ul style="list-style-type: none"> • Greater resilience to abiotic stresses 	<ul style="list-style-type: none"> • Less sulphur 	<ul style="list-style-type: none"> • Use as feed/ for power cogeneration
<ul style="list-style-type: none"> • Farmer friendly 	<ul style="list-style-type: none"> • High octane 	
<ul style="list-style-type: none"> • Meets fodder/ food needs 	<ul style="list-style-type: none"> • Automobile friendly (up to 25%) 	

Table 3: Earnings from grain sorghum vs. sweet sorghum				
	Sweet sorghum		Grain sorghum	
	Rainy	Postrainy	Rainy	Postrainy
Grain yield (t ha ⁻¹)	1.0	2.0	3.0	2.0
Stalk yield (t ha ⁻¹)	40	25	10	7
Grain value (US\$ annum ⁻¹) ³	326		543	
Stalk value (US\$ annum ⁻¹)	707 ¹		370 ²	
Total value (US\$ annum ⁻¹)	1033		913	
Leaf stripping (US\$ annum ⁻¹)	40		-	
Net value (US\$ annum ⁻¹)	993		913	

Data based on two crops per annum; on-station performance.
1. Sweet stalk @ US\$ 10.87 t⁻¹; 2 Stover @ US\$ 22 t⁻¹; 3Grain @US\$108.7 t⁻¹





Crop of sweet sorghum.



Stillage after extracting juice.

Potable alcohol from grain.



Sweet sorghum research at ICRISAT

ICRISAT's two-pronged strategy

- Developing improved hybrid parents and varieties
- Facilitating incubation of sweet sorghum-based ethanol production technology by perspective entrepreneurs.

Progress in research

- Research on the development of sweet sorghum cultivars was initiated in 1980 with the evaluation of 70 germplasm accessions
- Two landrace lines, IS 6872 and IS 6896 with high stalk sugar content and biomass, were selected in 1981
- Later, several sweet sorghum lines were identified among Nigerian and Zimbabwean lines, and among advanced breeding progenies
- Sweet sorghum research discontinued in early 1990s due to changed focus driven by donors' perceptions and needs of national agricultural research systems (NARS).
- Research was renewed in 2002 to meet the increased demand for ethanol, driven by government policies to blend ethanol with petrol
- The wide variability in germplasm and hybrid parents for the traits related to ethanol production, such as sugar content and high stalk yield, offers bright scope for the development of high stalk yielding sugar-rich varieties and hybrids.
- Promising varieties/restorer lines viz., NTJ 2, SPV 422, Seredo, ICSR 93034, S 35, ICSV 700, ICSV 93046, ICSV 25263, SP 4487-3, SP 4484-1, SP 4484-3, SP 4482-1, SP 4482-2 and SP 4481-1 have been identified.





Sweet sorghum grows well in waterlogging conditions in the Philippines.



ICSR 93034 – Sweet sorghum R-line in the Philippines.

Sweet sorghum variety NTJ2 – in the Philippines.



SPV 422- a promising sweet sorghum variety in the Philippines.



Hybrids

- Photoperiod and thermo-insensitiveness is essential to facilitate plantings at different dates. This will ensure year-round supply of sweet sorghum stalks for ethanol production.
- Hybrids are relatively more photoperiod- and thermo-insensitive besides being earlier than pure-line varieties.
- Research on hybrid parents is given a high priority at ICRISAT
- Promising hybrid seed parents are: ICSB 264, ICSB 293, ICSB 321, ICSB 401, ICSB 405, ICSB 472, ICSB 474, ICSB 722 and ICSB 729.
- A sweet sorghum hybrid, CSH 23 (NSSH 104), developed by the National Research Center for Sorghum (NRCS), Hyderabad, India using ICSA 38, an ICRISAT-bred male-sterile line and SSV 84 (sweet sorghum variety bred and released by the Indian national program in 1992/93) was released for commercial cultivation during 2005.
- The performance of selected sweet sorghum hybrids bred at ICRISAT is given in Table 4.

Second-generation ethanol from sorghum

- Ethanol can also be produced from lingo-cellulose biomass feed stocks such as cereal crop residues (stover)
- Cereal stover, including that of sorghum, contains lignin, cellulose and hemicellulose
- Sorghum stover with brown midrib (which contains significantly lower lignin content by up to 50%) takes less energy for conversion into ethanol
- ICRISAT is developing high biomass brown midrib sorghums.





Sweet sorghum hybrids.



ICSB 474 – sweet sorghum hybrid seed parent.

ICSR 93034 – sweet sorghum R-line.



Brown-midrib sorghum source line.



Improved brown-midrib sorghum line.



Table 4. Performance of selected sweet sorghum hybrids during 2006 rainy season at ICRISAT, Patancheru, India

Hybrid	Days to 50% flowering	Brix	Cane yield (t ha ⁻¹)	Juice yield (kl ha ⁻¹)	Sugar (t ha ⁻¹)	Grain yield (t ha ⁻¹)	Per day ethanol productivity (l ha ⁻¹)*
ICSA 749 × SSV 74	85	18.00	57.8	27.2	9.2	3.3	18.5
ICSA 502 × SPV 422	88	20.32	45.1	19.9	8.1	6.2	14.1
ICSA 511 × SSV 74	88	17.97	49.1	22.7	7.8	5.8	15.4
ICSA 474 × SSV 74	82	16.33	52.4	25.4	7.6	7.2	17.1
SSV 84 (control)	94	15.65	35.2	16.8	5.0	2.7	10.5
NSSH 104 (control)	91	15.65	35.2	16.8	5.0	4.1	10.7

*Ethanol productivity estimated at 40 liters per ton of millable cane yield

Technology sharing

- Both seed-based (improved cultivars) and crop production technologies shared with NARS.
- Seed samples of sweet sorghum cultivars/breeding lines were supplied to Philippines (49), Thailand (24), Turkey (22), Egypt (16), Japan (16), Colombia (16), Uruguay (12) and Azherbaijan (6).





Ambassador of the Philippines in India viewing sweet sorghum at ICRISAT – Patancheru.



JIRCAS president from Japan at one of the sweet sorghum fields at ICRISAT, Patancheru.



Hon'ble minister of Agriculture, Govt. of Andhra Pradesh, India, Raghuvendra Reddy examines sweet sorghum plants and the crushing operations.



Dr Dar shows Melody Aguiba, Senior Reporter, Manila Bulletin, a sorghum field.

Belum Reddy shows ICRISAT's sweet sorghum varieties to the visitors.



Hon Yujuico, special envoy from Philippines and Belum Reddy deep in discussion on sweet sorghum.



Agri-Business Incubator (ABI)

The Agri-Business Incubator (ABI) at ICRISAT is a technology commercialization wing of ICRISAT. ABI-ICRISAT supports prospective entrepreneurs to commercialize agro-technology through business facilitation support.

ABI Support to M/s Rusni Distilleries Pvt Ltd

The ABI incubated Rusni Distilleries Pvt. Ltd, which is promoted by a non-resident Indian for sweet sorghum based ethanol production. In terms of Agro-technology support, ABI-ICRISAT provided four cultivars of sweet sorghum – NTJ 2, SSV84, ICGR 93034 and S 35. Based on the performance of these four cultivars for their stalk-sugar content and millable cane yield in a preliminary testing at ICRISAT, Patancheru in the 2004 post-rainy season, NTJ 2 and SSV 84 were selected for commercialization.

ABI-ICRISAT facilitated the multiplication of sufficient quantities of seed material of NTJ 2 and SSV 84 through a private seed company. Additionally it provided consultancies by providing a package of practices for cultivation of sweet sorghum, facilitating the recruitment of field workers, promoting and popularizing sweet sorghum cultivation by farmers through *melas* (exhibitions) and farmers' days.

Business support was provided to Rusni Distilleries in areas such as facilitating the government clearance for ethanol production from the Government of Andhra Pradesh. It assisted the company in sourcing equity investment through private partnership and a loan from Syndicate Bank, Hyderabad, India. ABI-ICRISAT also provided office space for extension work and agriculture land for seed production.





Dr William D Dar, Director General, ICRISAT inaugurates Rusni Distilleries at Sanga Reddy, Andhra Pradesh, India.



Since M/s. Rusni Distilleries was a start-up company and the concept of sweet sorghum based ethanol production was new, it was difficult to commercialize this idea. Hence, ABI-ICRISAT stepped into the shoes of the client by conducting a proof of concept study and ensuring the prototype success. The prototype study of sweet sorghum cultivation by ICRISAT and ethanol recovery study by M/s. Rusni Distilleries have instilled confidence in the minds of investors and bureaucrats ensuring anchoring of this project.

Dr William D Dar, Director General, ICRISAT, inaugurated the production of commercial ethanol at Rusni Distilleries Ltd on 2 October 2006.

This project, the first of its kind in the world, will directly benefit 20000 farm workers. Through this project farmers can earn additional returns of Rs 4000/acre/crop. Encouraged by the successful commissioning of sweet sorghum based ethanol production project at Rusni Distilleries, there are several enquiries by both domestic (TATA Chemicals Ltd. and Reliance Industries Ltd.), and international (Mitsui Company Ltd., Japan, and JN Agritech International Ltd., Uganda), research and development institutions and entrepreneurs. ABI-ICRISAT envisages providing turnkey consultancy support to these entrepreneurs for sweet sorghum based ethanol production in collaboration with M/s Rusni Distilleries Private Limited.

Product Profile of M/s Rusni Distilleries Pvt Ltd

M/s. Rusni Distilleries Pvt Ltd intends to manufacture bio-fuel (fuel ethanol) and Extra Neutral Alcohol (ENA) from agro-based raw materials such as sweet sorghum stalks (juice) and grains.





Dr Belum Reddy explains sorghum grain productivity to Drs William Dar, Dyno Keatinge, CLL Gowda and HC Sharma.



ICRISAT Governing Board members visit Rusni Distilleries.

Delegates from China visit sweet sorghum fields at ICRISAT, Patancheru.



Sweet Sorghum-Based Ethanol Production



- Twenty-four hectare sweet sorghum stalks (870 t) needed per day for 40 KLPD unit
- US\$ 10.8 paid per ton of sweet stalks
- Stalks passed in series of two rollers, so crushed twice
- Juice yield to an extent of 40% of cane yield on weight basis
- Juice pasteurized at 100°C for 30 minutes – batch type
- Enzymes added to breakdown starch to glucose
- Yeast is added and allowed to ferment for 34 to 45 hours
- 40 to 45 l ethanol per ton of cane obtained
- Sweet sorghum stillage – 2200 K Cal kg⁻¹ at 50% moisture
- CO₂ produced: 30 t day⁻¹ and sold at US\$ 0.1 m⁻³
- Methane collected from spent wash, used as fuel in boiler (3300 m³ day⁻¹)
- Molecular sieve used to convert Rectified Spirit into fuel ethanol upto 99.8%
- Plant operates 270 days as per law (potential of 300 days with sweet sorghum)
- Production cost: US\$ 0.39 l⁻¹
- Public outlet pays US\$ 0.51 l⁻¹ while private outlet pays US\$ 0.60 l⁻¹ of ethanol.





Philippines delegates visit Rusni Distilleries.



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About ICRISAT®



The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a nonprofit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Centers of the Consultative Group on International Agricultural Research (CGIAR).

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