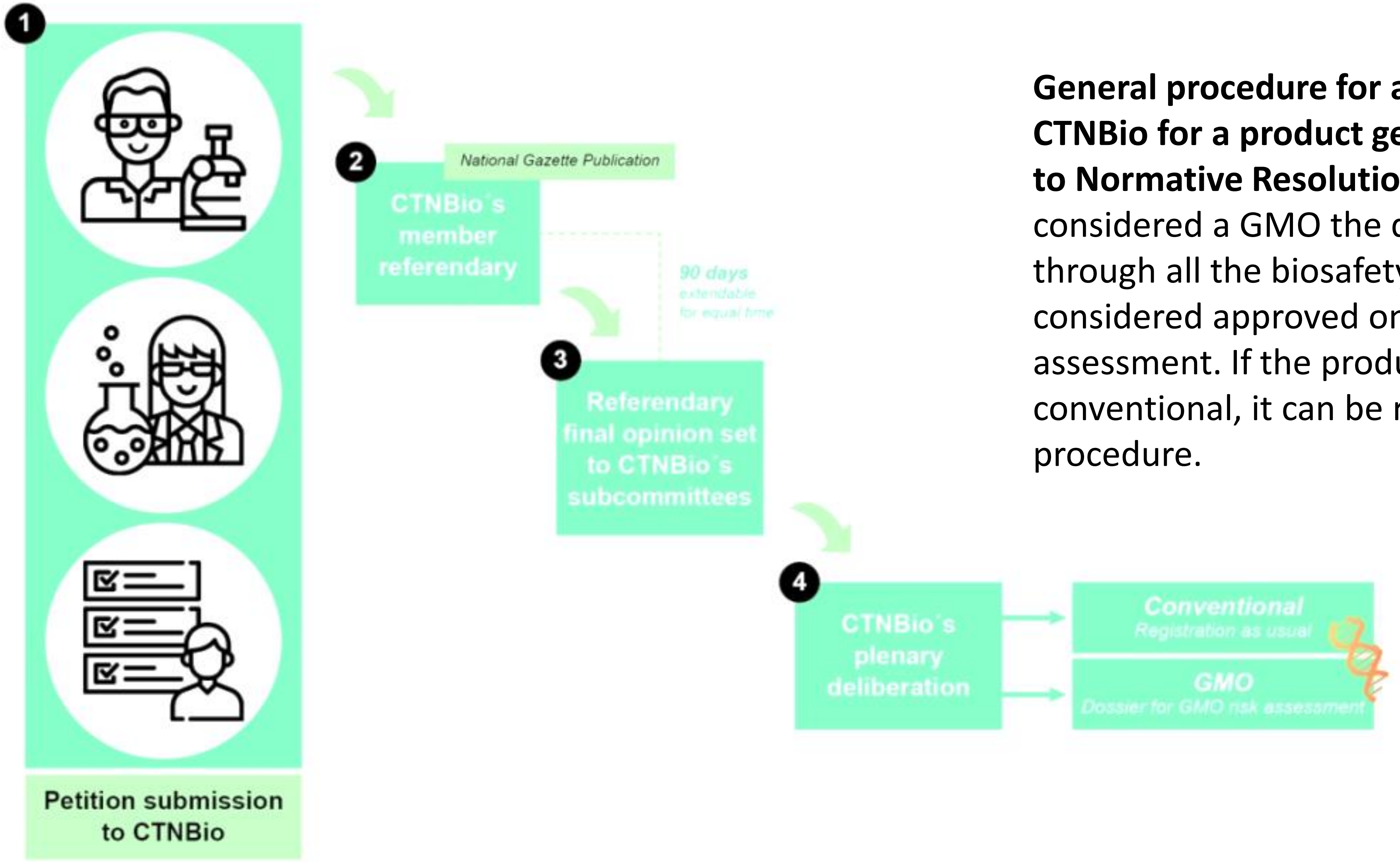
Scientific and regulatory advances of genome editing in Brazil

Hugo B. C. Molinari, DSc.

Plant Breeding Innovation

CTNBio Normative Resolution Nº 16 of January 15, 2018



General procedure for a case-by-case consultation at CTNBio for a product generated by TIMP, according to Normative Resolution nº 16. If the product is considered a GMO the developer will have to go through all the biosafety requirements and will be considered approved only after the CTNBio's risk assessment. If the product is considered a conventional, it can be registered using the existing procedure.

comissão técnica nacional
CTNBio
de biossegurança

CTNBio RN 16
Gene Editing, RNAi, etc

DIÁRIO OFICIAL DA UNIÃO

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RESOLUÇÃO NORMATIVA Nº 16,.DE 15 DE JANEIRO DE 2018

ANEXO I

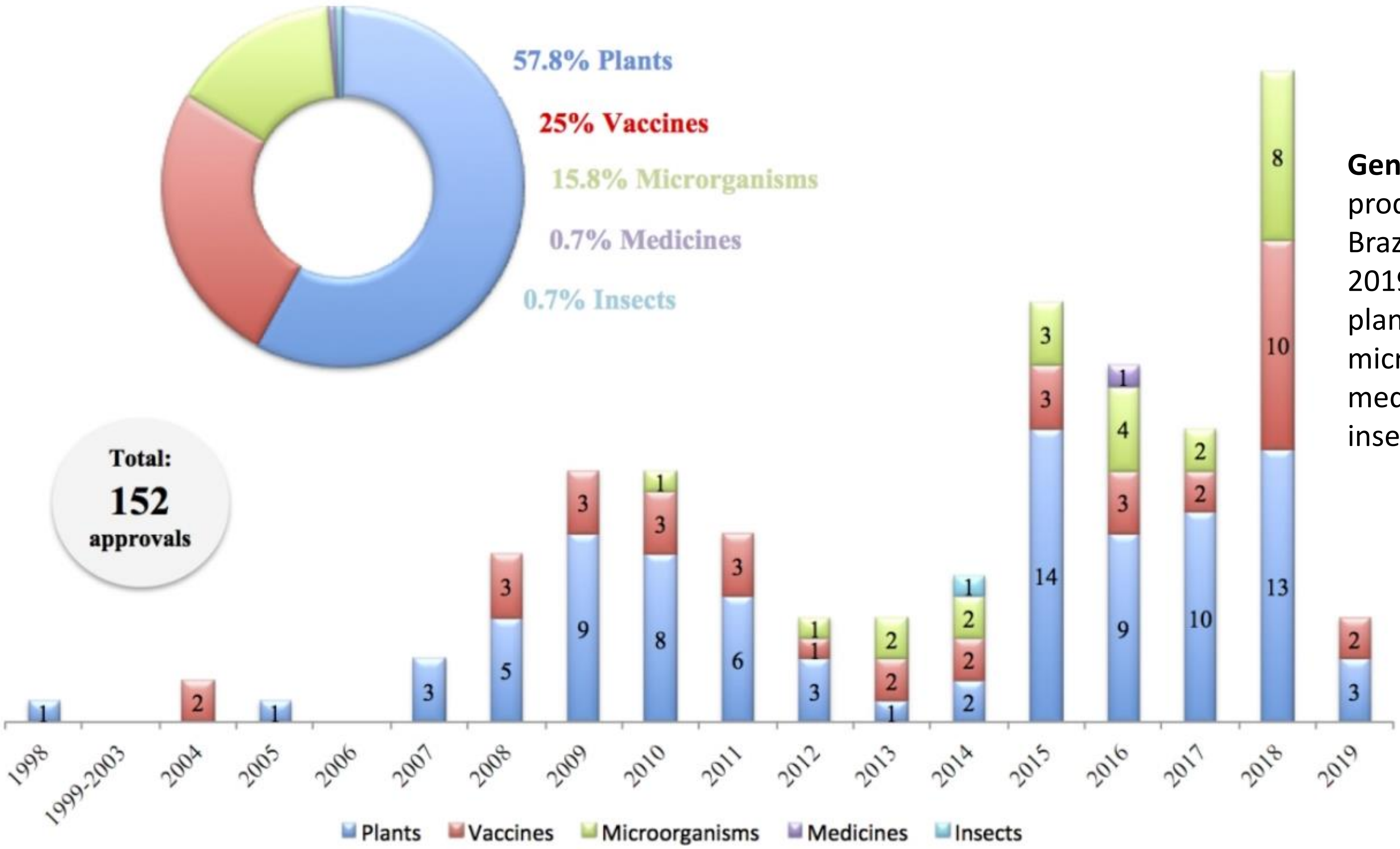
Estabelece os requisitos técnicos para apresentação de consulta à CTNBio sobre as Técnicas Inovadoras de Melhoramento de Precisão

A COMISSÃO TÉCNICA NACIONAL DE BIOSSEGURANÇA - CTNBio, no uso de suas atribuições legais e regulamentares e em observância às disposições contidas nos incisos XV e XVI do art. 14 da Lei nº 11.105, de 24 de março de 2005;

CONSIDERANDO a necessidade de avaliar as Técnicas Inovadoras de Melhoramento de Precisão (TIMP), do inglês Precision Breeding Innovation (PBI) e que também englobam as denominadas Novas Tecnologias de Melhoramento, do inglês New Breeding Technologies -NBTs, à luz dos preceitos previstos na Lei nº 11.105, de 24 de março de 2005;

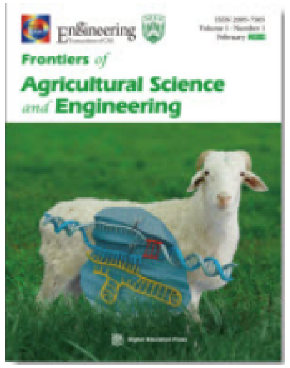
Considerando que a Lei nº 11.105, de 2005, define moléculas de ADN/ARN recombinante, engenharia genética e organismo geneticamente modificado - OGM nos incisos III, IV e V de seu art. 3º, respectivamente;

Considerando que as TIMP abrangem um conjunto de novas metodologias e abordagens que diferem da estratégia de engenharia genética por transgenia, por resultar na ausência de ADN/ARN



Genetically modified products approved in Brazil from 1998 to 2019, including plants, vaccines, microorganisms, medicines and insects.

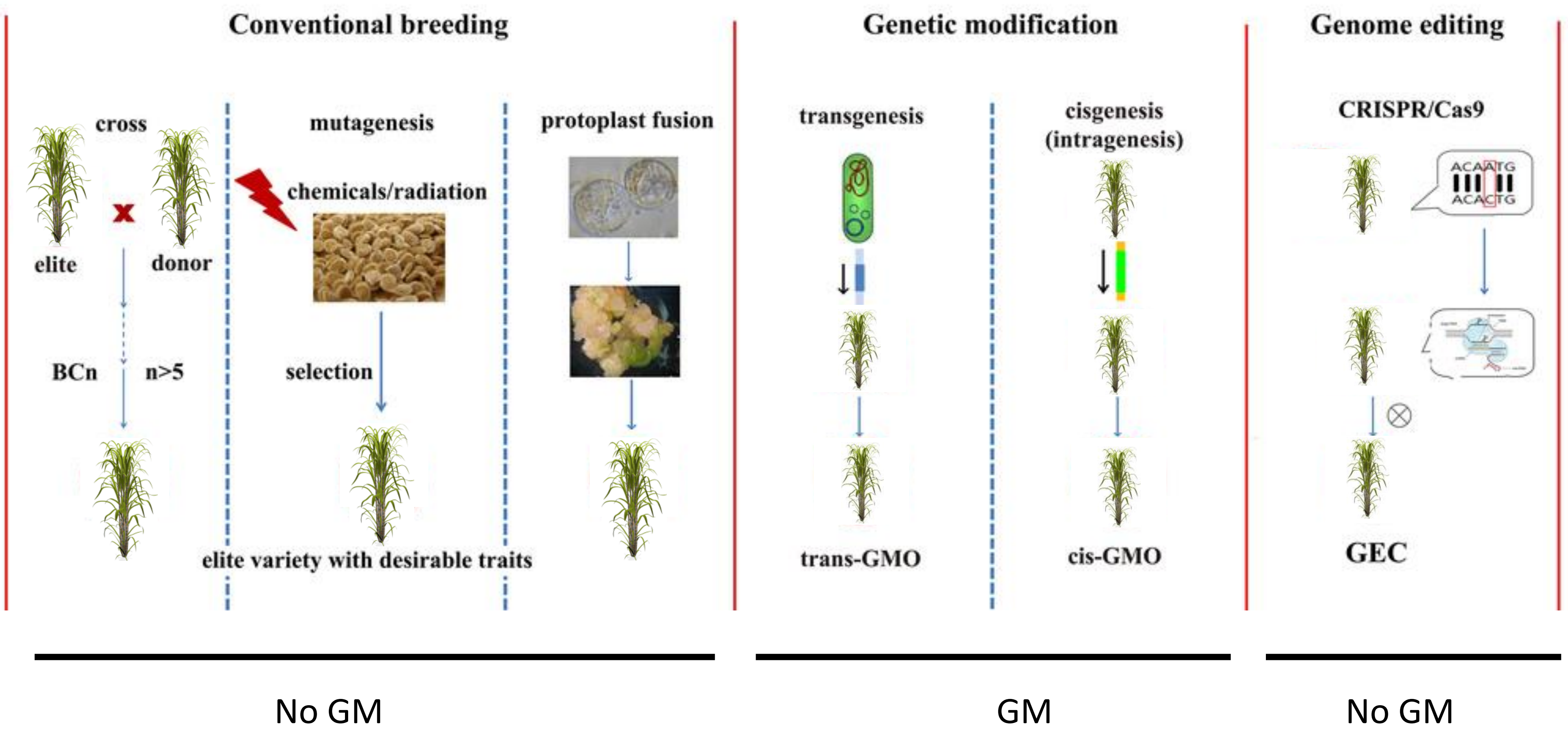
Available: Jan/2020



Brazilian Biosafety Law and the New Breeding Technologies

Journal:	*Frontiers of Agricultural Science and Engineering*
Manuscript ID	FASE-2019073
Manuscript Type:	Review
Date Submitted by the Author:	24-Aug-2019
Complete List of Authors:	Nepomuceno, Alexandre; National Biosafety Technical Commission Fuganti-Pagliarini, Renata; Embrapa Soybean Felipe, Maria Sueli; Catholic University of Brasilia; National Biosafety Technical Commission Molinari, Hugo Bruno; Embrapa Agroenergy; National Biosafety Technical Commission Vellini, Edivaldo; Paulista State University Julio de Mesquita Filho; National Biosafety Technical Commission Pinto, Eduardo; Embrapa Biotechnology and Genetic Resources ; National Biosafety Technical Commission Dagli, Maria Lucia ; São Paulo University; National Biosafety Technical Commission Filho, Galdino ; UEL; National Biosafety Technical Commission Fernandes , Patrícia ; Espírito Santo Federal University; National Biosafety Technical Commission
Speciality:	Agrobiotechnology, Crop Science, Crop Genetics and Breeding
Keywords:	Genetically Modified Crops, Brazilian Legislation, CTNBio

Different strategies for crop improvement



Huang et al. (2016) Nature Genetics , 48, 109-111 (Adapted)

Regulatory aspects of genetically modified crops

Transgenic technology

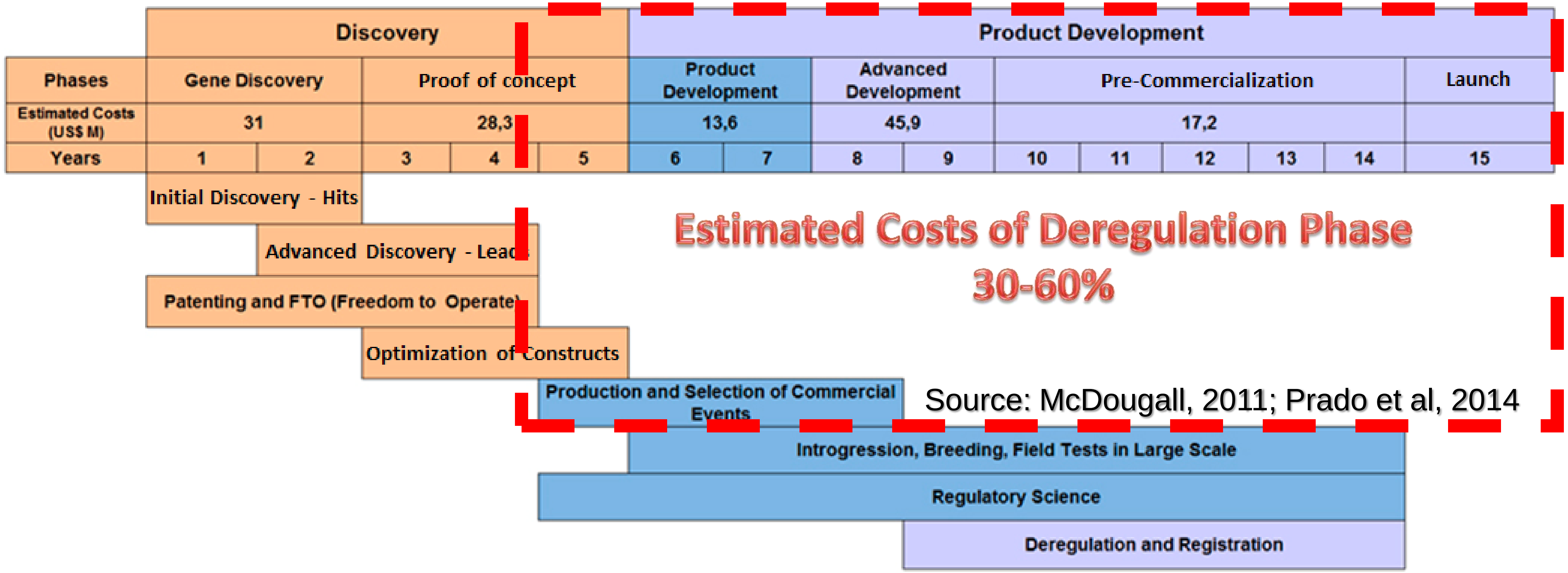
1:10:100

CRISPR system

- Low cost
- Technology non-GM
- Integration with breeding programs

- **Assays of protein expression (target and markers)**
- **Risk to animal/human health**
- **Compositional equivalence of sugar and ethanol** (Physical-chemical analyzes and quality indicators) – e.g. sugarcane
- **Industrial processing:** comparison between GMO versus native
- **Risks to the environment (class I)**
- **Risks to the environment (class II)**
- **Other relevant characteristics of the GMO in question**

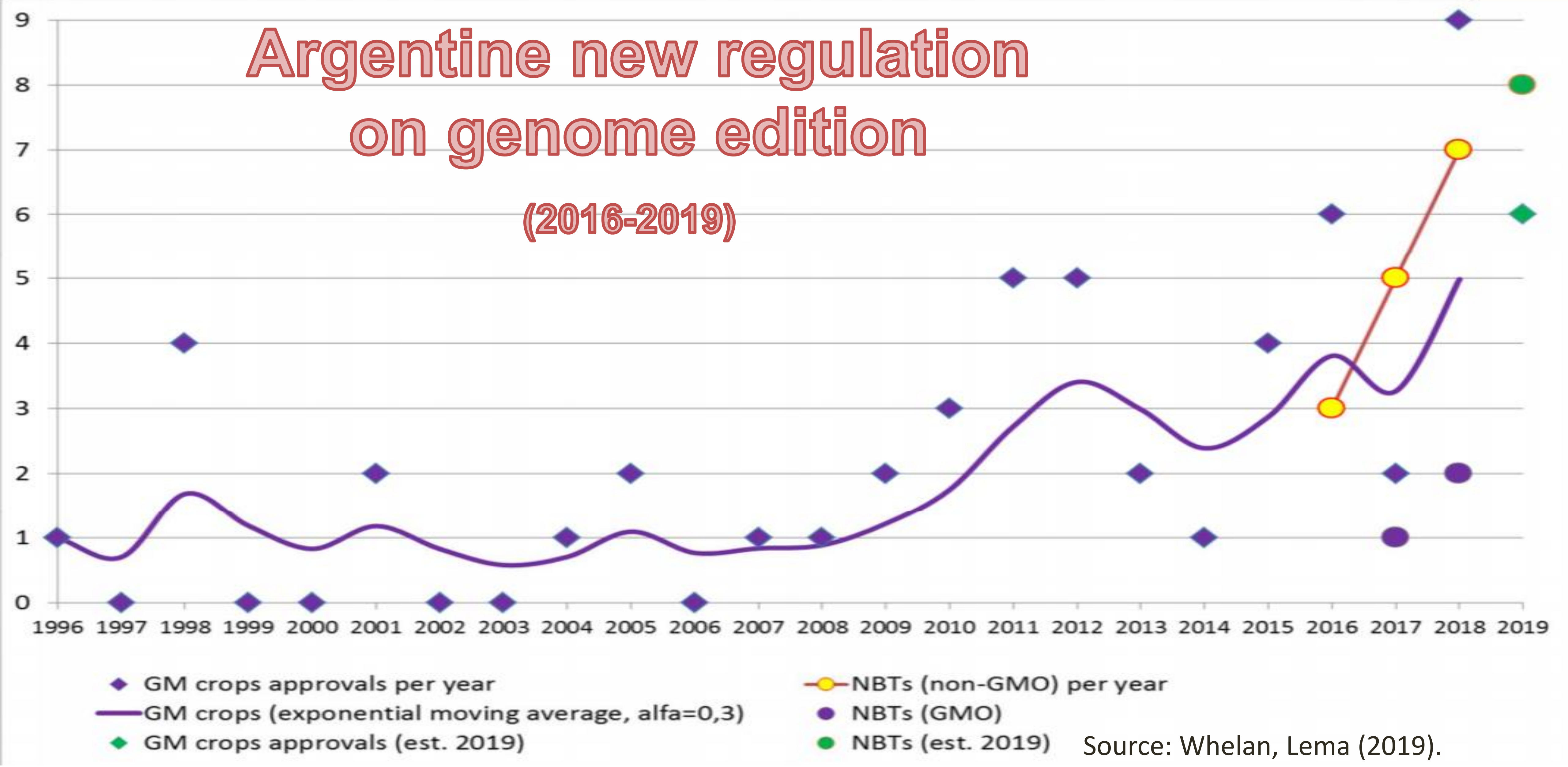
Development Phases of a GM Crop



Estimated Costs: U$136 million

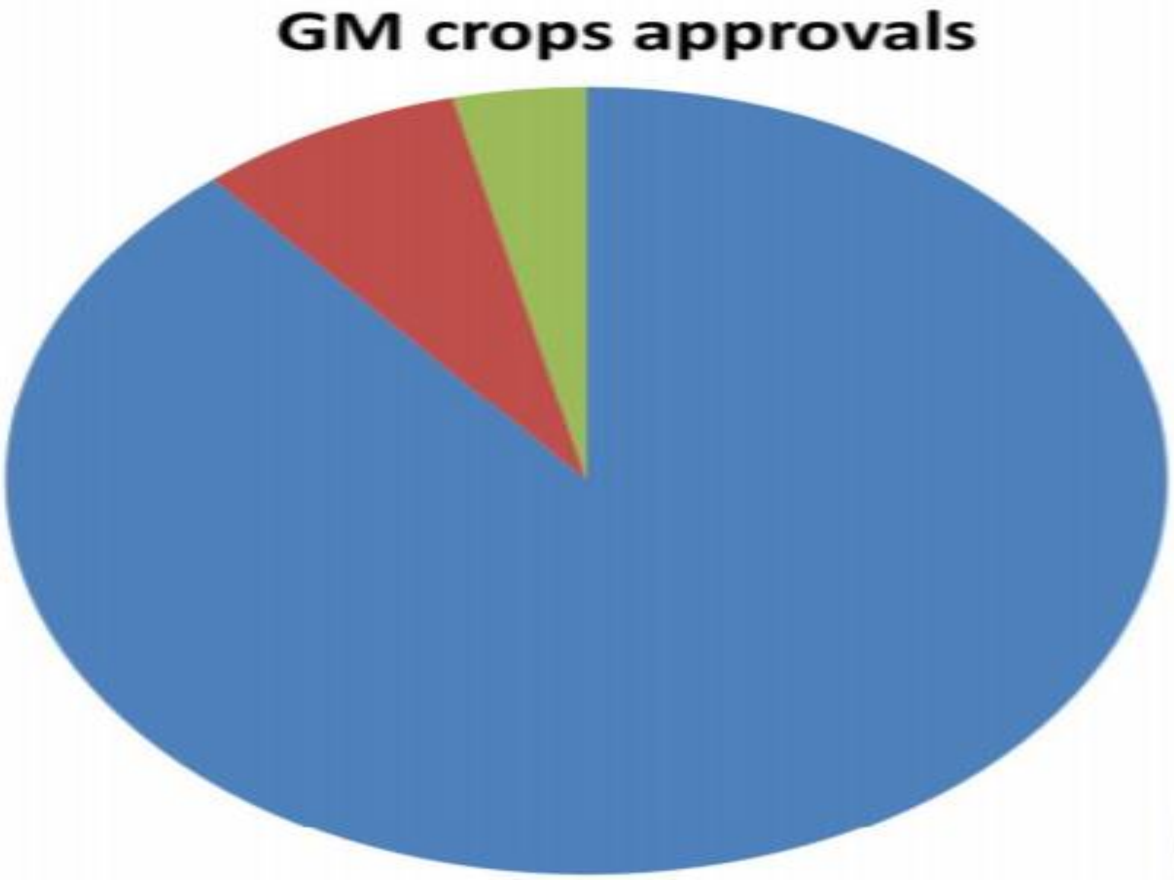
It can take ~12-20 years from discovering a gene(s) and placing a GM Commercial Variety in the Market

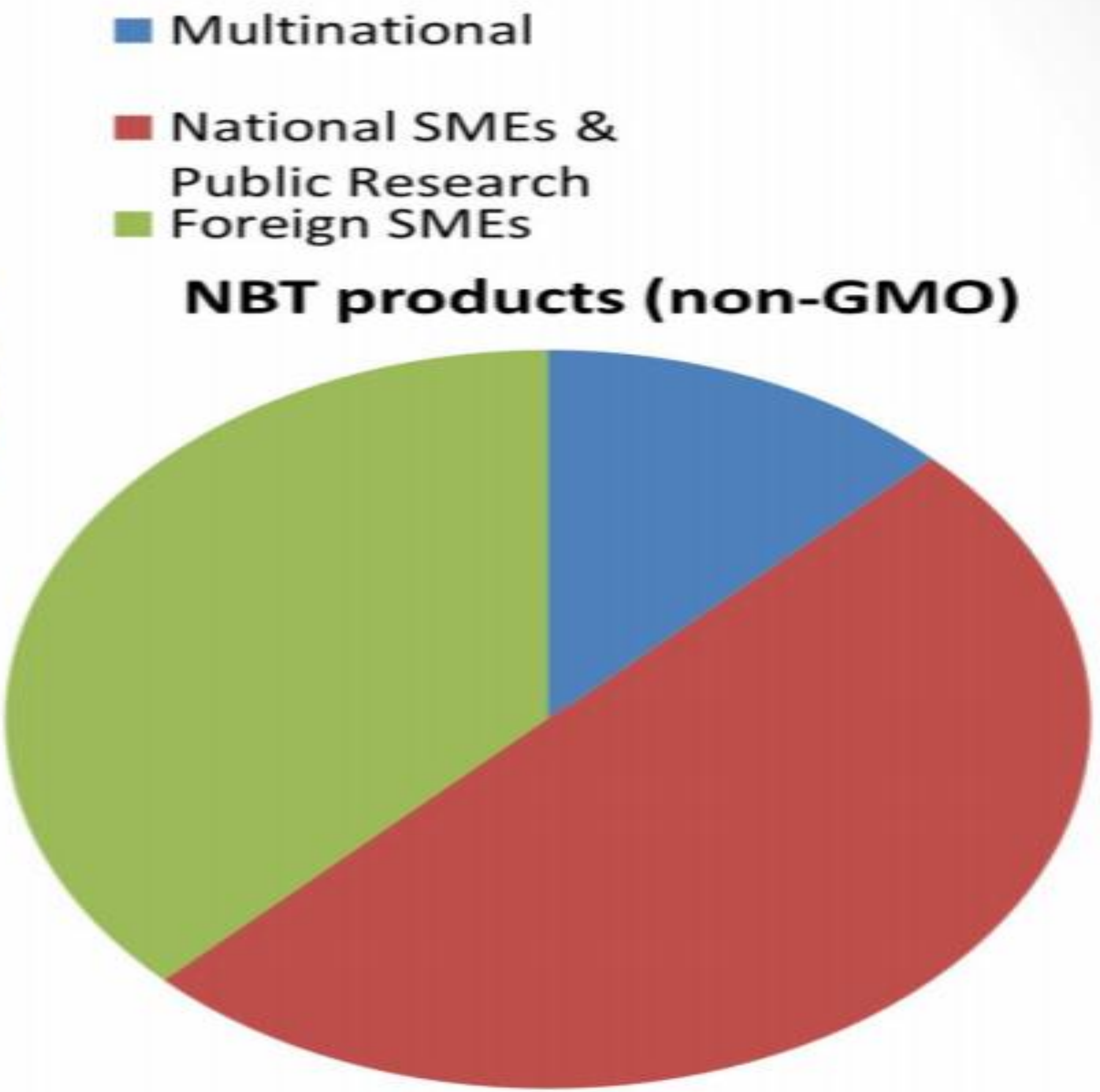
Comparative timeline



Source: Whelan, Lema (2019).

Developer profile



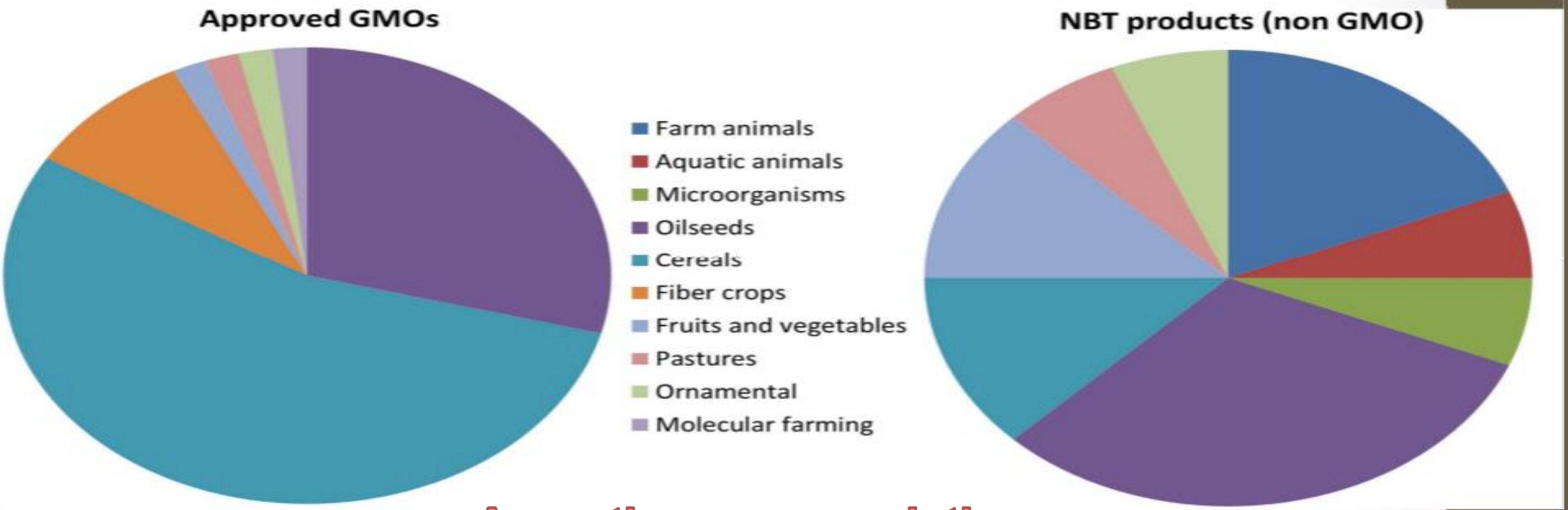


Argentine new regulation on genome edition

(2016-2019)

Source: Whelan, Lema (2019).

Diversity by type of organism



Argentine new regulation on genome edition

(2016-2019)

Source: Whelan, Lema (2019).

Genome Editing in other countries

Table 2 Events (nonmicrobial) that have been obtained by directed mutagenesis and which have been approved for commercialization in the respective jurisdiction.

Country	Organism	Trait	Technique	Developer	References
Brazil	Cow	Hornless			CTNBio (2018)
Canada	Oilseed rape	Herbicide tolerance	ODM	Cibus	CFIA (2013)
Canada	Oilseed rape	Herbicide tolerance	SDN	BASF	CFIA (2014)
Chile	Soybean	Low linolenic acid content	TALEN		SAG (2017)
Chile	*Camelina sativa*	High oleic acid content	CRISPR/Cas9		SAG (2018)
USA	Oilseed rape	Herbicide tolerance	ODM	Cibus	https://www.cibus.com/press/press031814.php

Edited Organisms approved for commercialization

Table 1 Examples of events obtained by directed mutagenesis which are in the pipeline for commercialization, and which regulatory authorities have declared to not be regulated as a genetically modified organism (GMO).

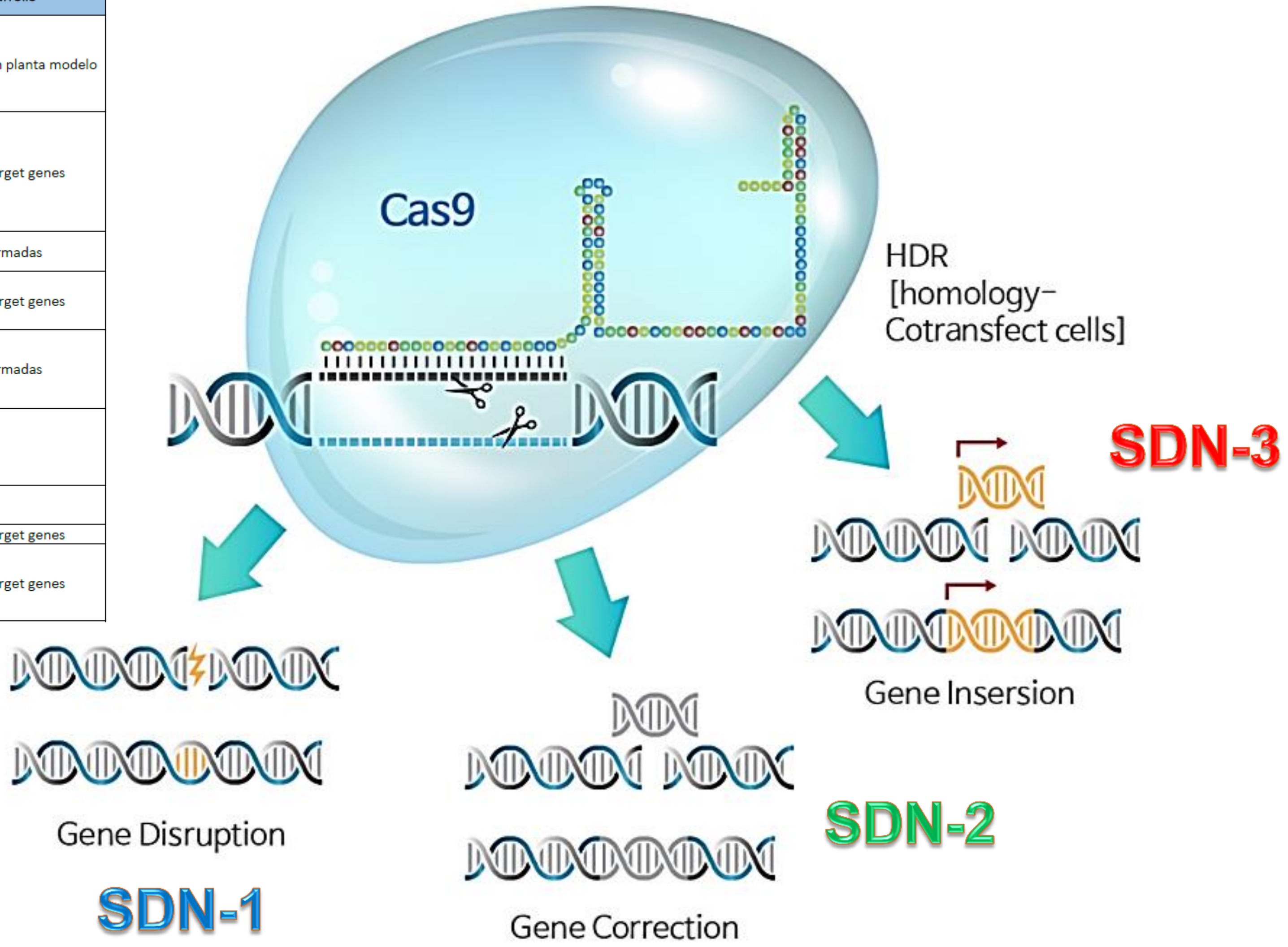
Country	Organism	Trait	Technique	Developer	Reference
USA	Soybean	Drought and salt tolerance	CRISPR/Cas	USDA ARS, Plant Science Research Unit	Waltz (2018)
USA	*Camelina sativa*	Increased oil content	CRISPR/Cas	Yield10 Bioscience	Waltz (2018)
USA	Green bristlegrass	Delayed flowering time	CRISPR/Cas	Donald Danforth Plant Science Center	Waltz (2018)
USA	Maize	High amylopectin starch	CRISPR/Cas	DuPont Pioneer	Waltz (2018)
USA	White button mushroom	Anti-browing properties	CRISPR/Cas	Pennsylvania State University	Waltz (2018)
USA	Soybean	High oleic acid, low trans-fatty acids	TALEN	Calyxt	Pennisi (2016)
USA	Potato	Improved storage, low acrylamide	TALEN	Calyxt	Pennisi (2016)
USA	Soybean	High oleic acid	TALEN	Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/
USA	Soybean	High oleic, low linolenic	TALEN	Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/
USA	Wheat	High fiber	TALEN	Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/
USA	Wheat	Powdery mildew resistance	Null segregant	Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/
USA	Potato	Cold storable		Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/
USA	Alfalfa	Improved quality		Calyxt	http://www.calyxt.com/products/products-in-our-development-pipeline/

Edited Organisms in the pipeline for commercialization

New Phytologist (2019) 222: 1673–1684
www.newphytologist.com

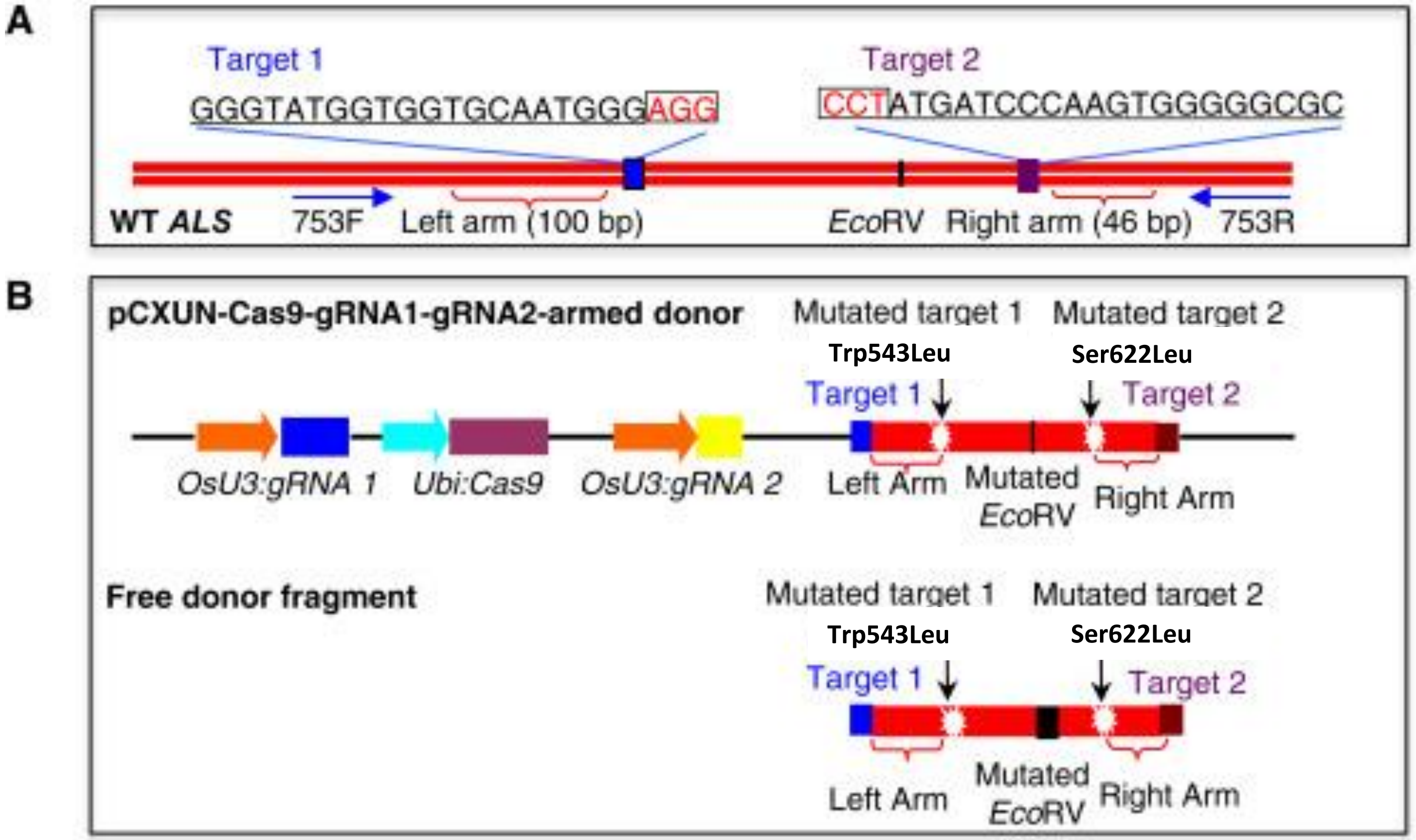
Genome Editing at Embrapa

Institución/ País	Tipo de NBT	Cultivo	Descripción de la técnica	Rasgo	Nivel de desarrollo
Embrapa/ Brasil	**Edición mediante CRISPR en plantas modelo**	Almorejo (*Setaria viridis*), *Arabidopsis thaliana*, tabaco	Expresión estable	Potencial para rasgo de interés	Prueba de concepto en planta modelo
	Edición mediante CRISPR en plantas cultivadas	Frutas (manzana, vid)	Expresión transitoria y estable	PPOs	Inicial, identificando target genes
		Pasturas		Resistencia a herbicidas, genes para tolerancia a la sequía	
		Caña de azúcar (*Saccharum spp.)*		Resistencia a herbicidas, modificación de la pared celular, genes para tolerancia a la sequía	
		Arroz		Brusone, genes para tolerancia a la sequía, aumento productividad, etc.	
		Maíz, Sorgo bicolor		Resistencia a herbicidas, genes para tolerancia a la sequía, modificación de la pared celular	Plantas siendo transformadas
		Trigo		Resistencia a roya, fusariosis	Inicial, identificando target genes
		Commom beans (frijoles)		Genes para tolerancia a la sequía, calidad del grano, aumento productividad, etc.	
		Glycine max (soja)		Resistencia a herbicidas, calidad del aceite, sustancias antinutricionales, genes para tolerancia a la sequía, resistencia a roya, resistencia a nematodos, aumento productividad, etc.	Plantas siendo transformadas
	Edición mediante TALENs y CRISPR en Animales	Bovinos de leche (Holandés) y de carne (Nelore)	Expresión transitoria y estable	Polled (hornless), MyO (myostatin), beta-lactoglobulina en ganado de leche (alergenicidad), genes para tolerancia al calor, garrapatas, edición de Brucella para producción de vacunas, Edición Epigenómica	Prueba de concepto
		Aves		Aumento de producción de lisozima en aves de postura por edición genética	
		Mosca de las frutas		Genes siendo prospectados	Inicial, identificando target genes
	Edición mediante CRISPR en hongos	Penicillium		Celulasas	Inicial, identificando target genes



SDN: Site Directed Nuclease

Edited sugarcane varieties with resistance to imidazolinones, sulfonylureas and triazolopyrimidines



Funding: Embrapa - project CRISPRCROPS

Targeted Precision Nucleotide Substitutions in Sugarcane Following CRISPR/Cas9 and Template Mediated Genome Editing Confer "Gain of Function"

Tufan Mehmet Oz, Ratna Karan, Aldo Merotto, **Fredy Altpeter**
University of Florida - IFAS, Gainesville, FL   Contact: altpeter@ufl.edu

1st Initiative: CRISPR in sugarcane

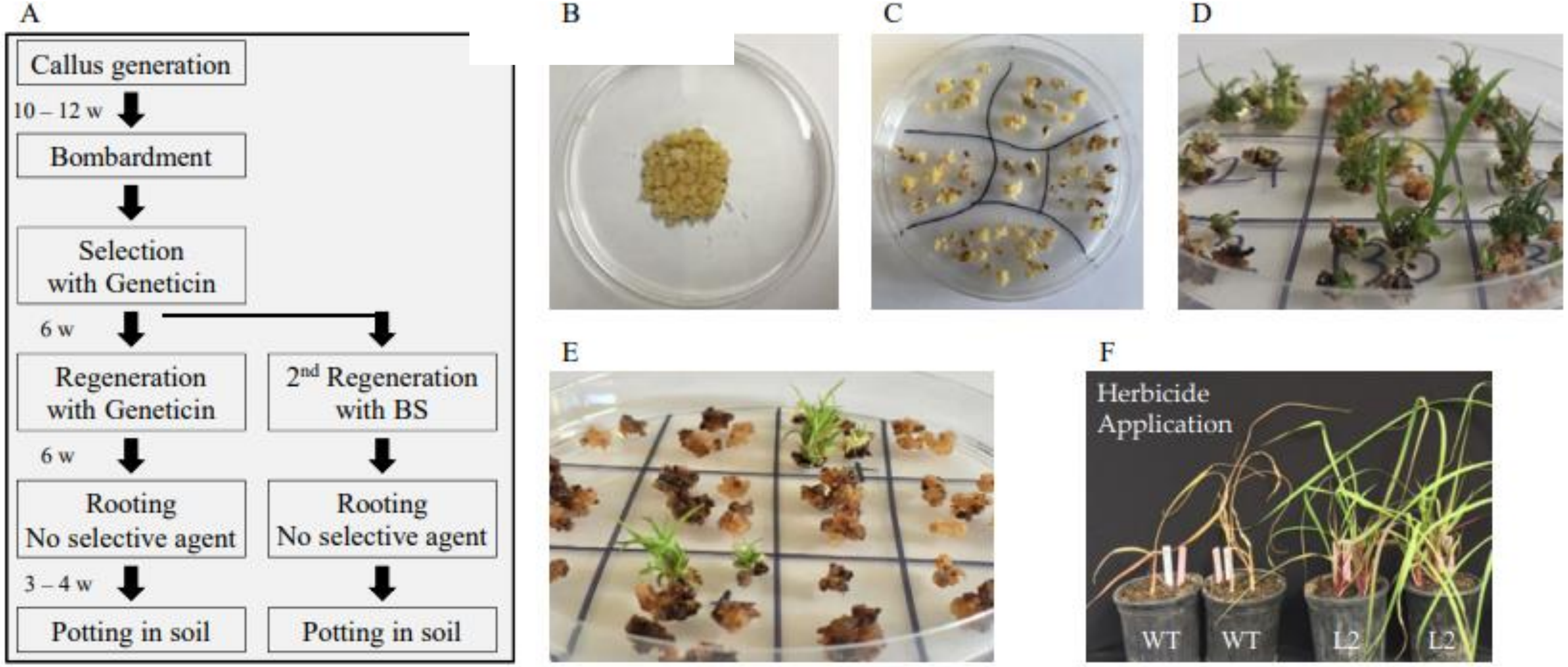
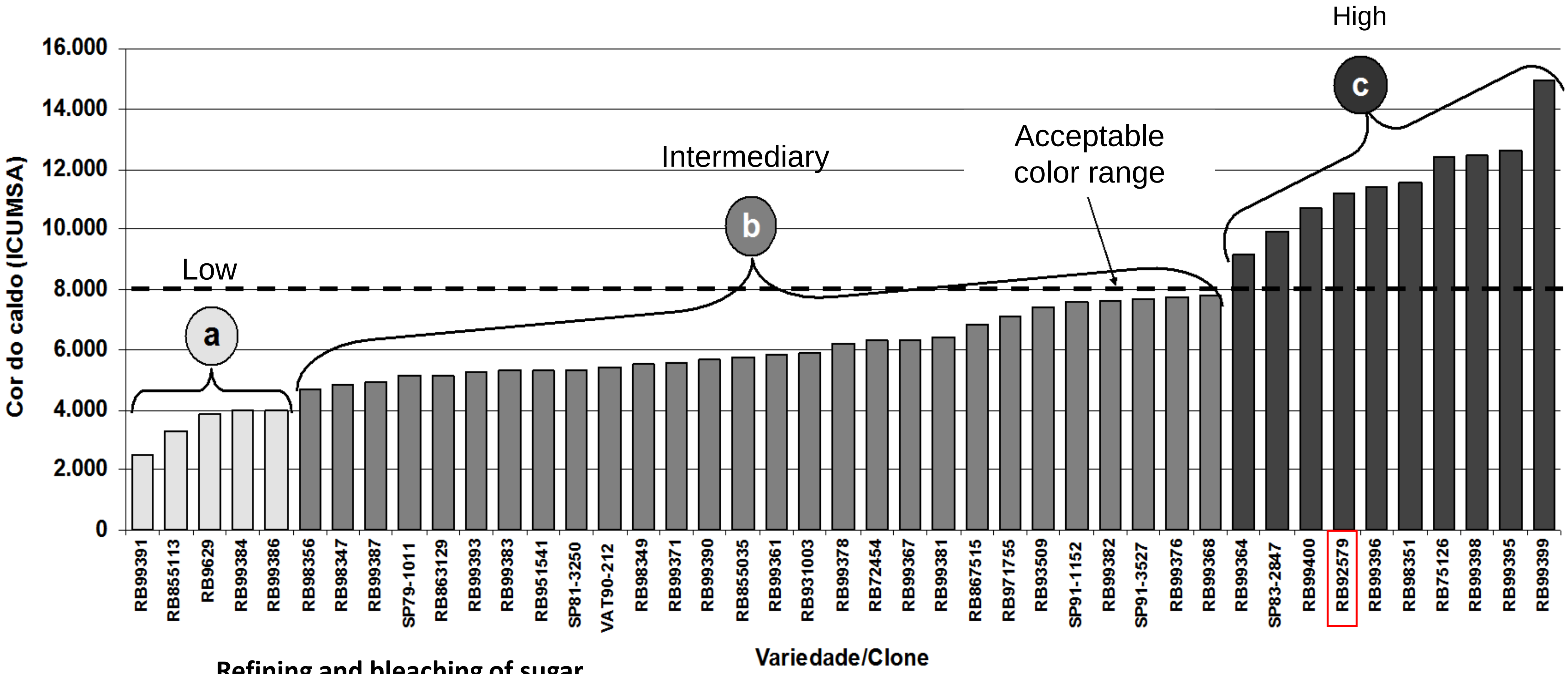
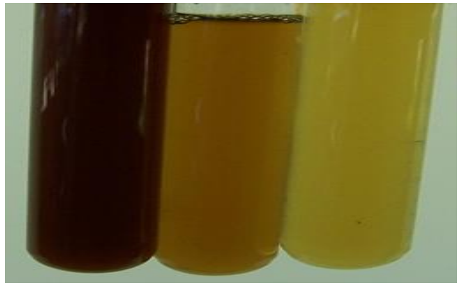


Figure 2. A) General outline of sugarcane tissue culture, plant regeneration and genetic transformation. B) Calli placed at the center of a petri dish for bombardment. C) Calli under selection. D) Regeneration under Geneticin. E) Regeneration under bispyribac sodium. F) Wild type (WT) and genome edited line L2 sprayed with imazapyr (Arsenal®) at 3 liter per ha (twice the labeled rate).

Edited sugarcane varieties with low PPO activity



Refining and bleaching of sugar



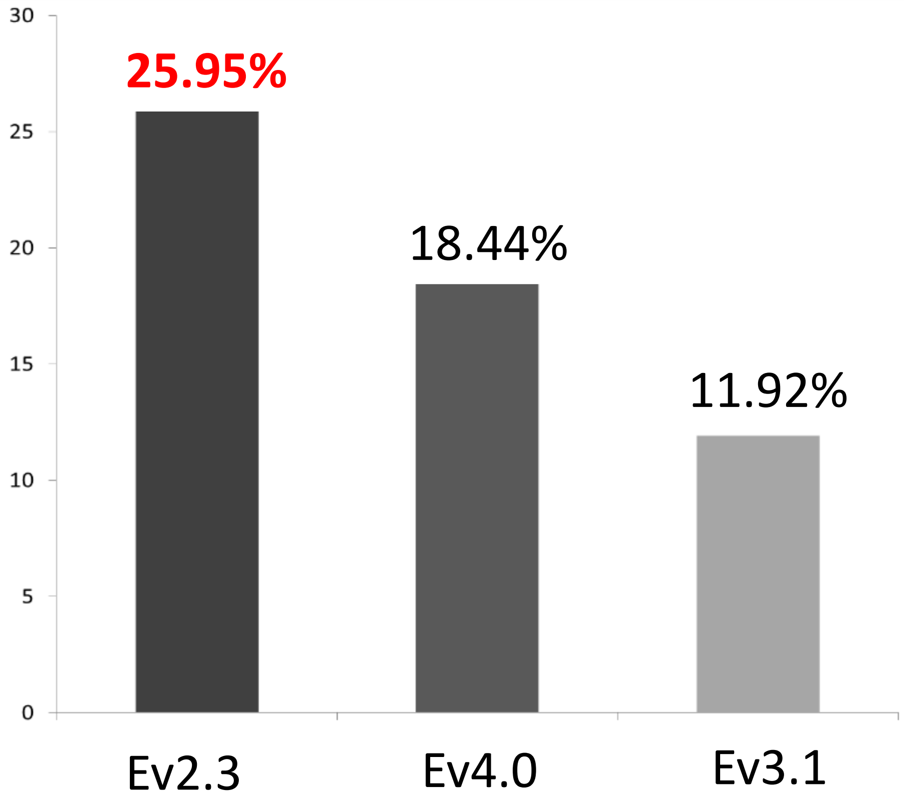
Cost of white crystal sugar 5 kg:
- Consumer → R$ 11,80
- Manufacturer → R$ 6,00

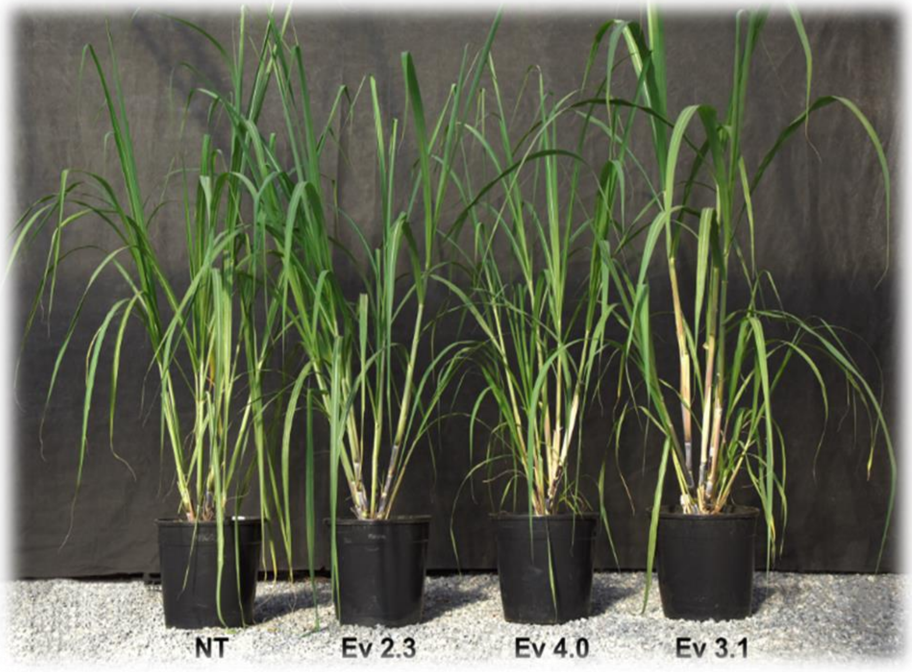
< 30% production cost
> 70% bleaching cost
< Nutritional quality

Increased glucose convertion (BAHD1 gene)

- More than 70% of the biomass cellulose was converted to glucose;
- No change in percentage of cellulose, hemicellulose and lignin;
- ART content of the biomasses Flex was equal to or greater than WT

Increased glucose in 48 hours of enzymatic hydrolysis

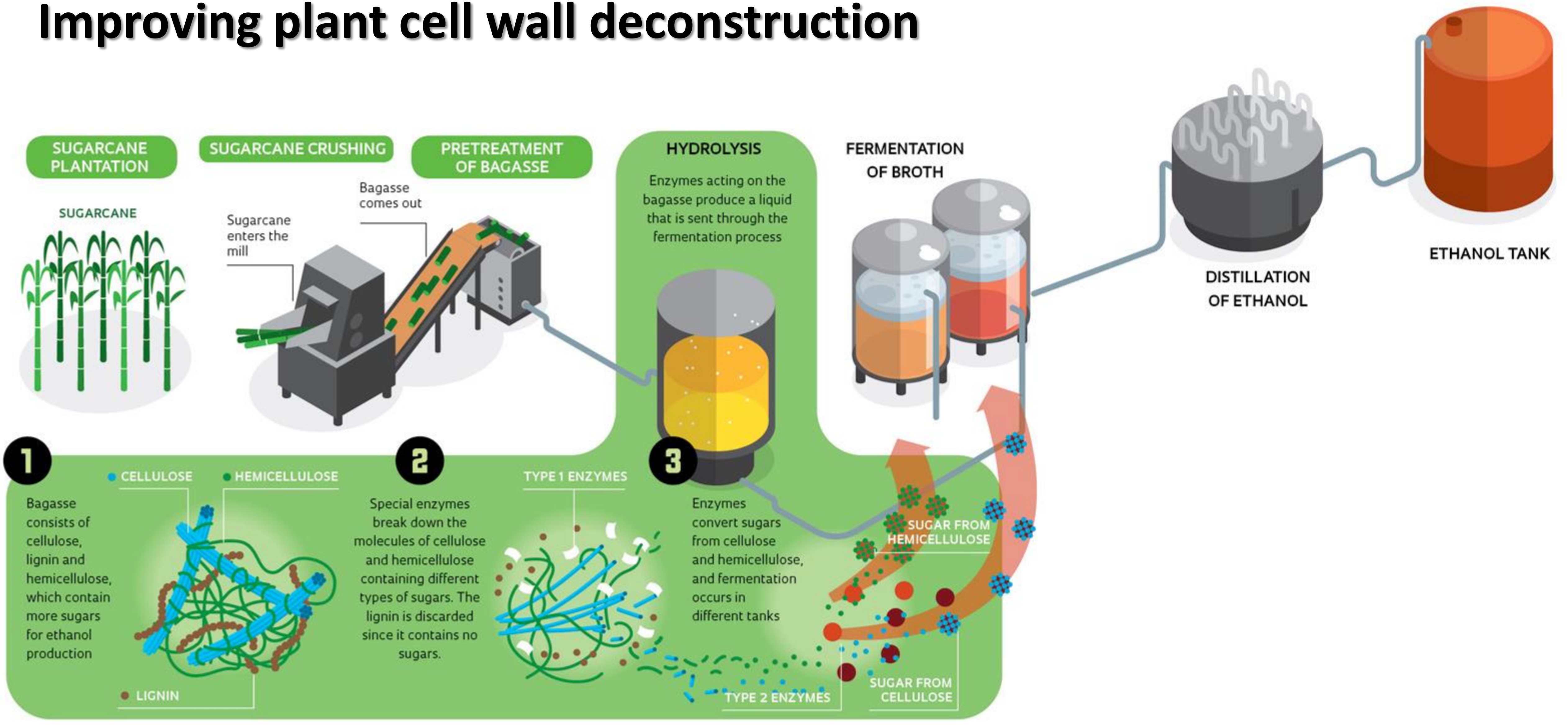




BR10201702383, INPI, 2017

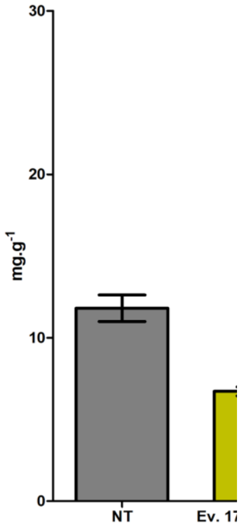
Source: De Souza et al., Biotechnology for Biofuels 12, 111 (2019).

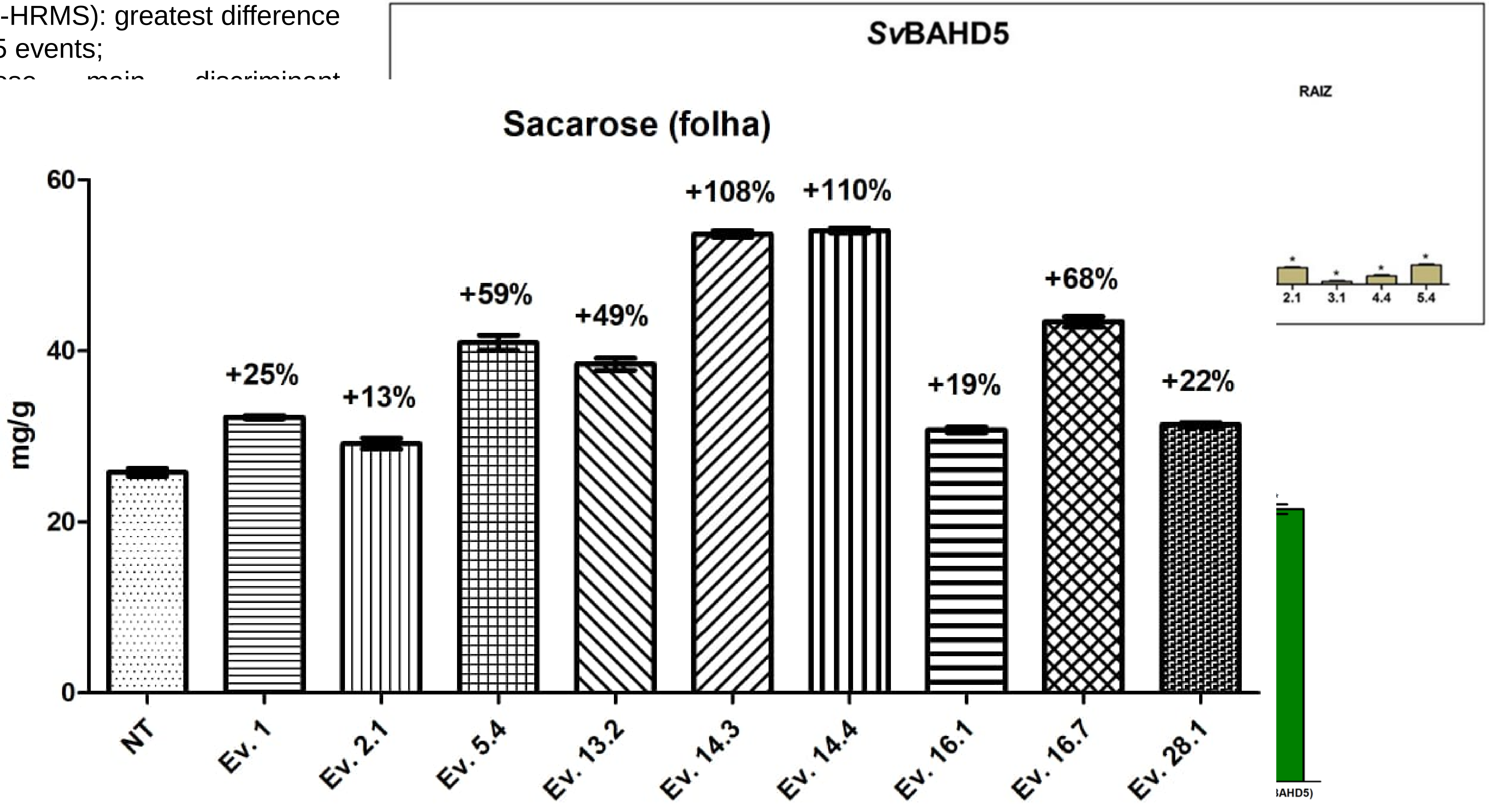
Improving plant cell wall deconstruction



BAHD5 – New gene for sucrose improvement in grasses

- Metabolic profile (HPLC-HRMS): greatest difference observed for the BAHD5 events;
- Desreplication: suc... main discriminant metabolite in the BAH
- We observed an incre leaf (Ev. 1.1 = 52.94% (Ev. 1.1 = 95.80%; E 94.05%) in compariso
- No significant diffenc carbohydrate content.



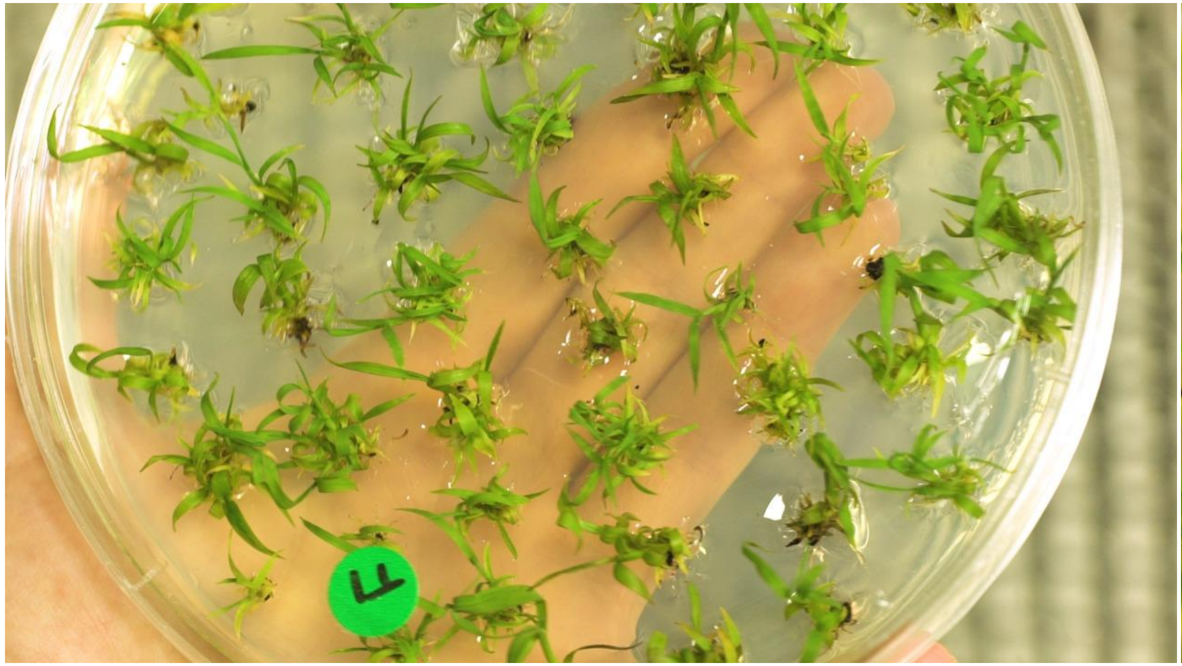


HPLC-HRMS: high performance liquid chromatography-high resolution mass spectrometry

BR10201702383, INPI, 2017

Source: Mota et al., (2019) in preparation.

Putatively edited sugarcane plants (no selection)



Gene A = 92 shots x ~120 plantlets = 11.040 regenerated plantlets
Gene B = 86 shots x ~120 pantlets = 10.320 regenerated plantlets

Bulk of 50 plantlets

Bulk PCR products will be sequenced using a NGS approach followed by software analysis

The expected **mutation efficiency** ranged from <u>0,001% to 0,01%</u>

11 – 110
10 – 103

Edited plants

Table 1. Examples of selection-free genome editing in different plant species.

Delivery Method	Cargo	Plant Species	Tissue	Selection	Mutation Efficiency	Calculation
Agrobacterium-mediated transformation	DNA (transient) CRISPR/Cas9	Tobacco *Nicotiana tabacum*	Leaf disks	No	2.57%	Mutated plants/total regenerated shoots
				No	17.2%	Non-transgenic plants/total mutant plants
Particle bombardment	DNA CRISPR/Cas9	Wheat *Triticum aestivum*	Immature embryos	No	3.3%, 2/26 plants homozygous and transgene-free	Mutated plants/bombarded embryos
	IVT mRNA CRISPR/Cas9			No	1.1%, 6/17 plants homozygous and transgene-free	Mutated plants/bombarded embryos
Particle bombardment	RNP CRISPR/Cas9	Maize *Zea mays*	Immature embryos	No	2.4–9.7%, 9.6–12.9% of mutated plants biallelic	Mutated plants/analyzed plants
Particle bombardment	RNP CRISPR/Cas9	Wheat *Triticum aestivum*	Immature embryos	No	4.4%	Mutated plants/bombarded embryos
Protoplast transfection (PEG)	DNA TALEN	Potato *Solanum tuberosum*	Protoplasts	No	11–13%	Mutated callus/total protoplast-derived callus
Protoplast transfection (PEG)	DNA TALEN	Tobacco *Nicotiana benthamiana*	Protoplasts	n.a.	70.5%	Deep sequencing of protoplasts
	mRNA TALEN			n.a.	5.8–16.9%	Without/with UTR
Protoplast transfection (PEG)	RNP CRISPR/Cas9	Lettuce *Lactuca sativa*	Protoplasts	No	46%, 6% mono-, 40% biallelic	Mutated callus/analyzed callus
Protoplast transfection (PEG)	RNP CRISPR/Cas9	Grapevine *Vitis vinifera* cv. Chardonnay	Protoplasts	n.a.	0.1%	Deep sequencing of protoplasts
		Apple *Malus domestica* cv. Golden delicious	Protoplasts	n.a.	0.5–6.7%	Deep sequencing of protoplasts
Protoplast transfection (PEG)	RNP CRISPR/Cas9	Petunia *Petunia x hybrida*	Protoplasts	n.a.	5.3–17.8%	Deep sequencing of protoplasts

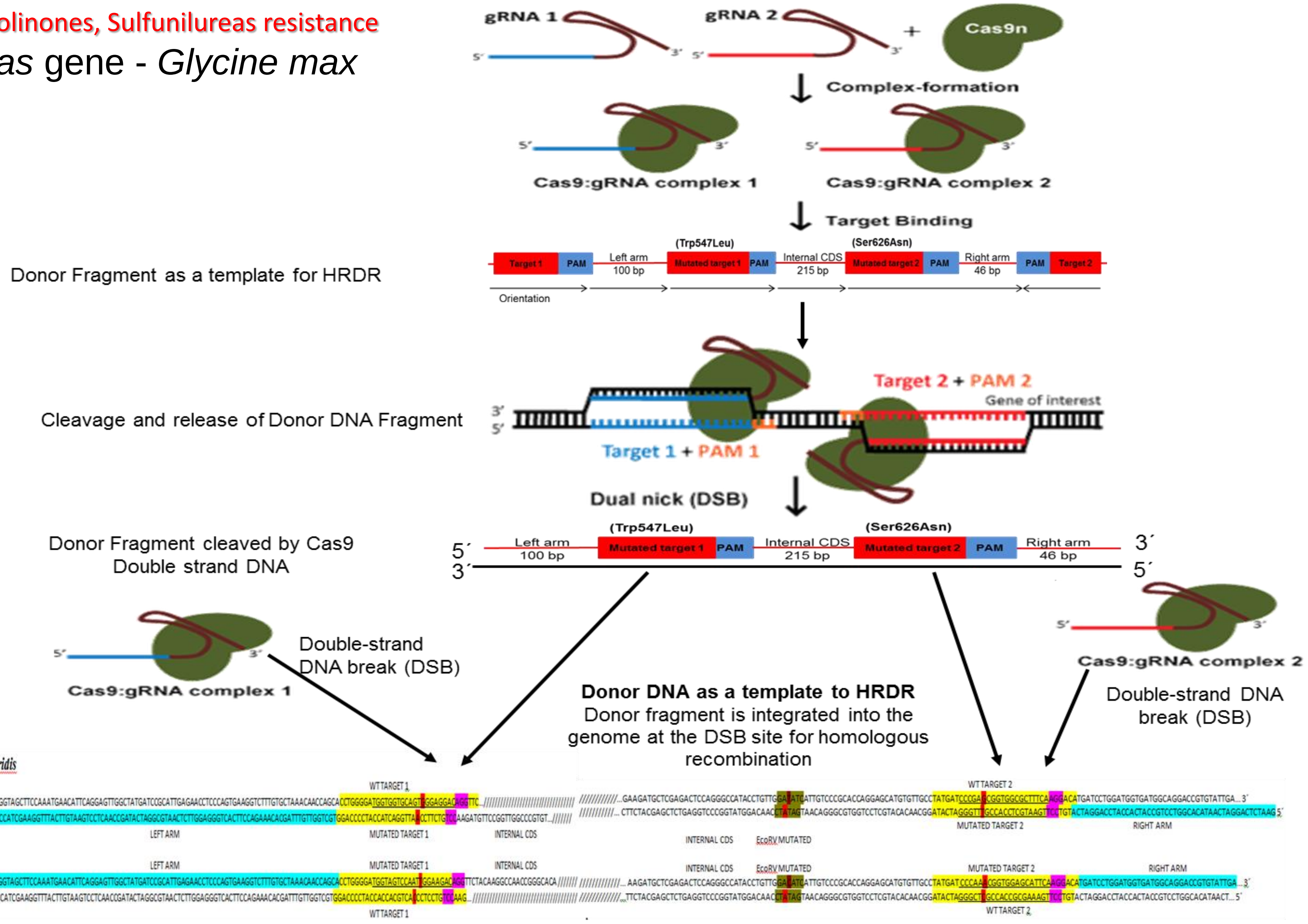
Jansing et al., 2019. *Int. J. Mol. Sci. 20*(12), 2888

Soybean with Herbicide Resistance

Imidazolinones, Sulfunilureas resistance

ahas gene - *Glycine max*

CRISPRs Homologous Recombination

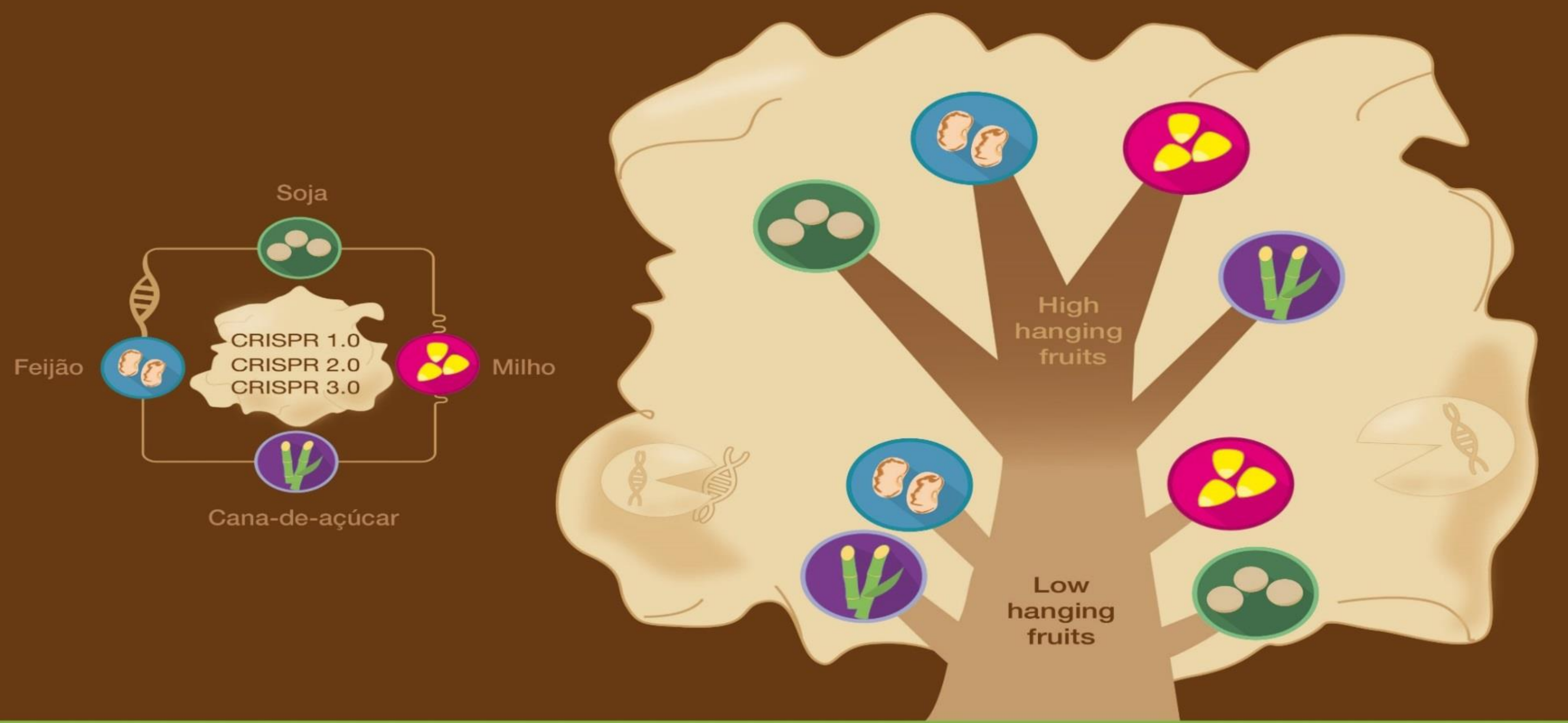


RHDR (homologous recombination directed repair)

Funding: Embrapa - project CRISPRCROPS

PROJETO CRISPRevolution

Plantas de importância econômica com genoma editado pela tecnologia CRISPR visando melhoria da qualidade nutricional e industrial e tolerância a estresse hídrico



Cultivares / Variedades superiores para aumento da competitividade do agronegócio

- Geneticamente editado para redução do escurecimento da semente
- Geneticamente editada para redução dos fatores antinutricionais
- Geneticamente editada para aumento da digestibilidade da biomassa
- Geneticamente editado para aumento da digestibilidade da biomassa

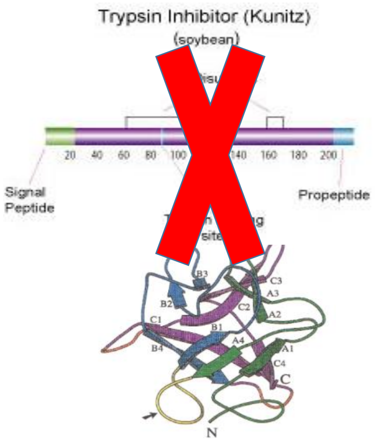
Geneticamente editados para tolerância à seca

Projeto em parceria com as Unidades Descentralizadas: Embrapa Agroenergia, Embrapa Arroz e Feijão, Embrapa Milho e Sorgo, Embrapa Recursos Genéticos e Biotecnologia, Embrapa Soja e Unidade Mista de Pesquisa GenClima

Embrapa

EMBRAPA Soybean Center - CRISPRs Systems

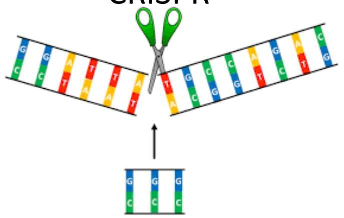
Soybean: Protein Quality and Drought Tolerance

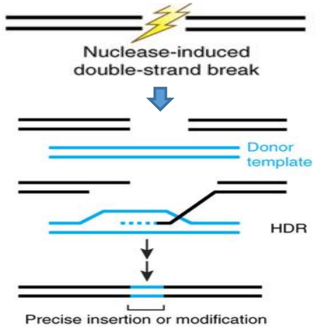


HR at promoter elements

Knock Out

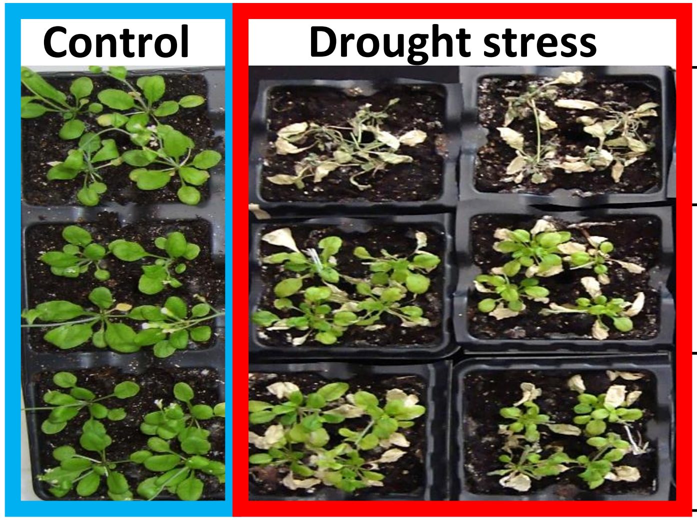
CRISPR





Candidate genes for Knock Out and HR:
Stay green1 (D1); Stay green2 (D2);
Pheophorbidase (PH2) , DREB, AREB, DRIP, etc

REHYDRATION AFTER 2 WEEKS OF DROUGHT STRESS



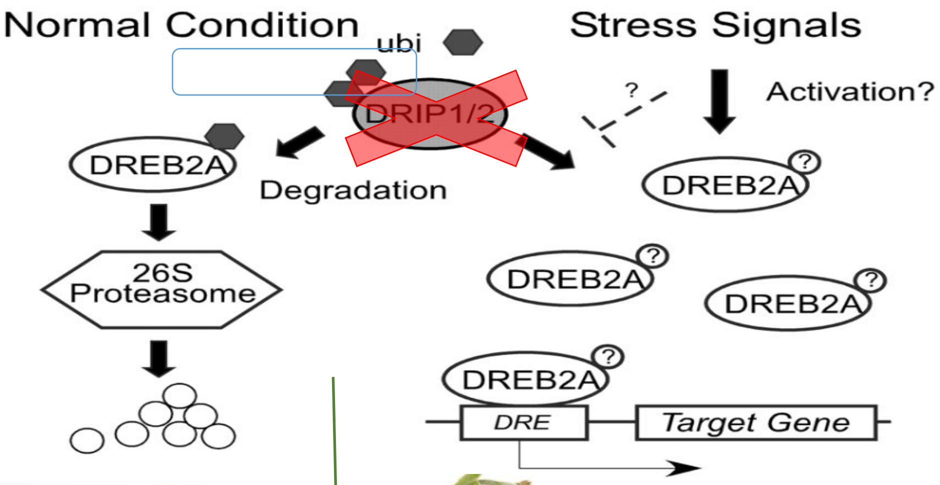
Wild Type	
F5-8	**Enhanced drought tolerance**
F3-6	

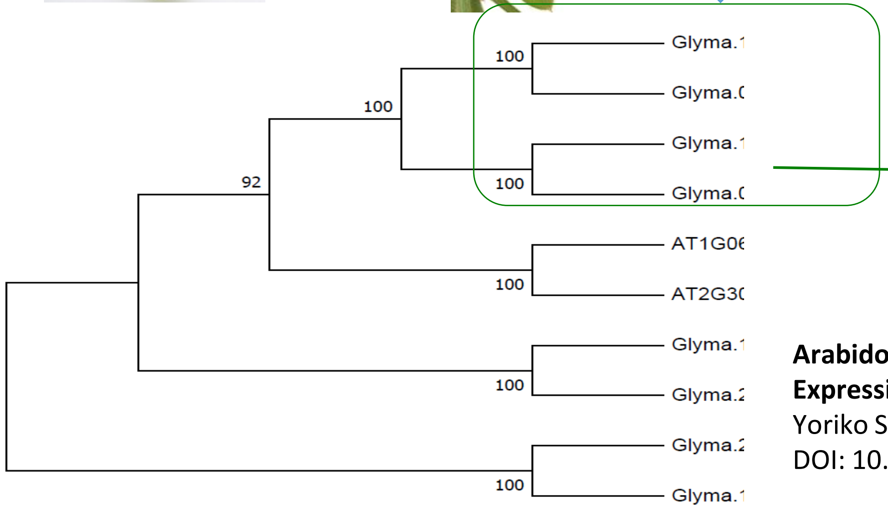
Dr. Alexandre Nepomuceno

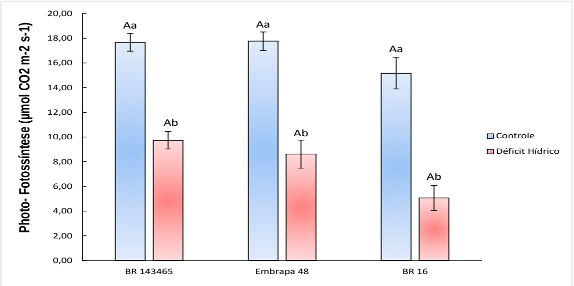
Dr. Liliane Henning

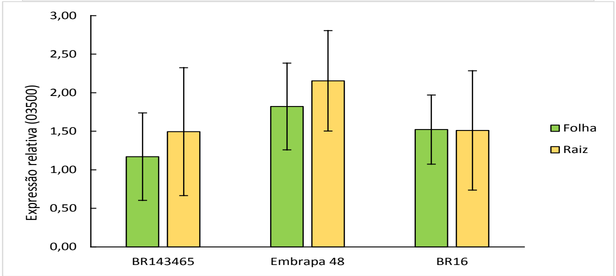
Checking Expression levels of DREB Interacting Proteins (DRIPs) aiming to choose the best(s) targets for CRISPR-Cas9 - SDN1 system.

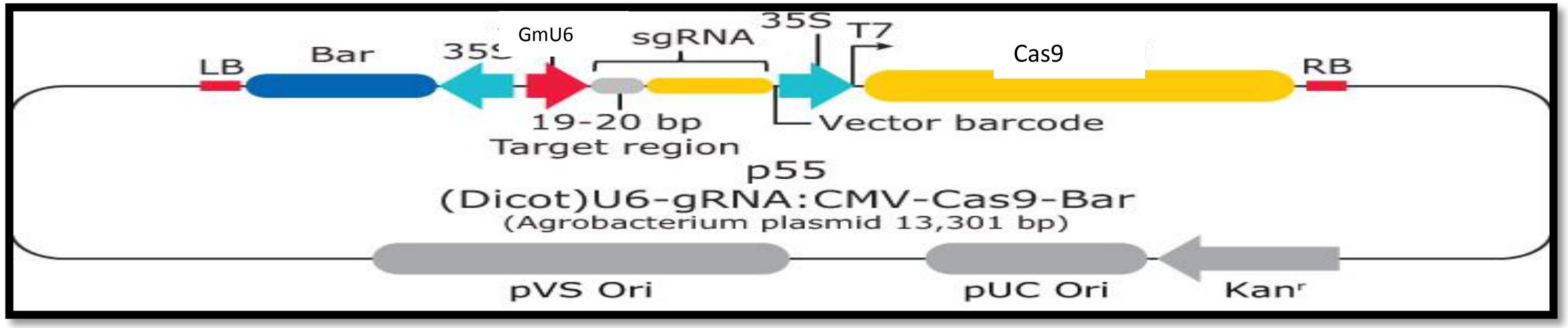
Objective: Increase DREB expression under drought conditions since DRIP is a negative regulator of DREB.









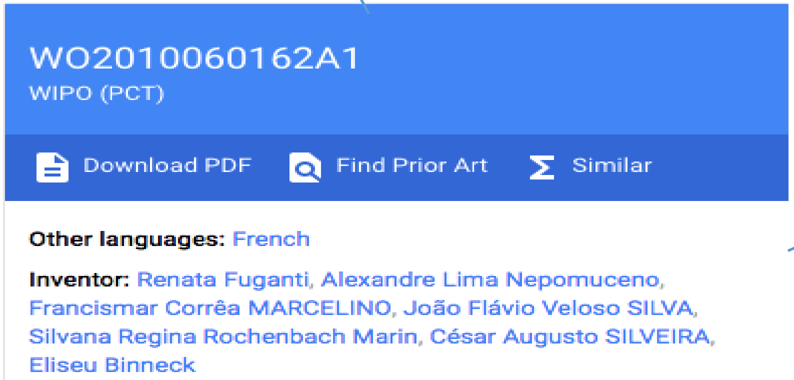


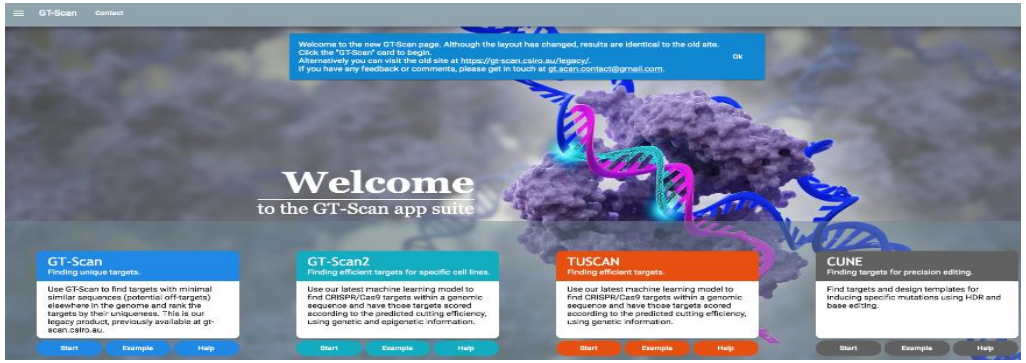
Arabidopsis DREB2A-Interacting Proteins Function as RING E3 Ligases and Negatively Regulate Plant Drought Stress–Responsive Gene Expression. Feng Qin, Yoh Sakuma, Lam-Son Phan Tran, Kyonoshin Maruyama, Satoshi Kidokoro, Yasunari Fujita, Miki Fujita, Taishi Umezawa, Yoriko Sawano, Ken-ichi Miyazono, Masaru Tanokura, Kazuo Shinozaki, Kazuko Yamaguchi-Shinozaki. The Plant Cell Jun 2008, 20 (6) 1693-1707; DOI: 10.1105/tpc.107.057380

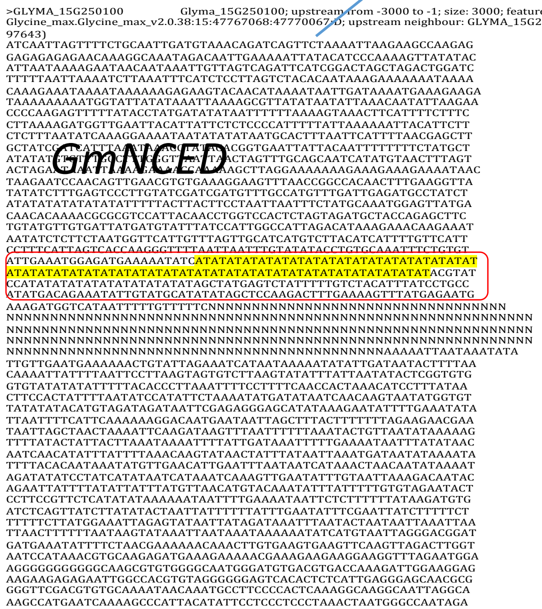
Use of at(n) insertions (CRISPRs - SDN2 system) in the promoter elements for controlling the expression levels of coding sequences.

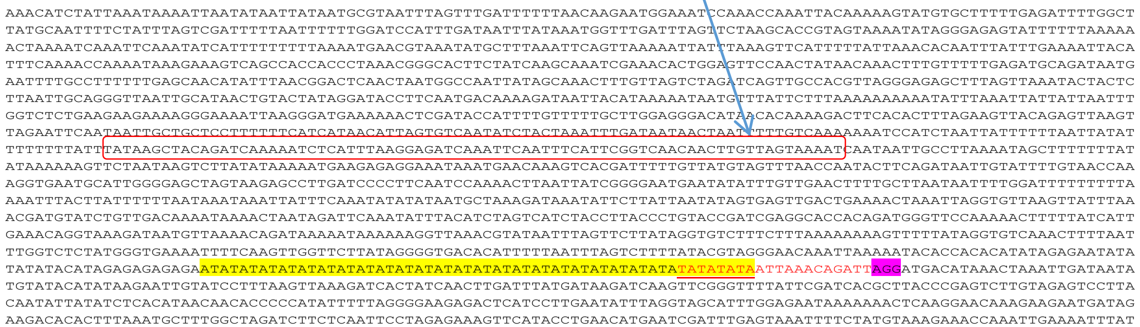
Objective: increase the expression of native genes involved in defenses against cell dehydration, without the use of DNA elements considered transgenic such as 35S promoter

Embrapa Patent









EMBRAPA Genetic Resources Center

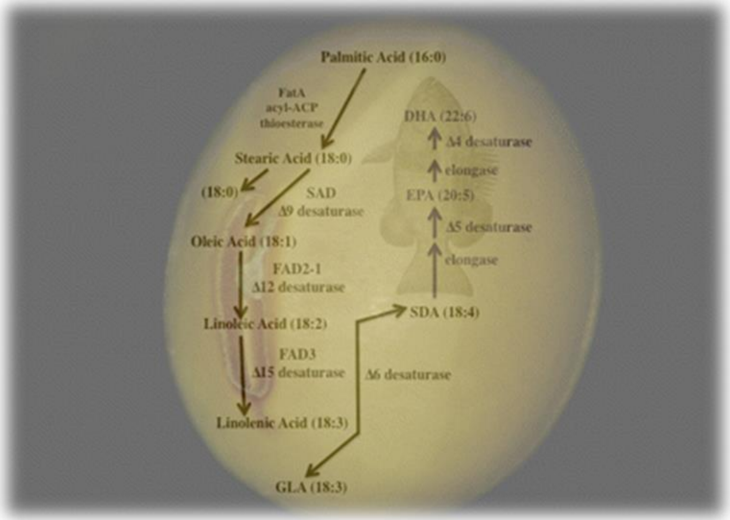
CRISPRs Systems

Knockout of Key genes Oil Pathways

Improvement on Soybean Biofuel

Oleic acid ↑ —— **Δ12 desaturase** / ***FAD 2 gene*** ——→ **Linoleic acid** ↓

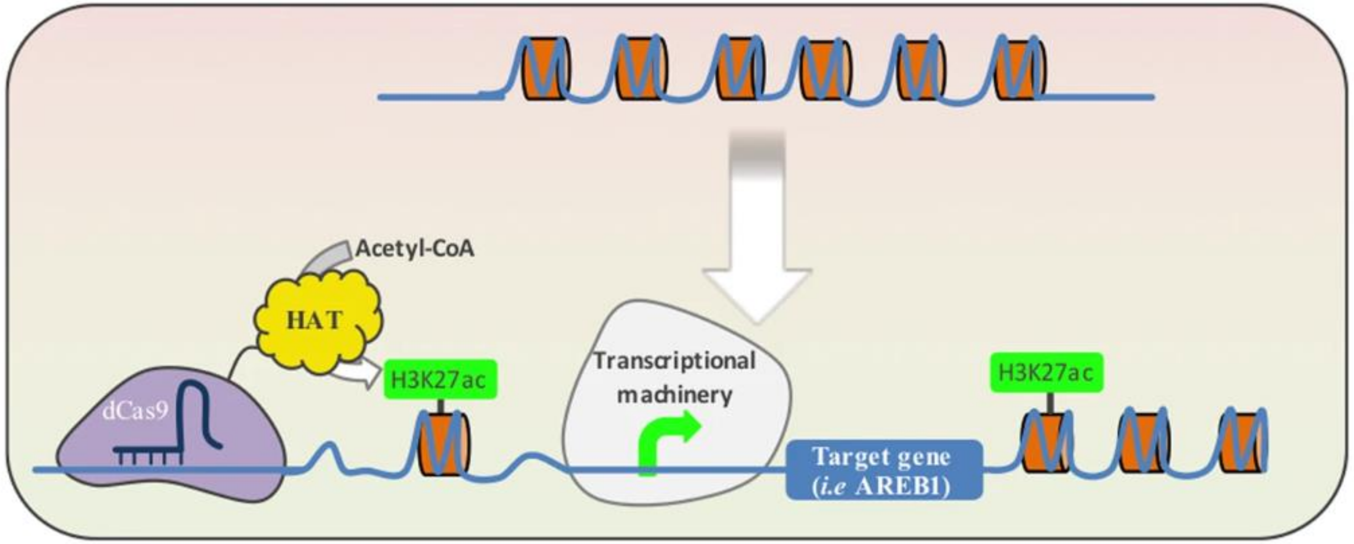
—— **Palmitoyl thioesterase** / ***Fat B gene*** ——→ **Palmitic acid** ↓



Dr. Elíbio Rech

EMBRAPA Genetic Resources Center

PROMOTER MODULATION OF DROUGHT-TOLERANCE RELATED GENE WITH dCas9 CONFERS DROUGHT TOLERANCE IN *Arabidopsis thaliana*



Embrapa

Dr. Maria Fátima Grossi-de-Sá

SCIENTIFIC REPORTS

OPEN

Improved drought stress tolerance in Arabidopsis by CRISPR/dCas9 fusion with a Histone AcetylTransferase

Received: 11 September 2018
Accepted: 9 May 2019
Published online: 30 May 2019

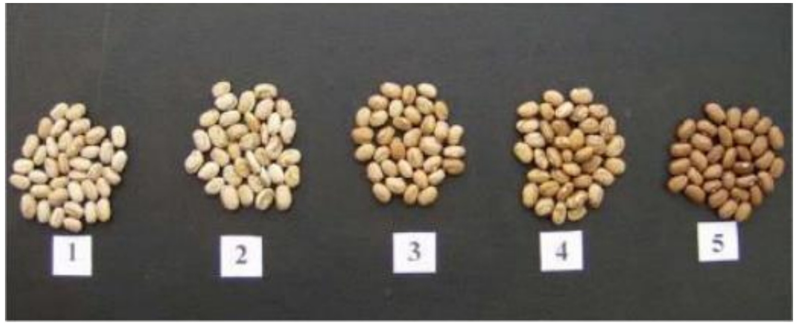
Joaquin Felipe Roca Paixão[1,2], François-Xavier Gillet[1], Thuanne Pires Ribeiro[1], Caroline Bournaud[1], Isabela Tristan Lourenço-Tessutti[1], Daniel D. Noriega[1], Bruno Paes de Melo[1], Janice de Almeida-Engler[2] & Maria Fatima Grossi-de-Sa[1,3]

EMBRAPA Rice and Bean Center

COMMON BEAN **CRISPR** TARGETS:

- Post Harvesting Darkening (PHD)
- Drought stress

CRISPR in Common Beans



Dr. Josias Correa de Faria

Dr. Rosana Vianello

Embrapa Maize and Sorghum center

- Drought tolerance
- Herbicide tolerance
- Aluminum resistance
- Disease resistance

Embrapa Grapes and Wine center

- Disease resistance
- Flavor alteration

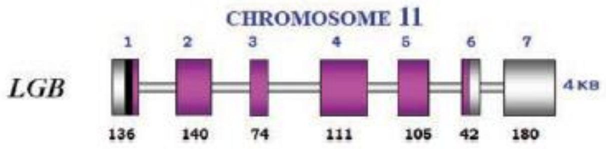
Embrapa Coastal Tablelands center

- Disease resistance (coconut lethal yellowing disease)

Cow´s milk allergy

Beta-lactoglobulin (LGB) is the main whey protein of cow's milk
- 13-76% patients can react to this protein
  - Mainly infants
- Milk processing does not eliminate the allergy completely
  - Processed milk has high costs

Project aim: knock-out the the BGL variant A and B using TALENs /CRISPR
- Targeting the promoter region and exon 1 or 2
- Generate cows producing LGB-free milk



REVIEW ARTICLE

World Allergy Organization (WAO) Diagnosis and Rationale for Action against Cow's Milk Allergy (DRACMA) Guidelines

Alessandro Fiocchi, (Chair), Jan Brozek, Holger Schünemann, (Chair), Sami L. Bahna,

J. Dairy Sci. 92:5335–5352
doi:10.3168/jds.2009-2461

***Invited review*: Milk protein polymorphisms in cattle: Effect on animal breeding and human nutrition**

A. M. Caroli,*[1] S. Chessa,† and G. J. Erhardt‡
*Dipartimento di Scienze Biomediche e Biotecnologie, Università degli Studi di Brescia, Viale Europa 11, Brescia, 25123 Italy
†Dipartimento di Scienze e Tecnologie Veterinarie per la Sicurezza Alimentare, Università degli Studi di Milano, Via Trentacoste 2, Milano, 20134 Italy
‡Institut für Tierzucht und Haustiergenetik, Justus-Liebig-Universität, Ludwigstr. 21 b, 35390 Gießen, Germany

Dr. Luiz Sérgio Camargo

Heat stress in dairy cows

- High producing dairy cows: low conception and milk production under high temperatures (summer) – caused by the heat stress
  - The predicted increase of global average temperature is likely to aggravate the effects of heat on animal production
  - Some individuals and some breeds are more tolerant to high temperature than others
- Project aim:
  - Short and medium term: identification of polymorphism/mutations associate to thermotolerance for genome selection
  - Long-term: edition of the genome using CRISPRs, accordingly to gene function and the SNPs found previously in the project
    - Generate high producing dairy cows more tolerant to high temperatures

Organisms with edited genome evaluated by CTNBio according to RN16 that were considered Not GM

June 2018

First microorganism
Edited in Brazil

Yeast for ethanol production

Estimated cost savings: R$ 1.5 million

globalyeast
Selected By Excellence.

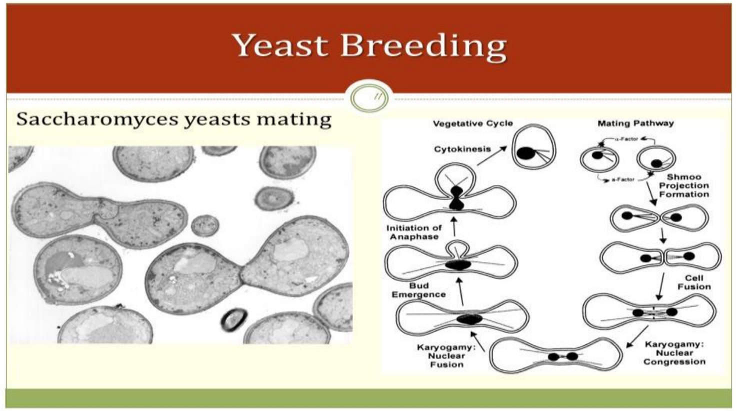
Belgian-Brazilian biotechnology startup

Saccharomyces cerevisiae

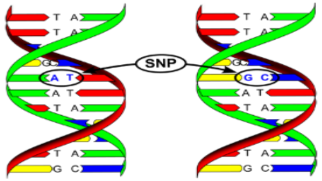
Development Procedures

Yeast Germplasm Bank: 80 Strains tested for high alcohol and low glycerol production

Three S. cerevisiae strains chosen and crossed by classical breeding

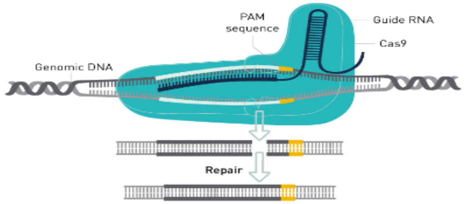


Excellomol



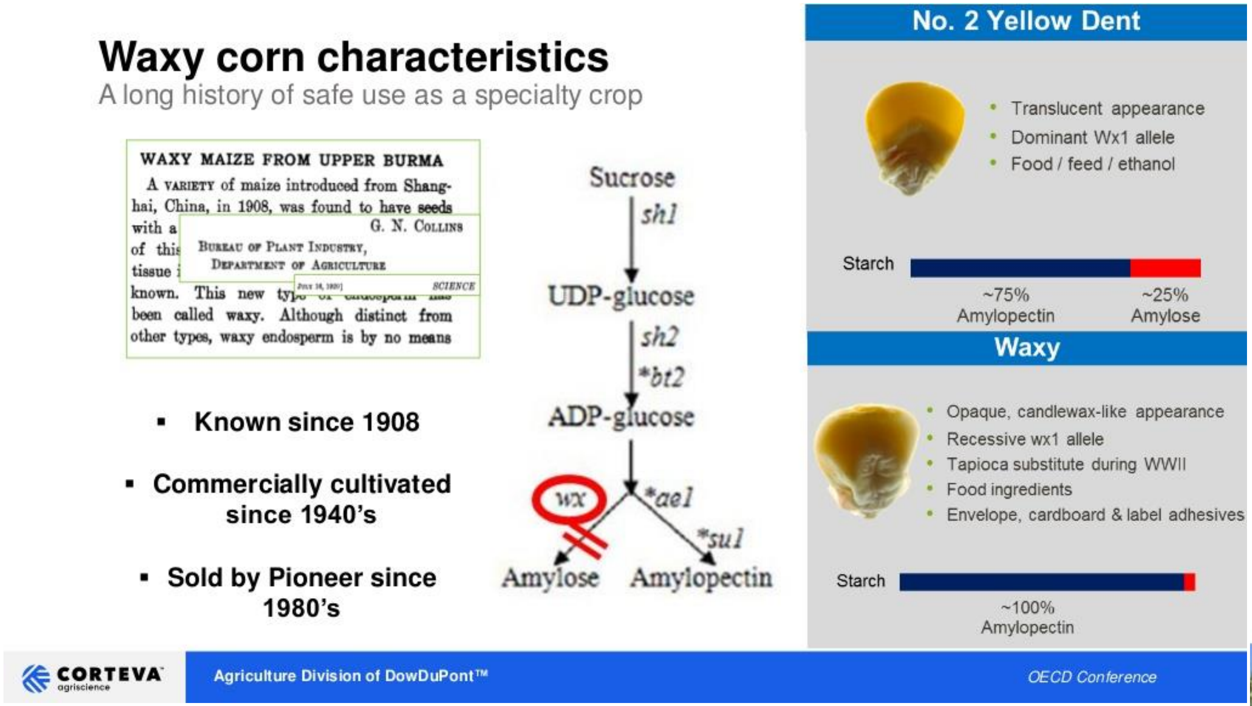
A Forth strain with very high alcohol production was identified. Mutation in 4 genes are responsible for this high efficiency.

Excellomol 4.0 Next



All four mutations were introduced by CRISPR/Cas9 into the Excellomol strain

First Edited Plant considered non-GM in Brazil

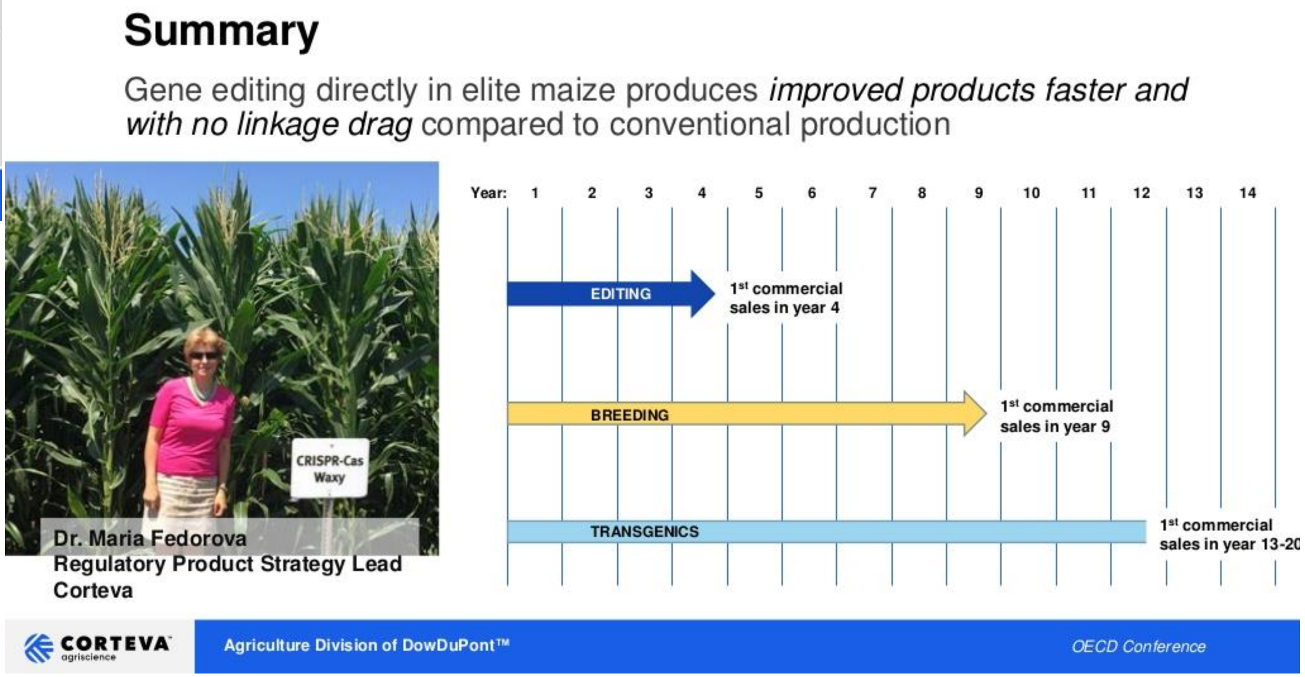


Considered non-GM in USA, Canada and Argentina.

Brazil: December 2018

Uses of Waxy corn:

- Essential functions in food industry to improve uniformity, stability, and texture in various food products;
- Binding qualities for the papermaking process;
- Additional applications in the, corrugating, textile and adhesive industries.



August 2019

PRECISION GENETICS FOR IMPROVING PRODUCTION TRAITS OF TILAPIA

The Fish Site

Find species, diseases, articles... | Breeding & genetics | Farm management | Health & welfare | Nutrition | Environment | Post-harvest

Gene edited tilapia secure GMO exemption

REGULATIONS · POLITICS · GENETICS & BREEDING · BIOTECHNOLOGY

by The Fish Site
18 December 2018, at 2:06p.m.

A line of tilapia that has been gene edited will not be classified as a genetically modified organisms (GMOs) in Argentina, according to a government advisory commission.

The line, known as FLT 01, has been developed by Intrexon and its subsidiary AquaBounty Technologies., the biotechnology company best known for its AquaAdvantage salmon strain. The tilapia were developed using gene editing

While AquaBounty's GMO salmon remains blocked in US, Argentina exempts the company's sustainable gene-edited tilapia from regulation

Fish Farming Expert | December 19, 2018

Image Credit: Medium

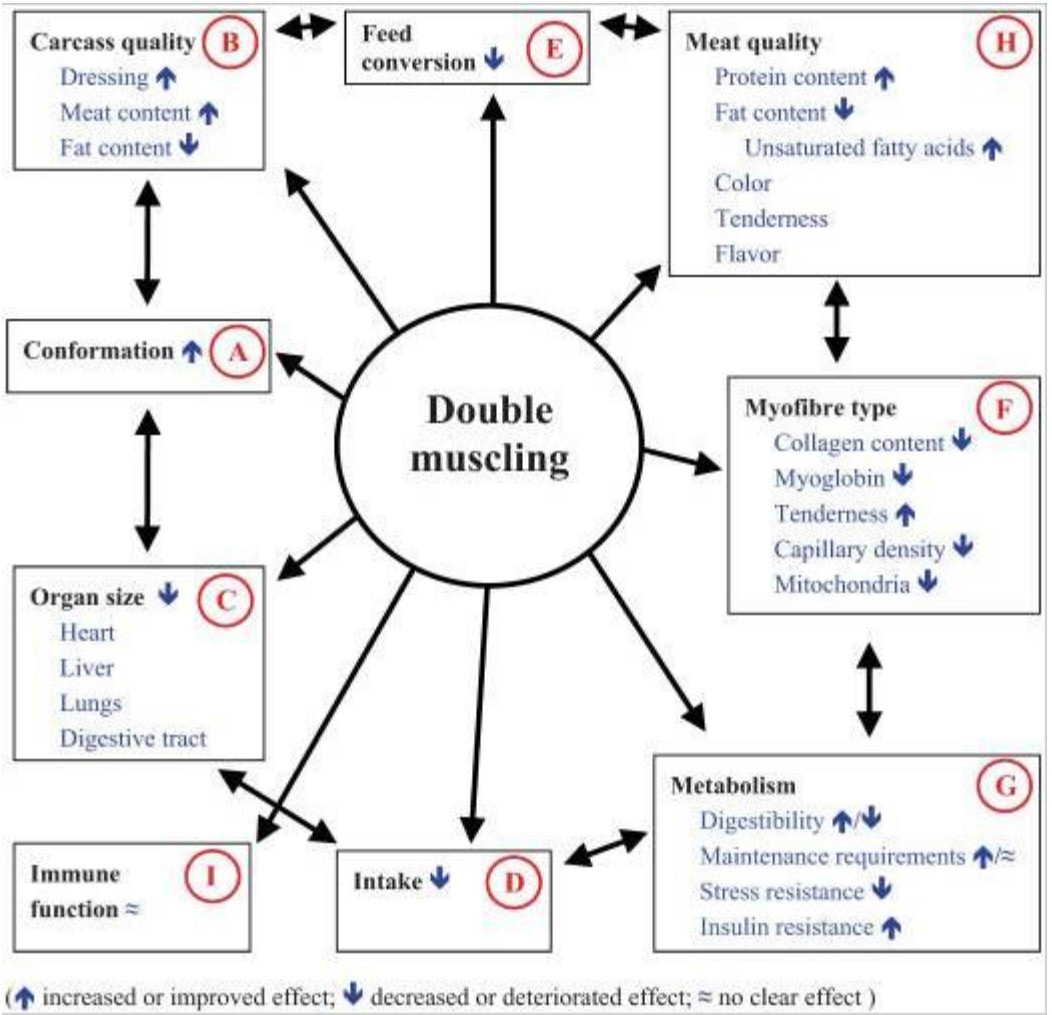
This precision breeding approach has successfully <u>increased the fillet yield by 25%</u> without negatively impacting growth rate, feed efficiency, or nutritional quality of the fillets. An increased fillet yield will provide producers an opportunity to either (i) shorten the production cycle while maintaining the same amount of saleable meat, or (ii) maintain the production cycle with more fillet to sell to the market. This technology can be used to improve other production traits and can be used in other species of finfish.

Meat quality

Myostatin (MSTN) – restrain muscle growth

- Some breeds have natural mutations (ex. Belgian blue) that causes muscle hypertrophy called double-muscle
  - Superior carcasses (less bone and low fat)
- Myostatin can be edited in zebu breeds to improve carcass quality

Image: http://www.progressivegenetics.ie/Store/Beef-Sires/Belgian-Blue



Meat quality

Transgenic Res (2015) 24:147–153
DOI 10.1007/s11248-014-9832-x

ORIGINAL PAPER

Genome edited sheep and cattle

Chris Proudfoot · Daniel F. Carlson · Rachel Huddart · Charles R. Long ·
Jane H. Pryor · Tim J. King · Simon G. Lillico · Alan J. Mileham ·
David G. McLaren · C. Bruce A. Whitelaw · Scott C. Fahrenkrug

- Myostatin mutation
  - TALENS
    - Cattle (Nelore) and ovine - Proudfoot et al., 2015
  - CRISPR/Cas9

Thank you for your attention!

Hugo Bruno C. Molinari
Embrapa Agroenergia (CNPAE)
hugo.molinari@embrapa.br

"In the moment the best thing you can do is the right thing, the next best thing is the wrong thing, the worst thing you can do is nothing" Theodore Roosevelt

Take Action