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Sweet sorghum as a bioethanol feedstock: Challenges and opportunities

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Outline

- Introduction
- Food *vs* fuel
- Target materials
- Breeding and adaptation
- Feedstock supply
- Economic feasibility
- Rusni experience
  - Linking farmers and industry
  - Linking farmers and inputs dealers
  - Coalition of researchers, industry and farmers
  - By-products enterprises development
- Policy issues
- Looking forward

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Introduction

- **Sorghum - 43 m ha in 99 countries; mostly rainfed tropics and subtropics**
- **Sweet sorghum (SS) - similar to grain sorghum, but in >700 mm rainfall areas**
- **ICRISAT BioPower research strategy - stalk sugars, grain – for small holder farmers**
- **ICRISAT incubated the technology with Rusni Distilleries Private Limited**

Food, feed and fuel

- **Multiple uses of SS:**
  - **stalk juice for ethanol; grain for food/feed**
  - **stripped leaves and bagasse/stillage used for animal feed**
  - **bio-compost/power cogeneration by distillery**
- **SS ensures food and feed security and provides opportunities for additional income for small farmers while protecting the environment**



Trade-off between food and fuel

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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**

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Trade off - sugar yield at flowering and maturity[1]

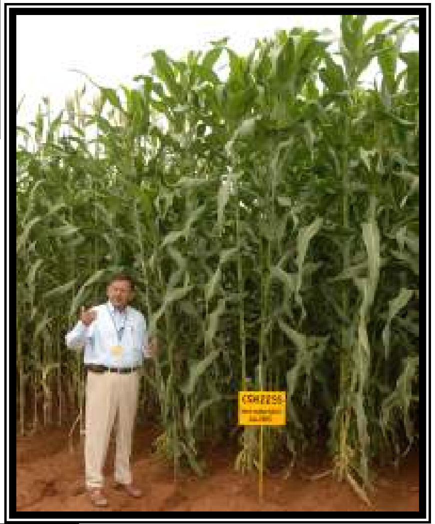
Trial	No. of entries	Brix (%)		Sugar yield (t ha^{-1})	
		Flowering	Maturity	Flowering	Maturity
Hybrids					
SSPHT 2005K	**40**	**9.38**	**13.9**	**3.2**	**4.0**
SSL×THT 2004K	**143**	**10.6**	**15.4**	*	*
SSPHT 2006K	**73**	**13.9**	**16.1**	**3.1**	**3.1**
ISSHT 2006R	**44**	**8.3**	**12.7**	**1.2**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

β and R^2 of traits on stem 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

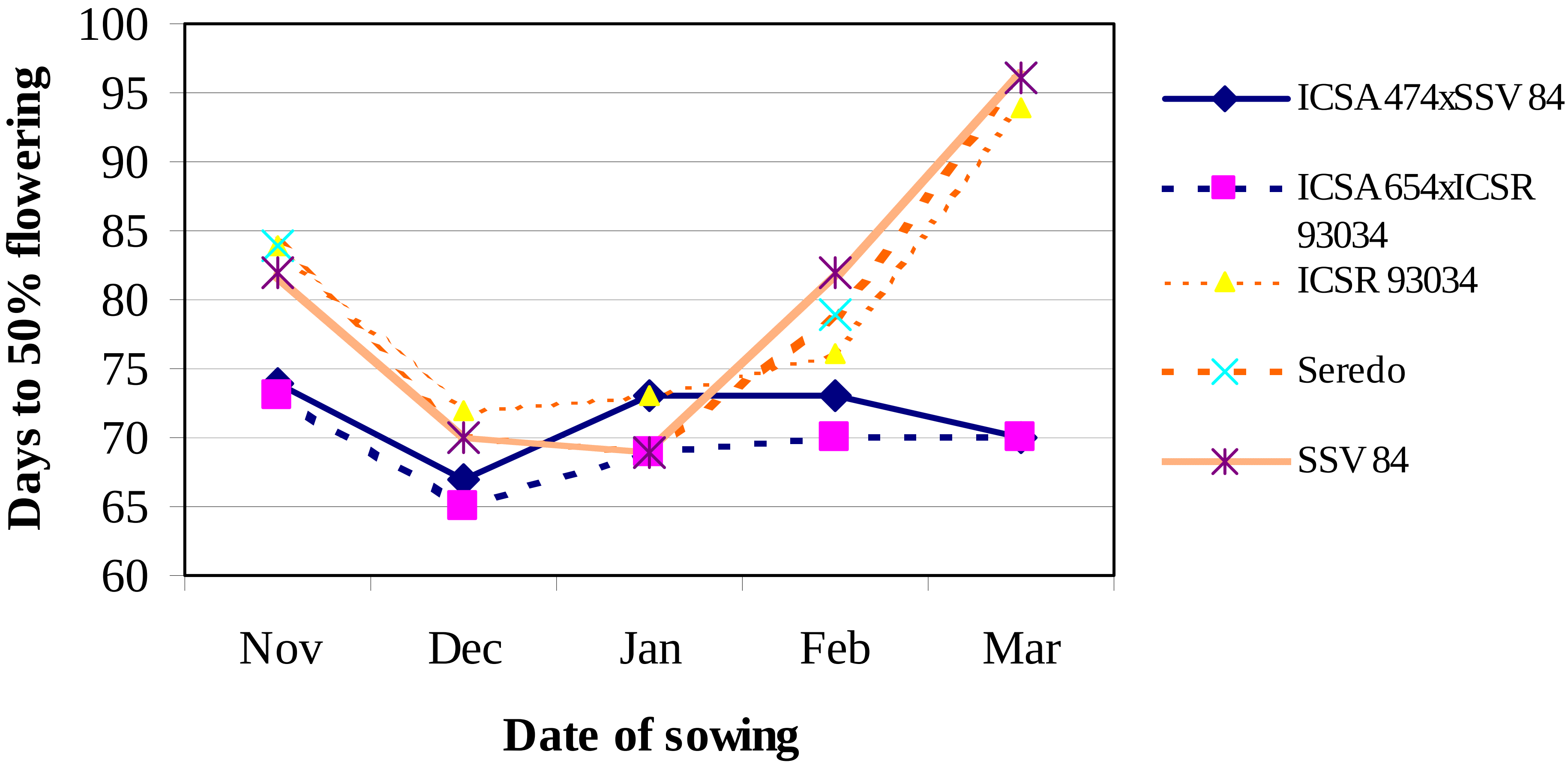
Target materials

- **SS varieties and hybrids**
- **SS varieties photoperiod sensitive, hybrids less sensitive**



- **Hybrids are early maturing, maturity predictable and needs less water**
- **Cane supply schedule to the industry easy due to predictable maturity**

Response of sweet sorghum hybrids *vs.* varieties in different dates of planting



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Hybrids in relation to variety, 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	16.65	16.84	4.98	2.67	10.50

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

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Rainy season *vs.* postrainy season

Hybrid[1]	Brix reading (%)		Sugar yield (t ha^{-1})[2]				Grain yield (t ha^{-1})			
	R[3]	PR[4]	R	Rank	PR	Rank	R	Rank	PR	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 (check)	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

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Variability for stem girth (mm) in hybrid parents and hybrids

Cultivar	Range	Mean
Postrainy season		
B-lines	11.9 to 21.7	16.4
R-lines	14.3 to 18.2	15.8
Hybrids	12.8 to 21.1	16.5
Rainy season		
B-lines	14.6 to 26.2	18.1
R-lines	*	*
Hybrids	16.1 to 32.6	20.9

Promising insect pest resistant seed parents

Resistant trait	Response score		Grain yield ($t\ ha^{-1}$)	
	Best B-lines	Susceptible control (296B)	Best B-lines	High yielding control (296B)
Shoot fly[1] (postrainy)	14.2-31.1	50.5	2.7-5.3	3.0
Shoot fly (rainy)	36.7-52.6	77.5	2.3-3.5	3.3
Stem borer[2] (postrainy)	31.7-37.0	56.2	2.6-4.2	3.3
Stem borer (rainy)	36.7-48.7	71.1	2.1-4.5	3.3
Head bug[3]	4.7-5.1	6.3	2.5-4.7	3.2
Midge[4]	1.1-2.2	5.8	2.9-5.8	3.1

[1]Shoot fly deadhearts percentage over healthy plants,
[2]Stem borer dead hearts percentage over healthy plants,
[3]Head bug score taken on a scale 1-9 where 1= a few grains with bug feeding punctures and 9= most of the grains with shrivelling due to head bug damage,
[4]Midge score taken in caged heads on a 1-9 scale where 1= <10% chaffy florets and 9= >80% chaffy florets

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bmr 1 source (IS 21887) and their derivatives

Line	Lignin (%)	*In vitro* organic matter digestibility (%)	Nitrogen on dry matter basis (%)	Days to 50% flowering	Plant height (m)	Grain yield (t ha^{-1})
(IS 21887 × ICSB 101)-3-1-1-1-1	3.14	59.56	0.76	103	1.5	1.6
(IS 21887 × ICSB 73)-13-1-1-1-1	3.65	55.02	0.66	101	1.5	1.6
(IS 21887 × ICSB 93)-2-1-1-1-1	3.47	56.17	0.93	102	1.2	0.9
(IS 21887 × ICSB 93)-4-1-1-1-1	3.30	57.76	0.86	111	1.1	0.3
Average of derived progenies	3.39	57.13	0.80	104	1.3	1.1
IS 21887 (source)	4.24	49.44	0.57	87	1.1	*
ICSR 89058 (white midrib)	4.36	50.20	0.60	73	1.4	2.9

Extended feedstock supply - measures

- Cultivar maturity choice
- Plantings
  - Sequential
  - Different seasons
  - Wider areas
  - Clustering
- Decentralized syrup units
- Widening harvesting window

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Widening harvesting window for four days

Cultivar	Juice volume (kl ha^{-1})		Random Brix of juice		Sugar (t ha^{-1})		% sugar increase
	a	b	a	b	a	b	
ICSA 38 × SSV 84	13.6	17	12.5	13	1.76	2.31	31.34
ICSA 724 × SPV 1411	19.8	25.3	11	11	2.24	2.94	31.04
NTJ 2	13.4	19.8	11	9	1.51	1.82	20.50
SPV 422	19.3	24.8	16	16.5	3.23	4.28	32.27
SSV 84	9.8	14.3	16	13.5	1.63	1.99	22.36
ICSB 38	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 sorghum 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.

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Production of ethanol per ha from sweet sorghum, sugarcane and maize (India)

	Sweet sorghum[1]	Sugarcane[1]	Maize[2]
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. 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]
2. Corn (grain) ethanol: 400 $l\ t^{-1}$; maize stover ethanol: 227 $l\ t^{-1}$ [Ref. Badger (2002) Trends in New Crops and New Uses]

Feedstock production cost[1] for 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$)	220	-	211
Cost of cultivation with irrigation water cost (US$)[5]	238	995	287
Feedstock cost per kilo liter (US$)[6]	69.6	111.5	65.6
Feestock cost per kilo liter (US$)[7]	81.6	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

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

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Rusni experience - coalition building

- **A member of the ICRISAT-Private Sector Sweet Sorghum for Ethanol Research Consortium**
- **Large scale cultivation by supply of seeds to farmers in 2007**
- **Adapted a contract farming model with backward and forward linkages**
- **Innovative collaboration between researchers, industry and farmers**

Partnership for the poor

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ICRISAT & Rusni Distilleries tie-up through ABI

Rusni experience

By-product enterprise development

- **Bio-compost**
- **Co-generation**
  - **Calorific value:**
    - **2200 Kcal kg^{-1} in sweet sorghum *vs***
    - **2150 Kcal kg^{-1} in sugarcane**
- **Bagasse feed value**

Intake and body weight gain for different feed blocks

Treatment	Intake (g/kg live weight)	Weight gain (kg/day)
Commercial feed block	3.64	0.975
Bagasse-leave feed block	3.76	0.871
Sorghum stover (chopped)	1.24	-0.457

Source: Michael Blümmel et al. 2007 (unpublished).

Commercialization

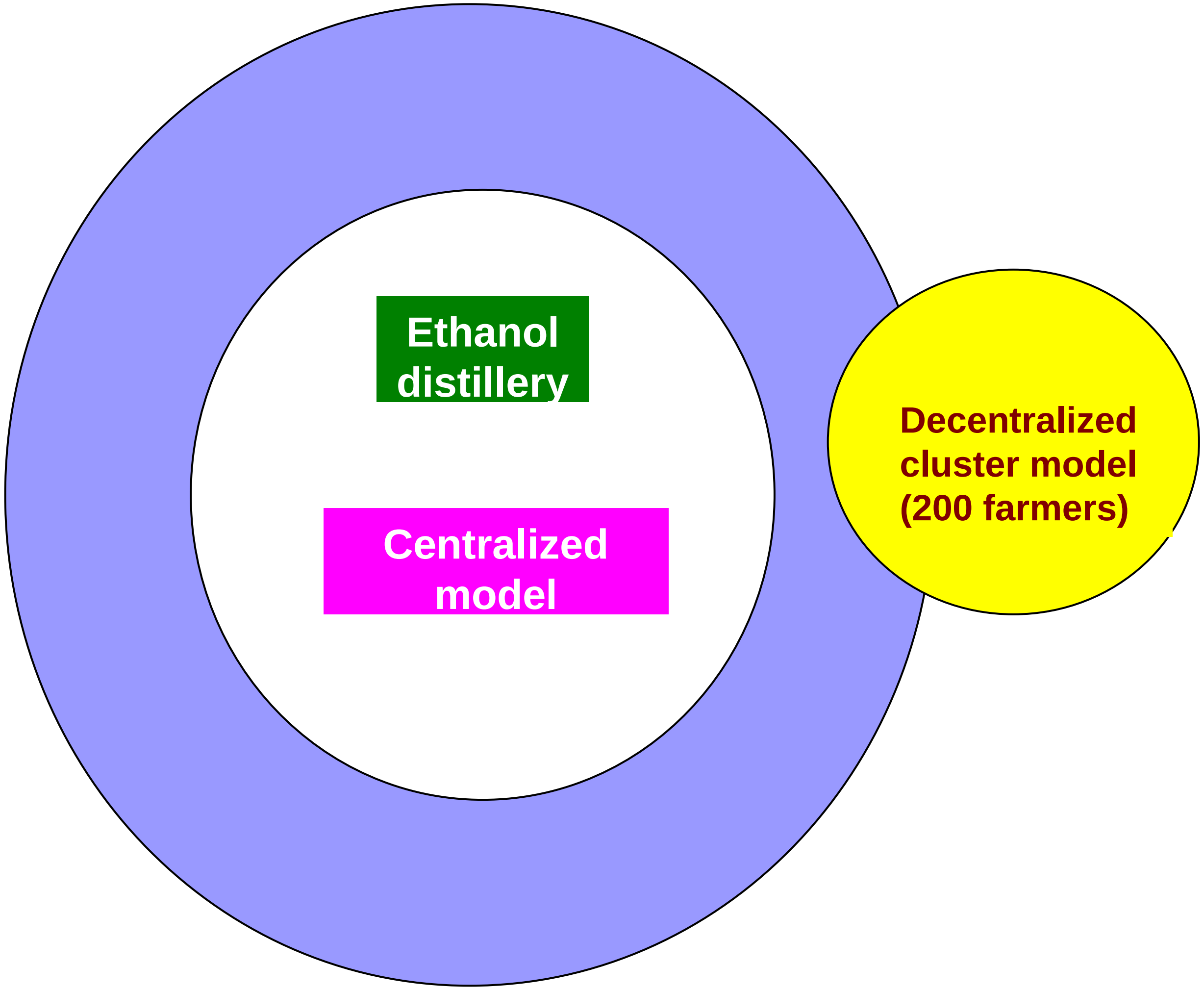
A report by Dr KPC Rao

- **ABI, Rusni, AAI & ICRISAT**
- **791 farmers; 538 ha in Medak District**
- **200 farmers sample (171 sole; 29 SS+PP)**
- **No reduction in stalk yield up to 15 July**
- **Recommended package increased stalk yield**
- **Break-even stalk yield: 22 t ha^{-1} @ US$ 14.29 t^{-1}**
- **13% farmers reported higher yields**
- **Average realized yields 20 t ha^{-1}; then cost should be US$ 15.91 t^{-1}**

Commercialization (contd..)

- Timely procurement is a must
- Sowing time expansion—decentralized crushing, planting wider area
- Farmers expect 37 t ha^{-1}; @ US$ 21.43 t^{-1} of stalk
  - Hybrids
  - Recommended package of practices
  - Increased price for cane by Rusni

Methodology



Project design depicting Centralized and Decentralized models

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Policy issues

- **Incentives to dryland farmers**
- **Large scale seed production**
- **Start up incentives to ethanol industry (tax holidays, etc.)**
- **Ethanol price parity to imported ethanol and petrol**



Looking forward

- **Feedstock improvement for stalk sugar yield**
- **Feedstock improvement for biomass and quality (*bmr* types)**
- **Life cycle analysis ([e]energy/[c]CO_2 emissions)**
- **Up-scaling decentralized model**
- **Expansion of ICRISAT-Private Sector Sweet Sorghum for Ethanol Research Consortium**
- **Expansion of collaboration (India, Brazil, China, USA, etc.) on specific research areas**

Looking forward

- **Sensitizing policymakers to the multiple uses of SS**

- **Scenario analysis of growing and using sweet sorghum for ethanol under varying competing crop scenarios under varying price regimes**

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In summary….

"Sweet sorghum is a smart crop for it provides food, feed, fodder and fuel without significant trade-offs in any of these."

William D Dar
Director General
ICRISAT

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Thank you

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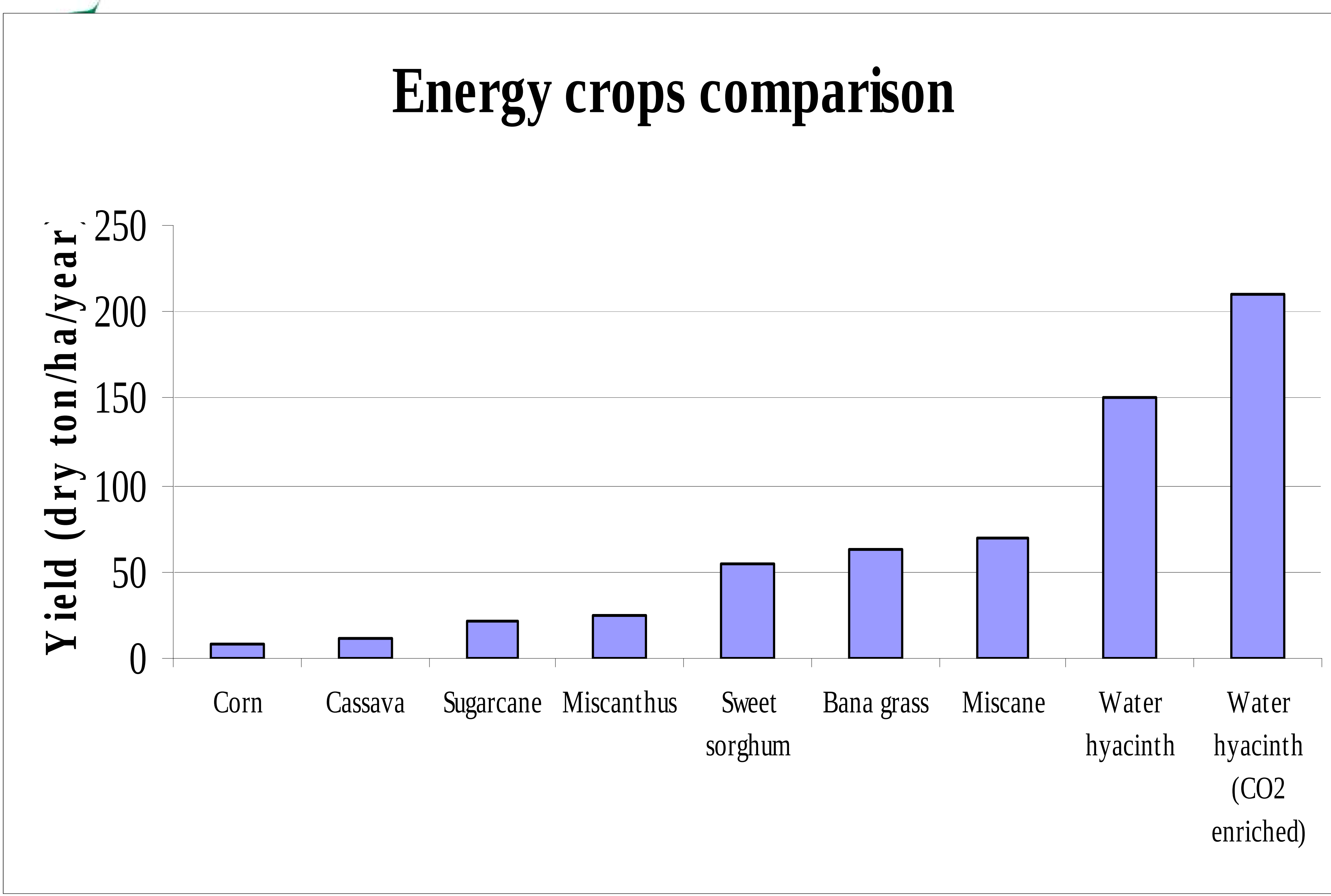
Sweet sorghum is CO_2 neutral

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



***e*Adopted from Texas A&M University, College Station, USA**