Agronomy of Energy Sorghum in Temperate Climates

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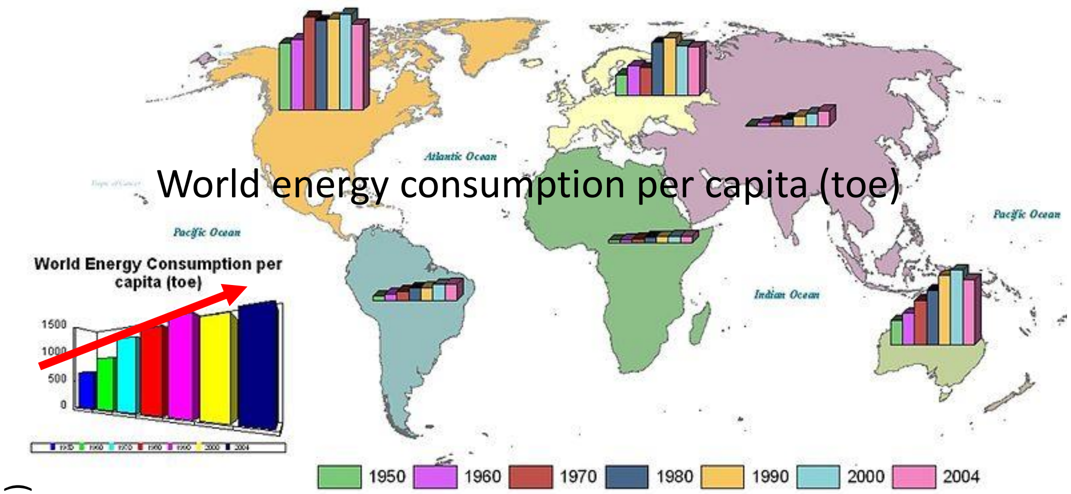
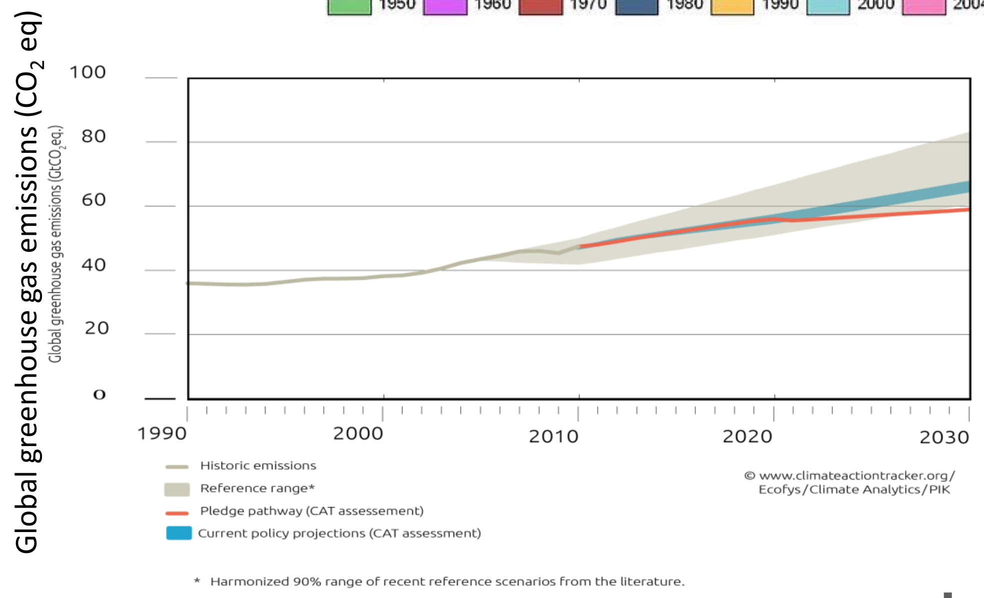
Sweet sorghum: feedstock for bioenergy

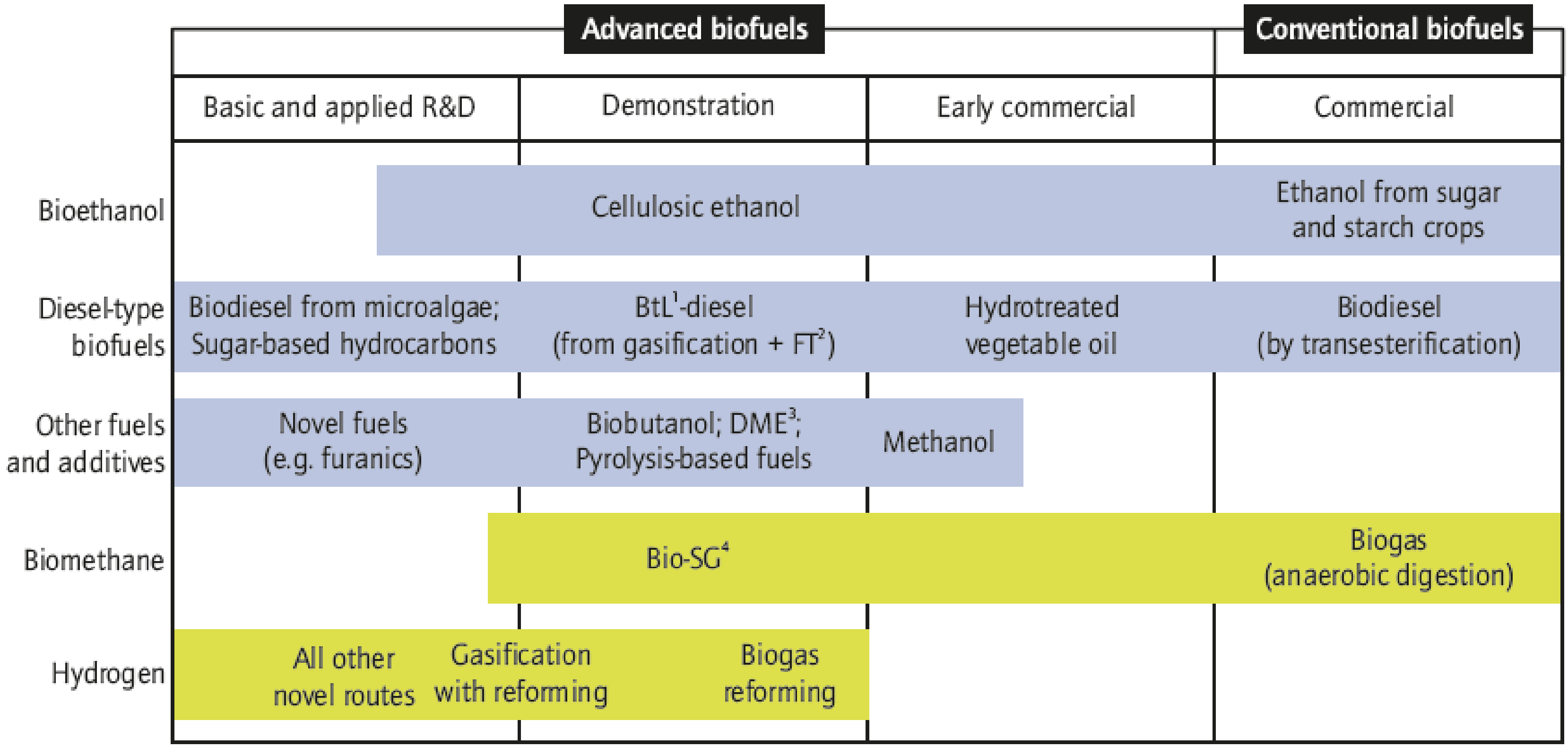
Sweet sorghum

- Versatility
- High yield potential
- Growth characteristics





Technological advancement status of alternative renewable energy sources



Liquid biofuel   Gaseous biofuel

1. Biomass-to-liquids; 2. Fischer-Tropsch; 3. Dimethylether; 4. Bio-synthetic gas.

Source: IEA 2011

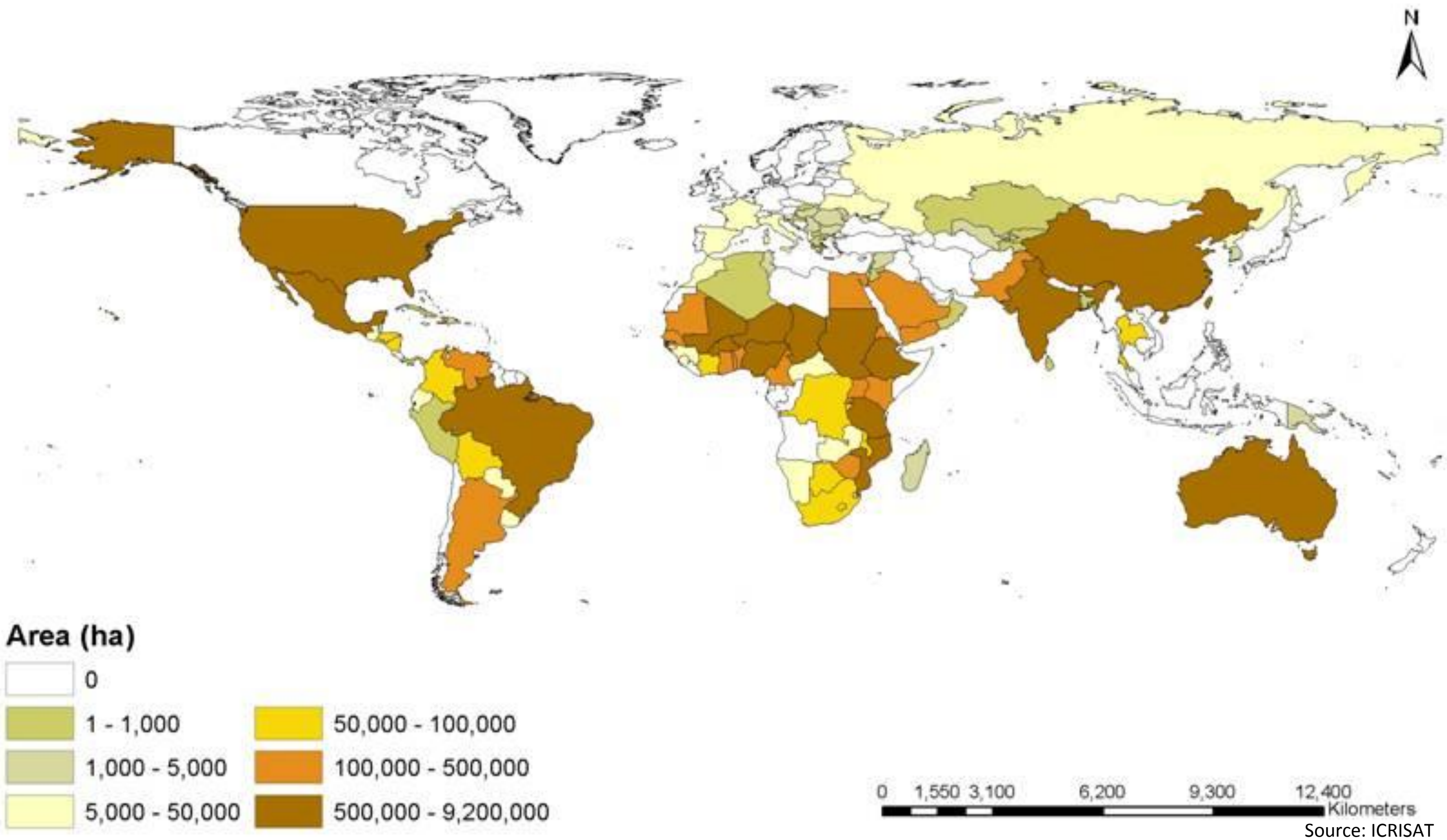
Sweet sorghum, grain sorghum, forage sorghum (*Sorghum bicolor*, Moench.)

Sweet and fibre sorghum are similar to grain sorghum with sugar- or cellulose-rich stalks, respectively

Sweet sorghum Height: 3 to 4 m
Sugar content: average 16-18 %

Fiber sorghum: cellulose-rich stalks

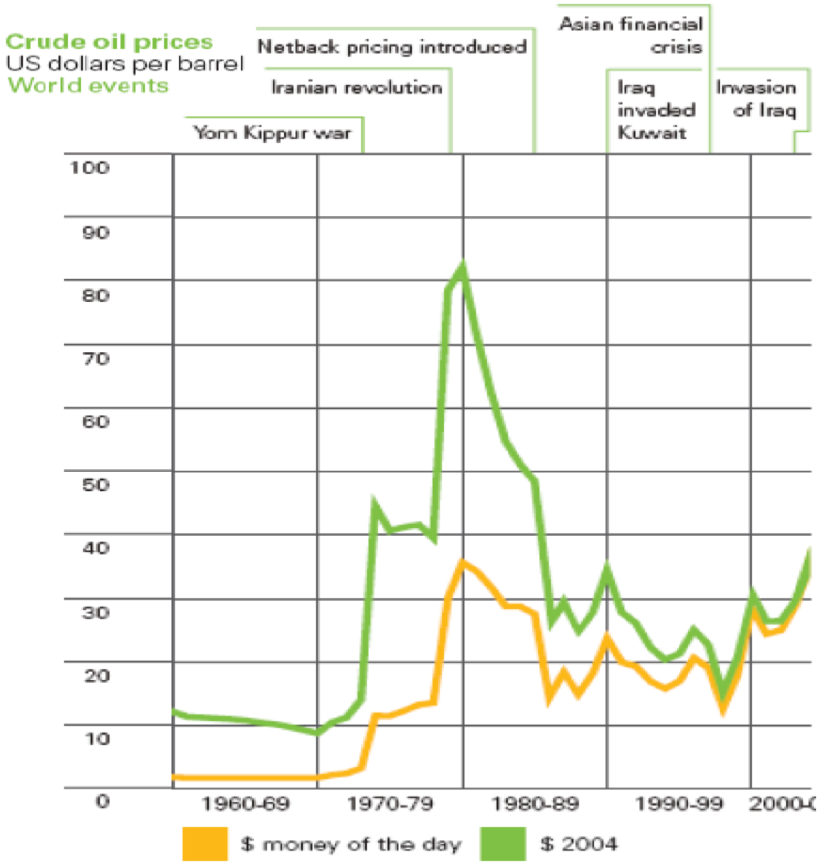
Potential interest and cultivation areas

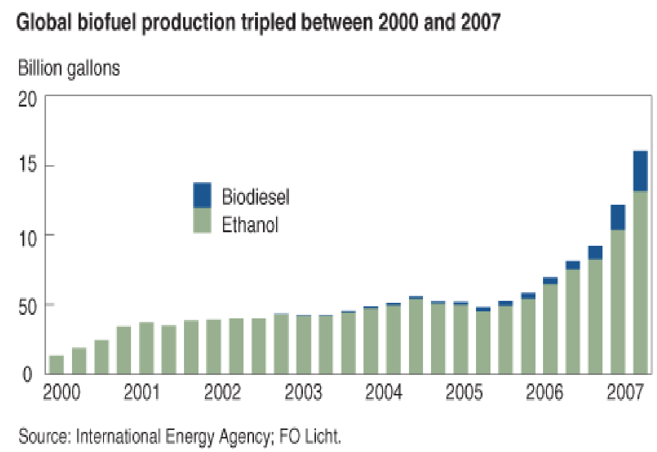


Source: ICRISAT

Origin: Central-Africa (Ethiopia, Sudan);
Low agronomic requirements compared to other sugar crops;
But the development of sweet sorghum as a dedicated energy crop is still far behind the development of maize, sugar beet or sugarcane

Research interest on sweet sorghum





Gaps on best agricultural practices

General information available (not especific for a determined environmental situation)

Source: Giacomazzi E., 2012

Sweet sorghum a row crop

Soils: Loam, sandy loam

Seed establishment

Panting density: 12-20 plants m^{-2}

Cultural methods easily adapted from maize

Sweet sorghum can be cultivated in soil not suitable for other crops

Sweet sorghum a row crop

Table 3 – Effect of row width on biomass and sugar yield of sweet sorghum.

Soil type	Row width (cm)	Stalk DM yield ($Mg\ ha^{-1}$)		Yield of sugar (kg)			
				Metric ton of stalk		ha^{-1}	
		Gross	Stripped	Sucrose	Fermentable	Sucrose and other water-soluble carbohydrates	Fermentable
Loamy sand[a]	53	23.1	17.9	82.8	135.0	4863	8046
	105	19.1	14.7	91.1	140.2	4426	6884
Silt loam and	35	18.7	13.2	–	–	7210	–
stony mottle red soil[b]	70	16.5	10.7	–	–	5860	–
	105	14.1	8.4	–	–	4280	–

a Data taken from [22]; average values of five cropping seasons; stalk yield data is originally presented in wet basis, for comparison purposes we computed the theoretical dry matter (DM) production assuming 70% moisture content.
b Data taken from [23].

Row width and plant density, an important management option to improve yields

Narrow rows and high plant density increase lodging susceptibility

Sweet sorghum sowing time

Table 4 – Effects of sowing date on yield and quality of sweet sorghum.

Cultivar	Treatment (sowing date)	Dry matter yield ($Mg\ ha^{-1}$)	Extractable juice (%)	Sucrose (%)	Juice purity (%)	Sucrose yield ($Mg\ ha^{-1}$)
Rio[a]	April 15	–	44.1	14.8	73.0	3.4
	May 15	–	45.5	14.7	73.2	3.4
	June 15	–	44.4	14.3	72.2	2.5
Roma[b]	October 12	13.3	–	12.0	83.0	5.2
	December 12	10.3	–	11.7	85.0	3.5
	December 21	8.5	–	11.0	82.3	3.2
Average[c]	April 24–29	23.0	–	–	–	4.2
	May 4–6	21.3	–	–	–	4.0
	May 15–16	20.8	–	–	–	3.6
	May 26–25	20.3	–	–	–	3.8
n.i.[d]	June 8	–	41.2	13.3	79.8	–
	June 23	–	40.2	12.3	76.2	–
	July 8	–	34.6	11.4	74.8	–
	July 23	–	30.4	10.2	68.8	–

a Data taken from [25]; average of four years (subtropical climate).
b Data taken from [26] (subtropical climate).
c Data taken from [20] average of four cultivars (301, 405, 8361A Northup King Co. hybrids and Keller) and two years (temperate climate).
d Data taken from [27]; n.i. not indicated the cultivar name (tropical climate).

Early spring sowing not recommended due to the low cold tolerance and reduce growth rates
Late spring not recommended due to the reduced effective growing season

Sweet sorghum sowing

Well cultivated seedbed

Sowing depth, 2.5 to 3.5 cm

Maize planter

No-tillage sowing possible

Sweet sorghum weeding

Weed control in sorghum with late salvage herbicides, Manhattan, Thompson / Peterson, 0903corn

Treatment	Rate	Yield	injury	PAAM	VELE	Sunf
	Prod/a	Bu/a	7/14	14DAT	14DAT	14DAT
Atrazine+COC	1.5+1%v/v	72	0/0	73	75	100
Aim EC+ NIS	.5oz+.25%	55	23/7	40	100	57
Aim+Atra+NIS	.5oz+1.5+.25	65	28/10	60	96	87
Rage D-Tech+NIS	.5pt+0.25%	68	38/18	80	100	93
2,4-D ester	16 oz	109	13/5	77	95	92
2,4-D ester+atra	8oz+.56lb	98	17/7	82	98	96
Ally + 2,4-D amine	.05oz+8oz	82	12/10	79	75	88
Permit+Atra+COC	.67oz+1lb+1%	76	2/0	82	68	94
Yukon+atra+COC	6 oz+1lb+1%	112	7/5	82	77	95
Marksman	2 pt	99	10/5	88	88	95
Untreated		19				
LSD (0.05)		30	9		10	15

Source: Thompson C., 2010

Treated

Untreated

Sweet sorghum pest control

Table 5 – Effect of different infestation levels of Lepidoptera (*Diatraea saccharalis*) on the larval survival, adult emergence and sweet sorghum sugar yield.[a]

Infestation level[b]	Number of larvae per plant[c]	Adult emergence per plant	Sweet sorghum sugar yield (Mg ha^{-1})
0–0	0.0	0.00	7.2
0–15	0.9	0.05	6.2
0–30	0.8	0.07	5.6
15–0	2.0	0.41	6.3
15–15	2.6	0.47	5.4
15–30	3.0	0.42	5.7
30–0	3.6	0.48	5.6
30–15	4.5	0.62	5.2
30–30	4.6	0.47	4.9

a Data taken from [31].
b Number of larvae placed on a plant three and one weeks before panicle appearance.
c Number of live larvae, 15 days after infestation.

Implementation of good agricultural practices

Integrated pest and disease management

Soil fertility and water management

Crop rotations

Use of high quality seeds

Sweet sorghum nutrient management

Table – 1: Mean comparisons[1] among planting dates and stages of nitrogen application for stem height at different growth stages.

Treatment	Stems height (cm)			Stem diameter (cm)	
	3-5/8 leaf	Flowering	Hard dough	Flowering	Hard dough
Planting date					
May 4	9.4c	194.2a	203.1a	1.23	1.37a
May 19	12.6b	193.7a	195.1a	1.30	1.22b
June 3	12.8b	188.5a	194.5a	1.17	1.16bc
June 18	14.7a	165.7b	168.0b	1.17	1.12c
Stages of nitrogen application					
3-5/8 leaves	13.7a	186.3	189.2	1.29a	1.28a
Booting	11.9b	186.0	190.2	1.20a	1.19b
Soft dough	11.6b	185.9	189.3	1.16b	1.18b

[1] Means comparisons were made using Duncan's multiple range test. Means with the same letter are not significantly different at 5% level.

Source: Almodares and Darany, 2006

Low fertilization requirements (e.g. 40% < maize)

Lower N uptake

More N uptake at latter growth stages

Table – 4: Mean comparisons[1] among planting dates and stages of nitrogen application for total dry weight at different growth stages.

Treatment	Total dry weight (g/m^2)			
	3-5/8 leaf	Flowering	Hard dough	Physiological maturity
Planting date				
May 4	26.8	1413.0a	2281.2a	2085.0a
May 19	38.5	1389.3a	1885.6b	1870.2a
June 3	38.4	1123.3b	1494.8c	1482.1b
June 18	39.8	972.7b	1198.1c	1126.9b
Stages of nitrogen application				
3-5/8 leaves	44.8a	1338.5a	1811.8	1938.5a
Booting	30.9b	1175.3b	1651.7	1549.4b
Soft dough	31.9b	1159.8b	1680.7	1577.0b

Means comparisons were made using Duncan's multiple rang test. Means with the same letter are not significantly different at 5% level.

Sweet sorghum nutrient management

Table 6 – Biomass production, nutrient uptake, juice quality and calculated ethanol yields of late maturing and early maturing sweet sorghum cultivars at different N application levels.

Soil type	Cultivar	Treatment ($kg\ N\ ha^{-1}$)	Yield ($Mg\ ha^{-1}$ d.w.)	Nitrogen uptake ($kg\ N\ ha^{-1}$)	Phosphorous uptake ($kg\ P\ ha^{-1}$)	Total dissolved solids in juice (%)	Theoretical ethanol yield ($L\ ha^{-1}$)
Clay loam[a]	MN 1500	0	16.0	98	21	14	2601
		112	19.7	140	25	14	3241
		224	18.2	132	22	13	2830
	Rio	0	9.0	48	14	21	2197
		112	12.6	80	16	20	2899
		224	12.9	90	16	20	3036
Clay loam[b]	Average	0	27.2	–	–	–	3170
		84	26.7	–	–	–	3216
		168	26.8	–	–	–	3156
Silty clay loam[b]	Average	0	18.8	–	–	–	3209
		84	19.7	–	–	–	3225
		168	20.1	–	–	–	3175
Sandy clayed[c]	Keller	0	26.4	206	–	–	–
		60	26.4	217	–	–	–
		120	24.1	200	–	–	–

a Data taken from [37].
b Data taken from [34], average of four cultivars (Dale, Keller, Rio, Grasll) and two years.
c Data taken from [38].

Excessive N fertilization can reduce biomass yields, juice quality, and ethanol yields

Sweet sorghum harvest

Table 8 – Effects of harvesting times and method on sweet sorghum juice quality.

Treatment		Juice extraction (%)	°Brix	Sucrose (%)	Coeff. of apparent purity
Harvest time	Flowering stage[a]	50.4	14.5	8.0	55.1
	Milk stage[a]	47.8	17.6	12.4	70.5
	Dough stage[a]	46.2	20.0	14.6	73.2
	Ripe[a]	44.2	21.0	15.2	72.6
	One week after ripe[b]	45.2	20.2	14.7	73.0
	Two weeks after ripe[b]	44.6	20.0	14.6	72.7
	Three weeks after ripe[b]	44.5	19.9	14.5	72.1
	Four weeks after ripe[b]	44.4	18.8	14.0	73.0

a Data taken from [53].
b Data taken from [25].
c Data taken from [54].

°Brix readings from anthesis may be used to determine the optimum harvest time

Maximum sugars production restricted to 30 40 days period

Cultivars with different maturities and scalar sowing times may extend the best harvesting period

Sweet sorghum harvest

Table 8 – Effects of harvesting times and method on sweet sorghum juice quality.

Treatment		Juice extraction (%)	°Brix	Sucrose (%)	Coeff. of apparent purity
Deheading[c]	At boot stage	42.5	19.7	14.9	75.4
	At flowering	42.2	19.6	14.6	74.7
	Non deheaded	44.0	18.9	14.1	74.6

a Data taken from [53].
b Data taken from [25].
c Data taken from [54].

Deheading eliminates the competing sink force of reproductive organs thus helping to increase the sugar content and reduce the chances of lodging before harvest

Sweet sorghum harvest


Cutting bars, silage harvesters, straw balers, and sugarcane harvesters

Each harvesting system produce material with specific storage and handling requirements

Sweet sorghum harvest

Table 9 – Juice characteristics of sweet sorghum harvested with different methods and stored for different times.

Cultivar	Storage (days)	Harvest method								
		Whole steam			Billeted stem (40–60 cm)			Chopped stem (0.5–10 cm)		
		°Brix	Sugar content (%)	Recovery of ethanol (%)	°Brix	Sugar content (%)	Recovery of ethanol (%)	°Brix	Sugar content (%)	Recovery of ethanol (%)
Rio[a]	0	19.3	14.2	–	19.3	14.2	–	19.1	14.2	–
	1	20.1	14.8	–	19.3	14.4	–	19.0	14.1	–
	2	20.6	14.5	–	19.9	14.2	–	19.6	14.1	–
	Avg.	20.0	14.5	–	19.5	14.3	–	19.2	14.1	–
Wray[b]	0	15.9	10.9	87.3	17.1	–	85.3	15.4	9.9	79.3
	1	16.4	11.1	–	16.4	–	–	12.8	8.5	–
	2	17.0	11.3	86.7	16.5	–	85.3	11.8	8.6	65.7
	4	17.4	11.1	87.7	16.3	–	83.3	9.9	6.1	80.3
	7	17.9	11.0	81.3	15.8	–	82.3	7.0	5.0	67.0
	Avg.	16.9	11.1	85.8	16.4	–	84.1	11.4	7.6	73.1

a Data taken from [60].
b Data taken from [61].

Limited storability and fast decay affect sweet sorghum production system

Bottlenecks

i) **The limited availability of certified commercial seeds**

ii) Improved genotypes in different environments, soil conditions, and available agro-techniques

iii) **Appropriate harvest and post harvest logistic systems.**

Conclusions

i) **Development of sweet sorghum as bioenergy feedstock is behind the development of maize, sugar beet, or sugarcane**

ii) Can be grown as row crop and its establishment by seeds is easy and cheap

iii) Higher planting densities and narrower than conventional planting rows, could result in higher stalk and sugar yields but at the same time may increase lodging problems

iv) Lower nitrogen fertilizers than other row crops, but for energy purposes it seems that the timing of fertilization is more important than the fertilization rate

v) **Several harvesters are being tested worldwide, but they still need to be improved /adapted**

vi) **The fast decaying of the harvested material a major problem for sweet sorghum production system**

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