Sweet sorghum for food and fuel

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ICRISAT's Vision and Mission

Vision

Improved well-being of the poor of the semi-arid tropics

Mission

To reduce poverty, enhance food and nutritional security and protect the environment of the semi-arid tropics by helping empower the poor through science with a human face

The New ICRISAT

2004-05
- Fourth King Baudouin Award
- Rated Superior by CGIAR
- US $ 30 M budget (surplus)
- High staff morale

2006-07
- New vision and strategy to 2015
- Two CGIAR Science Awards
- Fourth year of budget surplus
- High staff morale
- Rated Outstanding by CGIAR
- US $ 35 M budget (2007)

2002-03
- Team ICRISAT
- Third King Baudouin Award
- External reviews
  - Quality science
  - Sound management
- Institutional innovations
- Budget surplus

Mid 90s:
- Financial and human resource challenges
- Declining support

2000-01
- Institutional transformation through Science with a Human Face
- Grey to Green Revolution
- US $ 22 M budget

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics

ICRISAT's BioPower Strategy

- **BioPower empowers the dryland poor to benefit from emerging bio-energy opportunities**
- **Ensures both food and energy security**
- **Focuses on biomass, juice and grain**
- **Greater smallholder incomes**
- **Sustaining environments**

Growing ethanol demand

- **Blending petrol with ethanol recommended in many countries including India, China, Brazil, US, Europe and the Philippines**
- **Sugarcane, sugarbeet and corn are currently the feedstocks**
- **India: Ethanol requirement by 2011-12 is 1035 million liters**
- **Philippines: Ethanol deficit is 205 million liters (5% blending) by 2007**

World ethanol production
(All grades, in millions of liters)

Country	Ethanol production (2004)
Brazil	15,110
US	13,390
China	3,650
India	1,750
France	830
Total	34,730

Recently US surpassed Brazil in ethanol production (Renewable Fuels Association, USA, 2005)

Sweet sorghum bioethanol

- **Sorghum grown in dry areas by small farmers (43 million ha in more than 90 countries)**
- **Sorghum types:**
  - **Grain**
  - **Dual (grain & fodder)**
  - **Sweet stalk (fuel, food, feed and fodder)**
- **Sweet sorghum is similar to grain sorghum**
- **Sweet sorghum – a bioethanol feedstock**

ICRISAT's has been working on sweet sorghum for the last 12 years

Bioethanol from sweet sorghum

- **Production similar to grain sorghum**
- **Sugar-rich stalks (16-23% Brix)**
- **Ethanol from juice of stalks after fermentation**
- **Grain – food; stillage – feed**
- **A cheaper and eco-friendly option**
- **No sulphur and aldehydes**

Cost[1] of production of ethanol from sweet sorghum, sugarcane and maize (India)

	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**

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]

Cost[1] of production of ethanol from sweet sorghum, sugarcane and maize (contd..)

	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
Corn oil (l ha^{-1})[4]	-	-	140
Income from corn oil (US$ ha^{-1})	-	-	61
Cost of cultivation (US$ l ha^{-1})	220	995	272
Cost of cultivation (ha^{-1}) after corn oil profit (US$)	220	995	211
Cost of cultivation with irrigation water cost (US$)[5]	238	995	287
Ethanol cost per kilo liter (US$)[6]	69.6	111.5[7]	65.6
Ethanol cost per kilo liter (US$)[8]	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: US$ 0.37 l^{-1}; oil sale price: US$ 0.87 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. Sugarcane is grown mostly under irrigation in India; 8. After accounting for water cost

Energy balance for gasoline and ethanol, by feedstock

Feedstock	Energy output/ fossil energy input
Sugarcane (Brazil)	8.3
Sugar beet (European Union)	1.9
Corn (United States)	1.3–1.8
Wheat (Canada)	1.2
Fossil-fuels	0.8*
Sweet sorghum (Hosein Shapouri, USDA)	8 (12-16 in temperate areas)

*** For one unit spent;** www.americanprogress.org

Sweet sorghum is CO_2 neutral

CO_2 absorption	CO_2 emission
45 t CO_2 ha^{-1} during the growing cycle	1.5 t CO_2 ha^{-1} during growing cycle
	8.5 t CO_2 ha^{-1} for conversion
	35.0 t CO_2 ha^{-1} for utilization (combustion)
45 t Total CO_2 ha^{-1}	45 t Total CO_2 ha^{-1}

The total CO_2 balance = 0

Source: LAMNET & G Grassi, EUBIA

Sweet sorghum scores over sugarcane-products

As a crop	As ethanol	As stillage
• Shorter gestation period • Dryland crop • Greater resilience • Farmer friendly • Meets food/ fodder needs • Higher fermentation efficiency (90-92%)	• Eco-friendly process • Superior quality • Less sulphur • High octane • Automobile friendly (up to 25%)	• Higher biological value • Rich in micronutrients • Use as feed/for power cogeneration

Net returns from sweet sorghum and grain sorghum (India)*

	Sweet sorghum	Grain sorghum
Grain yield (t ha^{-1})	1.6	2.5
Stalk yield (t ha^{-1})	20	4 (dry)
Grain value (US$ season^{-1})	234	365
Stalk value (US$ season^{1})	293	50
Total value (US$ season^{-1})	527	415
Leaf stripping (US$ season^{-1})	15	-
Net value (US$ season^{-1})	512	415
Gain from sweet sorghum (US$ season^{-1} ha^{-1})	97 (23%)	

*** Adopted from Rajasekhar 2007**

ICRISAT's strategy

1. **Development of**
   a. **Improved sweet sorghum varieties, hybrid parents and hybrids**
   b. **Improved *bmr* varieties, hybrid parents and hybrids**
   c. **Improved crop management practices**
2. **Public-Private-People Partnerships**

Sweet sorghum

bmr sorghum

Distillery

Sweet sorghum varieties

NTJ 2

Brix: 17%

Cane yield ha^{-1}: 53 t

Juice yield ha^{-1}: 28 kl

Estimated ethanol yield $ha^{-1}day^{-1}$: 21

SPV 422

Brix: 19%

Cane yield ha^{-1}: 48 t

Juice yield ha^{-1}: 26 kl

Estimated ethanol yield $ha^{-1}day^{-1}$: 21

Variation of Brix with internode

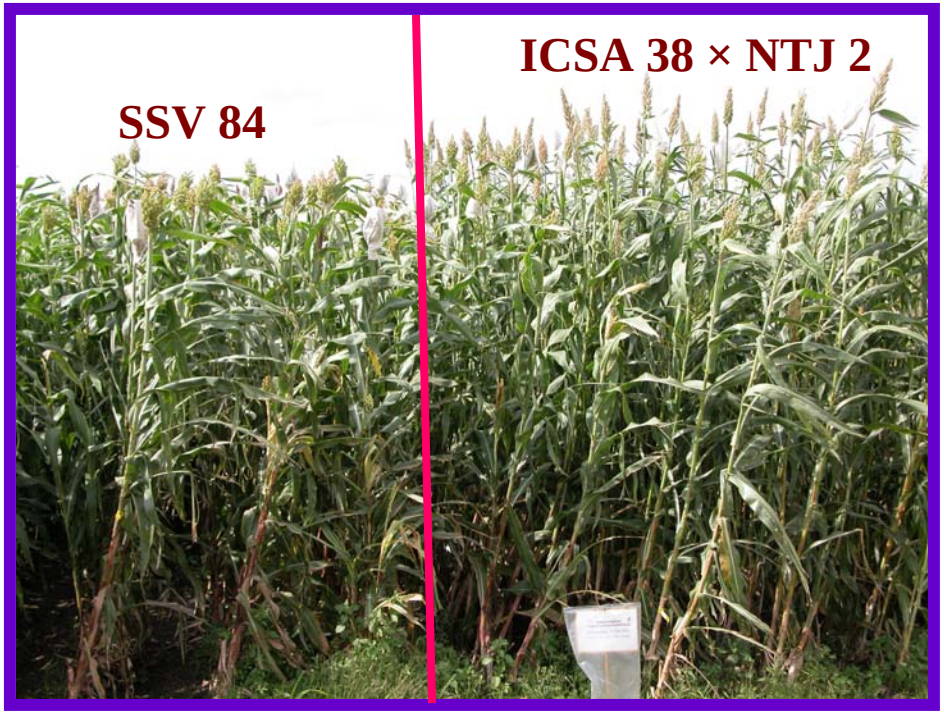
Variation in the Brix value of the sweet sorghum cultivars in different internodal regions, April, 2007, Patancheru

Cultivar/Internode No.	2	3	4	5	6	Mean
Hybrid						
ICSA 38 x SSV 84	11	12	**12.6**	13.5	13.4	**12.5**
ICSA 724 x SPV 1411	7.4	7.4	**8.1**	8.7	7.7	**7.9**
Variety						
NTJ 2	7.4	7.4	7.5	**6.6**	5.7	**6.9**
SPV 422	12.9	13.0	13.0	**14.1**	14.5	**13.5**
SSV 84	14.6	14.3	16.1	**16**	15.4	**15.3**
B-line						
ICSB 38	7.6	**6.8**	6.4	6.7	6.6	**6.8**
Mean	10.2	10.2	**10.6**	10.9	10.6	**10.5**

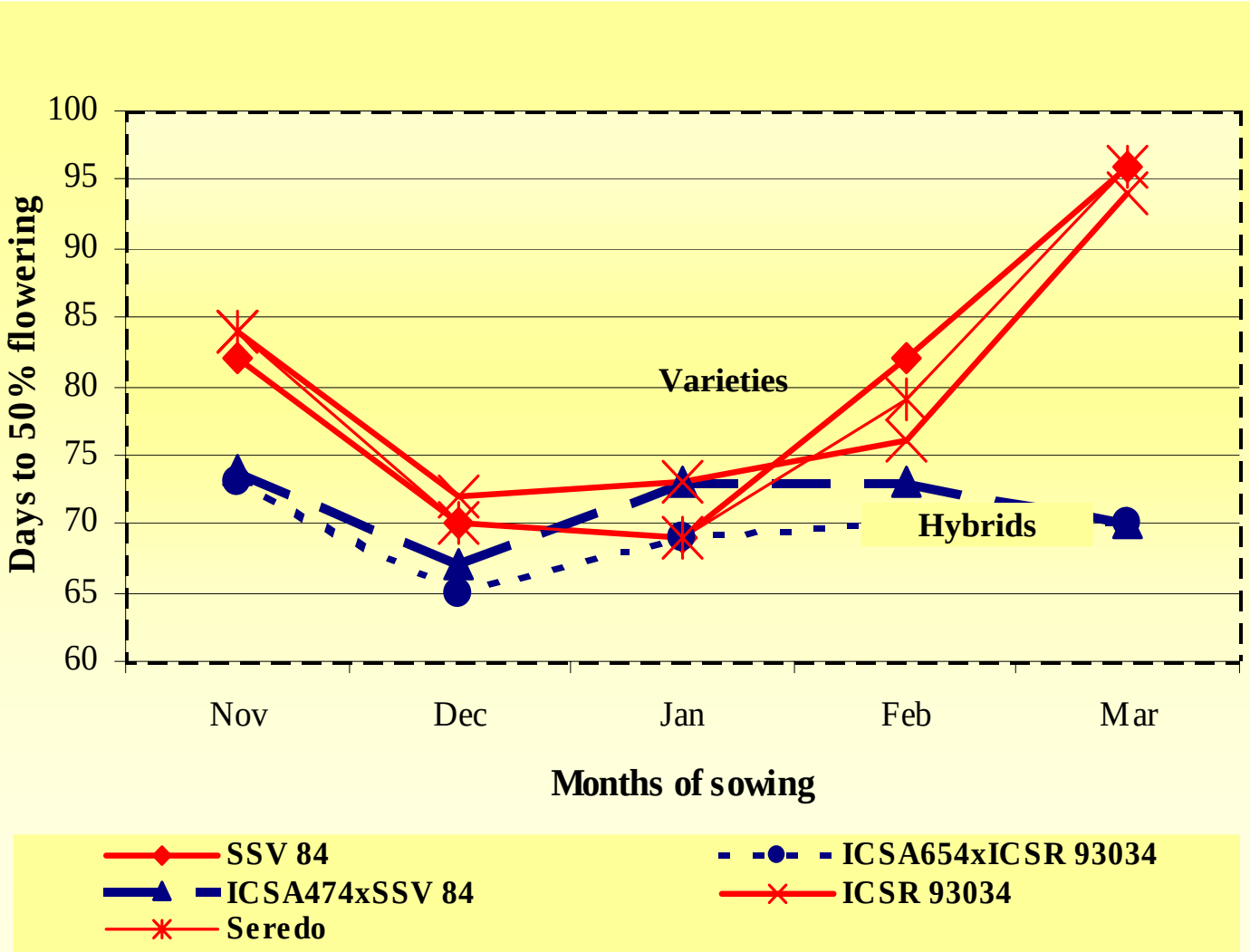
Hybrids

Heterosis for cane and juice yields, and total sugar

- More stable compared to varieties
- Early and predictable maturity
- Easy to schedule cane supplies



Sweet sorghum cultivar options



Performance of sweet sorghum hybrids, India

	Days to 50% flowering	Brix	Juice yield (kl ha^{-1})	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})	Per day ethanol productivity (l ha^{-1})*
Hybrids						
ICSA 749 × SSV 74	85	18.00	27.15	9.15	3.28	18.48
ICSA 511 × SSV 74	88	17.97	22.70	7.84	5.79	15.39
Variety						
SSV 84 (control)	94	15.65	16.84	4.98	2.67	10.50

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

Trade-off between food and fuel

Trade-off between sugar yield (t ha^{-1})/ethanol and grain yield (t ha^{-1})/food, Patancheru in 2005 and 2006.

Season		Stalk sugar yield (t ha^{-1})			Grain yield (t ha^{-1})		
		Sweet sorghum (SS)	Non-sweet sorghum	% gain in SS	Sweet sorghum (SS)	Non-sweet sorghum	% gain/ loss in SS
Rainy	Varieties	5.8 (7)	4.1 (15)	42	3.4 (7)	4.2 (15)	-18
	Hybrids	5.5 (7)	4.6 (10)	21	7.4 (7)	6.5 (10)	15
Postrainy	Varieties	2.0 (5)	1.3 (17)	53	4.1 (5)	5.2 (17)	-21
	Hybrids	1.6 (6)	0.9 (11)	78	6.0 (6)	7.2 (11)	-16

Message: Negligible trade-off; hybrids in rainy season advantageous both for stalk sugar and grain yield

Rainy season *vs* postrainy season

Hybrid[1]	Brix reading (%) R	Brix reading (%) PR	Sugar yield (t ha^{-1}) R	Sugar yield Rank	Sugar yield (t ha^{-1}) PR	Sugar yield Rank	Grain yield (t ha^{-1}) R	Grain yield Rank	Grain yield (t ha^{-1}) PR	Grain yield Rank
ICSA 675 × SSV 74	16.6	10.3	6.3	1	1.1	9	6.7	8	7.1	8
ICSA 675 × SPV 422	17.3	11.7	6.1	2	0.9	14	6.6	9	6.7	10
ICSA 324 × SPV 422	16.5	16.1	4.8	13	1.7	2	4.9	17	3.9	20
ICSA 474 × E 36-1	13.5	14.3	4.8	14	1.7	3	6.3	14	6.2	15
NSSH 104 (control)	18.5	19.8	5.9	3	1.2	8	4.2	18	7.2	3

1. Trial entries: 20; RCBD; 2 years and 2 seasons testing
2. Calculated as the product of Brix and juice volume (kl ha^{-1})
3. R = Rainy season
4. PR = Postrainy season

Message: Breed separately for each season for sweet sorghum sugar

Brix and sugar yield at flowering and maturity

Performance pattern of hybrids, varieties, R-lines and B-lines for Brix% and sugar yield (t ha^{-1}) at flowering and maturity

Trial	No. of entries	Brix (%)		Sugar yield (t ha^{-1})	
		Flowering	Maturity	Flowering	Maturity
Hybrids					
SSPHT 2005K	40	9.38	13.9	3.2	4.0
SSLxTHT 2004K	143	10.6	15.4	*	*
SSPHT 2006K	73	13.9	16.1	3.1	3.1
ISSHT 2006R	44	8.3	12.7	1.2	1.2
R-lines/varieties					
SSVT 2004R	44	9.62	15.12	*	*
SSLxTHT 2004K	18	12.9	18.5	*	*
SSPHT 2006K	9	14.6	17.9	2.3	2.2
B-lines					
SSLxTHT 2004K	9	12.9	14.9	*	*
SSPHT 2006K	19	11.8	13.4	0.8	1.1

Effect of Alfisols and Vertisols

Performance of sweet sorghum varieties in alfisols and vertisols, 2006 postrainy season, Patancheru

Entry	Cane weight (t/ha)	Juice volume (kl/ha)	Brix	Sugar yield (t/ha)	Grain yield (t/ha)
Red soil					
NTJ 2	8.08	3.90	12.30	0.49	3.69
SPV 422	13.10	5.54	18.30	1.06	4.27
SSV 84	8.06	3.44	16.60	0.60	3.54
Mean	**9.75**	**4.29**	**15.73**	**0.72**	**3.83**
Black soil					
NTJ 2	17.21	7.49	12.8	0.99	8.14
SPV 422	40.71	15.42	19.5	3.25	7.65
SSV 84	22.58	8.1	16.7	1.42	7.53
Mean	**26.83**	**10.34**	**16.33**	**1.89**	**7.77**

Irrigation after cutting

Effect of irrigation on the sweet sorghum traits after harvesting grain

Cultivar	Cane weight (t ha^{-1})		Juice volume (kl ha^{-1})		Random Brix of Juice		Sugar (t ha^{-1})		% sugar increase
	a	b	a	b	a	b	a	b	
ICSA 38 x SSV 84	28.5	35.5	13.6	17	12.5	13	1.76	2.31	31.34
ICSA 724 × SPV 1411	39.8	46.5	19.8	25.3	11	11	2.24	2.94	31.04
NTJ 2	25.3	36.9	13.4	19.8	11	9	1.51	1.82	20.5
SPV 422	39.4	50.8	19.3	24.8	16	16.5	3.23	4.28	32.27
SSV 84	23.5	27.8	9.8	14.3	16	13.5	1.63	1.99	22.36
ICSB 38	11.1	12.1	4.5	5.9	9.5	9	0.44	0.71	61.05

a Data recorded at physiological maturity

b Heads cut at physiological maturity, field irrigated and data recorded after four days

Ethanol-related traits in sweet sorghums with the delay in crushing

Days after harvest	Juice extraction (kl ha^{-1})	Brix's reading at maturity	Sugar yield based on Brix's reading and juice yield (t ha^{-1})	Reduction (%) in sugar yield after the day harvested
Same day	42.44	18.50	2.62	0.0
1	40.55	19.25	2.47	5.7
2	34.96	20.88	2.18	16.8
3	37.55	21.38	2.20	16.0
SE±	2.60	0.83	0.44	
CV%	13.89	8.01	39.34	
CD (5%)	7.84	2.49	1.33	

Note: All yield values are adjusted to overall mean of fresh stalk yield on harvested day.

Potential of ligno-cellulosic biomass for ethanol production - ICRISAT

Feedstock	Liters ethanol ton^{-1}
Bagasse	500
Maize/sorghum/rice stover	500
Forest thinnings	370
Harwood sawdust	450
Mixed paper	420

Source: Planning commission.nic.in/reports/genrep/cmtt_bio.pdf

Second generation bio-fuels: ligno-cellulose feedstocks

- **Brown mid-rib (*bmr*) mutants in sorghum, sudan grass, pearl millet and maize contains reduced (by 50%) lignin; hence 50% higher fermentable sugars; reduce cost of ethanol production**
- ***bmr* crop residues have higher rumen digestibility and palatability—good for fodder as well**
- **ICRISAT is developing *bmr* sorghum hybrid parents useful for developing high biomass *bmr* hybrids**

Brown midrib sources

- ***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)**
- **Sources used: *bmr* 1, *bmr* 3, *bmr* 7**
- **Potential sources: IS 21889, IS 40602**
- **Number of high biomass B-lines**
  - ***bmr* 1: 2, *bmr* 3: 3, *bmr* 7: 6**
- **Number of high biomass R-lines**
  - ***bmr* 1: 10, *bmr* 3: 3, *bmr* 7: 9**

Characteristics of selected sorghum *brown midrib* lines

Ligno-cellulose-based technology

Line	Midrib color*	Brix reading at grain maturity (%)	Green fodder yield (t ha^{-1})	Grain yield (t ha^{-1})
B-lines:				
ICSB 472	1.5	20.3	27.4	2.5
ICSB 664	1.5	22.9	26.9	1.7
ICSB 731	1.5	18.0	34.6	3.3
Varieties/R-lines:				
ICSV 96114	1.5	17.3	17.6	3.1
GD 65025	1.5	22.0	34.4	0.6

*** Midrib color at harvest on 1-5 scale, where, 1 = brown and 5 = more white**

How sweet sorghum varieties fared at MMSU, Illocos Norte

Variety	Stripped stalk yield (t ha^{-1})		Grain yield (t ha^{-1})		Brix (%)
	Main crop	Ratoon crop	Main crop	Ratoon crop	
NTJ 2	45-50	48-55	3.62	4.40	18.5
SPV 422	55-60	57-65	3.28	3.92	19.0
ICSV 700	43-48	45-50	3.46	4.11	18.0
ICSV 93046	47-52	48-55	3.40	4.08	15.0
ICSR 93034	46-52	47-53	3.46	4.25	18.0

Sweet sorghum resilience at MMSU, Batac, Illocos Norte, November 2006

Before floods

During floods

After floods

Sweet sorghum cultivars at Mariano Marcos State University (MMSU) Batac, Ilocos Norte, Philippines

Comparing feedstock cost in the Philippines

Feedstock	Price (Php)/MT		liter/ha/year*	Feedstock cost (PhP)/liter	
	Min	Max		Min	Max
Sugarcane	1,000	1,100	6,120	13.89	15.28
Molasses	4,550	5,400	806	19.06	22.62
Cassava	1,500	5,800	5,549	8.38	32.40
Corn	8,500	10,000	5,282	20.92	24.61
Sweet Sorghum			8138[2]	13.98[1]	15.672[2]
- Stalk	550	600	5,625	12.22	13.33
- Grain	6,000	7,000	2,513	17.91	20.90

Sources: GAIN Report on RP sugar industry, GAIN Report on Thai sugar industry, bas.gov.ph, Leyte State University Report on cassava, Biotechnology Coalition of the Philippines Speech, MMSU field tests, FAO & ICRISAT, 2004-2005.

1. Average for stalk and grain; 2. Total for stalk and grain.

*** Average ethanol output per hectare.**

Partnerships for the poor

ICRISAT & Rusni Distilleries tie-up through ABI

Rusni Distilleries

- **Set up a 40 KLPD distillery near ICRISAT**
- **Fermentation process patented**
- **Produces fuel ethanol (99.4% alcohol), extra neutral alcohol (96%) and pharma alcohol (99.8%)**
- **Feedstocks: sweet sorghum stalks and grain, cassava and sugarcane**

Ethanol production process at Rusni Distilleries

Ethanol long-term storage

↑

Temporary ethanol storage

↑

Distillation unit

↑

Fermentation section

↑

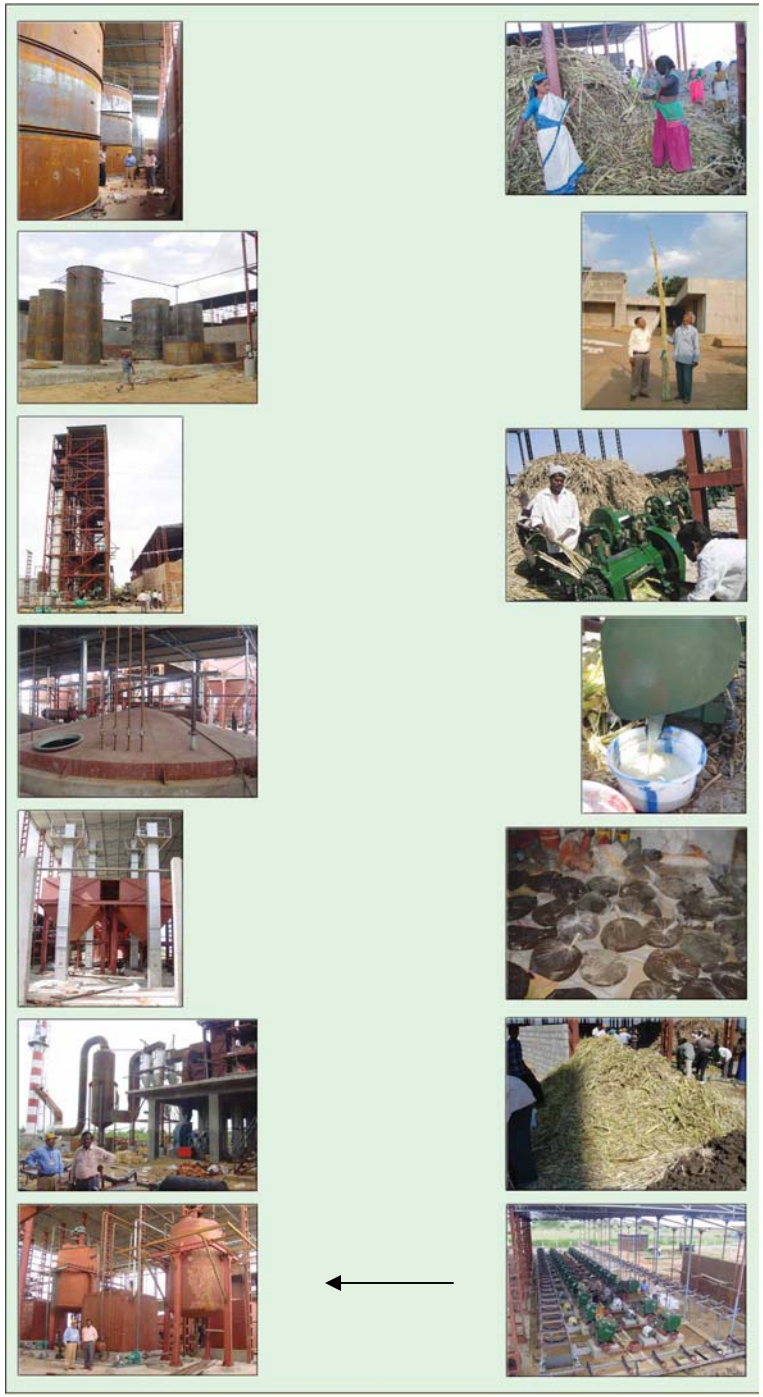
Grain processing and feeding

↑

Boiler and wet scrubber

↑

Pasteurizer



Processing stalks

↓

Stalks ready for crushing

↓

Crushing stalks

↓

Juice extraction

↓

Jaggery from juice

↓

Stillage

↓

Juice extraction section

Plant production capacity (Rusni Distilleries)

Requirements	Units
Ethanol day^{-1} (kl)	35-40
SS stalks required day^{-1} (t)	800-875
Stalks required for 105 days (t) per season	84000-91875
Area required (rainy season) ha	2300-2600
Area required (postrainy season) ha	3700-4200
Total sweet sorghum area required (ha)	6000-6800
No. of small farmers* to be involved	3000-3400

*** Small farmers: 2 ha holdings in India. **

Source: Rusni Distilleries.

The costs of setting up a distillery...

Distillery capacity	Cost[1] (US$ million)
40 KLPD	9
100 KLPD	28
200 KLPD	38

[1]Includes civil works and excludes facility for germ separation from maize, November 2006.

…and the employment generated by a 40 KLPD unit

Country	Beneficiary farmers	Labor (man days)	Direct staff (man days)
India	5000	40000	100000
Philippines	2500	20000	50000

Source: Rusni Distilleries (P) Ltd.

Together we can make a difference..

- **Sweet sorghum: Ensures both food and energy security and a clean environment**
- **A win-win situation for the farmer and industry**
- **Public-Private-People Partnerships**

Thank You

Explanatory notes

- Small farmers: those having < 2.0 ha farm holding
- US$: Rs. 42
- One t ethanol (weight): 810 liters (volume)
- Sweet sorghum (1 t cane): 40 liters ethanol t^{-1} cane
- Sugarcane (1 t cane): 75 liters ethanol t^{-1} cane
- Sorghum grain (1 t): 350 liters ethanol t^{-1} grain
- Sweet stalk cost (paid to farmer by industry): Rs. 500 = US$ 10.87
- Grain cost: Rs. 5000 t^{-1} = US$ 108.7 t^{-1}
- Stover cost: Rs. 1000 t^{-1} = US$ 21.74 t^{-1}
- Crop cycle: sowing to maturity: 105 days
- Ethanol sale: Rs. 26= US$ 0.543 l^{-1}

Cost of cultivation and product value are based on Report of Commission for Agricultural Costs and Prices. 2003. Ministry of agriculture and cooperation, Govt. of India, New Delhi.