Sorghum: A Sweet Proposition for Sustainable Biofuel Production in India

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Outline

1. Introduction
2. Status of sorghum (Grain and Sweet sorghum) R&D for 1st generation biofuels
3. Status of sorghum (Biomass) R&D for 2nd generation biofuels
4. Challenges
5. Way Forward

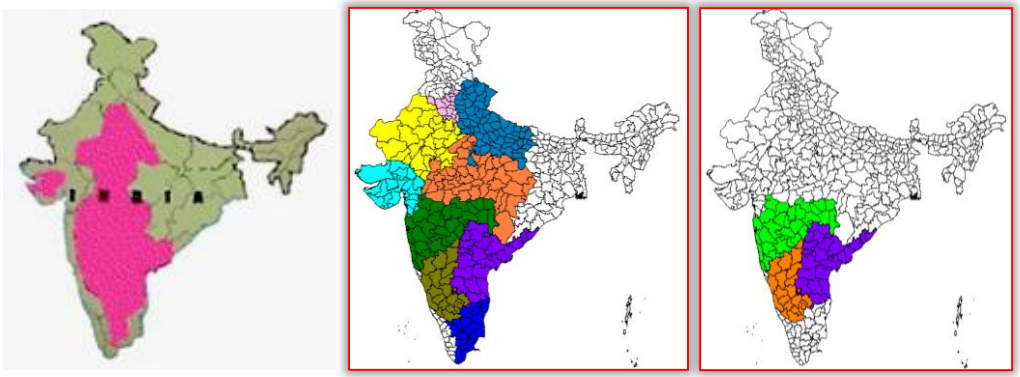
Introduction

Great Millet

- An important staple cereal crop for millions
- Fifth most important cereal crop of the world
- It is a low cost, low water requiring, dryland, short duration crop - 80% agri. area on earth
- Resilient to climate change -Stress tolerant
- Suitable to rainfed, low input agriculture
- Offers multiple uses such as food, feed, fodder, fibre and fuel
- Grown in rainy (kharif) & post-rainy (rabi) and summer seasons
- Worldwide water issues will make energy activities lean towards WU efficient crops
- Sorghum has tremendous potential as a biofuels crop worldwide including India

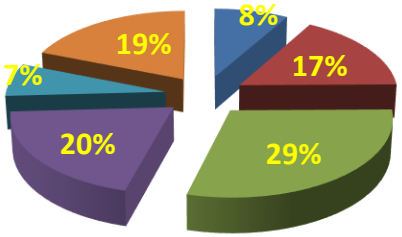
Major states

Kharif & Rabi sorghum

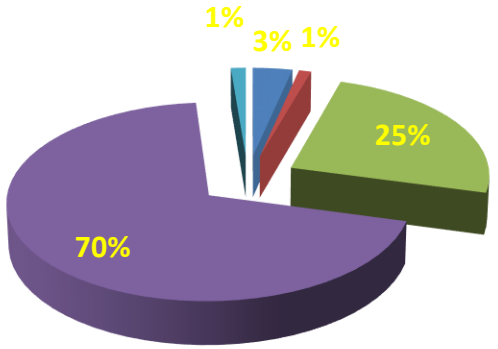


Geographical spread

Post-rainy sorghum
- 45% of total area
- 32% of total prodn..

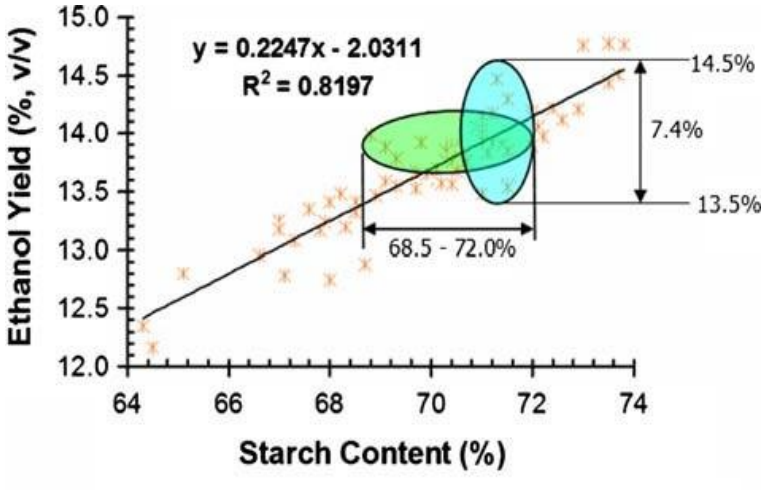


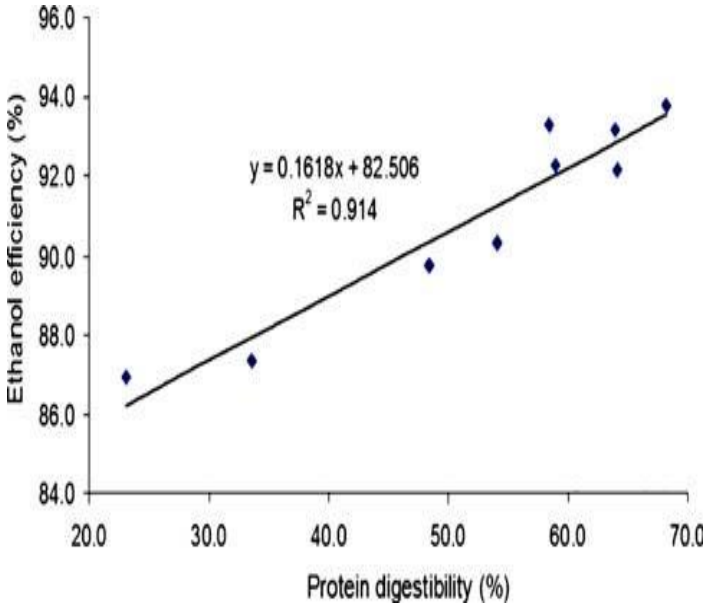
- Karnataka
- Madhya Pradesh
- Maharashtra
- Rajasthan
- Tamil Nadu



- Andhra Pradesh
- Gujarat
- Karnataka
- Maharashtra
- Tamil Nadu

Relationship of starch and protein with ethanol yield





Source: Wang et al 2008. J Ind Microbiol Biotechnol 35:313–320

Sorghum Beer

- Gluten-free beers for celiac people
- Beer from white sorghum-Higher phenolic contents than barley beer- High antioxidant activity
- The beer also contained significant amounts of γ -aminobutyric acids with potential antihypertensive activity, and also had α-glucosidase inhibitory activity
- This beer has low ethanol content, and consumption of this beer could promote human health if consumed with moderation.

Red sorghum for ethanol

Bioconversion of decorticated red sorghum + bran into ethanol

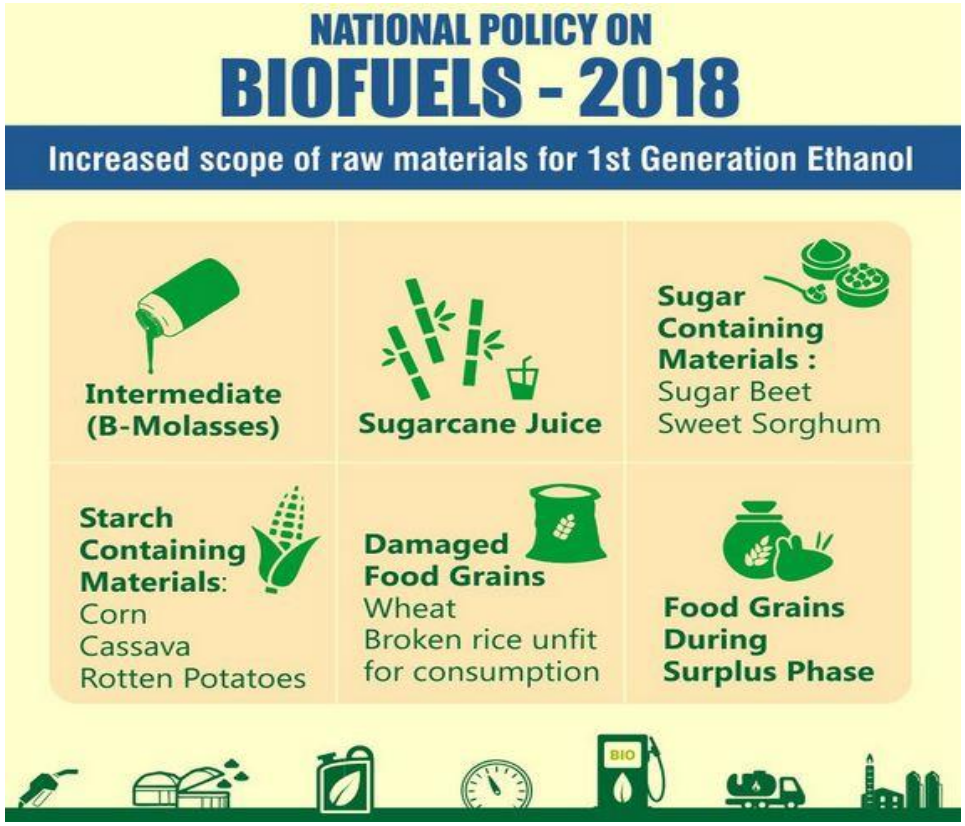
Treatment	ml Ethanol/g flour (mb)	ml Ethanol/g starch (mb)	Fermentation efficiency (%)
Whole red sorghum	0.35 ± 0.04	0.58 ± 0.06	94 ± 9.45
Decorticated red sorghum + spent bran	0.38 ± 0.04	0.61 ± 0.06	98 ± 9.6
Decorticated red sorghum + phenolic extract	0.35 ± 0.08	0.51 ± 0.12	84 ± 19.7
Decorticated red sorghum	0.37 ± 0.04	0.55 ± 0.06	88 ± 9.5
Maize	0.36 ± 0.05	0.53 ± 0.07	86 ± 11.9
Whole white sorghum	0.31 ± 0.04	0.47 ± 0.06	76 ± 10.2

Effect of grain type and addition of PE or spent RS bran to decorticated kernels on EY and FE

Source: Cristina Chuck-Hernandez et al 2012 Biotechnol Lett (2012) 34:97–102

CSV 50 Red- India`s first red colored sorghum variety

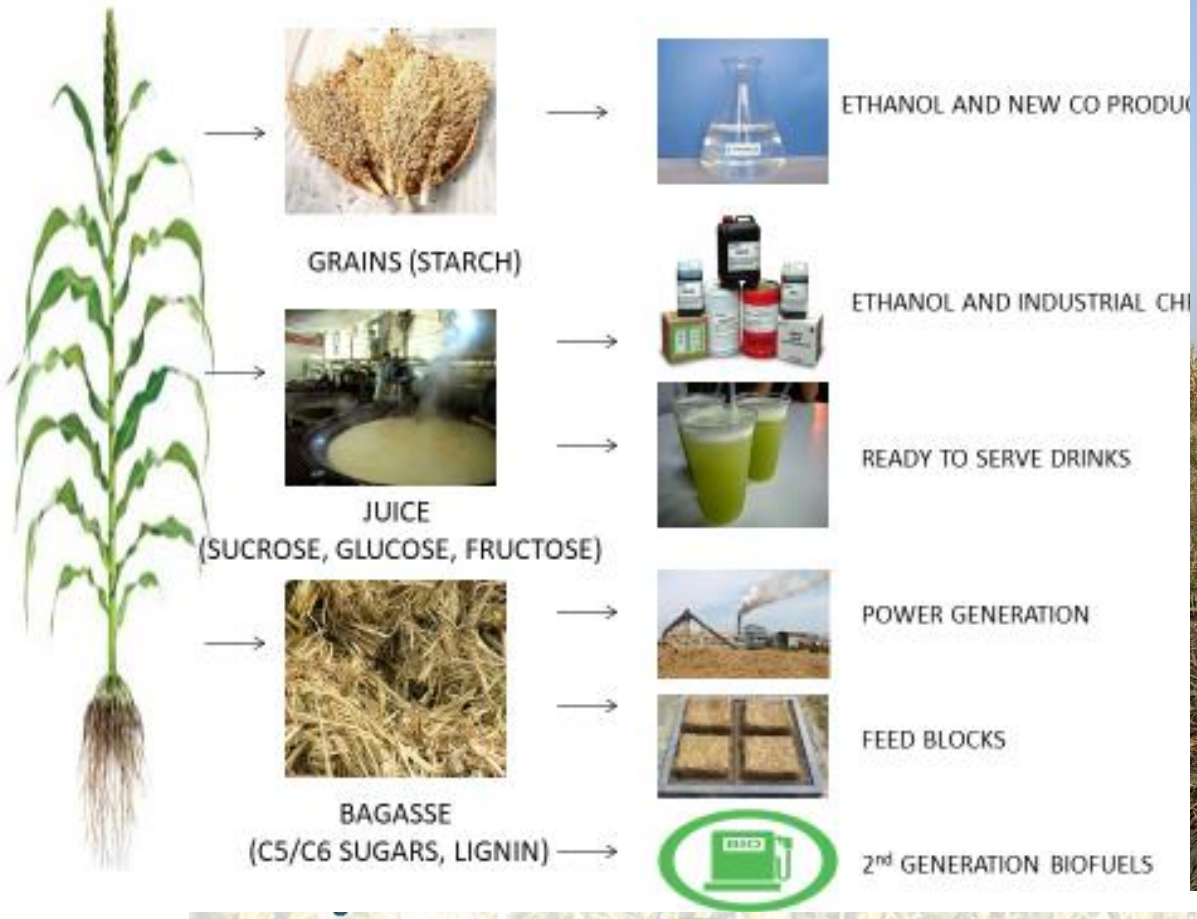
National Policy on Biofuels

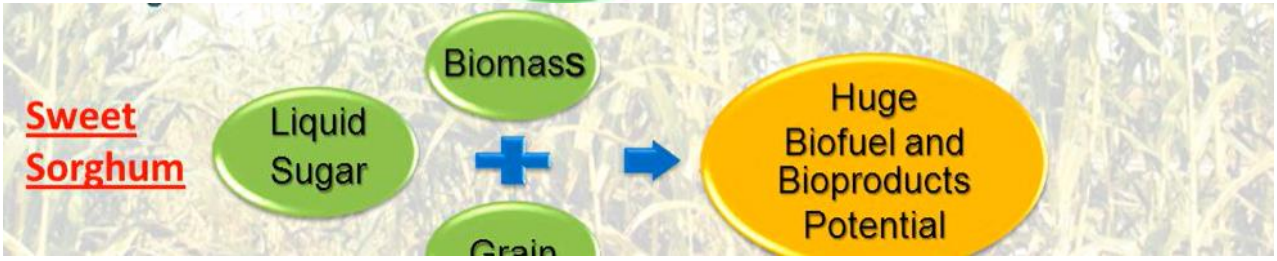


Type of raw material	Price (Rs/Lit)
Sugarcane juice / sugar / sugar syrup	63.45
B heavy molasses	59.08
C heavy molasses	46.66

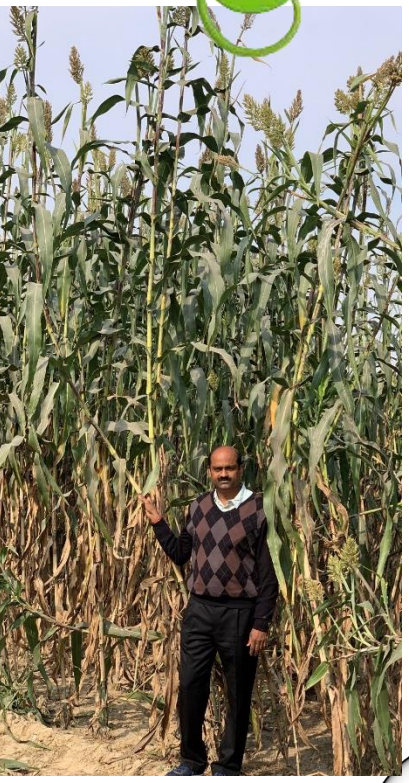
- Permits use of S`cane juice, B and C molasses, DFG, SFG to produce fuel ethanol .
- Sets prices for ethanol that are more remunerative
- Provides financial support to companies building distillery capacity
- Establishes, and accelerates, ethanol blending targets, culminating in nationwide adoption of E20 by 2025/26

Sweet sorghum for 1G ethanol





Advantages of sweet sorghum



- **Biomass production**: Efficient biomass producer
- **Energy balance:** Very high energy balance. Comparable relative energy efficiency as Sugarcane
- **Sowing window:** Long sowing window, multiple crops , improves economics immensely
- **Compatibility with sugarcane:** Easy integration into existing sugarcane cropping system (No CAPEX), can be processed with other feedstocks
- **Genetic Improvement:** Huge potential , hybrid technology in place

Comparison of sweet sorghum with sugarcane

Characteristics	Sugar Cane	Sweet Sorghum
Crop Duration	12 – 14 Months	4 Months
Propagation	Setts (40,000/ha)	Seed (8 Kg/ha)
Water Management	Requires more water (~36,000 m^3/ha)	Needs 1/4 of Sugarcane (~8000 m^3/ha)
Sugar content (weight basis)	10 – 12%	7 – 12%
Sugar yield (tons/ha)	5-12	3-7
Fertilizer Management	Intensive management N:P:K = 250-400:125:125 Kg/ha	Minimal management N:P:K = 80:40:40 Kg/ha
Cane Yield (tons/ha)	65 – 80 (Stalk)	45 – 60 (Stalk) for one cycle 90 – 120 for 2 cycles per year
Ethanol Yield (L/ha)	4350 – 7000	2000 – 3000 for one cycle 4000 – 6000 for two cycles
Cost of cultivation/ha (Rs in lakhs)	1.5-2.0	0.30-0.35

Ethanol yields from sweet sorghum

Ethanol (L/ha) from					
Juice	Cellulose	Hemicellulose	Grains[e]	Total ethanol (L/ha)	References
2800[a]	2125[b]	1320[c]	–	6245	Kim and Day (2011)
2252–5414[a]	2154–6591[d]		430–1223	4867–13,032	Zhao et al. (2009)
3820	7410		2370	13,600	Barcelos et al. (2016)
5000–6300	3154–4163		–	8300–10,500	Castro et al. (2017)

Comparison of Sweet sorghum and Sugarcane for Juice characteristics

Sl No.	Characters	Sweet sorghum	Sugarcane
1	Appearance	Thick and turbid	Clear and transparent
2	Density	High	Low
3	Purity (%)	70-90	90-98
4	Invertase activity	High	No activity
5	Sugar concentration in juice (As Brix)	10-22	16-20
6	Sucrose (%)	69-74	70-88
7	Proportion of sugar as reducing sugar	5-19	4-8
8	Starch (%)	0.4-5.3	0.001-0.005
9	pH	4.9-5.5	5.2-5.4
10	Aconitic acid	3.6-4.8	1.0-2.1
11	Protein (%)	0.9-1.3	0.5-0.6

Current thrusts in the Indian sorghum programme

- Development of high biomass and high sugar yielding sorghum hybrids/varieties with shoot pest tolerance suitable for use in bio-ethanol (1G) production
- Development of low lignin-high biomass sorghums utilizing *bmr* 6 and 12 genes suitable for lignocellulosic (2G) biofuel production

- Development of photo and thermo insensitive, drought and salinity tolerant sweet and high biomass sorghums
- Improving the shelf life of sweet sorghum cane/juice for preventing storage losses
- Exploring the production of other value added products

Sweet sorghum hybrids

Cane yield ha^{-1}: 45-55 t
Juice yield ha^{-1}: 14-18 KL
Brix: 17-18%

Cane yield ha^{-1}: 50-55 t
Juice yield ha^{-1}: 13-14 KL
Brix: 16-17%

Cane yield ha^{-1}: 45-50 t
Juice yield ha^{-1}: 16-18 KL
Brix: 16-17%

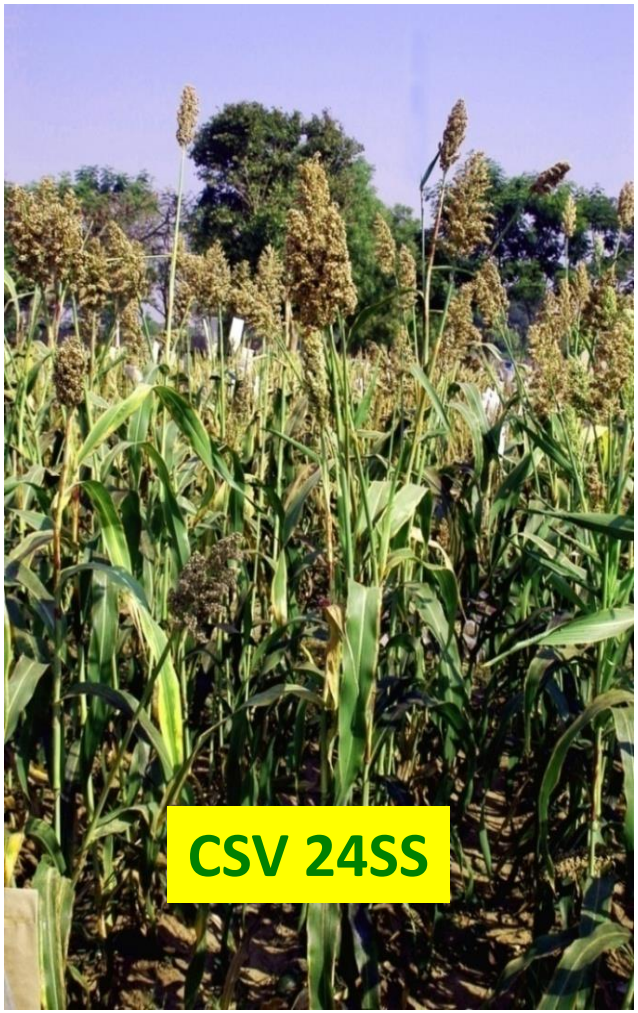
Sweet sorghum varieties

Cane yield ha^{-1}: 35-40 t
Juice yield ha^{-1}: 12-14 KL
Brix: 17-18%

Cane yield ha^{-1}: 40-45 t
Juice yield ha^{-1}: 12-14 KL
Brix: 17-18%

Cane yield ha^{-1}: 30-40 t
Juice yield ha^{-1}: 14-16 KL
Brix: 17-18%

Sweet sorghum varieties



Cane yield ha^{-1}: 35-40 t
Juice yield ha^{-1}: 12-14 KL
Brix: 17-18%

Cane yield ha^{-1}: 43-48 t
Juice yield ha^{-1}: 15-18 KL
Brix: 16-17%

Sweet sorghum variety-CSV 52SS

Released and notified during 2023 for the states of Maharashtra, Telangana, Tamil Nadu and Punjab

S No	Trait	Value
1	Brix (%)	16-17
2	Cane yield ha^{-1}	47-50 t
3	Juice yield ha^{-1}	15-16 KL

Sweet sorghum variety-CSV 58SS

Released and notified during 2024 for the states of Maharashtra, Telangana, Tamil Nadu, Punjab and Uttar Pradesh

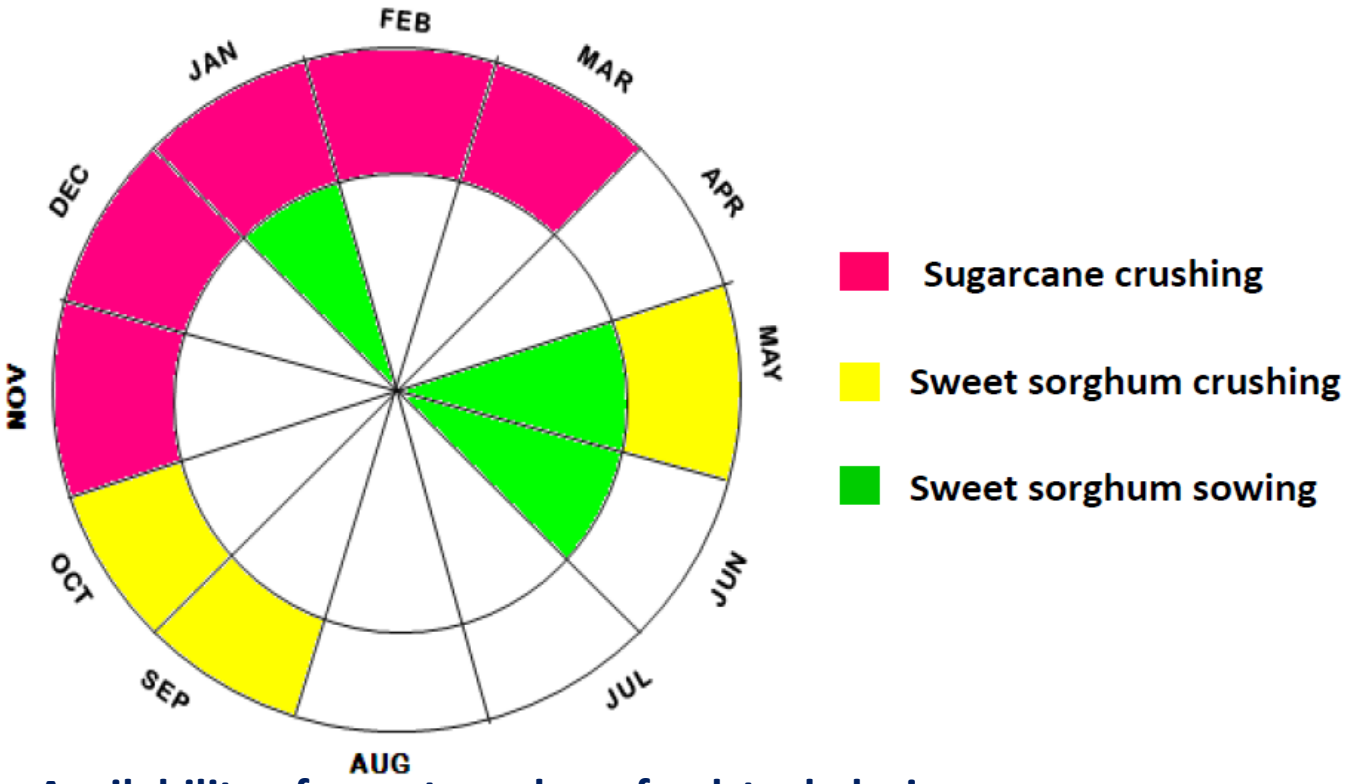
S No	Trait	Value
1	Brix (%)	16-17
2	Cane yield ha^{-1}	50-53 t
3	Juice yield ha^{-1}	15-16 KL

Sugarcane ratoon-Sweet sorghum Intercropping

Opportunities for sweet sorghum

- The wide space available between two rows of sugarcane
- Long duration for sprouting (30-45 days)
- Initially slow rate of growth
- Ability to compensate for any loss of tillers due to intercropping

Sweet sorghum based bioenergy calendar



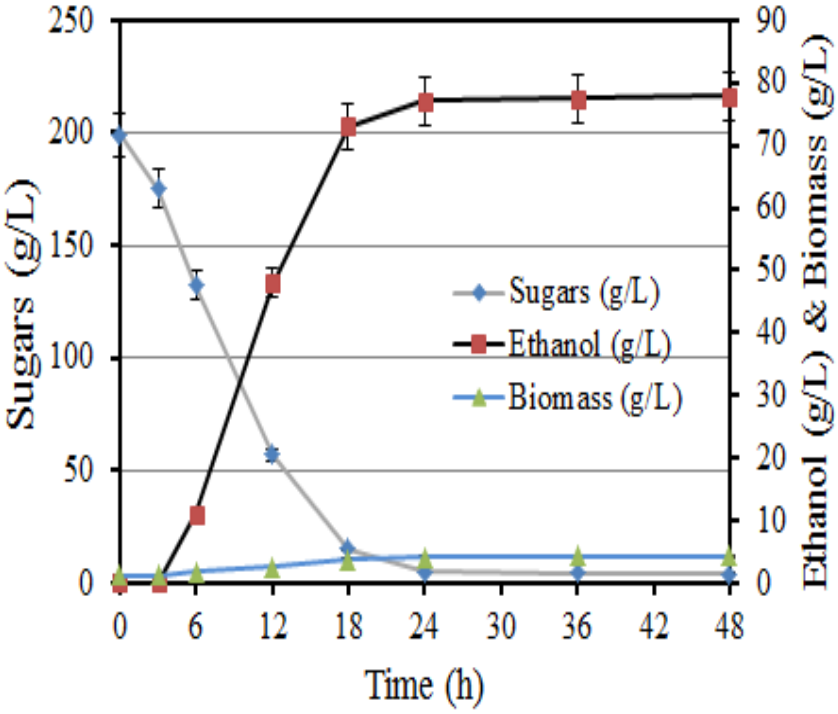
Availability of sweet sorghum feedstock during lean period of sugarcane crushing

Sweet sorghum sowing windows

1. Jan-Feb
2. May-July

Complementation of Sweet sorghum juice with molasses for ethanol production

Juice: Molasses	Initial Sugars (g/lit)	Final Sugars (gm/lit)	Ethanol (%)	Ethanol (gm/lit)	Ethanol yield (g/g)	Biomass conc (gm/lit)	dx/dt	μ=(1/x)*dx/dt
100: 0	198	0.0	9.3	62.4	0.3598	0.2231	0.0046	0.0208
90: 10	199	20.0	9.4	73.8	0.3784	0.1512	0.0032	0.0208
80: 20	200	20.0	9.4	73.8	0.3690	0.0593	0.0012	0.0208
70: 30	198	10.0	9.2	71.9	0.3995	0.0529	0.0011	0.0208
60: 40	201	30.0	9.4	73.8	0.3514	0.0519	0.0011	0.0208
50: 50	201	24.0	9.7	76.2	0.3630	0.0501	0.0010	0.0208
40: 60	**199**	**5.0**	**9.9**	**77.7**	**0.4091**	**0.0485**	**0.0010**	**0.0208**
30: 70	200	14.0	9.3	73.0	0.3651	0.0483	0.0010	0.0208
20: 80	198	18.0	9.9	77.7	0.3801	0.0493	0.0010	0.0208
10: 90	202	21.0	9.8	76.9	0.3497	0.0489	0.0010	0.0208
0: 100	202	1.3	9.5	75.4	0.3426	0.0426	0.0009	0.0208



Source: JNTU, Hyderabad

Fermentation with a mixture of 25% diluted molasses and 75% sweet sorghum juice resulted in around 17% higher ethanol productivity compared to the fermentation with sugarcane molasses alone.

*Source: Silva, E.H., Lemos, D.A., Cruz, A.J.G. et al. 2024. Bioethanol Production Using Mixtures of Sorghum Juice and Sugarcane Molasses. Sugar Tech **26**, 799–808*

Pilot Studies with sweet sorghum

35-58 lit of ethanol per ton of cane crushed

Big mill tests – 88% JE and Primary Brix: >17%

1. M/s Sri Renuka Sugars, Belgaum, Karnataka,
2. M/s Sagar Sugars, Chittoor, A.P
3. National Sugar Institute, Kanpur
4. M/s KCP Sugars, Lakshmipuram;
5. M/s Navbharat Ventures, Samalkot
6. Tata Chemicals Limited, Nanded
7. Madhucon Sugars, TS
8. EID Parry Ltd, A.P
9. Ganesh Sugars, Gujarat

Without changing a single nut and bolt in existing Sugarcane machinery, sweet sorghum could be crushed

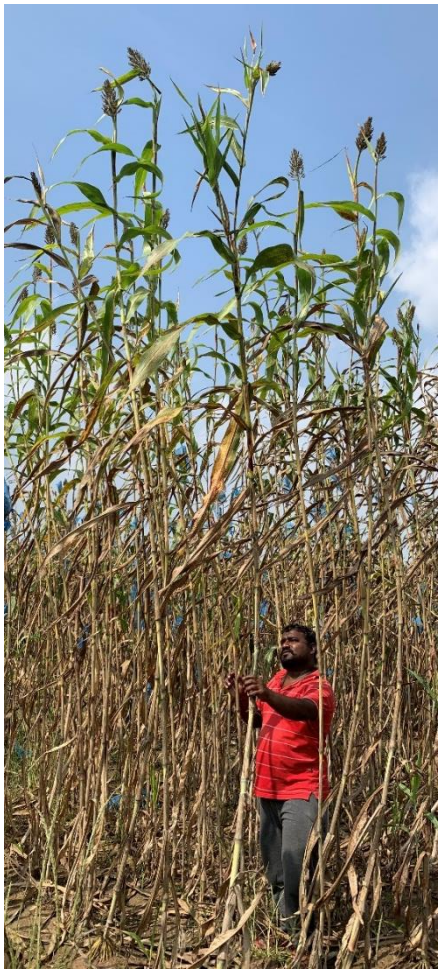

Biomass sorghum for 2G ethanol

Biomass sorghum as a feedstock for LC/2G biofuels

- Climate change ready crop
- Wider adaptability
- Productivity of >20 tons of dry biomass
- 2-3 crops per year
- Cultivars with variable maturities, ratoons for supply chain
- Hybrid technology in place
- Strong seed systems availability for scale up
- Low lignin sources available
- Easy storage of feedstock
- Atmanirbhar Bharat-Energy independent' by 2047

High biomass sorghum trial under AICRP on Sorghum-Kharif

Entry	Days to maturity	Fresh biomass (t/ha)	Dry biomass (t/ha)	Brix (%)
SPV2712	127	49.5	25.0	15.5
SPV2713	132	48.4	24.0	16.3
SPV2714	131	55.9	29.6	15.3
SPH 1798	144	73.5	32.4	15.7
SPV2611	138	45.7	22.0	15.4
SPV 2402	145	60.1	27.4	15.7
SPV2610	143	48.0	21.6	13.7
CSH 13	122	54.5	30.6	16.6
CSH 22 SS	133	63.2	32.1	16.8
P-Value	0	1	0	0.1
CD(5%)	7.86	19.3	2.5	1.96



Proximate analysis of LC biomass

Lines	Moisture (%)	Cellulose (%)	Hemi Cellulose (%)	Lignin (%)	Ash (%)	Ethanol Yield -C6 Sugars (L/Ton)	Ethanol Yield -C5 Sugars (L/Ton)	Total Ethanol Yield (L/Ton)
SPH 1798	7.0	35	28	22	2.02	182	198	380
SPH 1990	7.0	29	31	24	2.86	178	190	369
SPV 2402	7.3	32	28	23	2.83	177	198	374
SPV 2714	7.8	30	33	20	2.24	181	203	384
SPV 2810	6.7	28	31	23	3.37	173	187	360
SPV 2811	7.0	28	31	26	2.52	173	187	360
SPV 2812	6.5	31	30	24	2.57	187	184	372
CSH 13	7.1	32	32	23	2.58	196	197	393
CSH 22SS	6.5	29	31	22	2.74	174	187	361

ASTM Protocol

High biomass sorghum hybrid-CSH 47

FBM: 65-70 t/ha
DBM: 25-30 t/ha

Alcohol potential - DBT-ICT 2G Ethanol process

S No	Component	Result
1	Theoretical ethanol potential (L/ dry ton)	421
2	Actual ethanol potential (L/ dry ton)	334
3	Yield percentage (%)	79.3

Expected ethanol yield: 10,000 L/ha

High biomass sorghum variety-CSV 48 (*Jaicar Urja*)

Alcohol potential - DBT-ICT 2G Ethanol process

S No	Component	Result
1	Theoretical ethanol potential (L/ dry ton)	408
2	Actual ethanol potential (L/ dry ton)	293
3	Yield percentage (%)	72

Expected ethanol yield: 7,300 L/ha

Distilleries and Sweet sorghum utilization

- Establish a crushing section and connect to fermentation chambers
- Identify Cooperatives/FPOs in vicinity for promoting sweet sorghum cultivation
- Recruit a small field force for liaison
- Manage the supply chain (Agri team working with farmers)
- Link with an Oil Market Companies for lifting ethanol

Challenges

- Lack of policy support as there is no clear cut road map for commercialization of sweet sorghum
- Lack of awareness among the sugar industries of the country
- Absence of Multi feedstock model processing units
- Lack of mechanization in sweet sorghum cultivation
- Biotic stresses especially shoot pests and abiotic Stresses
- Storage losses

Way forward

- Commercialization of sweet sorghum cultivation is possible with required policy support
- Awareness creation in sugar industry-ISMA, AIDA and NFCSF about the complementarity
- Mechanization-Cultivation and processing
- Cultivation in non-traditional areas and problem soils
- Integration of 1G and 2G technologies.