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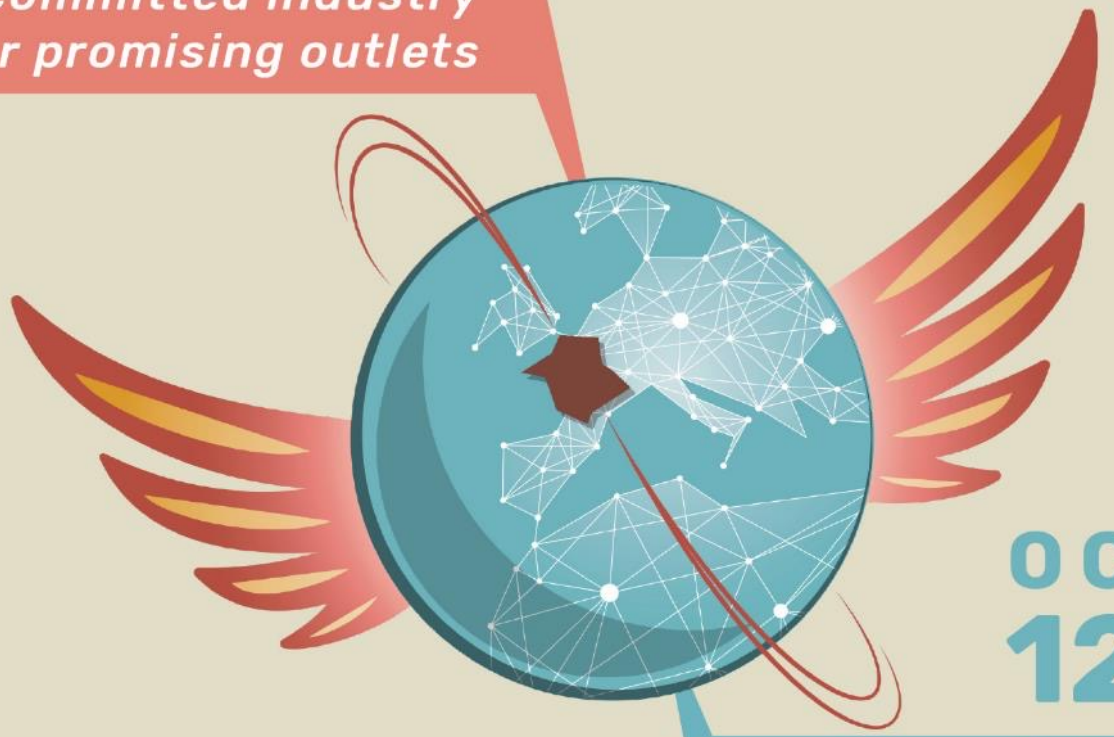
THE SORGHUM

A committed industry for promising outlets



OCTOBER
12TH & 13TH
TOULOUSE
2021

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Embrapa

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Development of sweet and biomass sorghum hybrids for bioenergy production in Brazil

Multidisciplinary Team

Dr. Rafael Augusto da Costa Parrella

Sorghum Breeder

October 12 and 13, 2021

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Embrapa Maize and Sorghum
Sete Lagoas-MG, Brazil

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Infrastructure for Bioenergy R&D
Embrapa Milho e Sorgo

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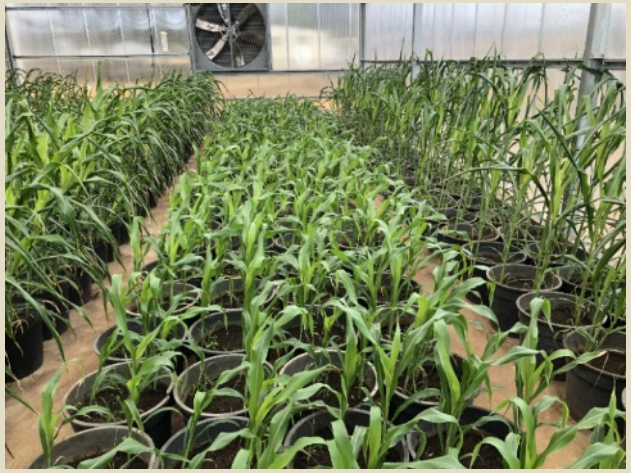

Greenhouse

Cold Storage

Hydrolic press

No-Till Plot Planter

Plot Forage Harvester

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SORGHUM MATERIALS AT EMBRAPA: INNOVATION ASSETS

Embrapa has developed genetic materials and production systems for different sorghum types and formed partnerships with a number of seed companies, the public R&D sector and energy companies

Grain Sorghum Crop Season 2020/2021

Area: 864,500 ha ↑

Productivity: 2.685 kg.ha-1 ↓

Production: 2,098,200 million t ↓

Conab, 2021
https://www.conab.gov.br/info-agro/safras

Sweet sorghum in sugarcane mill (cultivars and production systems)

Biomass sorghum for energy: electricity, second generation ethanol and biogas

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Bioenergy in Brazil

2nd Survey of the sugarcane crop (August 2021/2022-Conab);

Area: 8.243 million hectares (4.3 ↓)

Productivity: 71,821 t.ha-1 (5.5 ↓)

Sugarcane production: 592,031 thousand tons (9.5% ↓)

Sugarcane Ethanol Production: 25.8 billion liters (13.1% ↓)

Corn Ethanol Production: 3.4 billion liters (80.3% ↑)

Biogas and Ethanol 2G

RenovaBio

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Why Sorghum as a Source of Feedstock for Bioenergy Production?

⇨Fast cycle - can be harvested in 120 to 180 days after planting;

⇨ Grass – C4 – Associates high productivity of biomass, fermentable sugars and starch;

⇨Sorghum production can be completely mechanized;

⇨ Sorghum cultivation is established from seed (Cultural management and mechanized harvesting);

⇨ It has high water use efficiency, drought tolerance and high temperature adaptation;

⇨Sorghum has favorable characteristics for conversion into 1G, 2G ethanol, cogeneration and biogas;

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Sorghum for Bioenergy

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Sweet Sorghum

dd – Juice - stem

80-120kg TRS*

14-16% fiber

<5% lignin

1G Ethanol Biogas

Biomass Sorghum

Dry gene

DD ou D_– Pithy - dry stem

80-100kg TRS

20-25% fiber

<7% lignin

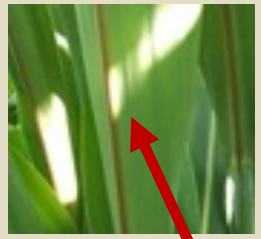
1G Ethanol Biogas

< 30kg TRS

20-25 % fiber

>8% lignin

Co-geração Biogas



bmr6bmr6 - Brown Midrib Low Lignin

< 30kg TRS

20-25 % fiber

<5% lignin

2G Ethanol Biogas

***TRS - Total recoverable sugars per ton of sorghum;**

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Energy Sorghum Breeding Strategies

(1) Photo-Insensitive Sweet Sorghum Hybrid

Female-Photo-Insensitive X **Male-Photo-Insensitive**

A&B – Lines
Short
Juice stem
High sugar content
High GCC for Biomass

R - Line
Tall
Juice stem
High sugar content
High GCC for Biomass

F_1 – Photo-Insensitive

Biomass Production

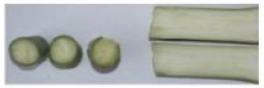
(2) Photosensitive Sweet Sorghum Hybrid

Female-Photo-Insensitive X **Male-Photo-Sensitive**

A&B – Lines
Short
Juicy stem
High sugar content
High GCC for Biomass

R - Line
Tall
Juicy stem
High sugar content
High GCC for Biomass

F_1 – Photo-Sensitive



High Biomass Production

(3) Photosensitive high lignin Biomass Sorghum

Female-Photo-Insensitive **Male-Photo-Sensitive**

A&B - Lines
Short
Dry stem
High lignin
Low sugar content
High GCC for Biomass

R - Lines
Tall
Dry stem
High lignin
Low sugar content
High GCC for Biomass

F_1 - Photosensitive

High biomass production

(4) Photosensitive low lignin Biomass Sorghum

Female-Photo-Insensitive x **Male-Photo-Sensitive**

A&B - Lines
Short
Dry stem
Low lignin (*bmr6*)
Low sugar content
High GCC for Biomass

R - Line
Tall
Dry stem
Low lignin (*bmr6*)
Low sugar content
High GCC for Biomass

F_1 - Photosensitive

High biomass production

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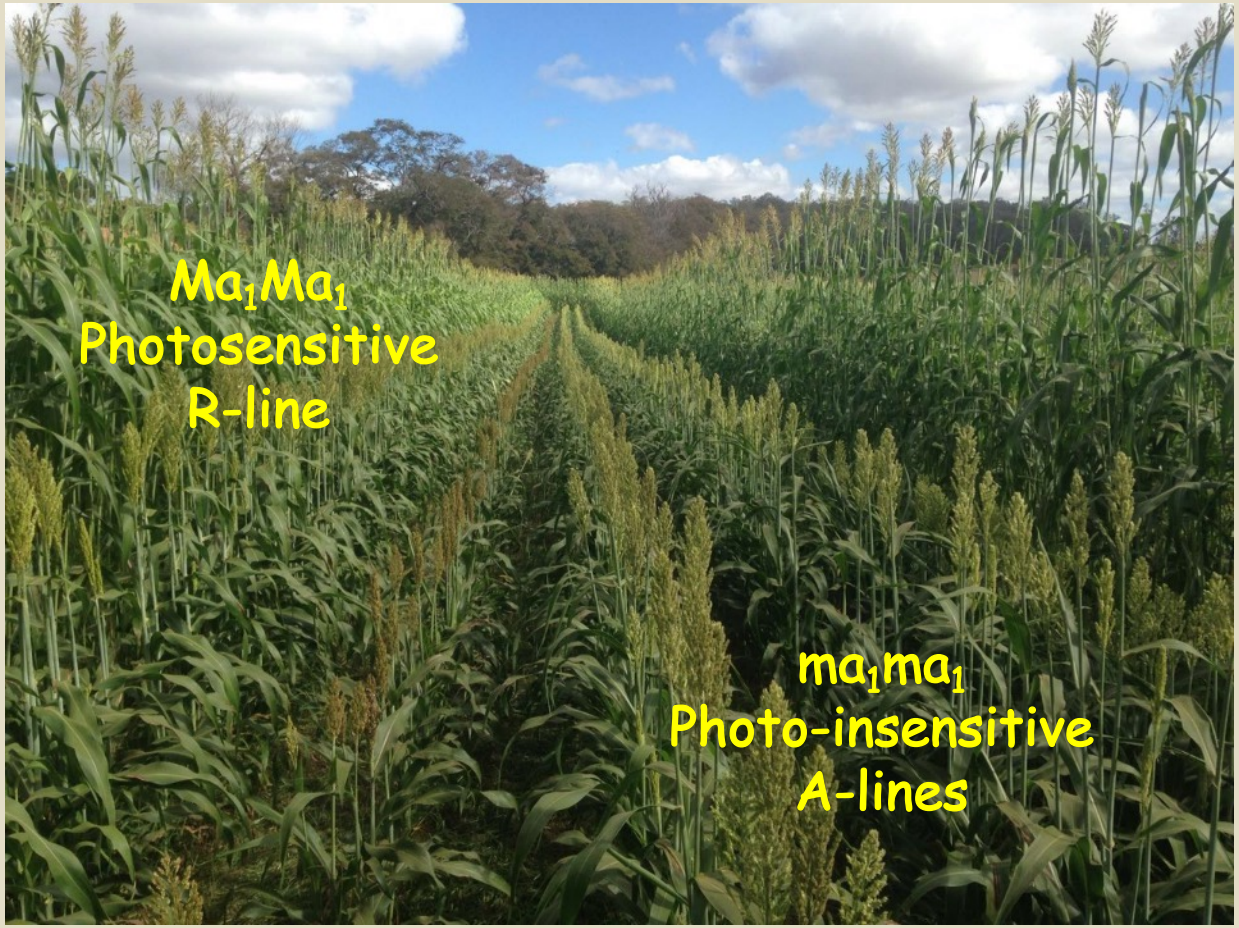
Isolated Field in Short Day Environment to Produce Experimental Photosensitive Hybrids for Biomass for use in both long and short days



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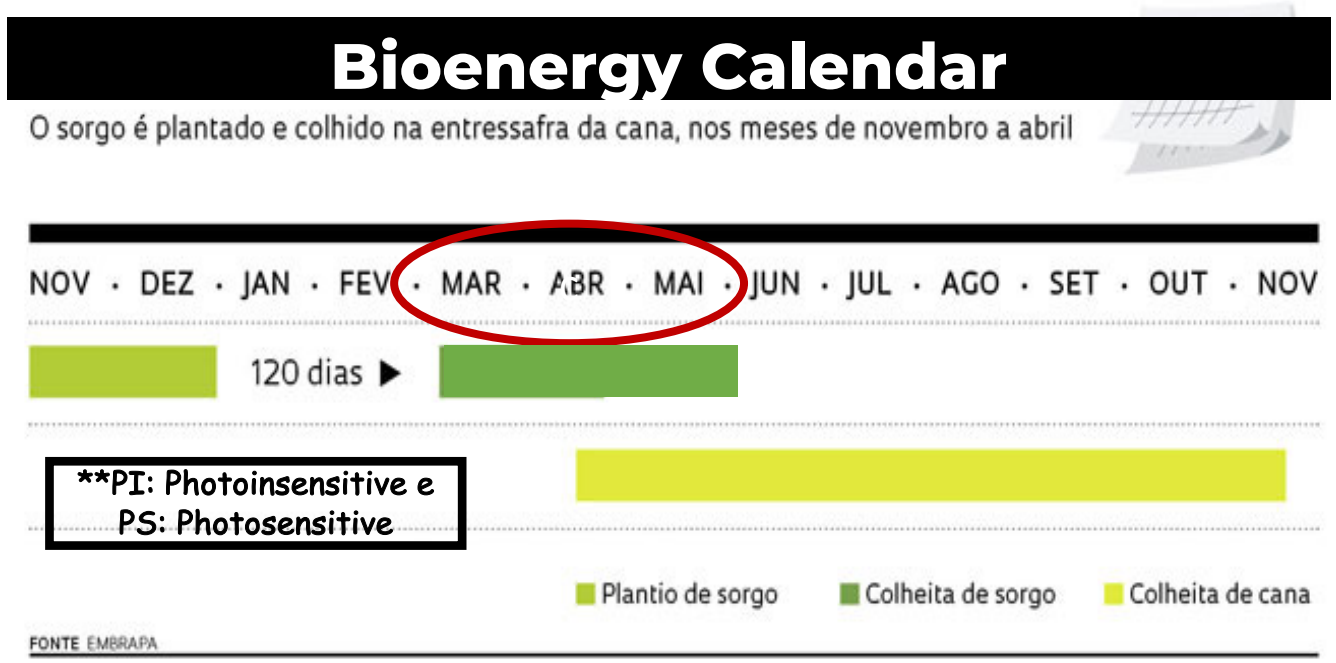
Scenarios for Bioenergy Sorghum in Brazil

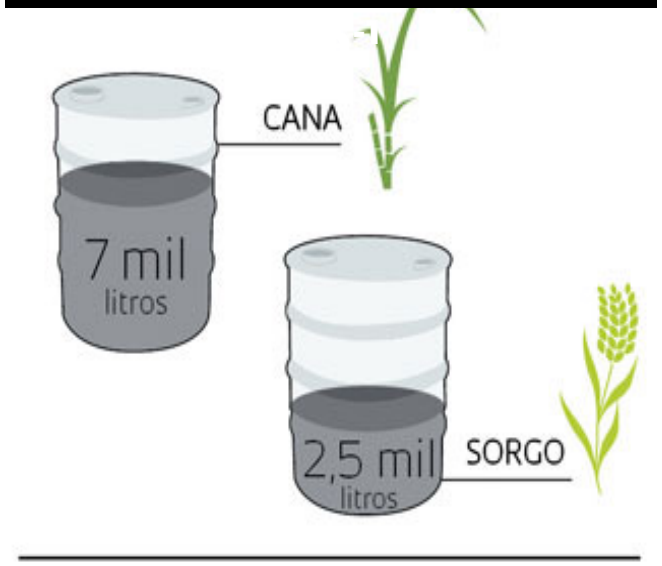
- **Sweet and Biomass sorghum is being proposed to be planted at the beginning of the rainy season (October to December) in areas of Sugarcane renovation to increase the period of industrial operation of large distilleries in Brazil;**

- **Second Crop or "Safrinha" generally after soybeans**

Bioenergy Calendar



Ethanol Production L



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- **Utilizing Sugarcane Distilleries for Sweet Sorghum Processing**
- **Some Fine Tuning may be Necessary, but Minimal**
- **Uses the same sugar cane harvester;**
- **Distance from field to smaller distillery 50km;**
- **Time between harvesting and processing less than 6 hours;**
- **2012 to 2014 - Pilot results with low ethanol productivity disappointed industries in the sector;**
- **Low stalk productivity and low sugar content (Minimum: 50 t.ha-1 x 60L of ethanol.t-1).**

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Main Pests, Diseases and Weeds

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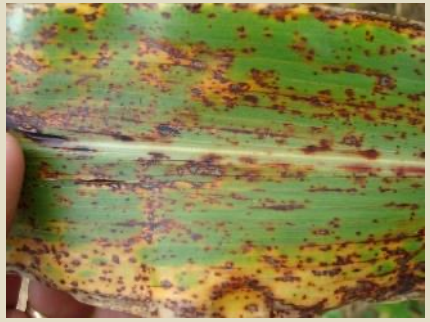
Weed control

Fall armyworm (Spodoptera frugiperda)

Sugarcane drill (Diatraea saccharalis)

Sugarcane aphid (Melanaphis sacchari)



Anthracnose

Rust

Hemitosporiosis

Ergot

Elasmus caterpillar (Elasmopalpus lignosellus)

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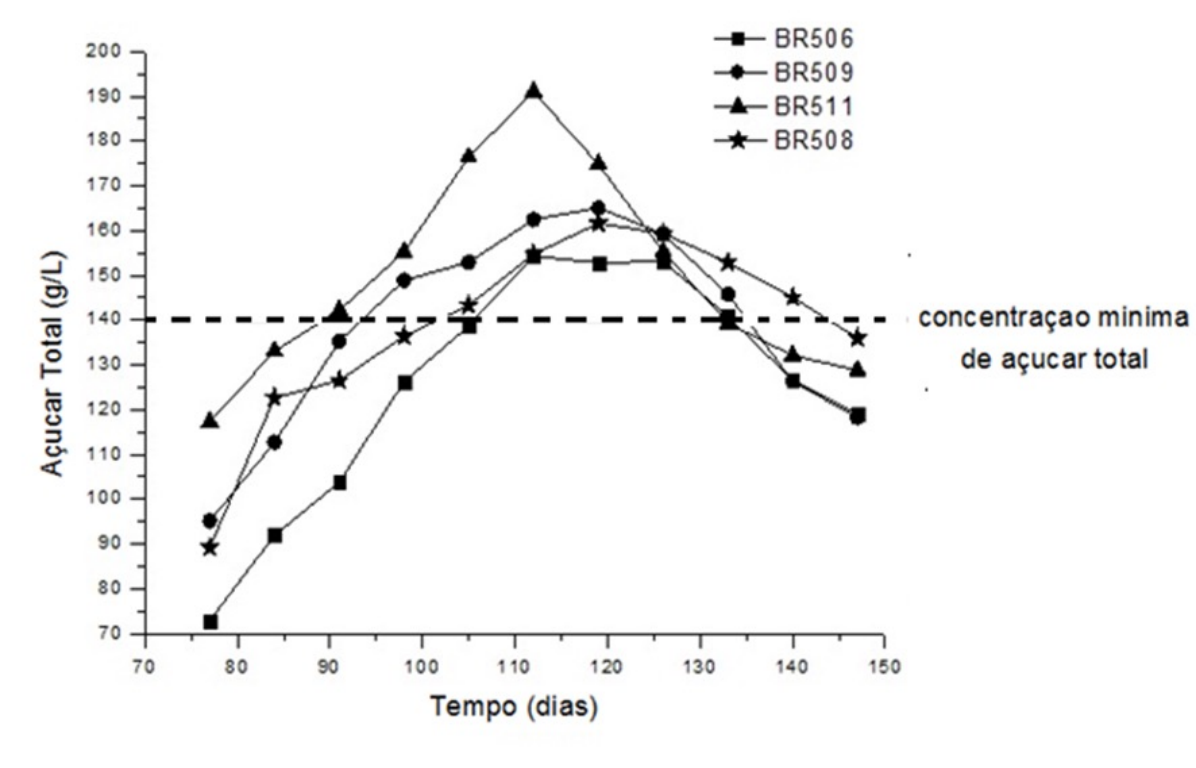
Period of Industrial Utilization (PIU) (Embrapa Milho e Sorgo)



Minimum Parameters for PIU

Total sugar (% juice): > 12,5%
Extracted sugars (hyd. press): >80 Kg t^{-1}
Period > 30 dias
(High Sucrose Desirable – Promotes longer PIU);
Necessary for Industrial Planning

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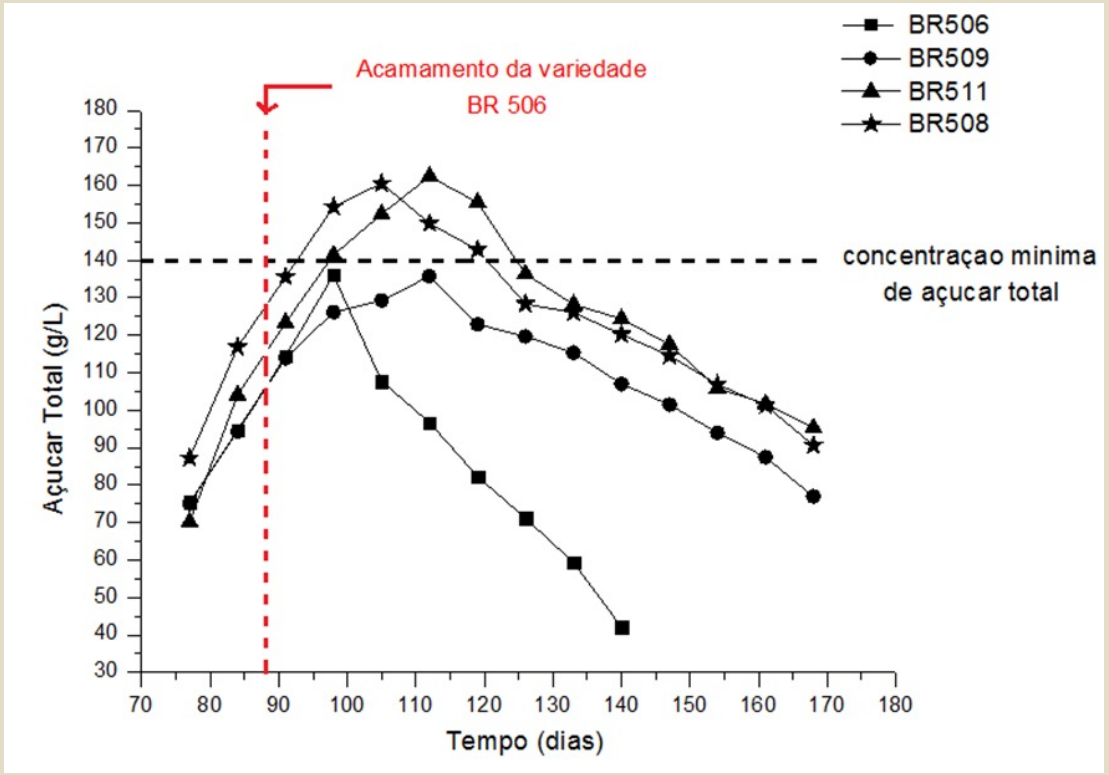
Lodging: Reduces sugar content and increases impurity content



Fernandes et al., 2014

Resistent to lodging

Susceptible to lodging

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Pilot areas with sweet sorghum in Brazil in the 2019/2020 Crop Season

Santo Antonio Plant, Sertãozinho-SP – 94 DAP - 23ha

F&H Seeds company, Jaborandi - BA – 94 DAP – 10 ha

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Evaluation of total reducing sugars, theoretical yield of ethanol and fresh biomass 25 cultivars of sweet sorghum in - Sete Lagoas - MG.

TRS = Total reducing sugars (mg.mL^{-1})

TYE = Theoretical yield of ethanol (L.ton^{-1}) ARTx10x0,6480x0,85 – Considering an efficiency of 85% of the process.

FB = Fresh Biomass (t.ha^{-1})

Averages followed by the same letter do not differ at the 5% level of significance by the Scott Knott test.

Genótipo	TRS		TYE		FB	
201837B01	133,38	a	**73,46**	**a**	**75,29**	**a**
201837B03	83,90	d	46,21	d	84,52	a
201837B04	81,13	d	44,69	d	93,33	a
201837B05	88,37	d	48,67	d	72,38	a
201837B06	99,85	c	55,00	c	77,19	a
201837B07	122,87	b	67,68	b	73,57	a
201837B08	98,88	c	54,46	c	87,67	a
201837B09	86,22	d	47,49	d	81,00	a
201837B10	100,48	c	55,35	c	71,52	a
201837B11	76,80	d	42,30	d	61,10	b
201837B12	91,69	c	50,50	c	61,33	b
201837B13	123,59	b	68,08	b	39,90	b
201837B14	147,53	a	**81,26**	**a**	**71,24**	**a**
201837B15	146,04	a	**80,44**	**a**	**95,81**	**a**
201837B16	128,26	b	70,65	b	89,43	a
201837B17	152,00	a	**83,73**	**a**	**81,62**	**a**
201837B18	130,60	b	71,94	b	78,76	a
201837B19	115,18	b	63,44	b	97,67	a
201837B2	96,30	c	53,04	c	78,29	a
201837B20	100,26	c	55,23	c	70,62	a
201837B21	103,83	c	57,19	c	62,52	b
CMSXS643	101,02	c	55,64	c	71,52	a
CMSXS646	108,84	b	59,95	b	69,62	a
BRS 511	89,93	d	49,53	d	54,19	b
BRS 508	107,62	c	59,28	c	52,86	b

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"Minimum Economic Thresholds" for Sweet Sorghum Cultivars in Brazil, Now and in the Future

	Photo Insensitive			
Parameter	2012 Variety PI	2018 Variety PI	2021 Hybrid PI	Future Hybrid PS
Biomass Production (t ha^{-1})	> 40	> 50	> 60	>80
Total Sugar (% Juice)	>12.5	>12.5	> 14	> 14
Ethanol Production (L t^{-1})	> 60	> 60	> 70	> 70
Ethanol Production (L ha^{-1})	> 2400	> 3000	> 4200	>5600
PIU (days)	> 30	> 30	> 30	> 30

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Demands for Biomass Sorghum in Brazil

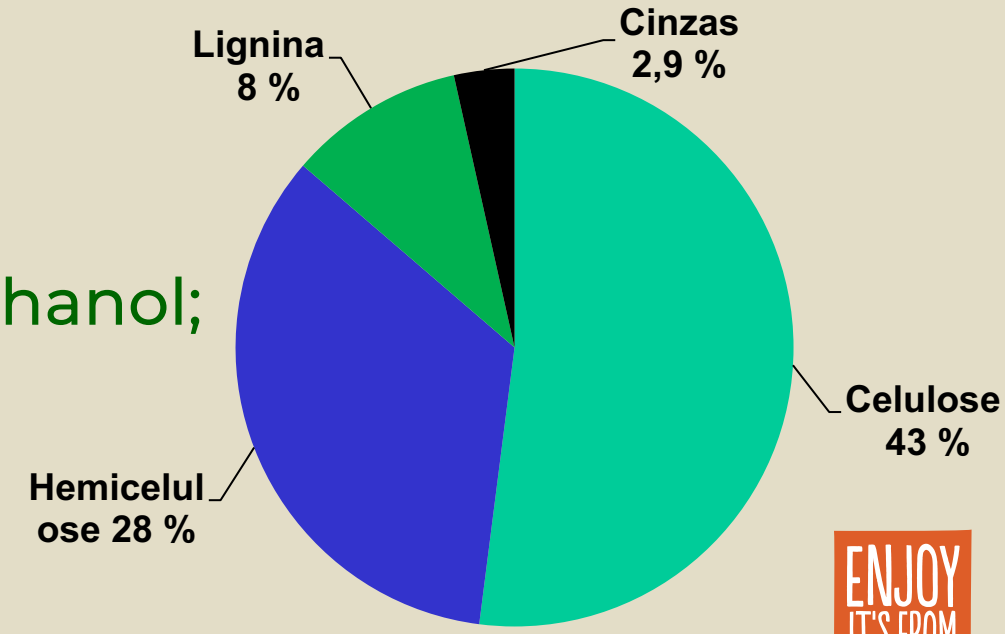
► The Industry is researching raw material as an alternative to eucalyptus for steam production and energy cogeneration. Cane straw, Elephant grass (Pennisetum purpureum Schum), bamboo (Phyllostachys aureosulcata - yellow groove bamboo), Mombaça grass (Panicum maximum cv. Mombaça);

► Biomass to produce biogás;

► Biomass to produce second generation ethanol;

► Animal feed;

► Organic Ground cover (No-tillage);



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Productive potential of biomass sorghum hybrids

Season/cycle	Fresh Biomass ($t.ha^{-1}$)	Dry Biomass ($t.ha^{-1}$)
1ª Season - PI (Cycle 110-130-PI)	60 - 70	18 - 21
1ª Season - PS (Cycle 150-170-PS)	80 - 150	24 - 45
2ª Season - PS (Cycle 100-120-PS)	50 - 60	15 - 18

150 DAP

206 DAP

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Partnership between EMBRAPA and COCAMAR to use of biomass sorghum for direct boiler burning

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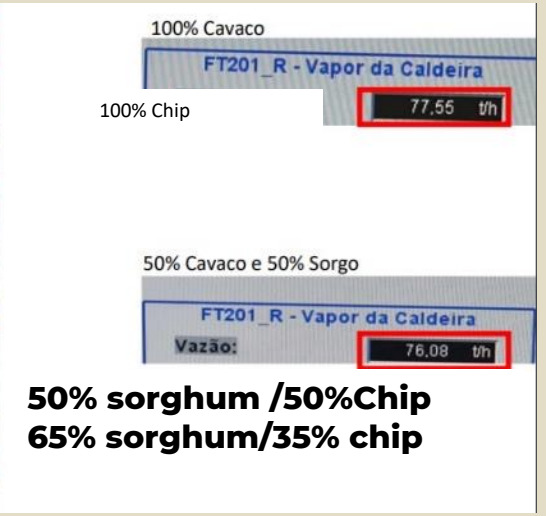
Pictures: Rusti Federle (rusti.Federle@cocamar.com.br)



50% sorghum /50%Chip
65% sorghum/35% chip

Implementation of a pilot area of 120 ha with biomass sorghum in this harvest season 2021/2022.

Estimate parameters for steam production (How many kg of sorghum to produce one kg of steam? Costs?)

Adjustments in Harvest and Logistics

cocamar COOPERATIVA AGROINDUSTRIAL

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Physicochemical and mechanical properties of sorghum pellets Biomass

Característica	Unidade	Resultado	Característica	Unidade	Resultado
Diâmetro	mm	6,12	Teor de carbono fixo	%	9,0
Comprimento médio	mm	14,62	Teor de matérias voláteis	% massa	79,6
Comprimento máximo	mm	30,16	Teor de cinzas	% massa	4,1
Comprimento mínimo	mm	3,53	Teor de umidade	% massa	7,3
Nº de pellets/100g	unidades	224	Poder calorífico superior	$J.g^{-1}$	17.662
Densidade aparente	$g.cm^{-3}$	0,658	Poder calorífico útil	$J.g^{-1}$	15.269
Densidade básica	$g.cm^{-3}$	0,775	Densidade energética	$GJ.m^{-3}$	10,04
Durabilidade	% massa	98,37	Carbono	%	41,4
Finos < 3 mm	% massa	1,63	Hidrogênio	%	4,7
Enxofre	% massa	0,06	Oxigênio	%	0,7
Potássio	% massa	1,2	Cloro	%	0,3
Nitrogênio	% massa	0,7			

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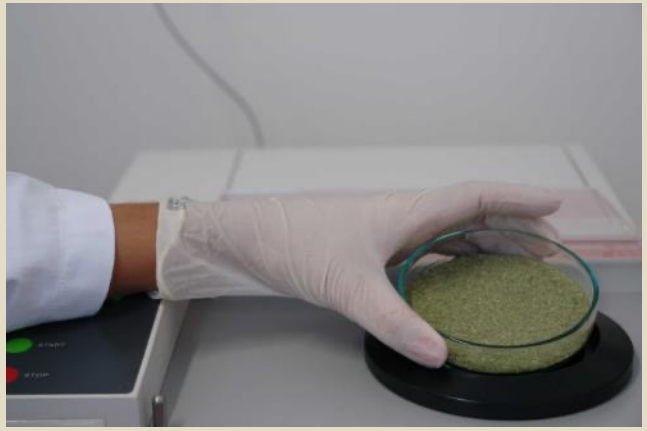
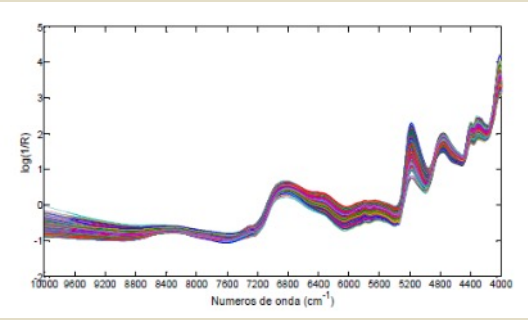
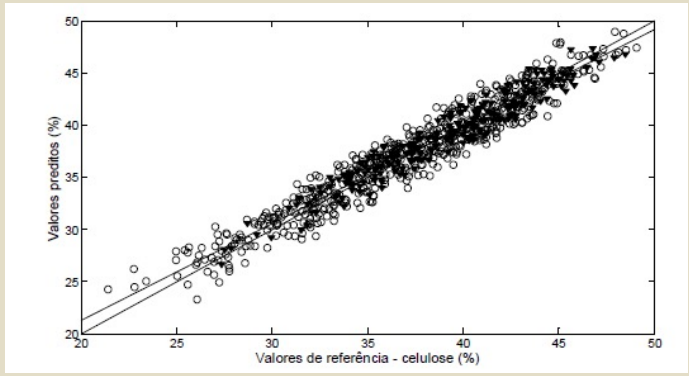
NIRs Calibration for high throughput characterization of sorghum for sugar, cellulose, hemicellulose and lignin







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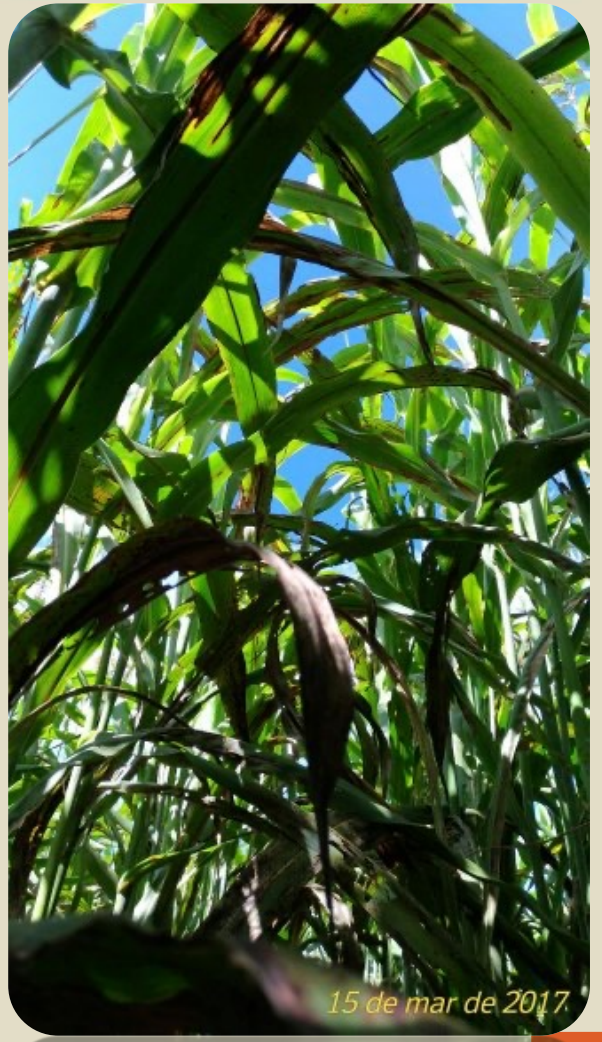
Characterization of thermochemical properties (immediate composition and calorific value) for 25 experimental hybrids of conventional biomass sorghum (201840B) in Sete Lagoas - 2019.

Parâmetro	HCV kJ/kg	NDF (%)	NDA (%)	CEL (%)	HEM (%)	LDA (%)
Média	17,16	79,58	52,88	46,47	26,7	6,410
Max	17,47	83,51	55,94	49,73	31,7	7,58
Min	16,7	73,14	46,58	40,92	24,1	5,14
DP	0,19	3,24	2,38	2,11	1,77	0,66

Biomass	Higher calorific value kJ kg^{-1}
Biomass sorghum	17,16
Elephante grass	16,96
Sugar cane bagass	16,68
Brachiaria	16,31



MARAFON, A.C. et al. Poder Calorífico do Capim-Elefante para a Geração de Energia Térmica. 2016. 30p. (Embrapa Tabuleiros Costeiros. Boletim de pesquisa e desenvolvimento, 115).

SILVA, M.B., MORAIS, A. S. Avaliação energética do bagaço de cana em diferentes níveis de umidade e graus de compactação. XXVIII encontro nacional de engenharia de produção. Rio de Janeiro, 2008.

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Ethanol yields by cellulosic genotype

Híbridos	L EtOH/ ha SFS ác.		L EtOH/ ha SFS ác.+bs		L EtOH/ ha SSF	
	Sete Lagoas	Couto M. Minas	Sete Lagoas	Couto M. Minas	Sete Lagoas	Couto M. Minas
201556(B)002	3821,21 Aa	4220,28 Aa	11567,86 Aa	9232,21 Bb	9288,38 Aa	8286,97 Bb
201556(B)003	3715,52 Aa	4196,27 Aa	6612,57 Ab	8080,50 Ab	7767,84 Ab	8511,44 Ab
CMSXS7027	2806,64 Bb	3577,77 Ab	6671,33 Bb	8459,30 Ab	7423,88 Ab	7369,04 Ac
CMSXS7016	3788,22 Ba	4520,18 Aa	7256,25 Bb	9316,34 Ab	9323,90 Ba	10330,07 Aa
BRS716	3976,62 Aa	4401,47 Aa	10587,97 Aa	11838,46 Aa	8166,88 Bb	10820,36 Aa

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***bmr* Sorghum : 0,51 L/kg de biomassa**

Biomass Sorghum: 0,35 L/kg de biomassa

Almeida et al. (2019) Characterization of cell wall polysaccharides and cellulosic ethanol potential in genotypes of sorghum biomass. **International Journal of Development Research**, v. 09, p. 26810-26820, 2019a.

Almeida et al. (2019) Composition and growth of sorghum biomass genotypes for ethanol production. **Biomass & Bioenergy**, v. 122, p. 343-348, 2019b.

CAMPAIGN FINANCED WITH AID FROM THE EUROPEAN UNION

Results of TS, VS and FS and biogas and methane production tests from biomass sorghum samples.

Genotype	TS (g/kg)	VS (g/kg)	FS (g/kg)	Biogas production (LNbiogás.kgsv^{-1})	Methane production (LNCH$_4$.kgsv^{-1})	Biogas production m³ de biogás.ton $^{-1}$
bmr03	913,9	942,4	57,6	449	237	386,7
bmr18	915,9	936,6	63,4	431	223	369,7
BRS716	924,4	958,5	41,5	450	242	398,7

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TS: total solids, VS: volatile solids and FS: fixed solids.

► 312.3 to 607.1 LNbiogás.kgsv^{-1}

(S.O. Dahunsi, A.T. Adesulu-Dahunsi, C.O. Osueke et al. / Energy Reports 5 (2019) 584–593).

CAMPAIGN FINANCED WITH AID FROM THE EUROPEAN UNION

Bioenergy sorghum for Animal Feed

Comparison of means for agronomic characteristics and chemical composition (% in Dry Mass) of different biomass and forage sorghuns.

FORRAGEM	CARACTERÍSTICAS								
TIPO DE SORGO	Hight	Fresh Biomas	Dry Biomass	FDA	LDA	FDN	CZ	CEL	HEM
Biomassa ***bmr***	m	t,ha^{-1}	t,ha^{-1}	%	%	%	%	%	%
CMSXS7500	4,20	75,71	22,77	42,3	4,6	71,4	6,9	37,7	29,2
CMSXS7502	3,98	75,78	17,85	43,3	4,6	72,6	9,5	38,8	29,3
CMSXS7501	3,96	70,63	18,69	42,8	4,3	71,9	10,4	38,5	29,2
CMSXS7527	4,45	80,98	21,83	43,7	4,6	74,8	8,4	39,1	31,1
CMSXS7515	4,54	77,23	24,25	41,7	5,0	71,9	7,0	36,7	30,2
Biomassa conventional									
BRS716	4,78	64,12	16,44	53,51	7,19	80,75	6,48	32,11	27,44
Forrageiro (FS)									
BRS 655	2,51	37,86	9,38	41,4	5,2	70,2	5,5	36,2	28,8
Volumax	2,88	49,00	11,68	41,5	5,3	71,5	8,9	36,2	30,00
bmr: nervura marrom									

QUEIROZ, F. E. et al., . Effect of row spacing and maturity at harvest on the fermentative profile, aerobic stability, and nutritional characteristics of biomass sorghum (BRS 716) silage in the semiarid region of Brazil. REVISTA BRASILEIRA DE ZOOTECNIA-BRAZILIAN JOURNAL OF ANIMAL SCIENCE, v. 50, p. 100-113, 2021.

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Reproduction factors (RF) and reactions of sorghum genotypes to nematodes Meloidogyne incognita, race 3, M, javanica and Pratylenchus brachyurus, Embrapa Soja, May, 2019.

Reduction of soybean complex nematodes

Genótipos	M, incognita		M, javanica		P, brachyurus	
	1/RF	2/Reaction	RF	Reaction	RF	Reaction
Doko RC (soja)	50,23	S	72,27	S	-	-
BRS Celeste (soja)	52,07	S	52,72	S	-	-
BRS 317 (soja)	57,38	S	75,33	S	-	-
201840B002	17,53	S	8,48	MR	0,00	R
201840B005	3,03	MR	13,47	S	0,00	S
201840B008	7,23	MR	29,45	S	1,00	MR
201840B011	1,53	R	5,08	MR	2,00	S
201840B012	0,87	R	2,28	R	0,50	MR
201840B018	9,75	S	6,08	MR	1,00	MR
201840B021	2,88	MR	19,95	S	0,50	MR
201840B022	7,22	MR	20,42	S	0,50	MR
201840B023	10,48	S	7,15	MR	2,00	S
201840B024	11,83	S	2,78	R	1,50	S
201840B025= PS	24,43	S	25,48	S	1,00	MR
AGRI002E (Sinop)	15,63	S	12,07	S	2,00	S
BRS 373 (sorgo gran,)	1,82	R	0,43	R	0,00	R
BRS 380 (sorgo gran,)	2,25	R	0,48	R	1,50	S
BRS 716 (Sinop)	2,28	R	17,88	S	2,00	S
BRS P, Negra (Sinop)	2,48	MR	7,22	MR	0,00	R

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Organic Cover for no-tillage systems

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Mechanized Harvesting of Biomass Sorghum

3RD EUROPEAN SORGHUM CONGRESS

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Final Remarks – Take Away

Sorghum has great potential to meet demand for quality biomass for bioenergy production;

We Now have Four Types of High Productive and High Quality Energy Sorghums Released or Ready for Release;

We are Interested in Collaborative Research & Development and Business Opportunities with Both Public and Private Sectors.

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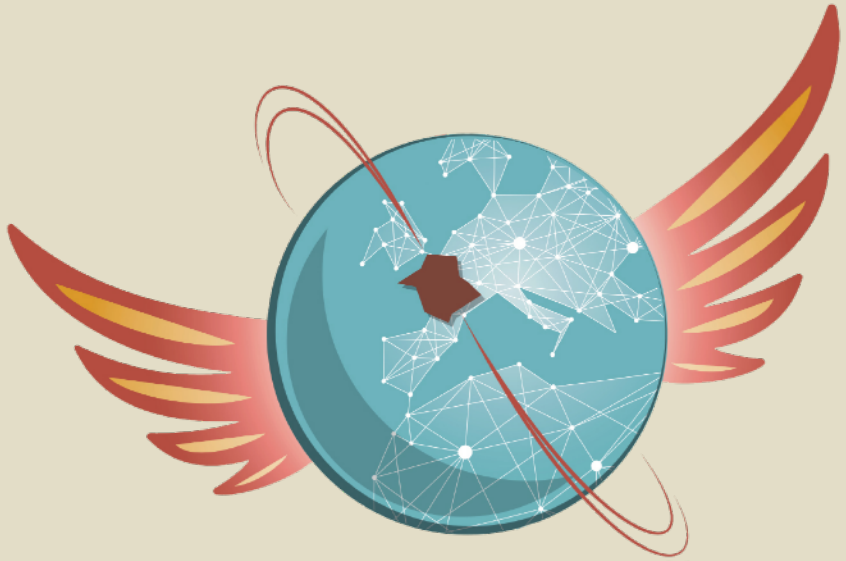

Thank you

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