DEVELOPMENT OF CULTIVARS FOR INDUSTRIAL PROCESSING/ETHANOL PRODUCTION IN BRAZIL

International Workshop on Sorghum for Biofuels

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Development of Energy Sorghums

• In the late 1970´s Brazil initiated a bio-energy program (Pro-Alcohol) anticipating an energy crises caused by a shortage of petroleum to meet Brazil's fuel needs.

• There was a strong incentive to develop technology for micro-distilleries (100 L hr^{-1}) and mini-distilleries (1000 L hr^{-1})

• Embrapa´s sweet sorghum program was developed to provide raw material for these small distilleries.

• Two New Sweet Sorghum Varieties ‘were Released (25 Varieties Shelved) in the mid 1980’s.

• Pilot Projects were successfully developed in the mid-1980’s at Sete Lagoas, Brasilia, and Pelotas to process sweet sorghum in micro-distilleries.

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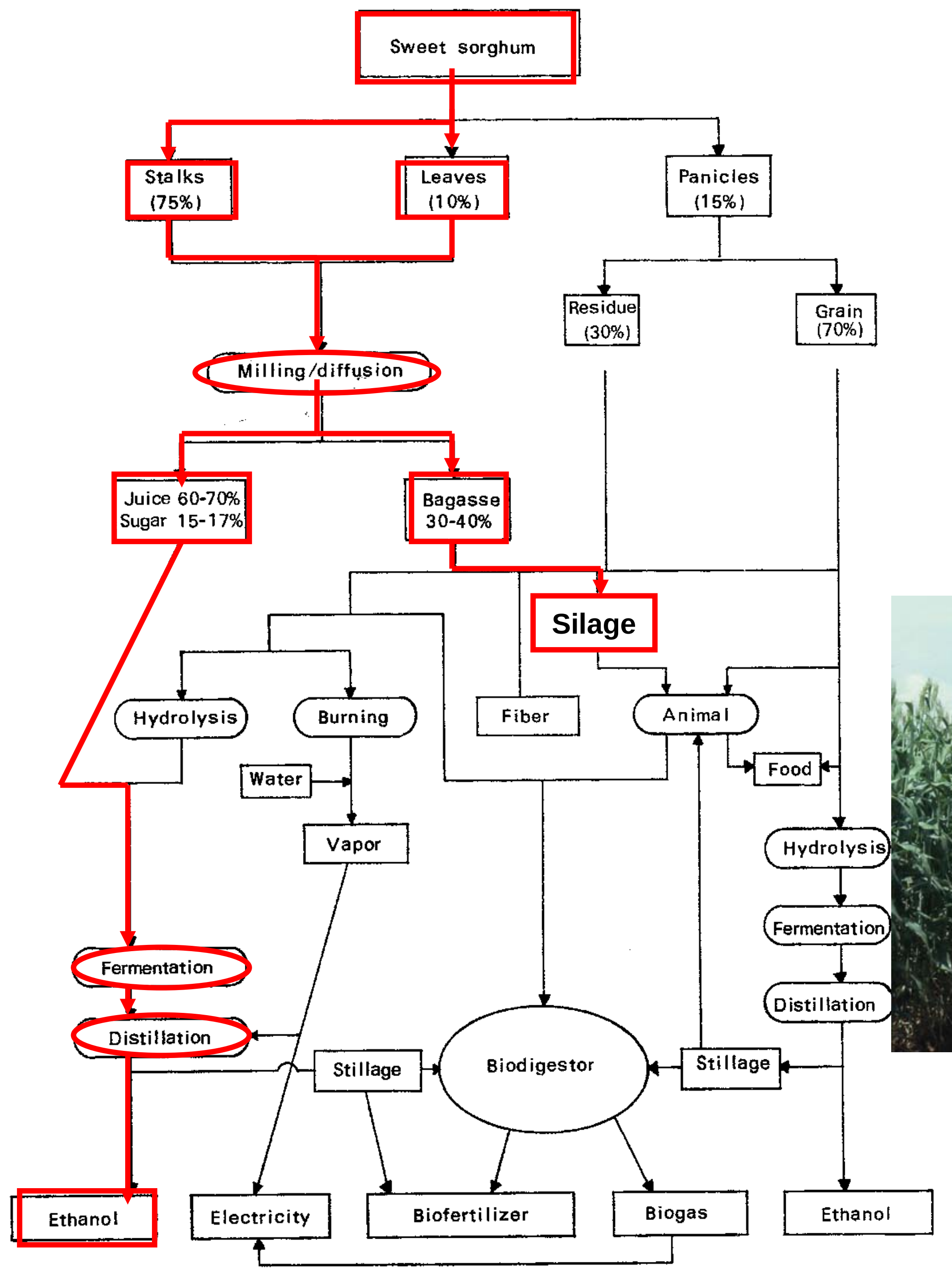
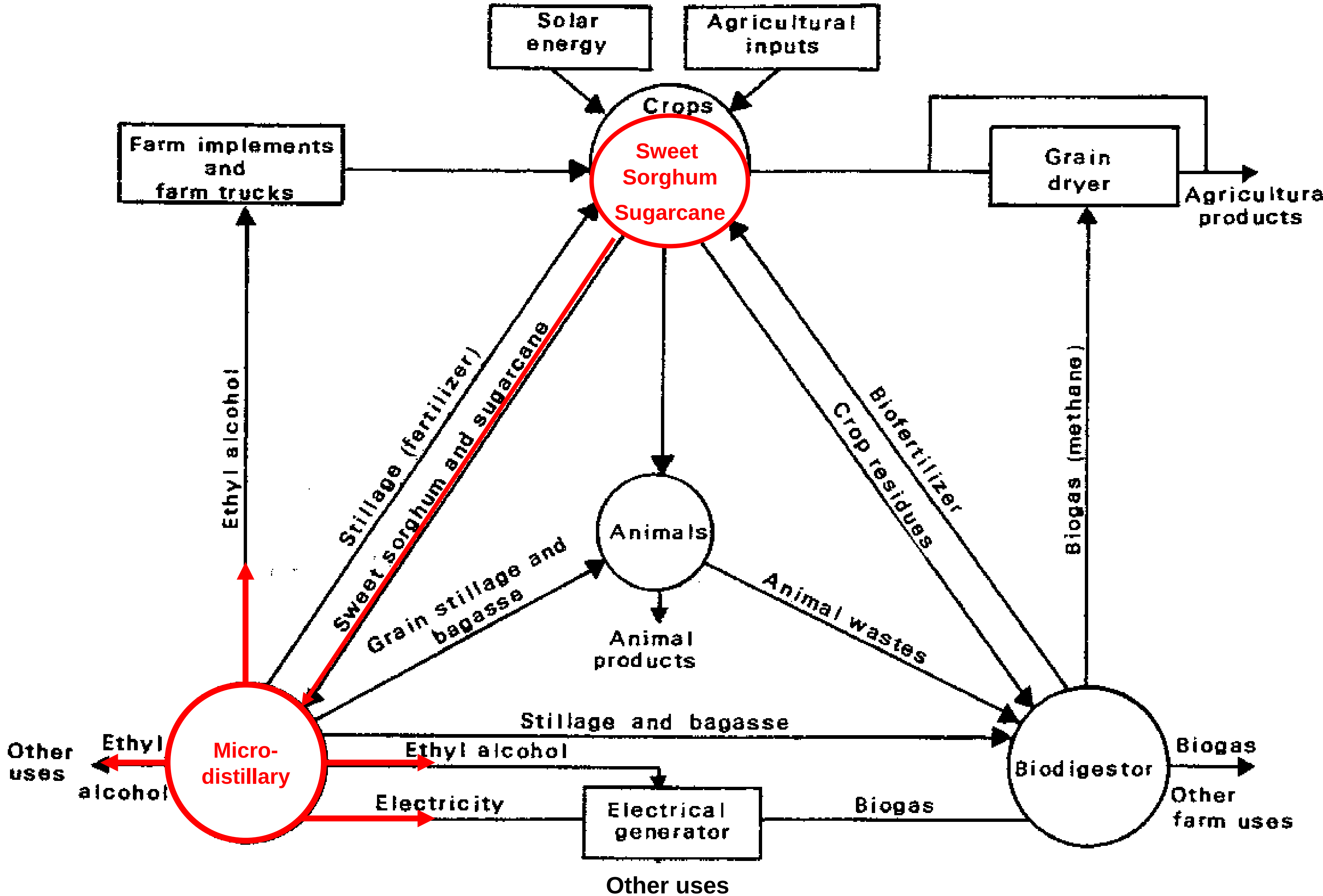
The potential uses of sweet sorghum for food, fiber, fertilizer, ethanol, and methane gas production

(Embrapa Maize and Sorghum)



Advantages of Using Sweet Sorghum vs. Sugarcane

- Sweet sorghum may be harvested 3 – 4 months after planting
- Sweet sorghum production can be completely mechanized
- The sweet sorghum crop can be established from seed
- The grain from sweet sorghum can be used as food, feed or fuel
- The bagasse from sweet sorghum has a higher biological value than the bagasse from sugarcane when used as a forage for animals
- Sweet sorghum is more water use efficient
- Compliments sugarcane by extending harvest period by up to four months per year



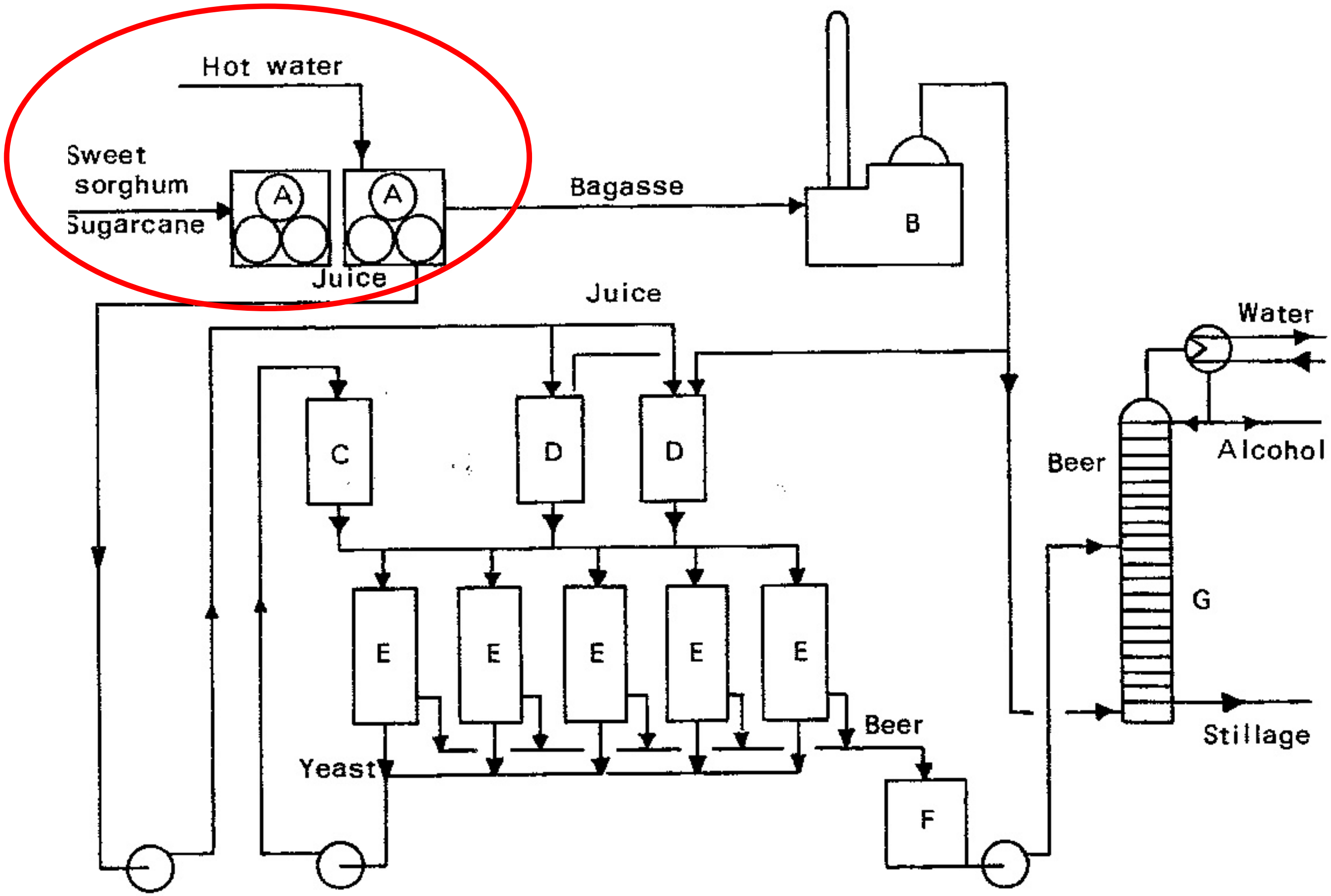
Integrated Rural Energy System Developed at Embrapa Maize and Sorghum 1980

Development of Sweet Sorghum Cultivars

Breeding priorities depend upon how the product will be used

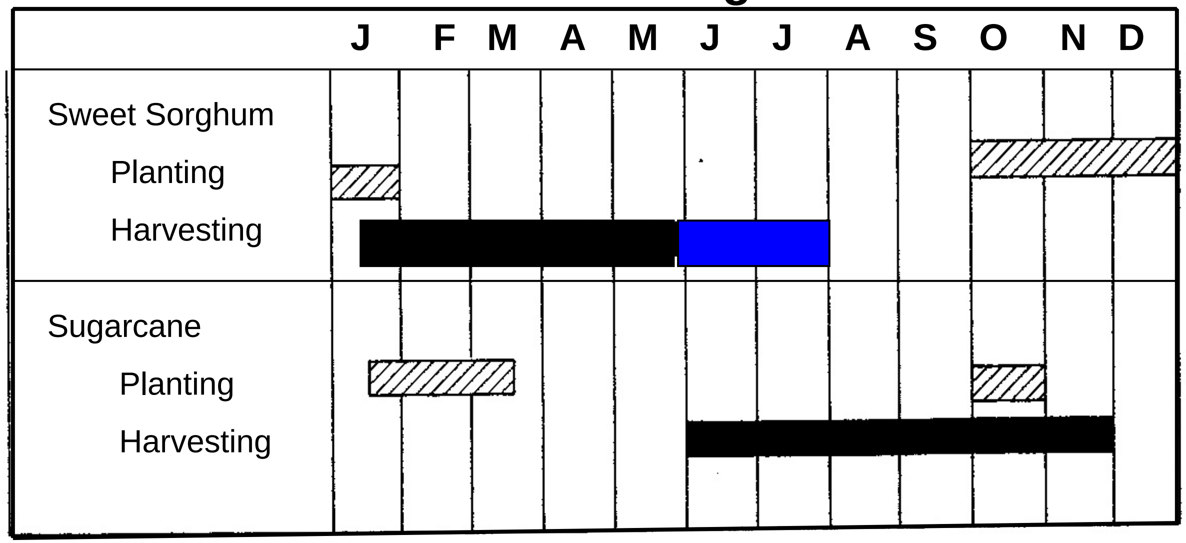
- Panicles removed for food or feed
  - Small vs. large panicles
- Juice is extracted from stalks and leaves
  - Not feasible to separate leaves and stalks
- Juice fermented in micro- and mini-distilleries
  - Juice extraction less efficient in smaller distilleries
- Bagasse used for forage or fuel
  - Starch present in sorghum juice and stalk
  - Biological value of sweet sorghum bagasse is greater for sweet sorghum than for sugarcane
- Tillering vs. non-tillering to control stalk diameter

A Simple Flow Diagram of a Roller Mill Micro-distillery; Used in Establishing Breeding Priorities at Embrapa Maize and Sorghum



A - roller mill, B - boiler, C - yeast treatment and distribution tank, D - juice distribution tanks, E - fermentation tanks, F – beer holding tank, and G - distillation column (Embrapa Maize and Sorghum)

Industrial Planning



Planting and harvesting periods for sweet sorghum and sugarcane in Brazil. (Embrapa Maize and Sorghum)

Ratoon Harvest
Irrigation Required

Yield and Quality Goals must be Established

- Minimum Biomass Yield - 40 tha^{-1}
- Minimum Total Sugar Extraction – 80 kg $1t^{-1}$ biomass

  Considering 60-65% Extraction Efficiency (low fiber and high extraction - easy juice higher brix and sugar)

- Minimum Total Sugar Content in Juice – 12.5%
- Minimum Alcohol Yield – 40L t^{-1} biomass

  Considering:

  60 -65% sugar extraction efficiency
  90% Fermentation Efficiency
  90% Distillation Efficiency or 81% Industrial Efficiency

- Establish minimum parameters for determining Period of Industrial Utilization (PIU - 80 kg 1t-1 biomass)
- Minimum PIU – 30 days

Minimum Parameters for Determining Period of Industrial Utilization (PIU)

- **Minimum Total Sugar Extraction – 80 kg 1t^{-1} biomass**

  Considering 60-65% Extraction Efficiency

- **Minimum Total Sugar Content in Juice – 12.5%**

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  Considering:

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- **Minimum PIU – 30 days**

Total Biomass Production of Two New Sweet Sorghum Varieties Developed at Embrapa for Micro-distilleries

National Forage Sorghum Trial - 1986/87 Embrapa Maize and Sorghum

Cultivar	Linhares ES 10.12.86	Goiânia GO 29.12.86	Capinópolis MG 01.12.86	Ituiutaba MG 16.12.86	Taquari RS 12.12.86	Cruz Alta RS 04.12.86	S.J. dos Campos SP 09.01.87	Mean	Relative Mean BR601 (%)
Biomass Production (t/ha wet weight)									
BR506 (V)	46.3	55.2	43.3	55.5	41.9	59.3	50.8	52.8	109
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BR126* (MV)	19.1	39.6	36.6	35.0	25.5	32.3	36.0	32.1	66
Biomass Production (t/ha dry weight)									
BR506 (V)	14.4	11.6	10.2	NA	13.4	17.7	18.7	14.6	108
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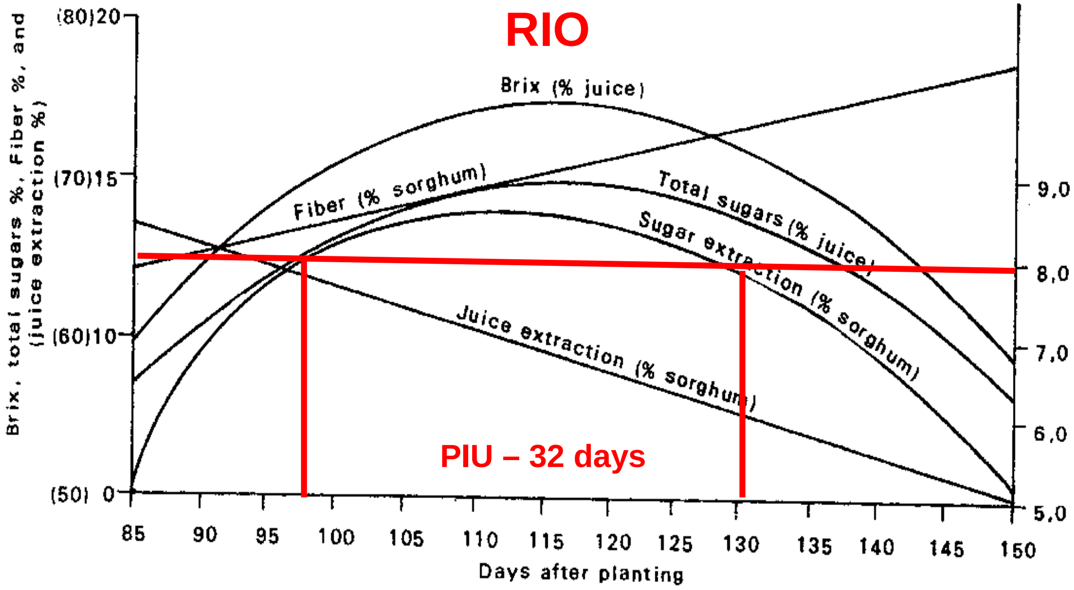
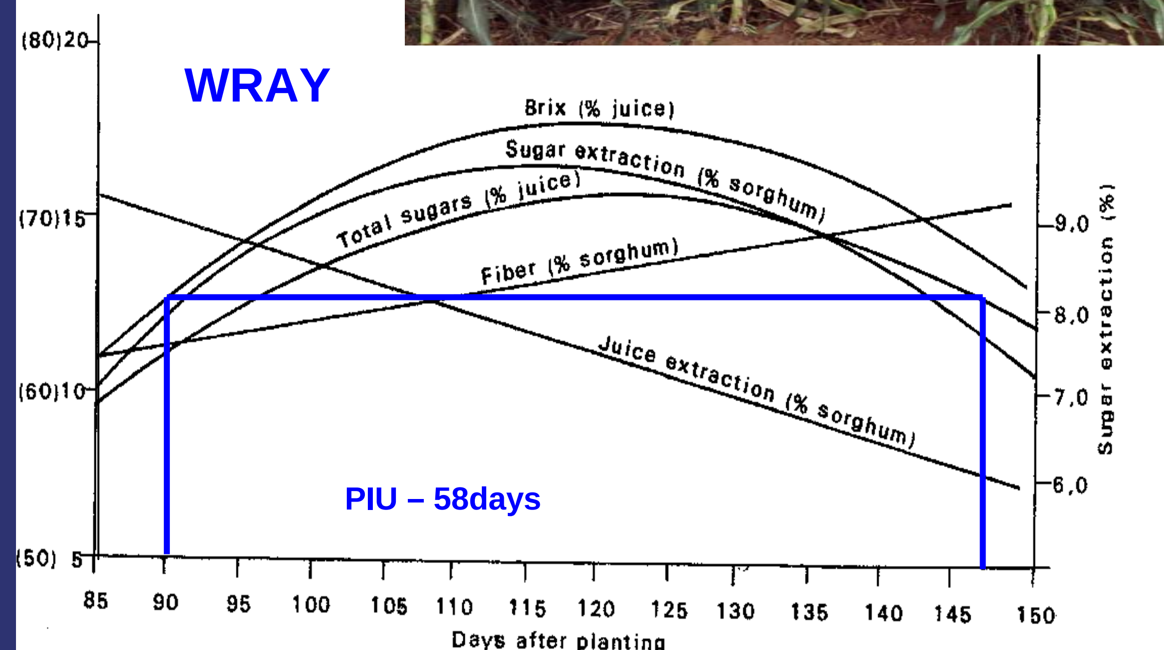
BR601(H)	12.0	14.6	12.7	NA	14.8	18.3	14.3	13.5	100
BR126* (MV)	7.4	16.9	15.4	NA	9.9	11.8	12.7	11.5	85

* Forage Maize Variety



The interaction of refractometry Brix and percent total reduced sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of sorghum stalks during the maturity phase for the varieties Rio and Wray grown in Brazil,

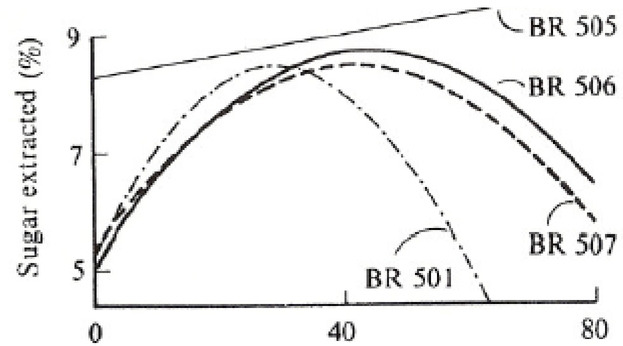
(Embrapa Maize and Sorghum)



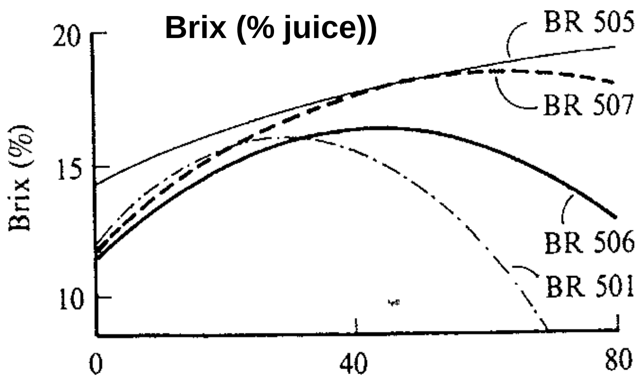
Brix, Total Sugars, Fiber and Percent Water of four sweet sorghum cultivars at Embrapa Maize and Sorghum, Sete Lagoas, Brazil, 1986/87.

BR 501 = Brandes, BR 505 = Wray, BR506 and BR507 are new derived varieties

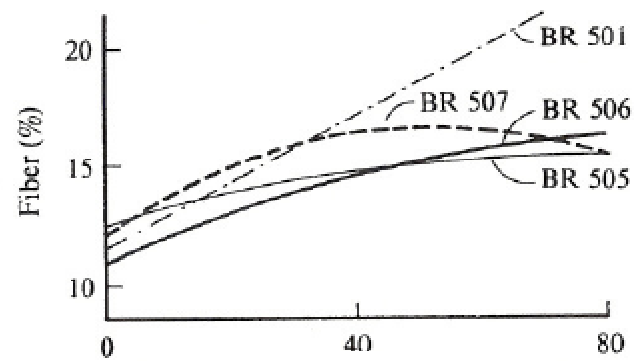
Sugar extracted (Kg 100 Kg biomass)



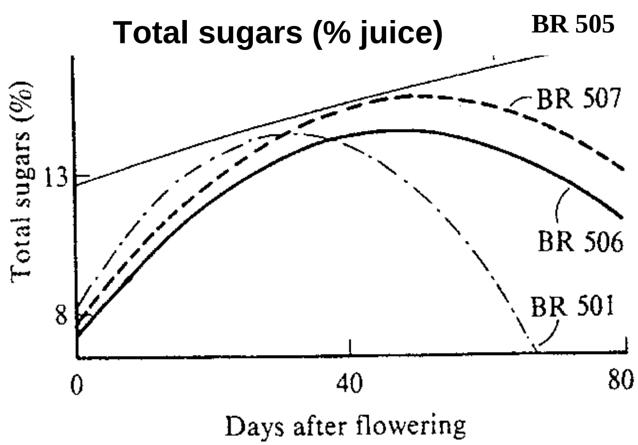
Brix (% juice))



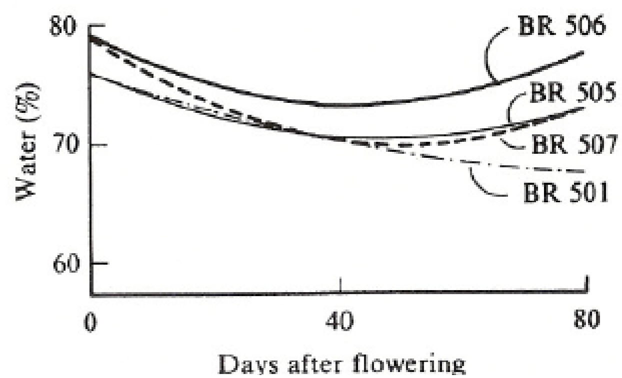
Percent fiber of fresh biomass



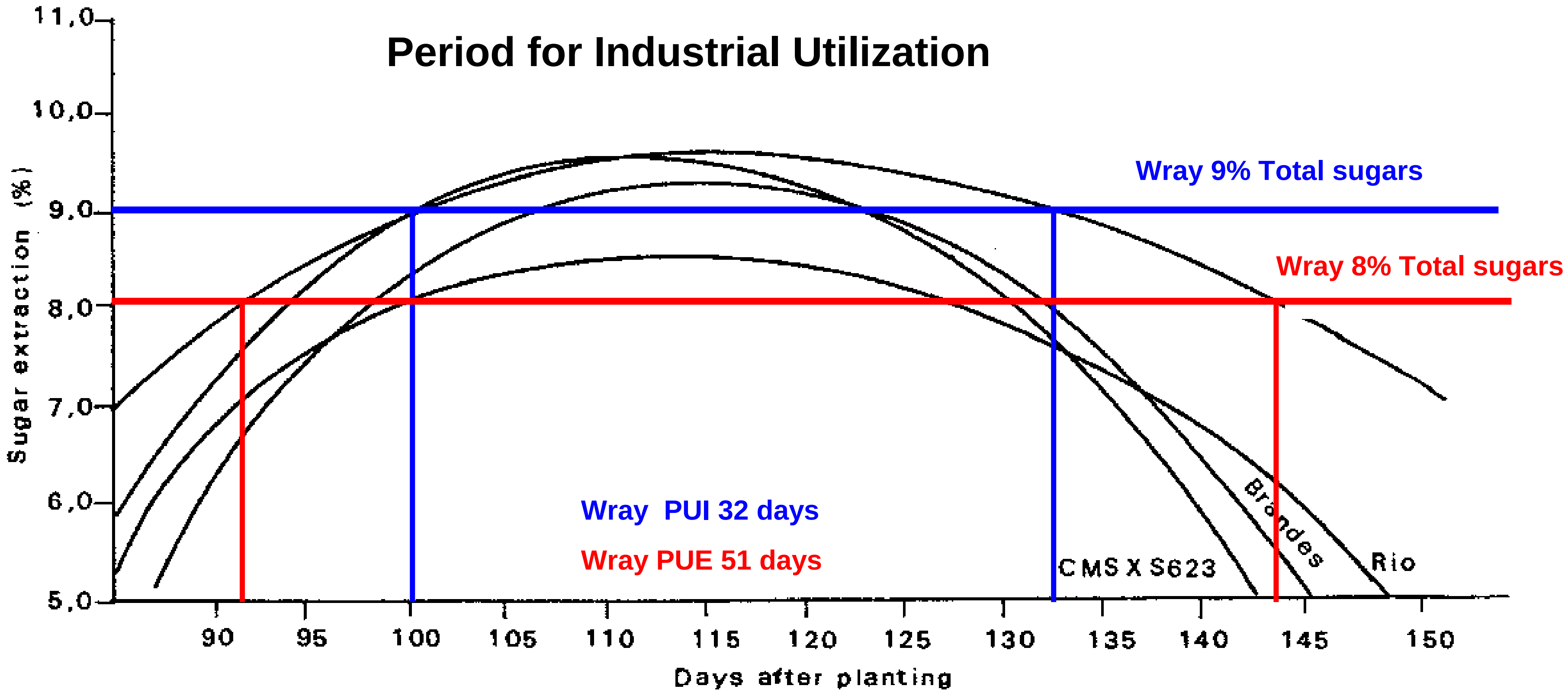
Total sugars (% juice)



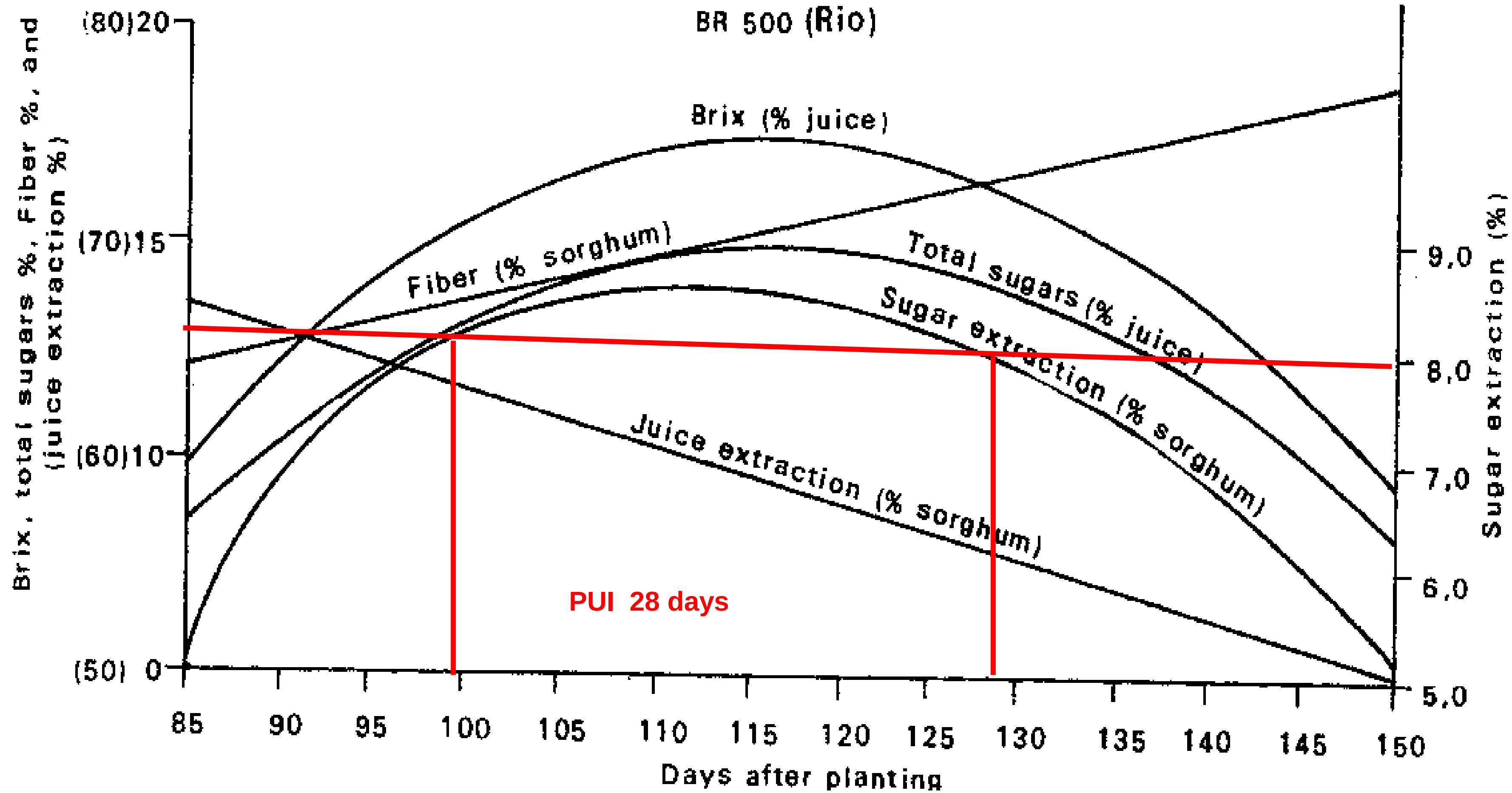
Percent water in the biomass



Period for Industrial Utilization



The differences between four cultivars grown in Brazil for total invert sugar extraction of the stalks during the maturity phase of production (CNPMS/EMBRAPA).



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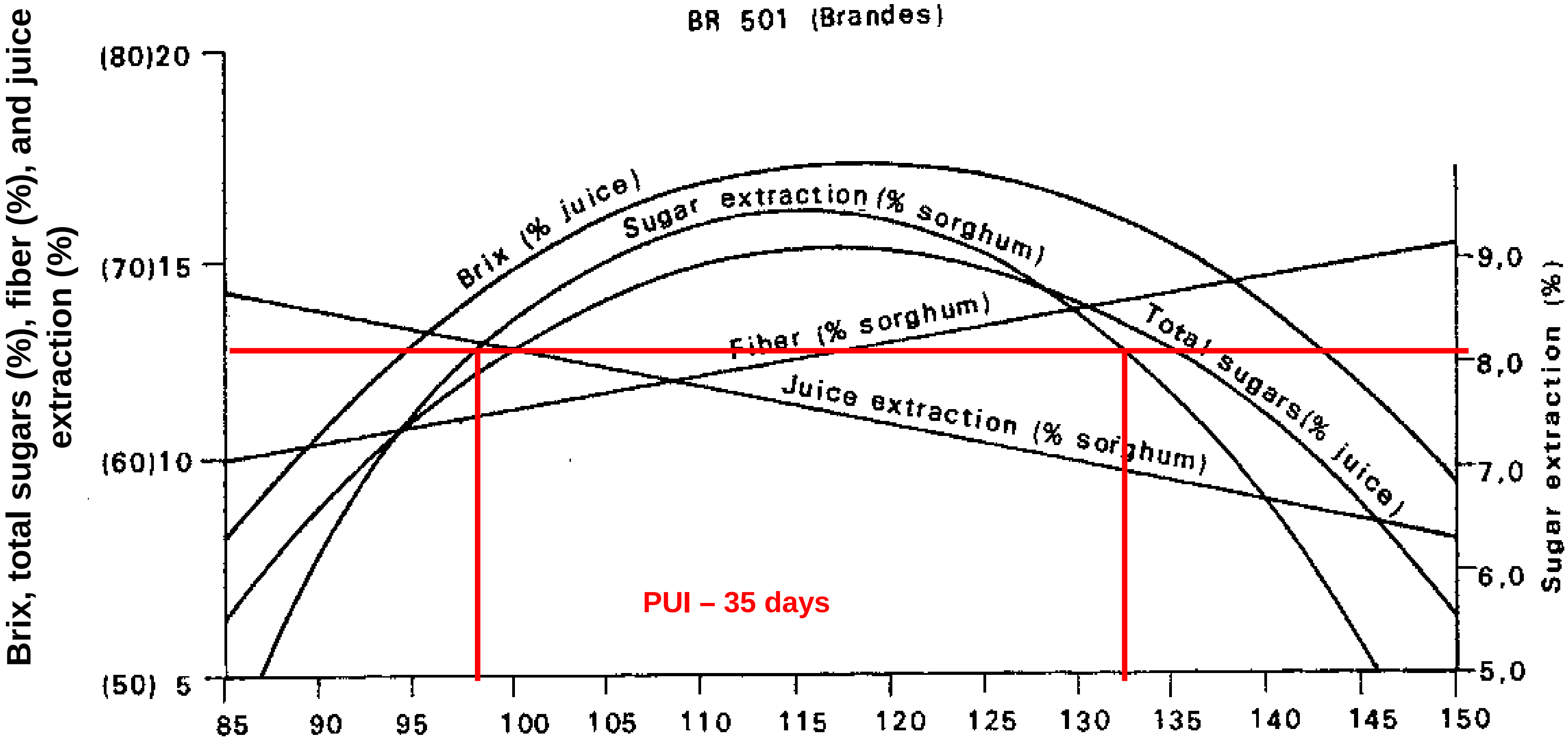
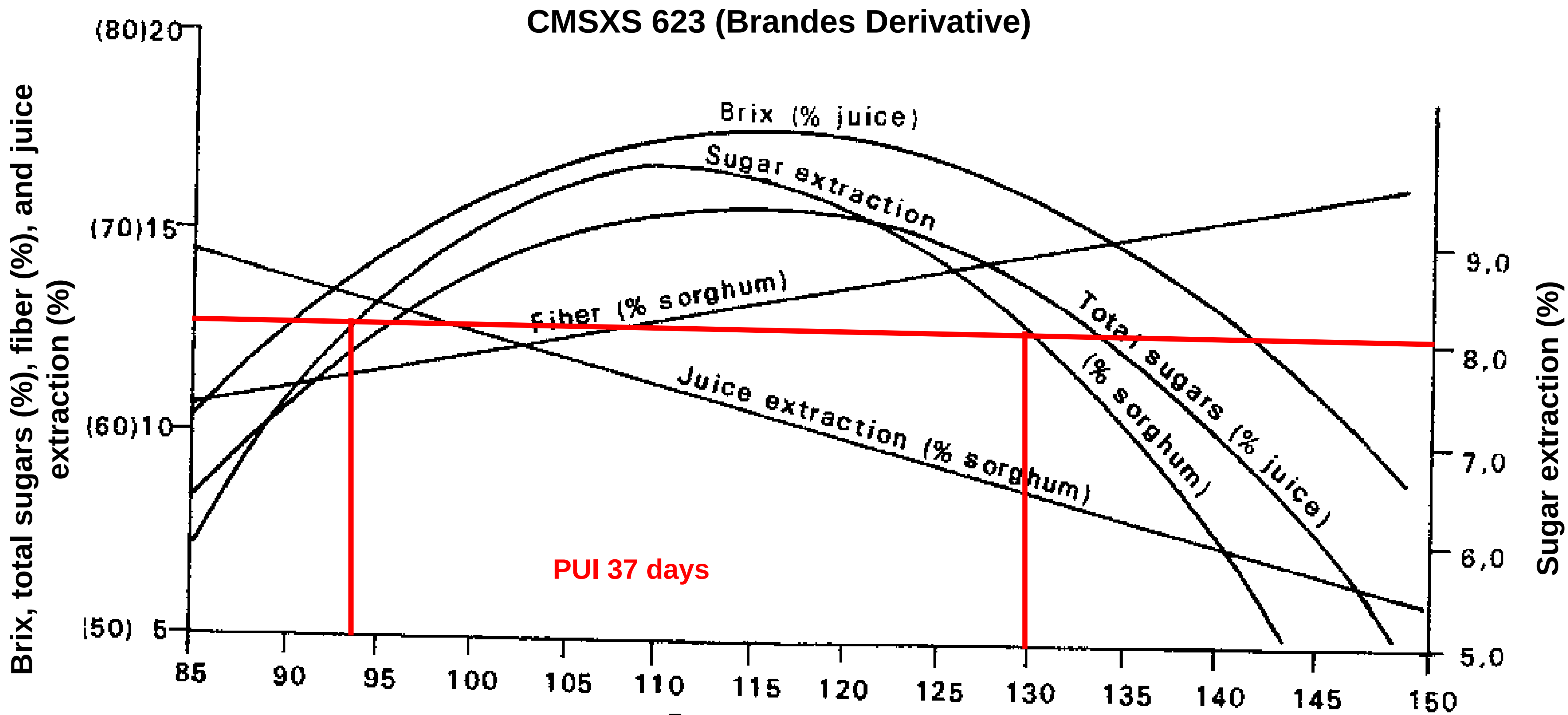


The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of stalks during the maturity phase for the variety Brandes grown in Brazil (Embrapa Maize and Sorghum).



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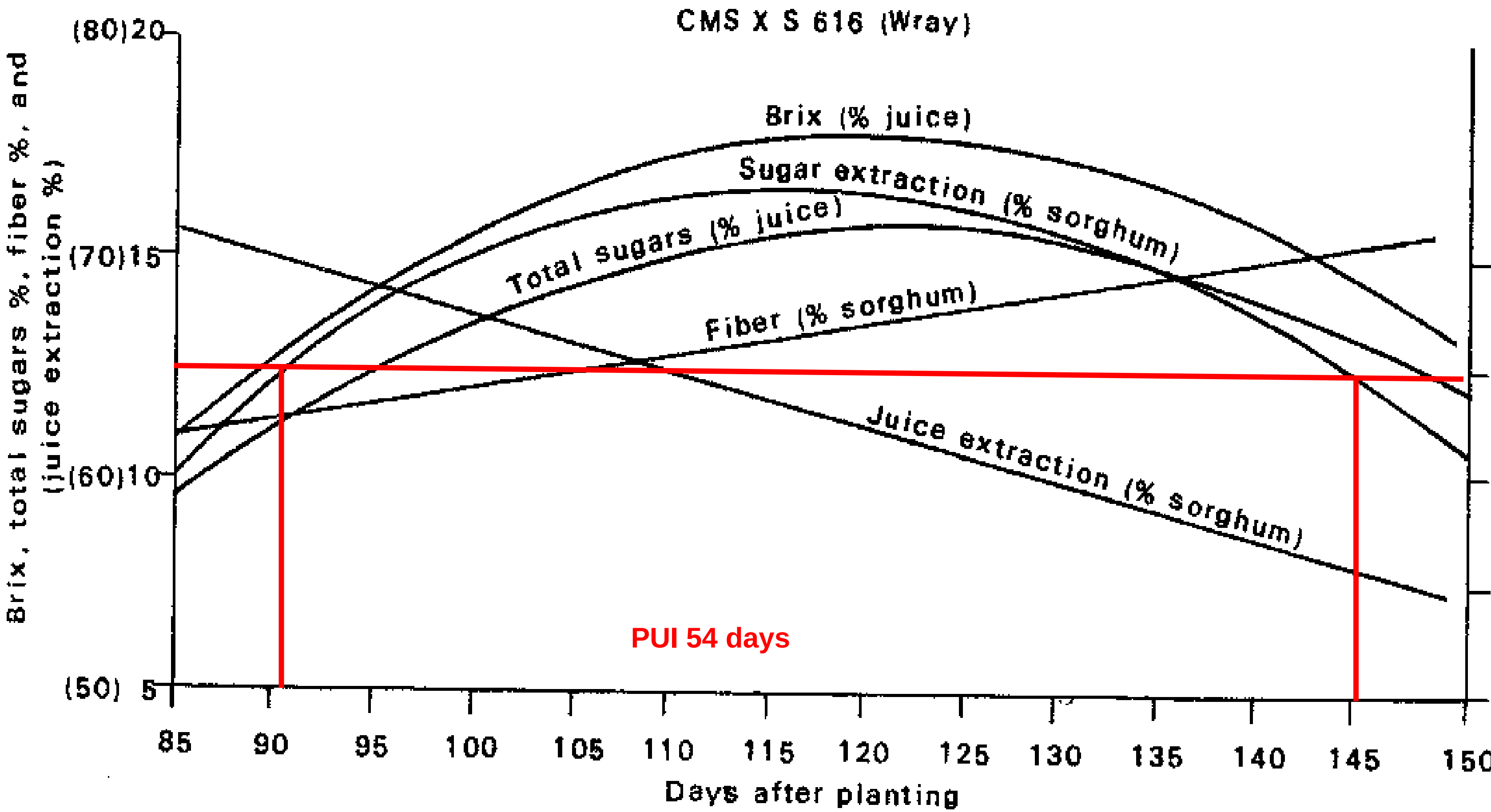

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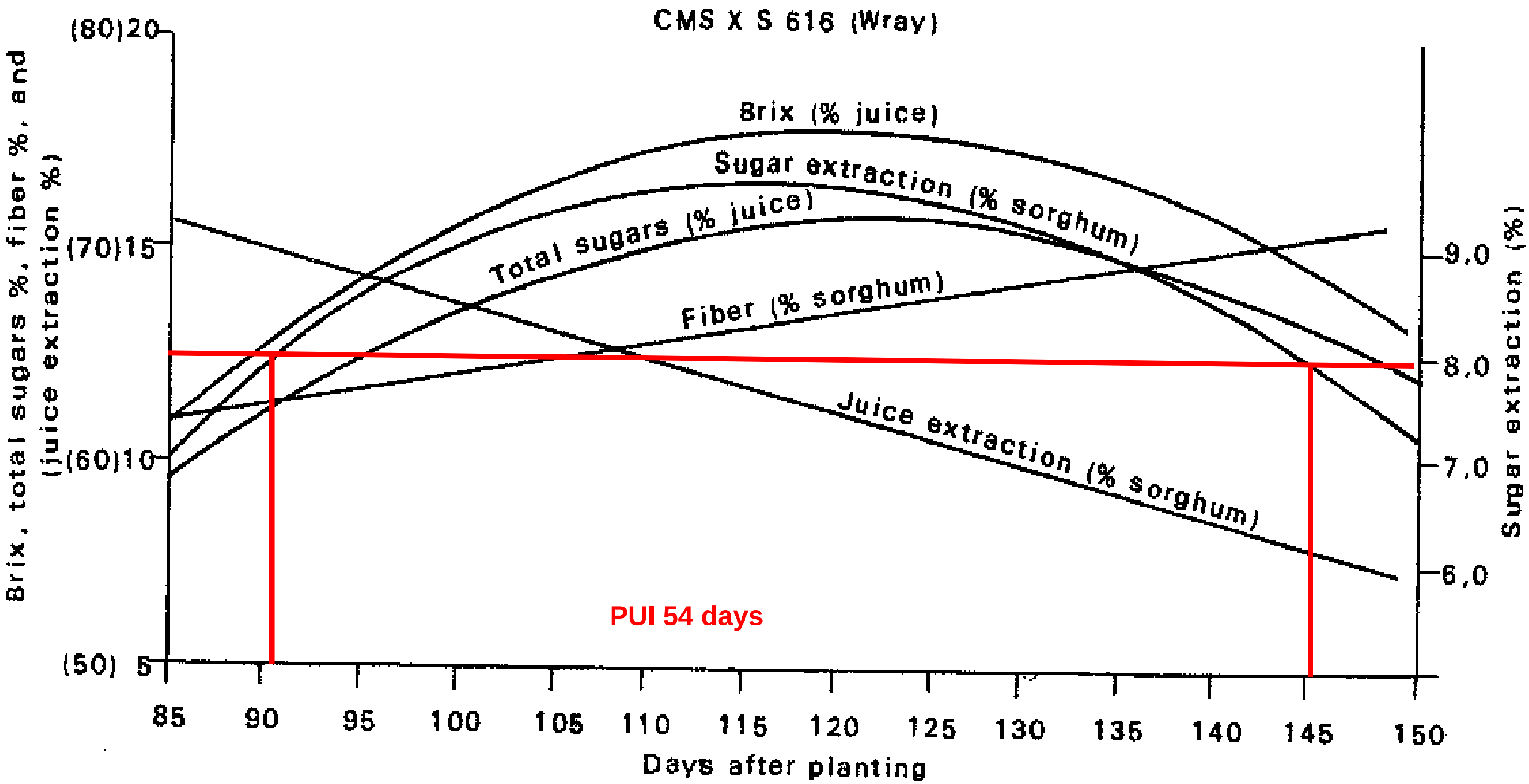

The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of stalks during the maturity phase for the variety Brandes grown in Brazil (Embrapa Maize

Current Plant Breeding Strategies and Priorities

- Develop sweet sorghum 3 dwarf A and B lines (female) to be used in hybrid development and production
  - Identify molecular markers for juicy stem and sweet juice
  - Incorporate genes for multiple stress (biotic and abiotic) resistance
- Evaluate existing new sweet sorghum cultivars (approx. 50) and develop new sweet sorghum R lines (male) to be used in hybrid development and production
  - Incorporate genes for multiple stress (biotic and abiotic) resistance
- Identify molecular markers for tillering - Non-tillering desired to be able to control stalk diameter with plant population (better extraction with large stem diameter)
- Develop transgenic sweet sorghum with sucrose isomerase gene (SI), a gene that regulates the transformation of sucrose to isomaltulose and thus can increase the sink capacity of sugar storage (Wu and Birch, Plant Biotechnology Journal (2007) 5 (pp109-117)

Plant Breeding Strategies and Priorities (cont.)

- Develop high yielding biomass cultivars for cellulose conversion to bio-energy
  - Identify molecular markers for maturity genes Ma5 and Ma6 to be able to develop photosensitive (PS) sorghum biomass hybrids

Ma5Ma5ma6ma6 is photo-insensitive (PIS) and flowers in approximately 60 days regardless of day length.
ma5ma5Ma6Ma6 is photo-insensitive and flowers in approximately 60 days regardless of day length.

The hybrid between these genotypes, Ma5ma5Ma6ma6 is photo-sensitive (PS) and floral initiation is only induced with day lengths less than 12h and 20min.

This can be useful in both sweet sorghum and biomass sorghum in locations farther from the equator where there is more variation in day lengths (McCollum et al. reported average yield increases of 25% of PS hybrids over PIS hybrids at Amarillo, Texas).

Plant Breeding Strategies and Priorities (cont.)

- Develop high yielding biomass cultivars for cellulose conversion to bio-energy
  - Identify molecular markers for brown midrib low lignin genes genes brm-6 and brm-12

    Homozygous brm-6 hybrids and brm-12 hybrids have been reported to reduce lignin content in sorghum biomass by 50%

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Production Cost of alcohol from sweet sorghum in Brazil in micro-distilleries in November, 1980.

Item	US$
Production Cost /ha	320.00
Cost/t stalks (30 t/ha)	10.67
Cost/t stalks (40 t/ha)	8.00
Cost/t alcohol (45 liter/t and 40 t/ha)	0.22
Cost/t alcohol (59 liter/t and 40 t/ha)	0.20
Cost/t alcohol (68 liter/t and 40 t/ha)	0.17

Source: Embrapa Maize and Sorghum, Sete Lagoas, MG, Brazil.

* The price of ethanol today is about US$ 0.35 L^{-1} at the distillery gate and US$ 0.75 to 0.90 at the pump, depending on the distance from distilleries

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Final Remarks

- Embrapa has a relative large number (25 - 30) of sweet sorghum varieties available for characterization for quality and utilization in developing experimental hybrids.
- The variety BR501 (Brandes) is tolerant to Al toxicity and is the restorer parent in two commercial forage sorghum hybrids. Brandes probably was selected 25 years ago because it was tolerant to Al toxicity.
- Brandes was successfully used in two pilot sweet sorghum distilleries in Jundiai, SP and Pelotus, RS.
- The proof of concept of sweet sorghum as a biofuel source has been determined. The next step is an economic evaluation for competitiveness with other available raw materials.
- Embrapa has reactivated its research and development program with sweet sorghum as a source for bio-fuels.

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Embrapa has initiated a research and development program for producing bio-fuels from lignocellulose sorghum using second generation technology

- High research priority for Embrapa
- Transform lignocellulose to ethanol or other fuel
- Sorghum is one of two priority lignocellulose crops
- Enzymatic hydrolysis
- Enhancement of enzymes
- Enhancement of sorghum, quality and quantity

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Thank You

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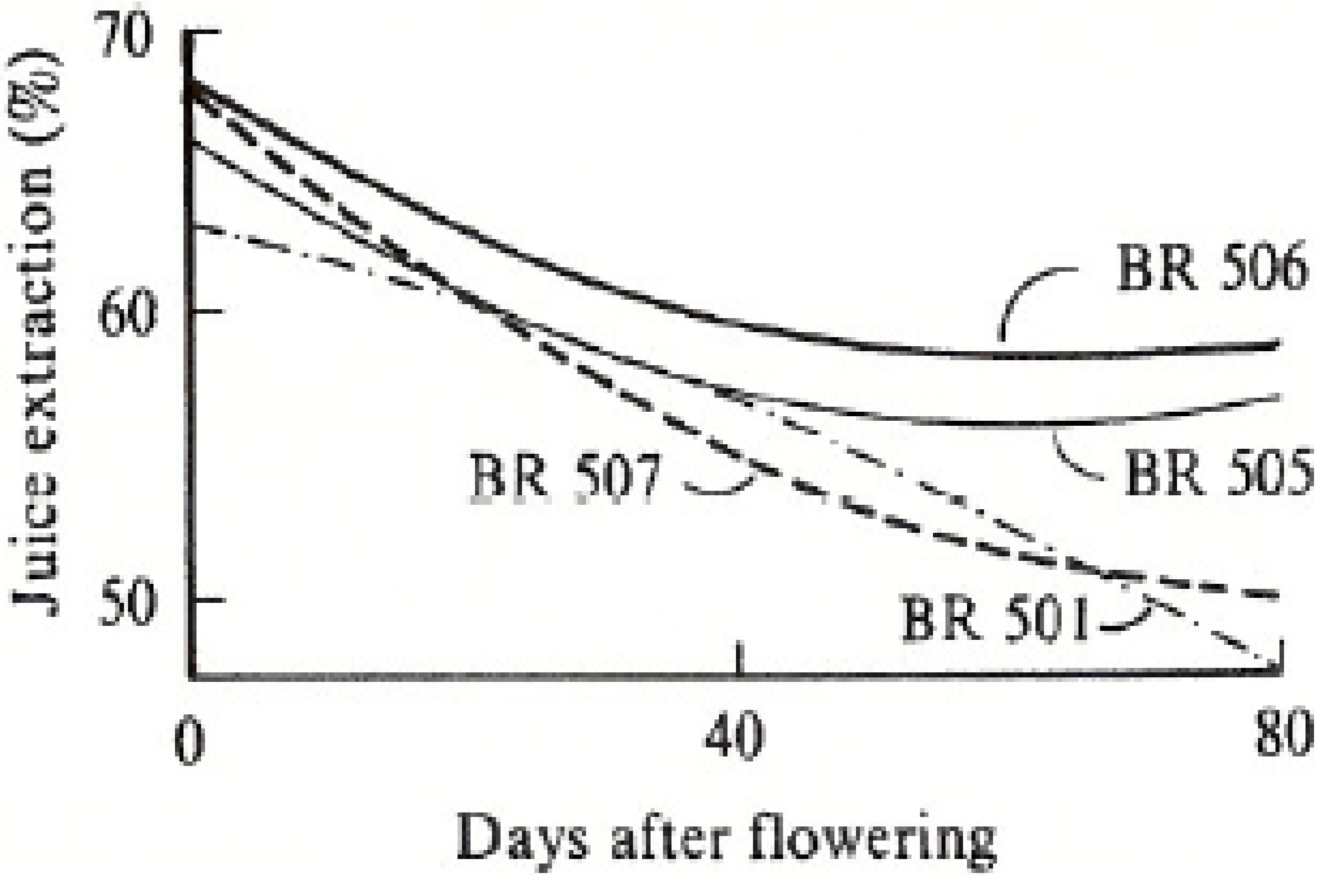
Juice Extraction Varies Between Cultivars



Percent juice extraction of four sweet sorghum cultivars at CNPMS/EMBRAPA, Sete Lagoas, Brazil, 1986/87, BR 501 = Brandes; BR 505 = Wray.

Agricultural and Industrial yields of sweet sorghum in Brazil.

Component		Agricultural Yield	Alcohol yield	
		(t/ha)	(liter/t)	(liter/ha per harvest)
Stalks	Range	22 - 66	55 - 85	1210 - 5610
	Average	37.7	70	2639
Grain	Range	1.4 - 6.6	310 - 370	434 - 2442
	Average	2.2	340	748
Total	Range			1644 - 8052
	Average			3387

Source: Schaffert and Borgonovi (1980)

Mean yield of stalk, fermentable sugar, alcohol, fresh biomass and seed of sweet sorghum in experiments at the Beijing Botanical Garden

	Cultivar					
	Theis	M-81E	Wray	Keller	Brandes	Rio
Stalk (kg/ha)	95	89	76	76	62	52
Fermentable sugar (t/ha)	10.6	9.6	10.3	10.5	6.4	6.2
Alcohol (l/ha)	6 159	5 607	5 981	6 131	3 696	3 617
Fresh material (t/ha)	125	128	106	107	89	82
Seed (kg/ha)	6 674	6 213	1 426	1 960	3 500	2 866

Comparison of juice between sweet sorghum and sugarcane in Brazil.

	Sweet Sorghum		
Trait	Literature	National Trials	Sugarcane (São Paulo averages)
Juice extraction (%)	350 - 600	500 - 700	600 - 800
Retractometer Brix	16 - 20	14 - 20.	18 -21
Sucrose (% juice)	10 -15	8 - 16.	15 - 18
Invert sugars (% juice)	1 - 4	0.7 - 7.3	0.2 - 1.5
Total invert sugars (% juice)	14 - 20	14 - 18	16 - 19

Source: Schaffert and Borgonovi (1980)

Sucrose vs. Total sugars

Maximum dry matter production and maximum growth rates of several crops.				
Crop	Dry Matter Production (t/ha)	Maturity (days)	Average Growth rate (gm/m^2 per day)	Maximum growth rate (gm/m^2 per day)
Napier	106	365	26	-----
Sugarcane	70	365	18	38
sugarbeet	47	300	14	31
Forage sorghum	30	120	22	-----
Forage sorghum	43	210	19	-----
Sudangrass	33	160	18	51
Alfafa	36	250	13	23
Bermudagrass	35	230	14	20
Alga	44 - 74	300	15 - 22	28

Source: Loomis and Willian (1963)

National Forage Sorghum Trial - 1986/87 Embrapa Maize and Sorghum

Location and Date of Planting

Cultivar	Linhares ES 10.12.86	Goiânia GO 29.12.86	Capinópolis MG 01.12.86	Ituiutaba MG 16.12.86	Taquari RS 12.12.86	Cruz Alta RS 04.12.86	S.J. dos Campos SP 09.01.87	Mean	Relative Mean BR601 (%)
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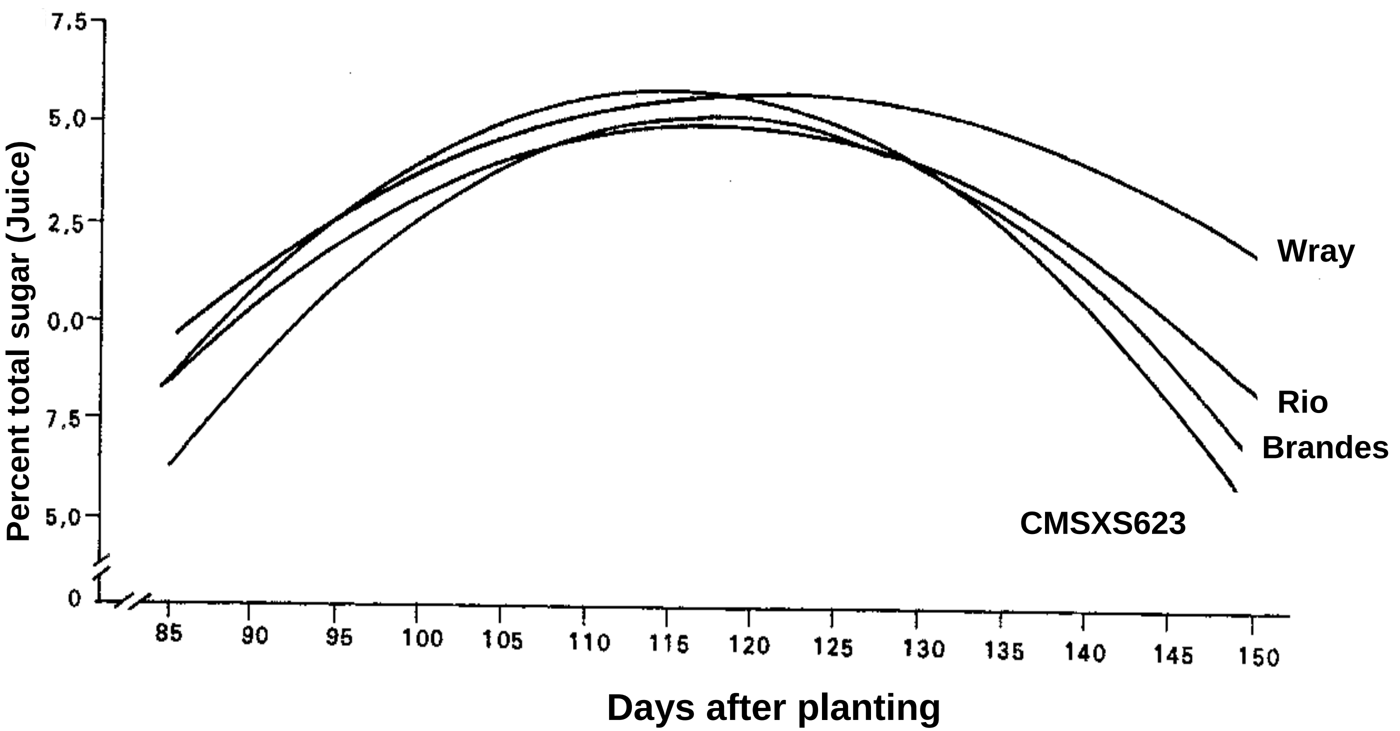

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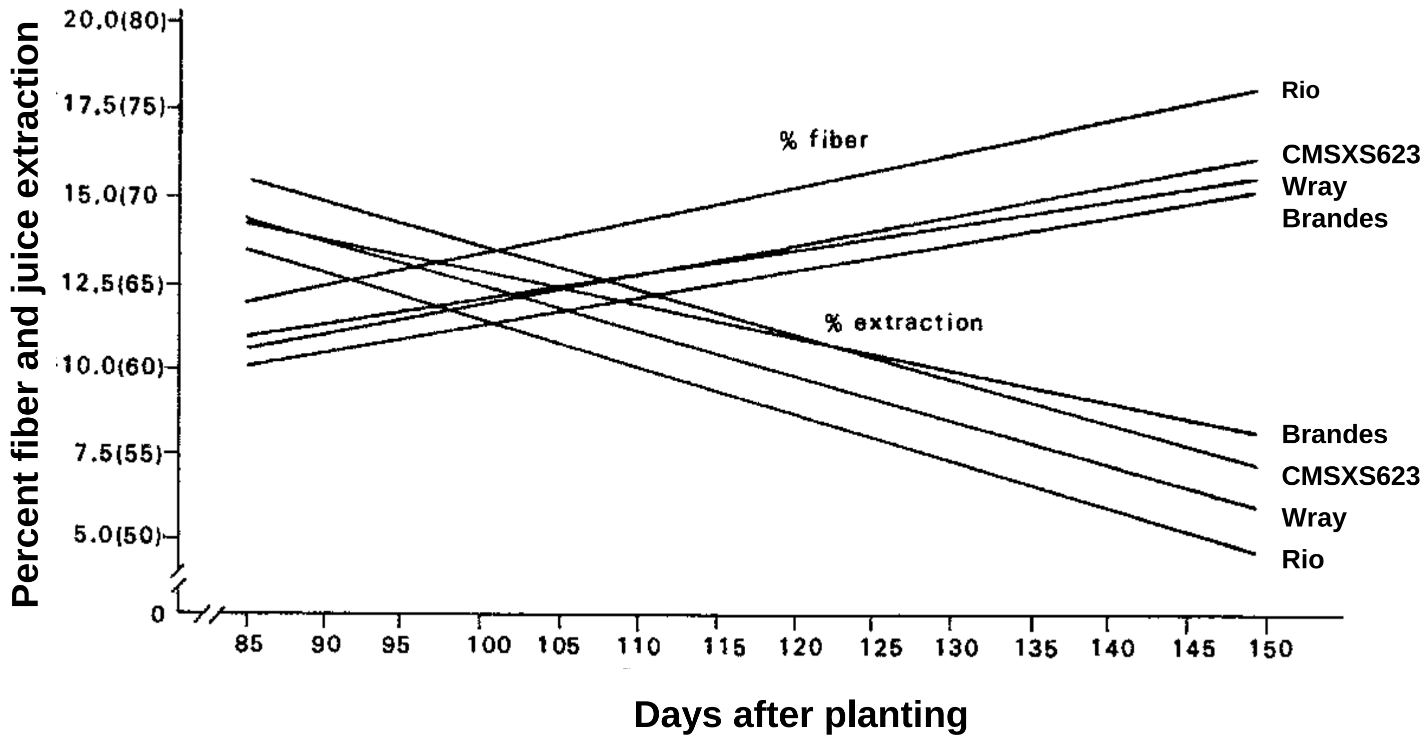
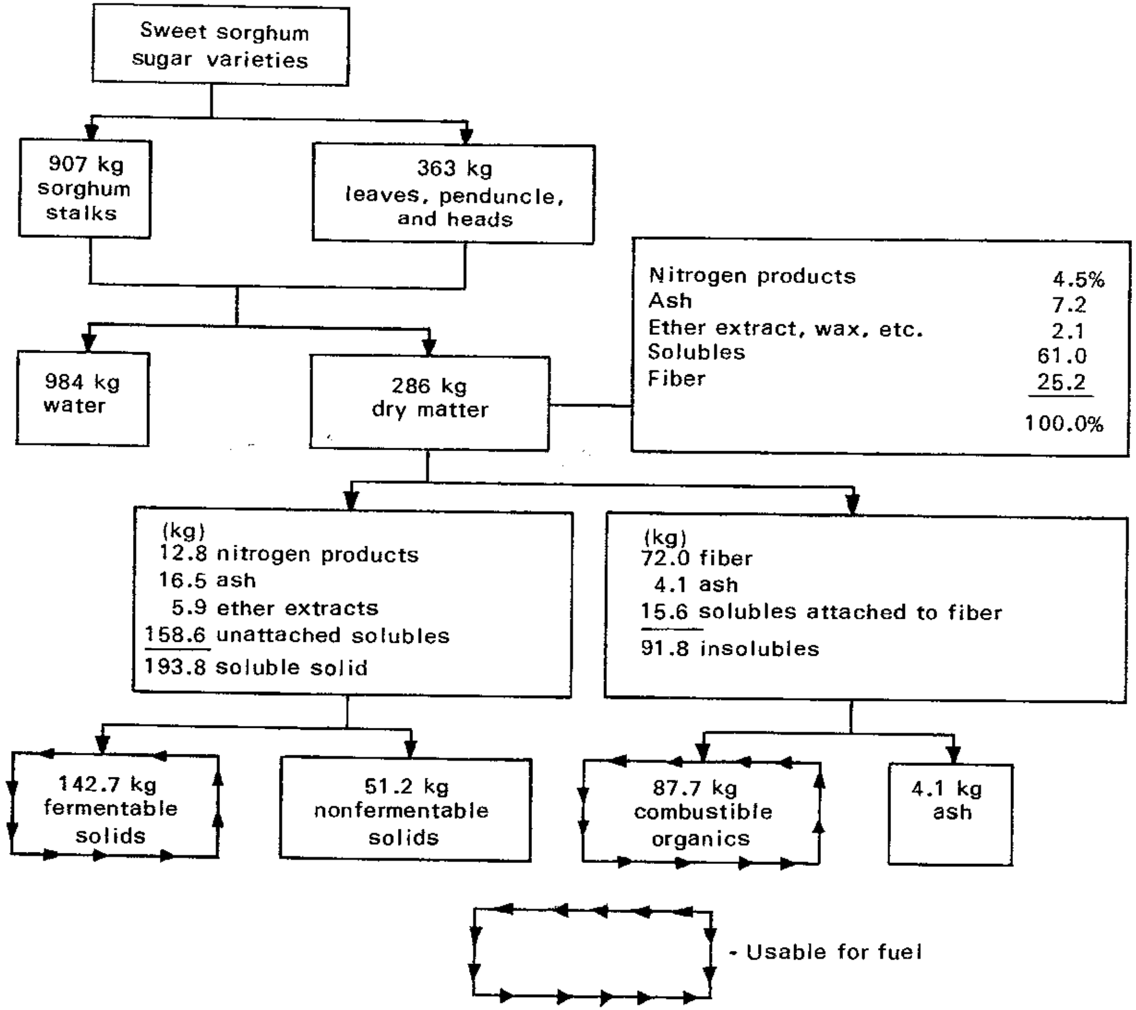
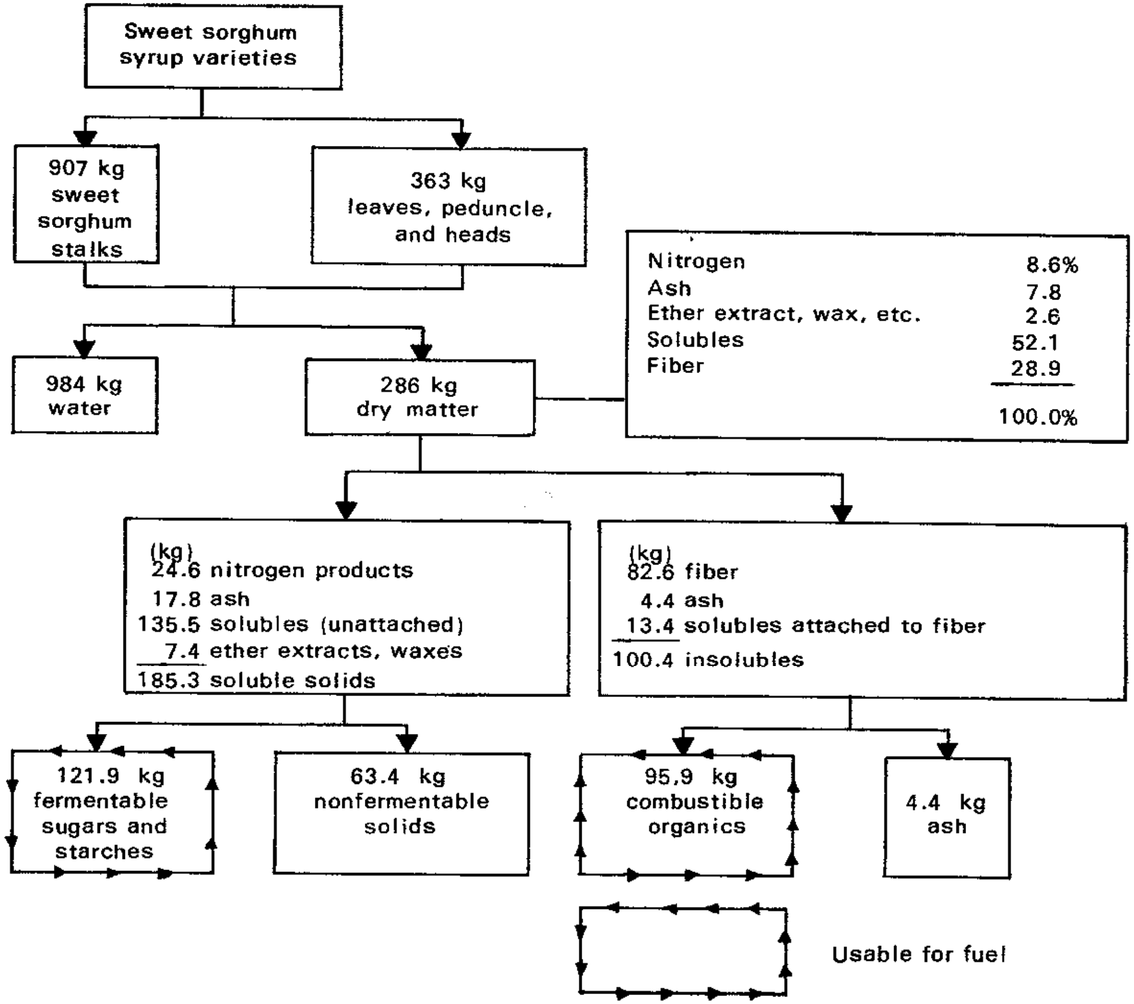


The differences between four cultivars grown in Brazil for juice extraction and fiber content of the stalks during the maturity phase of production (Embrapa Maize and Sorghum).



Average yields:	Tons/ha
Stalks	32.9
Leaves, peduuncle and	13.6
heads	46.5

Estimated approximate composition of sweet sorghum sugar varieties in the United States (Nathan, 1978)



Average yields:	Tonnes/ha
Stalks	47.4
Leaves, peduncle and heads	19.3
total	66.7

Estimated approximate composition of sweet sorghum syrup varieties in the United States (Nathan, 1978)