Adding value and minimizing losses: Small granule cassava starch for ethanol production

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On behalf of the Postharvest Quality Lab, Cassava Program

CIAT Palmira, 14/02/2023

POSTHARVEST QUALITY LABORATORY
ROOTS, TUBERS AND BANANAS

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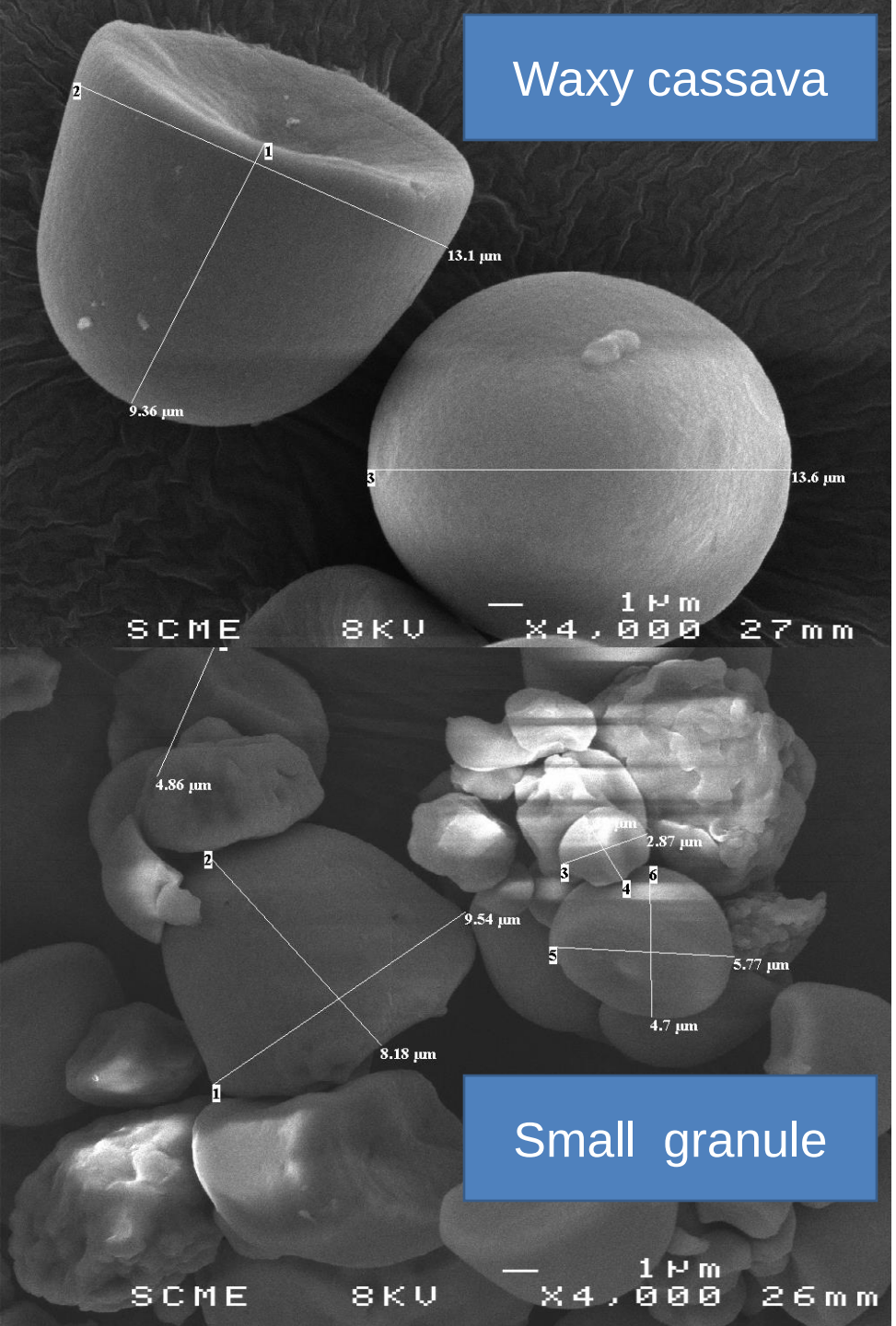
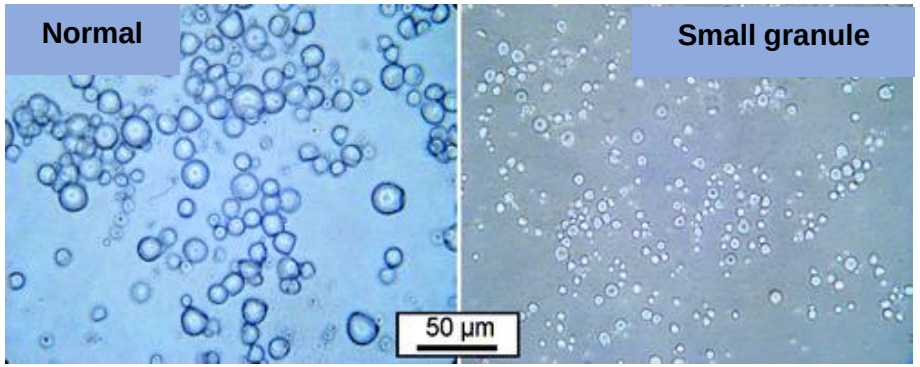
AGRICULTURAL RESEARCH FOR DEVELOPMENT



Cassava special starches

Unique genotypes developed at CIAT

	Amylose content (%)	Granule size (µm)	Crystallinity (%)
Waxy cassava	0.0	16.0	40.0
Small Granule	26	5.8	-
Double mutant	0.0	6.5	-
Normal Cassava	16.8	15.1	35.0



2003A - Shipment of 6 families of cassava sexual seed

Cross	Mother	Father	Source	Purpose	No. Seeds
CM 9331	SM 1210- 10	MNGA 1	GY199590	Z02	300
SM 3015	MCOL 1505		GY199960	Z01	300
SM 3045	HMC 1		GY199962	Z04	300
GM 155	MTAI 1	SM 2102- 34	GY199889	ASG	306
C - 4			GY200122	AFG	454
C - 127			GY200122	AFG	50

To be irradiated with Gamma Rays and Neutrons

2003B - Sowing trial F1 of irradiated seed in ICA - Palmira

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Self-pollination

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- 76 Families of plants from seed irradiated with Gamma Rays - 3616 Seeds
- 26 Families of plants from seed irradiated with Neutrons - 974 Seeds

2005 - Sowing trial F2 (S1) of irradiated seed in CIAT

Irradiation type	Families	Seeds	Plants in the field	Select plants for Laboratory
Gamma	76	3616	2189	1027
Neutrons	26	974	553	318

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Variety	Characteristic
5G190- 11	Low starch
5N14- 5	Low starch
2G28- 9	Hollow granule
5G160- 13	Small granule
5G160- 16	Small granule
5G160- 18	Small granule
SM3015G43-1	Small granule ????
5G108- 3	PPD resistance
5G108- 4	PPD resistance
4G15- 1	PPD resistance
3G77- 4	PPD resistance
3G77- 5	PPD resistance

2007 - Generation of Double Mutant varieties

Small granule	Waxy
5G160- 13	GM 4034- 1
5G160- 18	SM 3315- 5
	SM 3316- 24
	SM 3316- 32
	CL 41- 1
	CL 41- 6
	CL 42- 3

→

- 6 Families
- 260 Seeds

↓

2010 - Planting in a crossing nursery

2011/2012 - Generation of Double Mutant varieties

88 Families – 2388 Seeds

Cross	Families	Seeds	Plants in the field	Select plants for Laboratory
S1	49	1932	1109	263
F2	42	456	279	68

Waxy	Small Granule	Double Mutant
72	96	6

2020 - Planting for crosses with high Dry matter varieties

Small Granule	Dry Matter
5G 160- 13	SM2828-28
5G 160- 16	TAI8
5G 160- 18	CM4919-1
GM 4682- 7	SM3559-11
GM 4694- 4	HMC1
GM 4694- 22	
GM 4694- 39	

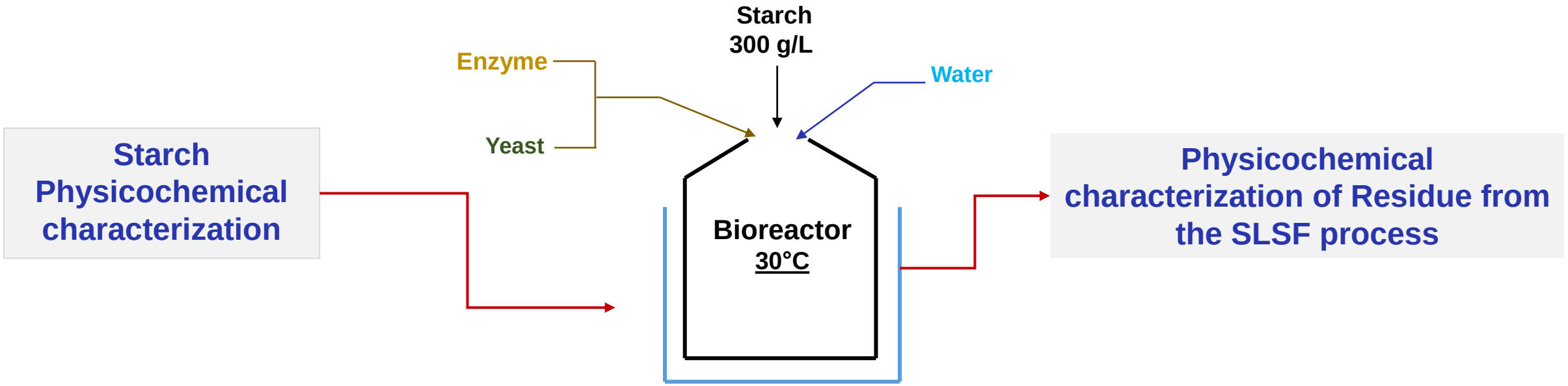
Planting F1-2021

Family	Mother	Father	Source	Group	No. Seeds	Trasplant.
GM9516A	5G160-16	SM2828-28	GY202003	SG_MD	33	30
GM13840A	GM4694-22	SM2828-28	GY202003	SG_MD	33	31
GM13843A	GM4694-22	TAI8	GY202003	SG_MD	33	31
GM13901A	5G160-16	CM4919-1	GY202003	SG_MD	33	30
GM13904A	5G160-16	TAI8	GY202003	SG_MD	33	31
GM13941A	GM4682-7	CM4919-1	GY202003	SG_MD	17	17
GM13942A	GM4682-7	SM2828-28	GY202003	SG_MD	33	30
GM13944A	GM4694-4	CM4919-1	GY202003	SG_MD	33	33
GM13945A	GM4694-4	SM2828-28	GY202003	SG_MD	33	31
GM13946A	GM4694-4	SM3559-11	GY202003	SG_MD	9	9
GM13947A	GM4694-4	HMC1	GY202003	SG_MD	4	3
GM13948A	GM4694-22	CM4919-1	GY202003	SG_MD	33	32
GM13949A	GM4694-22	SM3559-11	GY202003	SG_MD	33	33
GM13951A	GM4694-39	CM4919-1	GY202003	SG_MD	28	24
GM13953A	GM4694-39	SM2828-28	GY202003	SG_MD	33	27
GM13954A	GM4694-39	SM3559-11	GY202003	SG_MD	25	22
GM13958A	GM4694-39	TAI8	GY202003	SG_MD	33	28
					479	**442**

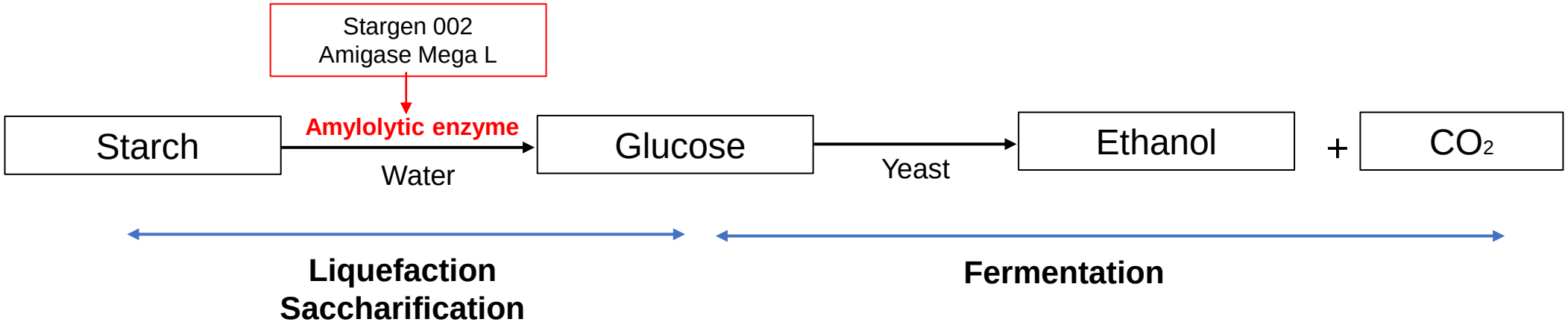
2021 - Planting for crosses with high Dry Matter varieties (2)

GY202112										
Entrada	Prior	Madre	Padre	Prop. 1	Prop. 2	Flores Total	Semilla Esp.		Prop. General	Prop. M+P
		GM 4682- 7	GM 4682- 7	S1	SG	4	2		SSG	S1_SG
		AM 1305- 21	SM 2828- 28	SG	DM	66	40		GDM	SG_DM
		AM 1305- 21	SM 3559- 11	SG	DM	15	9		GDM	SG_DM
		AM 1305- 42	SM 1219- 9	SG	DM	30	18		GDM	SG_DM
		AM 1305- 42	SM 2828- 28	SG	DM	31	19		GDM	SG_DM
		AM 1305- 42	SM 3559- 11	SG	DM	4	2		GDM	SG_DM
		GM 4679- 2	SM 1219- 9	SG	DM	39	23		GDM	SG_DM
		GM 4679- 2	SM 2828- 28	SG	DM	46	28		GDM	SG_DM
		GM 4679- 2	SM 3134- 73	SG	DM	11	7		GDM	SG_DM
		GM 4679- 2	SM 3559- 11	SG	DM	4	2		GDM	SG_DM
		GM 4682- 7	SM 1219- 9	SG	DM	23	14		GDM	SG_DM
		GM 4682- 7	SM 2828- 28	SG	DM	15	9		GDM	SG_DM
		GM 4694- 11	SM 3559- 11	SG	DM	31	19		GDM	SG_DM
		GM 4694- 22	GM 579- 13	SG	DM	233	140		GDM	SG_DM
		GM 4694- 22	SM 2773- 32	SG	DM	242	145		GDM	SG_DM
		GM 4694- 22	SM 2828- 28	SG	DM	59	35		GDM	SG_DM
		GM 4694- 22	SM 3134- 73	SG	DM	31	19		GDM	SG_DM
		GM 4694- 22	SM 3559- 11	SG	DM	84	50		GDM	SG_DM
		AM 1305- 21	SM 3386- 49	SG	DM_CQ	44	26		GDM	SG_DM_CQ
		GM 4694- 11	SM 3386- 49	SG	DM_CQ	21	13		GDM	SG_DM_CQ
						1033	620			

Very High Gravity (VHG): 30% dry matter



Simultaneous Liquefaction, Saccharification and Fermentation (SLSF)



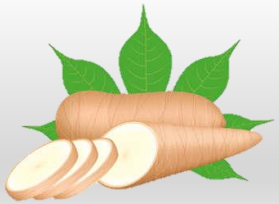
Chemical characterization of native starches

Sample	Characteristic	Amylose (%, db)	Starch content (%, db)			
			TS	RDS	SDS	RS
GM 4694-1	Small granule	21.95 ± 0.05 ^{e}	94.06 ± 1.88 ^{a}	**48.01** ± 0.64 ^{d}	43.14 ± 2.05 ^{ef}	2.91 ± 1.41 ^{ab}
AM 1288-17	Double mutant	< LQ	97.70 ± 1.48 ^{a}	**46.04** ± 0.14 ^{d}	47.96 ± 1.01 ^{fg}	3.70 ± 0.87 ^{ab}
AM 1290-1	Double mutant	< LQ	95.39 ± 1.29 ^{a}	**54.36** ± 2.61 ^{e}	36.14 ± 2.96 ^{cd}	4.89 ± 0.35 ^{ab}
AM 206-5	Waxy	1.59 ± 0.10 ^{a}	96.93 ± 0.57 ^{a}	16.91 ± 0.85 ^{b}	40.26 ± 2.25 ^{cde}	**39.77** ± 3.10 ^{c}
CUMBRE-3	Normal	16.05 ± 0.09 ^{c}	96.70 ± 3.37 ^{a}	16.95 ± 0.93 ^{b}	35.92 ± 1.08 ^{cd}	**43.83** ± 2.01 ^{cd}
MTAI-8	Normal	20.01 ± 0.13 ^{d}	91.02 ± 1.49 ^{a}	11.16 ± 0.31 ^{a}	33.90 ± 0.41 ^{bc}	**45.96** ± 0.10 ^{d}
RICE	Waxy	4.33 ± 0.07 ^{b}	95.90 ± 0.76 ^{a}	70.47 ± 1.42 ^{g}	24.78 ± 1.76 ^{a}	0.65 ± 0.34 ^{a}
MAIZE	Normal	23.60 ± 0.42 ^{f}	94.96 ± 0.59 ^{a}	40.76 ± 0.29 ^{c}	53.49 ± 0.18 ^{g}	0.71 ± 0.11 ^{a}

<LQ: less than the limit of quantification; TS: total starch; RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch. Data are shown as the mean ± standard deviation from two determinations. Value followed by different letter in the same column are significantly different (P<0.05).

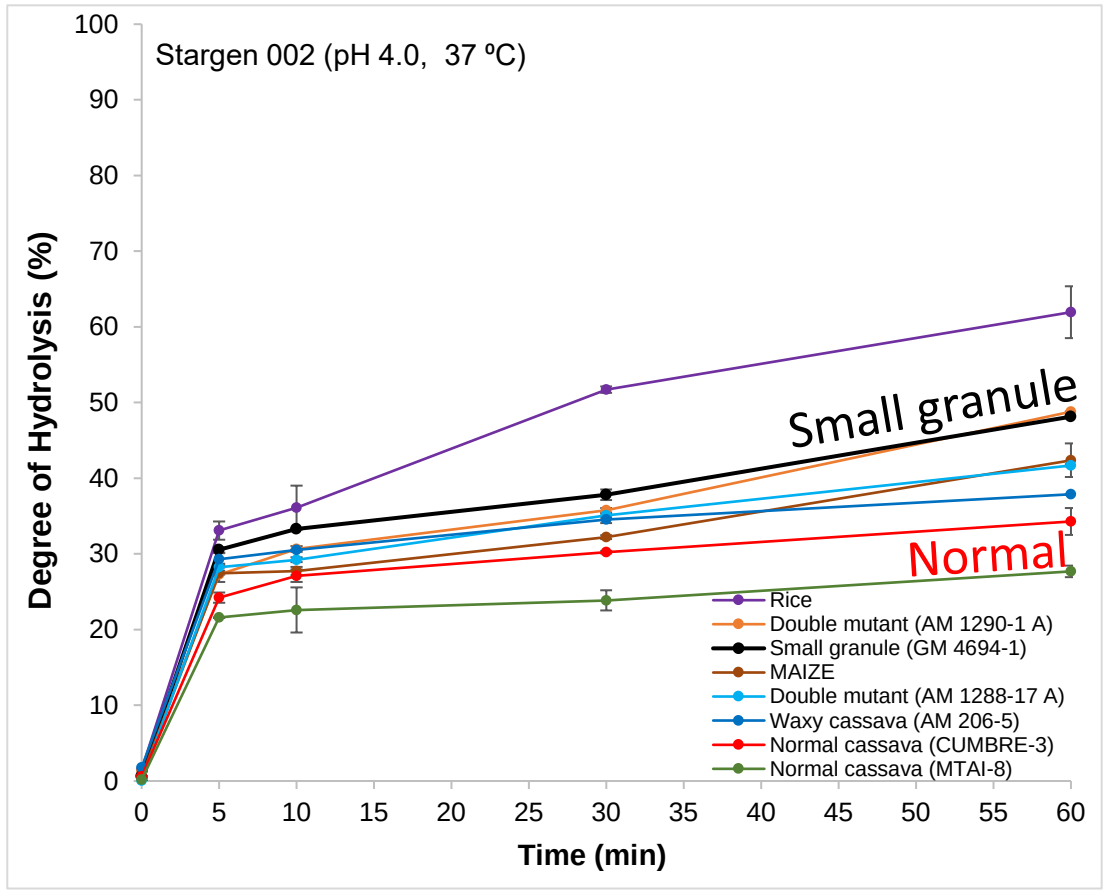
RDS: Rapidly digestible starch

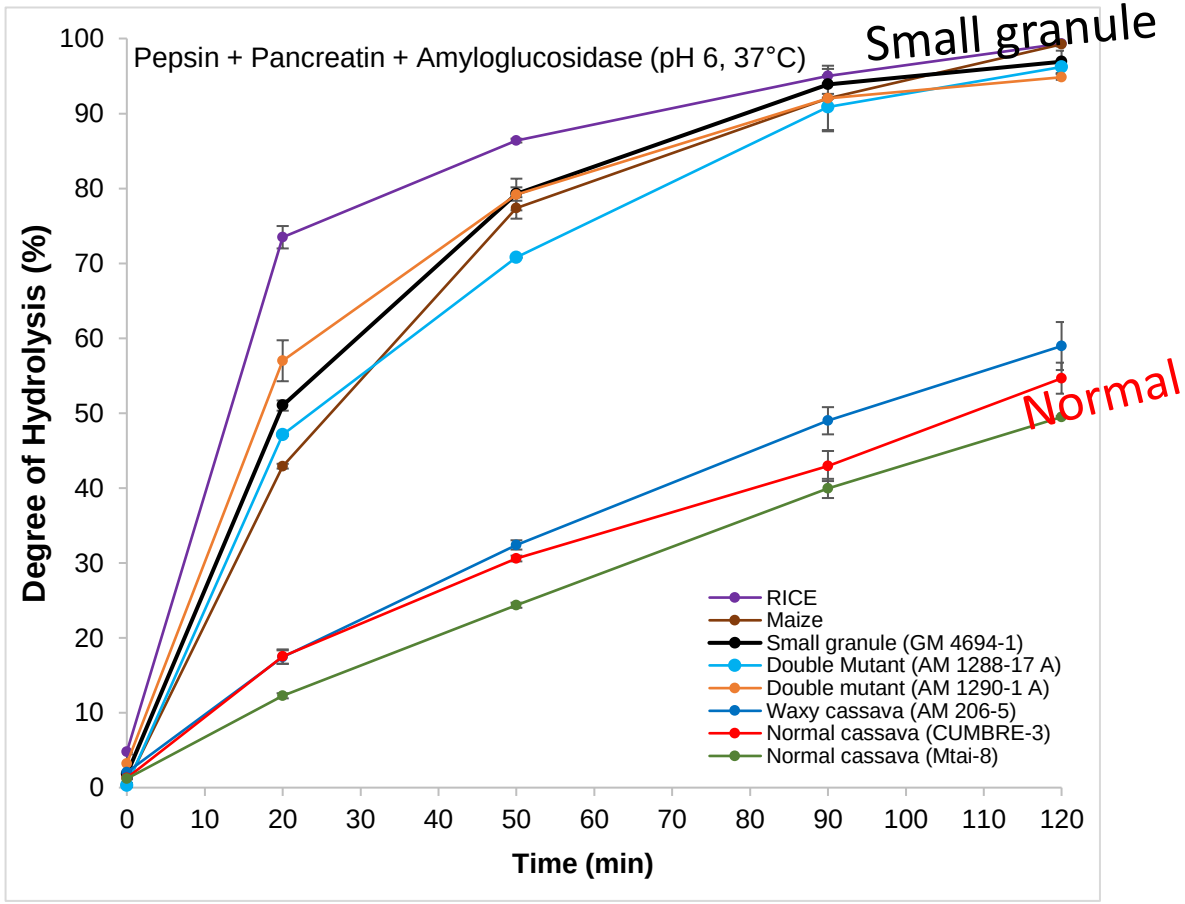
RS: Resistant starch

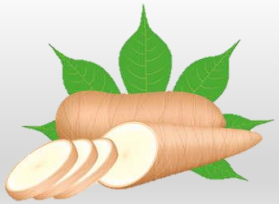


Small granule

Hydrolysis of native starches

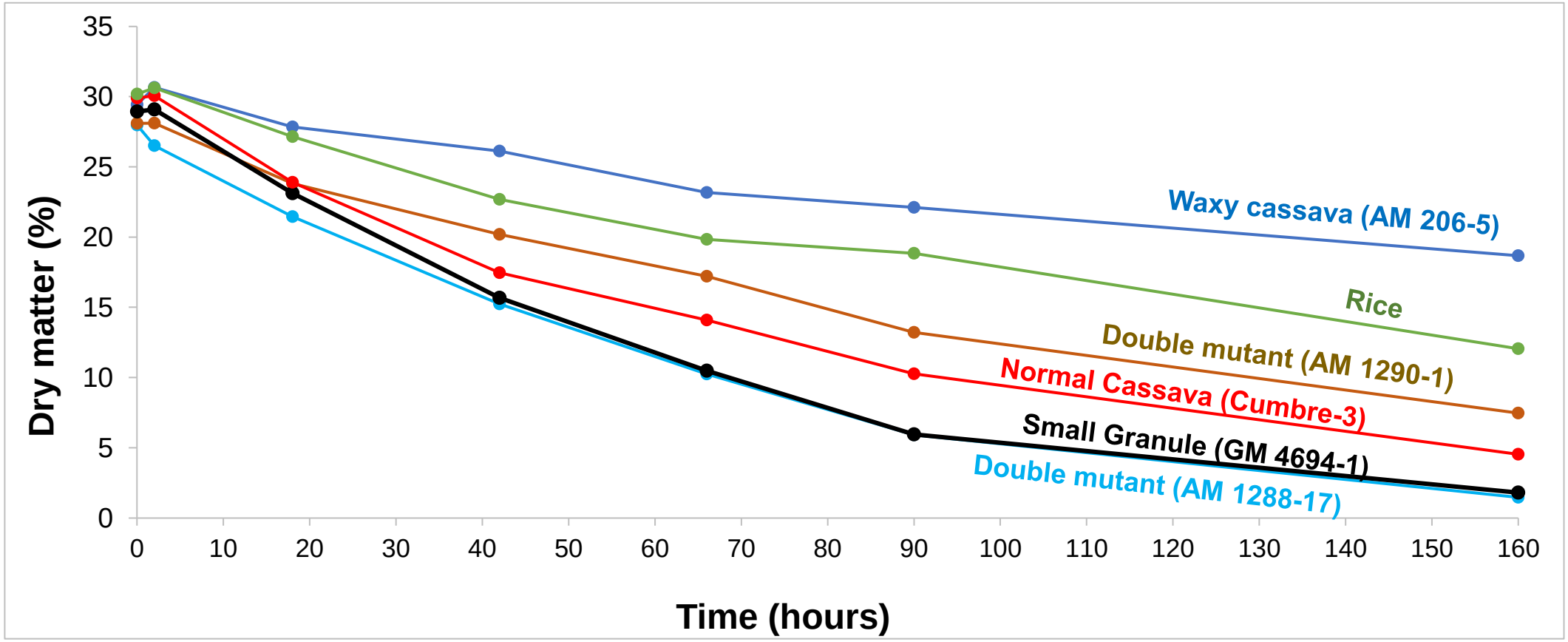


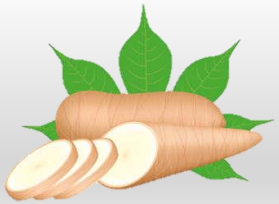




Small granule

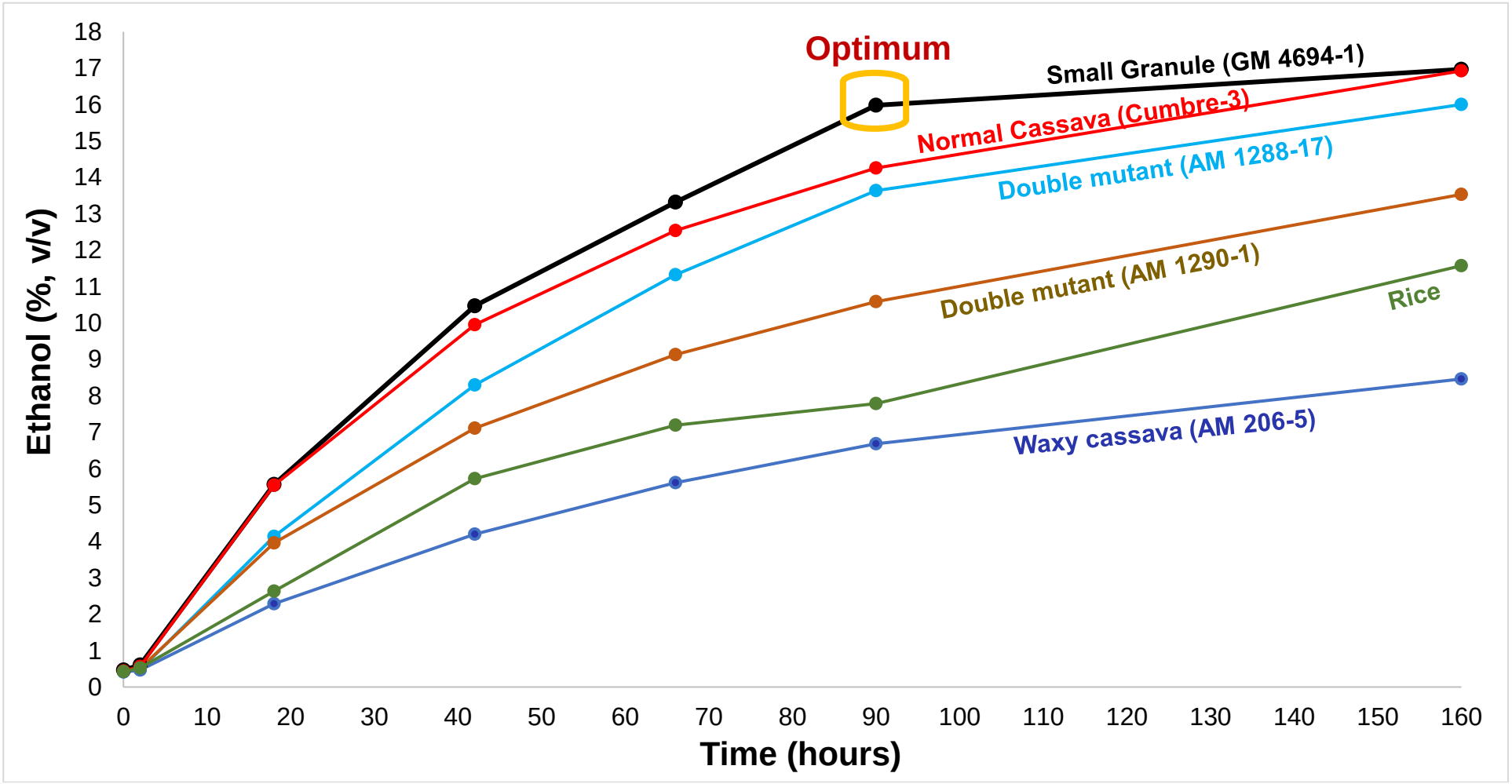
Dry matter content during SLSF process

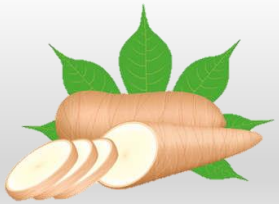




Small granule

Ethanol production during SLSF process





Small granule

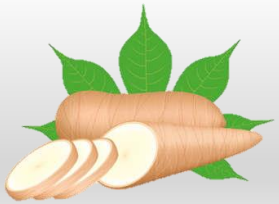
Optimum reached 3 days faster with small granules cassava, meaning higher production capacity

Highest rate of hydrolysis with Small Granule Cassava (GM 4694-1) and Double Mutant (AM 1290-1)

Combination of:

1) **Small granule variety**
2) **Very high gravity fermentation process**

Enables high ethanol yield at lower costs and shorter time – nearly 3 days faster for same ethanol production as the control.



Small granule

Cost savings of hydrolyzing small granule cassava at low temperature compared to normal starch at 90°C

Small granules cassava starch are more sensitive to amylase hydrolysis, and can be nearly fully hydrolyzed (95-99%) by incubation at 40°C, i.e. without gelatinization. No gelatinization means lower viscosity, allowing for higher concentration of starch (up to 35%), thus reducing the volume of water needed.

In contrast, to obtain the same hydrolysis with normal cassava starch, gelatinization is necessary with incubation at 90°C. Gelatinization means higher viscosity, limiting starch concentration to 10-15%.

	Unit	**Conventional 90°C + normal cassava**	**Low temperature 40°C + small granule cassava**
Temperature of hydrolysis incubation	°C	90	40
Starch concentration	%	12	35
Weight of water to incubate 1 kg starch	kg	7.3	1.9
Energy necessary to heat water from 30°C to incubation temperature	kJ	1843.6	77.8
Diesel to incubate 1 kg of starch (with heat transfer & losses factor 30%)	L	0.06193	0.00261
Diesel cost to incubate 1 kg of starch *	USD	0.093	0.004
Diesel cost to incubate 1 t of starch *	USD	92.89	3.92

** For this evaluation, diesel price was set at 1.5 USD/L*

granule

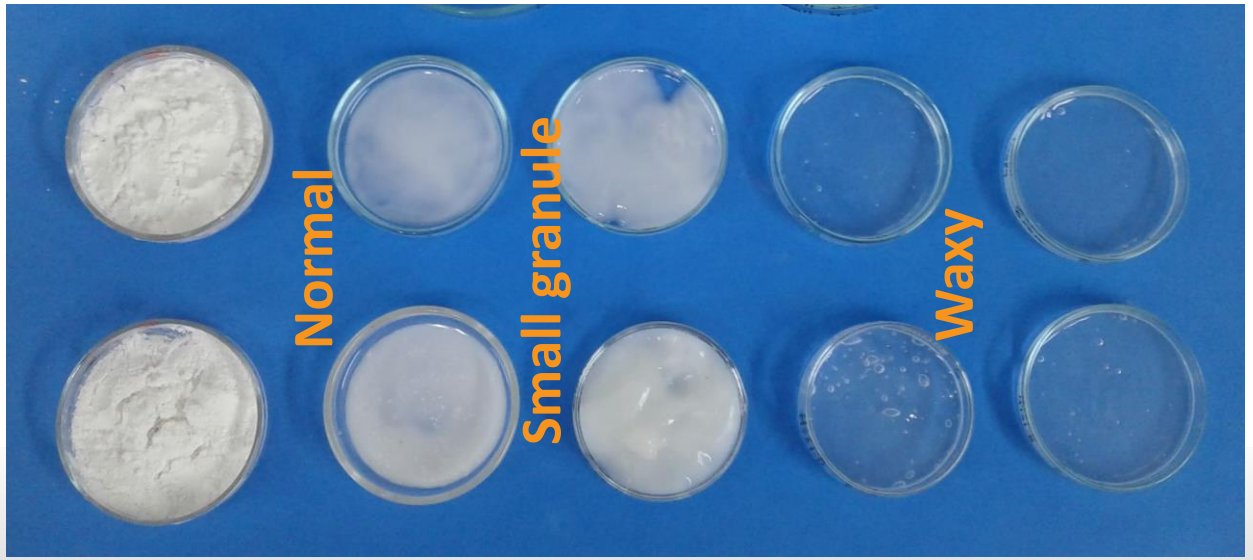
Other potential uses of small granules

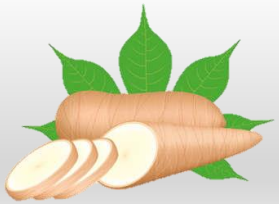
Production of glucose syrup

Other fermentations than ethanol: Lactic acid, glutamate, etc.

Direct applications as food ingredient / chemical:

- Low viscosity during gelatinization
- Opaque gels
- High solubility and high swelling power
- Bioplastics





Small granule

Gracias! Thank you!

CIAT Cassava Program

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CGIAR RESEARCH PROGRAM ON Roots, Tubers and Bananas