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Genome editing in crops: new tools in an old toolbox

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Outline of this presentation

Introduction

- Food security: Breeding challenges for the next decades

New tools:

1- Ideotype breeding of crop varieties

- The ideotype and model-based breeding
- Case study: Enhancing autogamy and fruit yield

***2- De novo* domestication of wild species**

- A novel approach to explore natural genetic variation
- Case study: domestication of a tomato wild relative

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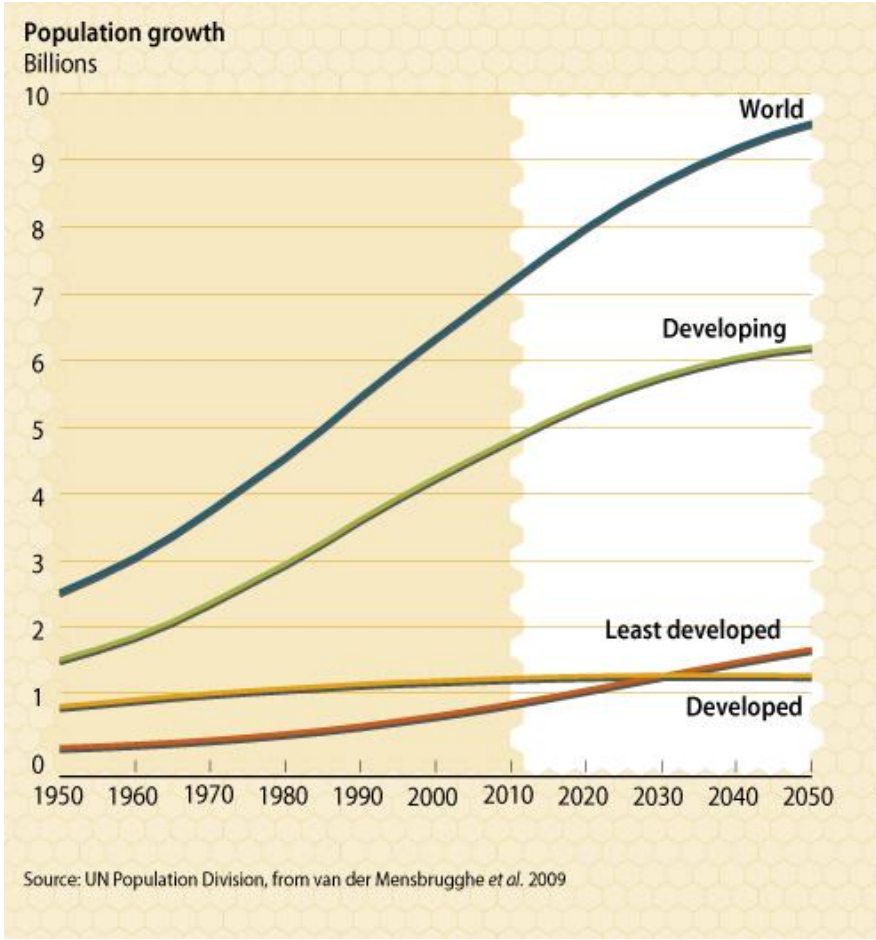
Food security: all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious **food** that meets their **food** preferences and dietary needs for an active and healthy life.

(UN Committee on World Food Security, 2017)

Nature, Outlook: Food Security (2017)

Food security faces multiple challenges

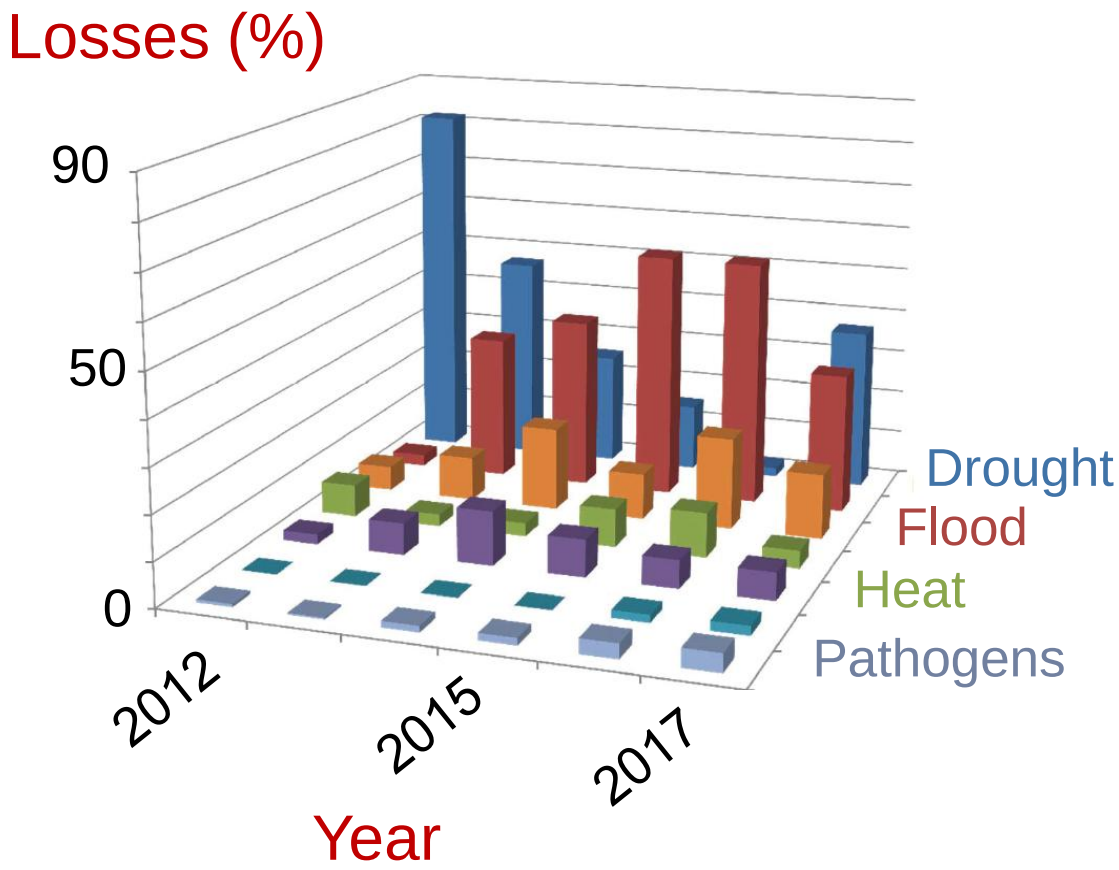
1- Population growth



200,000 new people every day (need to be fed)

Food security faces multiple challenges

2- Change in climate



Losses in the US are caused mainly by abiotic stresses

Food security faces multiple challenges

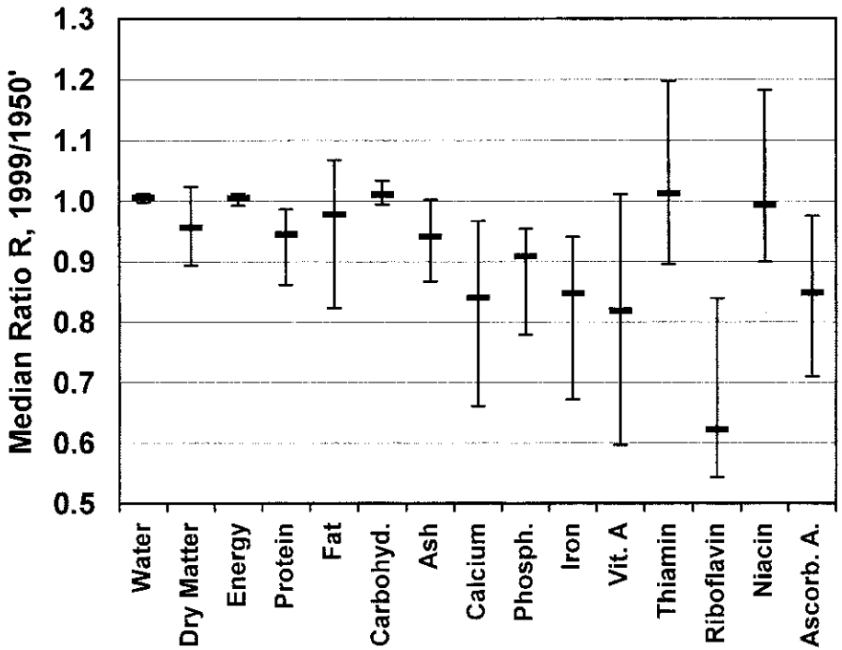
3- Nutritional losses: past

Original Research

Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999

Davis et al. (2004) *J. Am. Coll. Nutr.* 23: 669-682

Donald R. Davis, PhD, FACN, Melvin D. Epp, PhD and Hugh D. Riordan, MD

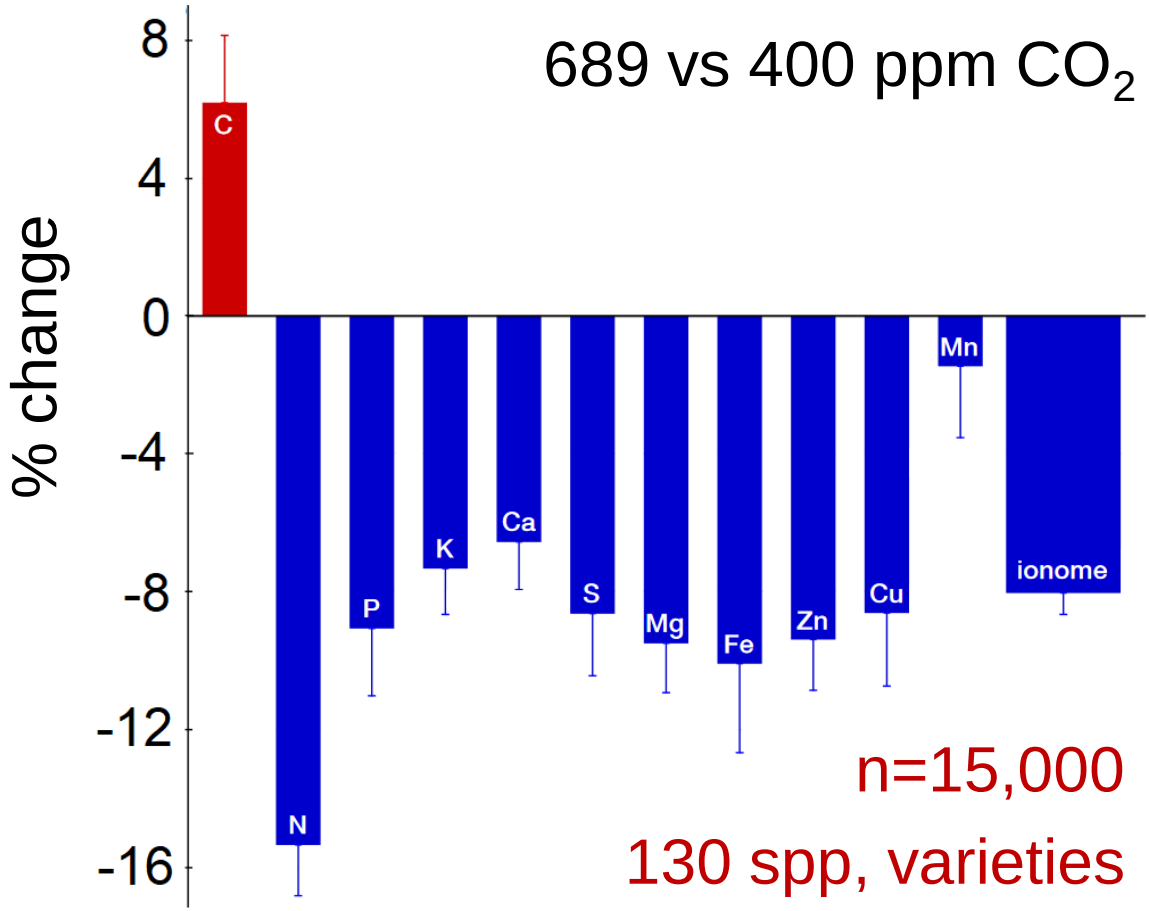


- Nutritional content in horticultural crops has been decreasing
- Biofortification (cereals, legumes)

www.harvestplus.org

Food security faces multiple challenges

3- Nutritional losses: future (the "Loladze Effect")



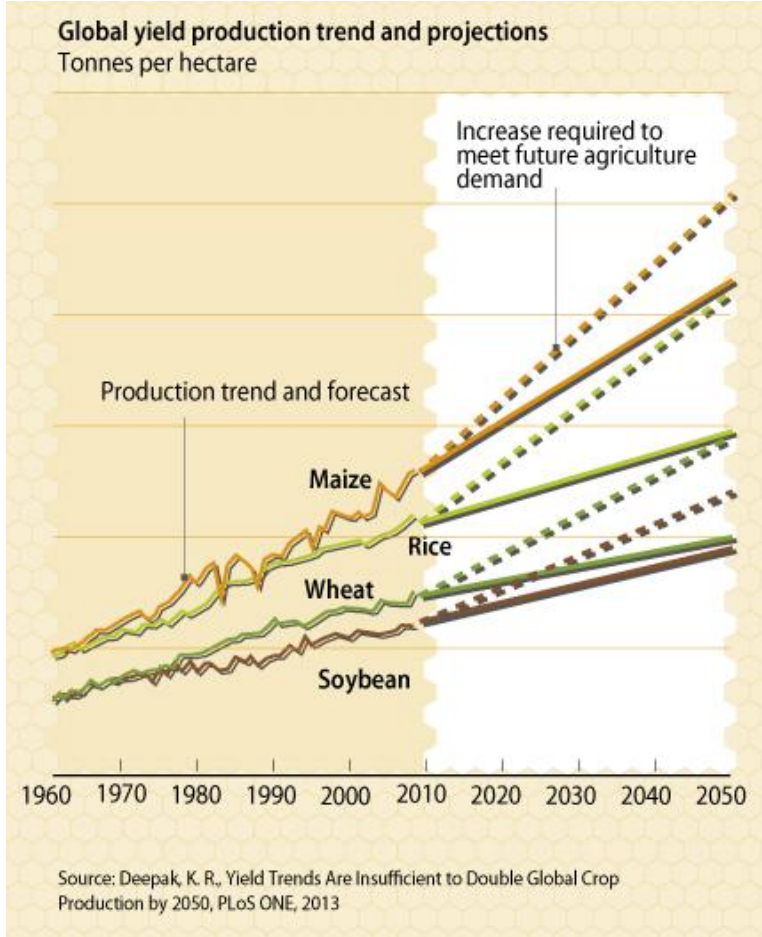
Loladze (2014) *eLife* doi:10.7554/eLife.02245

Challenges and goals for food security in the coming decades

Challenge	Goal
1- Population growth	Increased yield
2- Climate change	Resilience
3- Nutritional losses	Nutritional quality

Challenges and goals for food security in the coming decades

How can we deploy the revolutionary gene-editing technology to improve crops on a faster timescale?



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Ideotype breeding

Photo: CSIRO, Australia

Colin Donald
(1910-1985)

Euphytica 17 (1968): 385–403

THE BREEDING OF CROP IDEOTYPES

C. M. DONALD

Waite Agricultural Research Institute,
The University of Adelaide, South Australia

Breeding:
(1) Defect elimination
(2) Increased yield

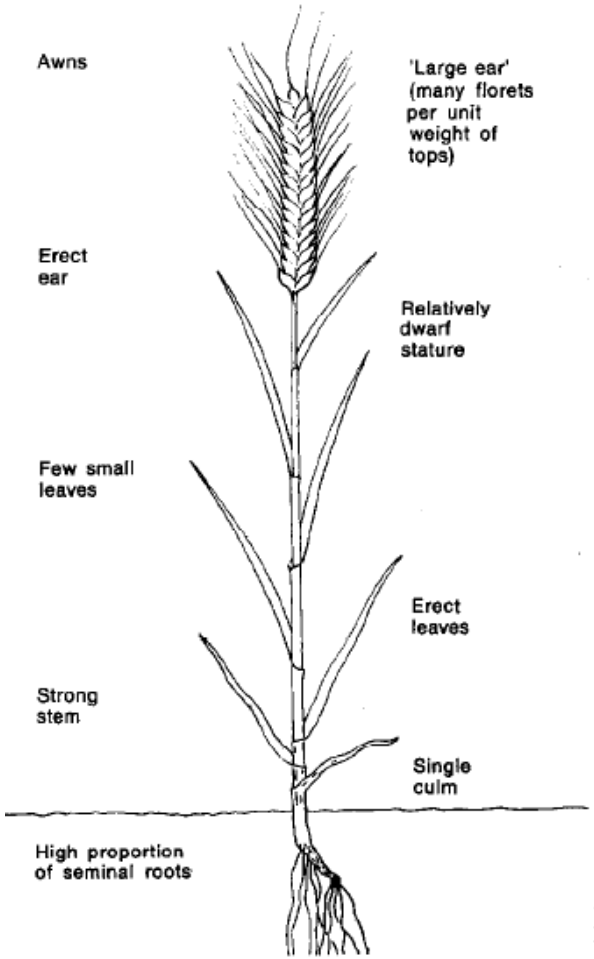
(3) A philosophy for breeding based on the use of models

He proposed **building theoretical models** based on

Knowledge	Experience	Imagination

Ideotype breeding

A philosophy for breeding based on the use of models



The **ideotype**: a plant that in a given environment is

(i) Theoretically capable of greater production

(ii) Designed to be bred from the material available (*reverse breeding*)

Knowledge

Genetic diversity

Suitable techniques

Donald (1968) *Euphytica* 17:385-403

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Enhancing autogamy and fruit yield

Capsicum (pepper) species are frequently allogamous

Naves et al (2019) *TIPS* 24:109-120

Enhancing autogamy and fruit yield

C. frutescens

C. pubescens

C. annuum

- Low fruit set and reduced yield
- Difficulties to produce pure seed (outcrossing)

Enhancing autogamy and fruit yield

C. frutescens

C. pubescens

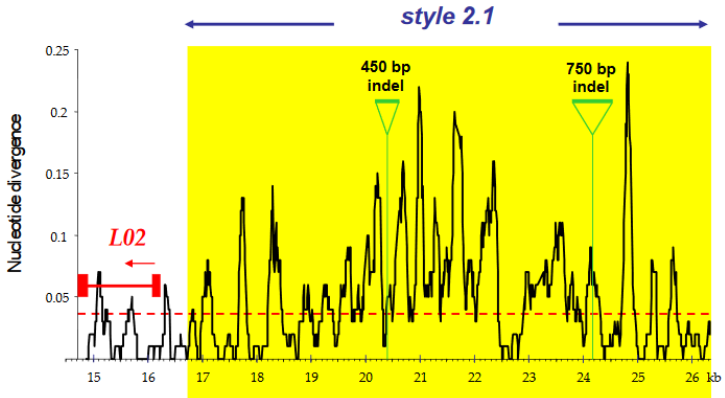
C. annuum

- Low fruit set and redu
- Difficulties to produce

Enhancing autogamy and fruit yield

In tomato, full autogamy is a key domestication trait

Style2.1 gene



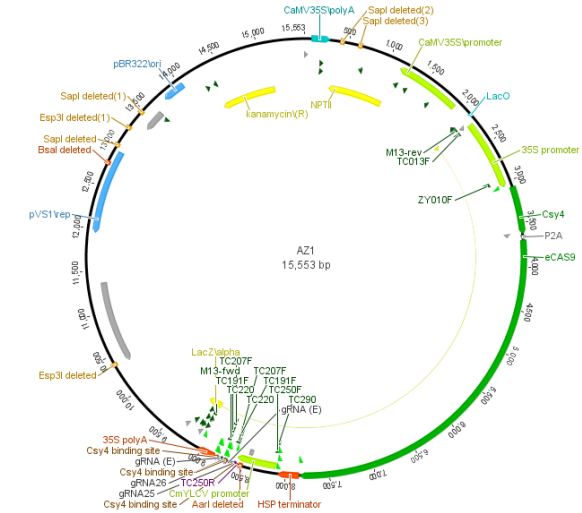
(1) Style length is reduced in cultivated tomato

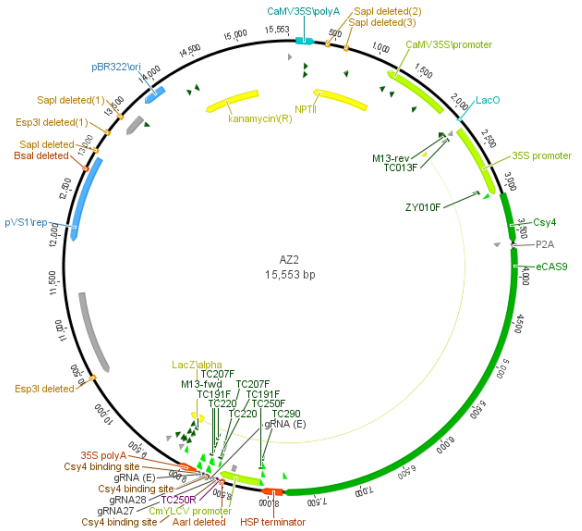
(2) The responsible gene has been identified – a change in the promoter region alters expression levels

Chen et al. (2007) *Science* 318: 643-645

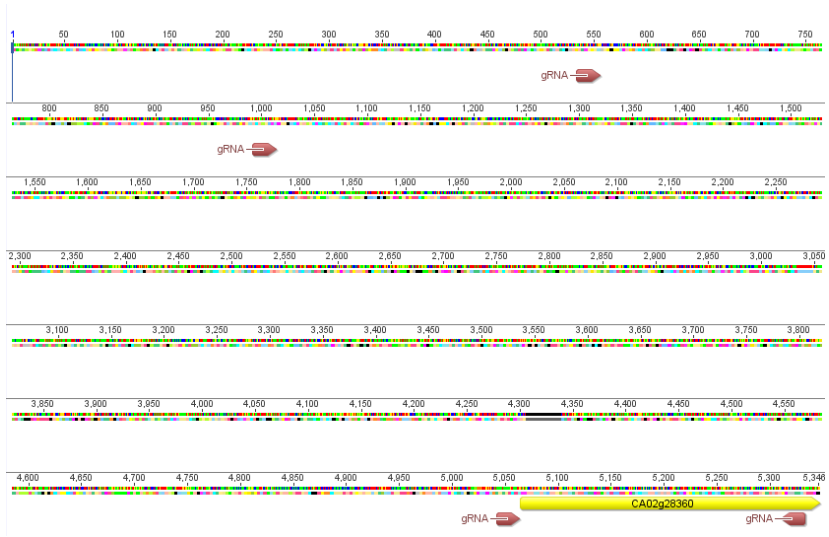
Enhancing autogamy and fruit yield

Two CRISPR/Cas9 constructs targeting *CaSTYLE2.1*





- Promoter and coding region of the gene
- Ensure maximal phenotypic variation to discover trait of interest



Enhancing autogamy and fruit yield

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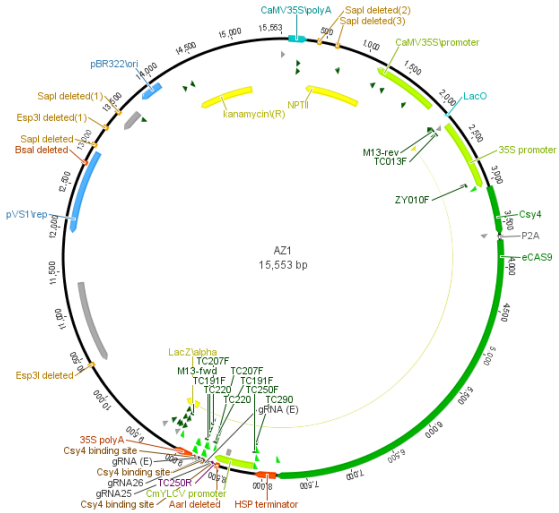

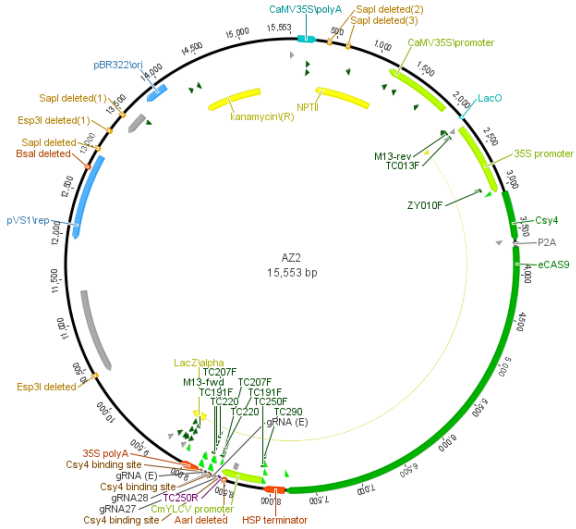

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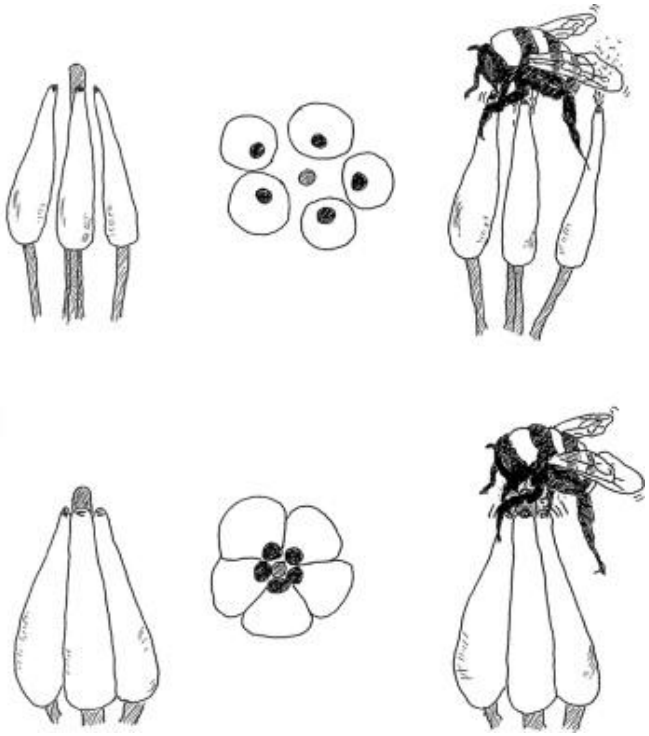
Enhancing autogamy and fruit yield

In tomato, full autogamy is a key domestication trait



(1) Fused anthers forming a cone

dialytic gene

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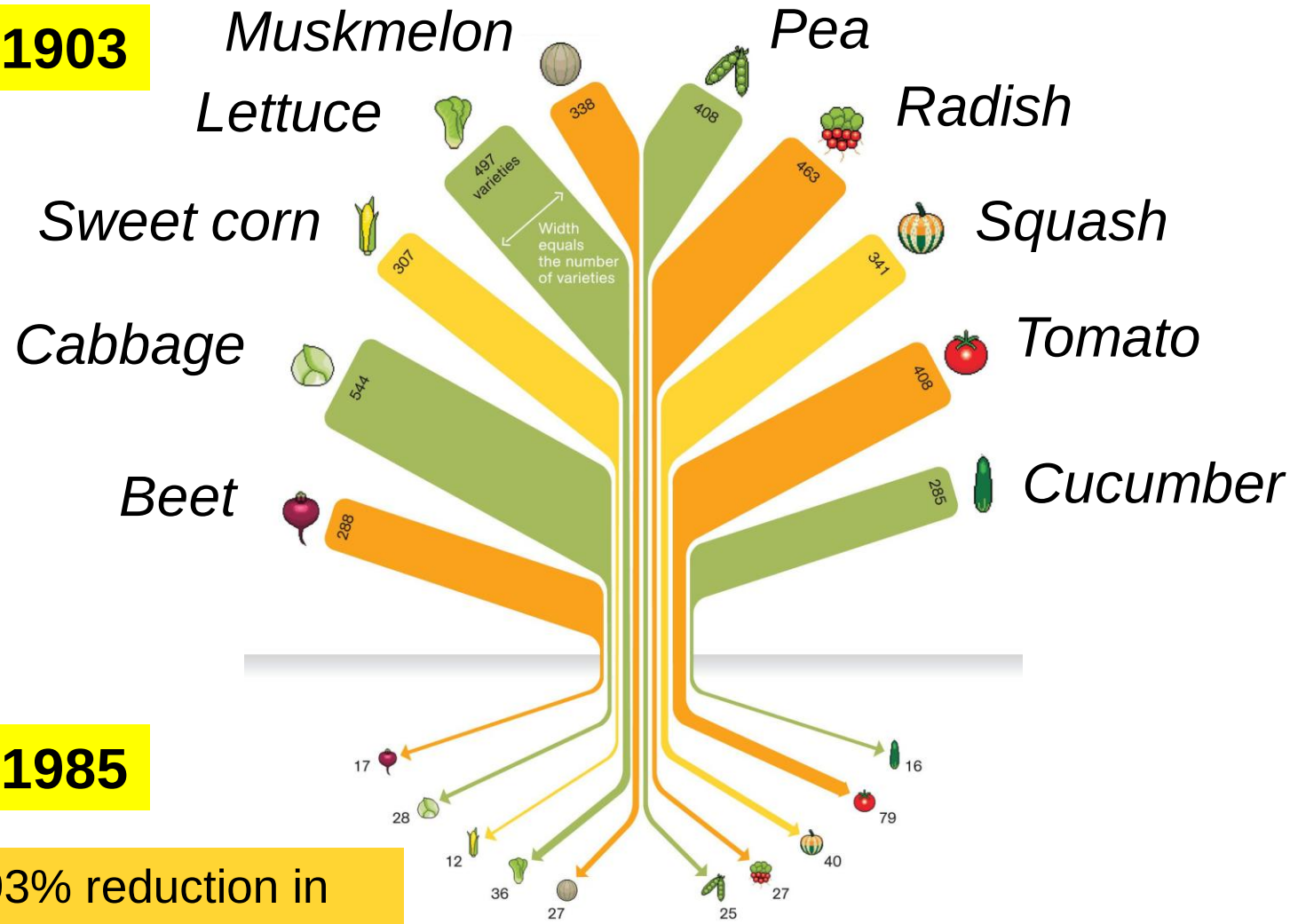
Domestication and breeding entailed loss of genetic diversity

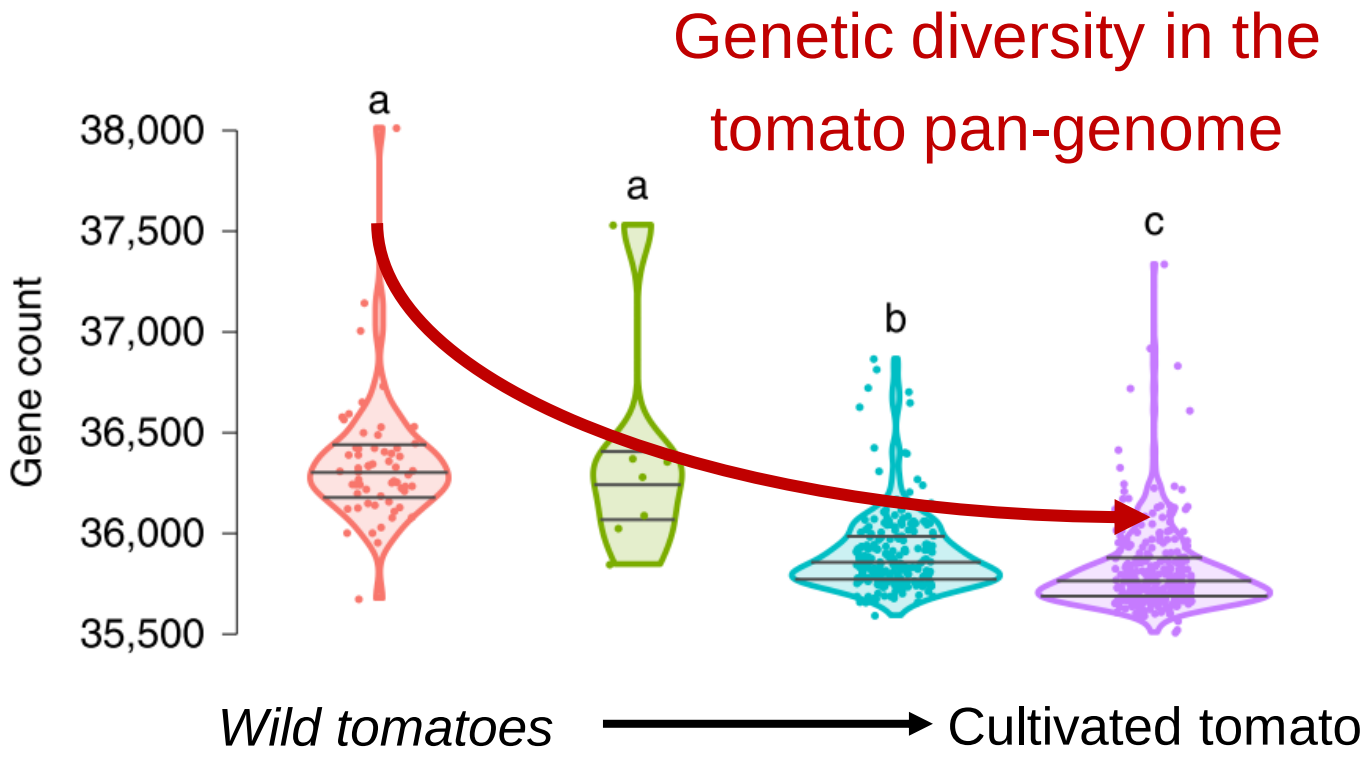


93% reduction in number of varieties

(National Geographic, 2012)

Domestication and breeding entailed loss of genetic diversity

Focus on yield



Loss of resilience and nutritional traits

Gao et al (2019) Nature Genetics

A novel approach to harness natural genetic variation

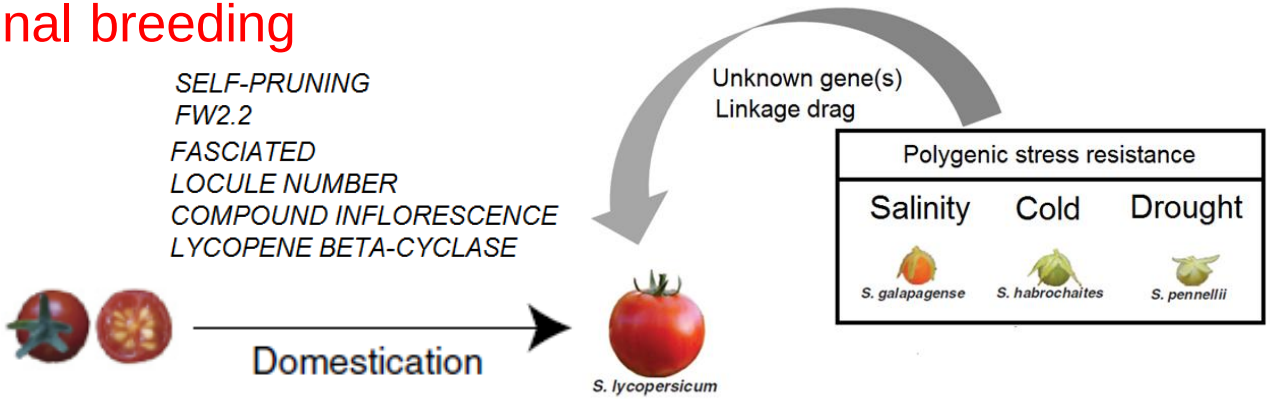
Review article

Plant Science 256 (2017) 120–130

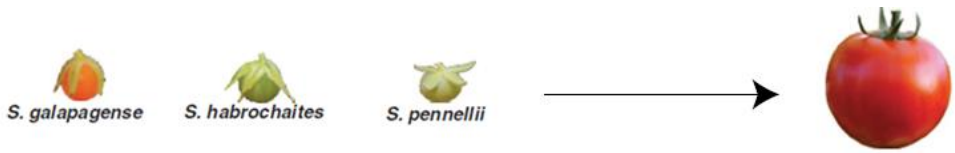
Genome editing as a tool to achieve the crop ideotype and *de novo* domestication of wild relatives: Case study in tomato

Agustin Zsögön[a,1], Tomas Cermak[b,1], Dan Voytas[b], Lázaro Eustáquio Pereira Peres[c,*]

Conventional breeding



De novo domestication



"Domesticated"
S. galapagense
S. habrochaites
S. pennellii

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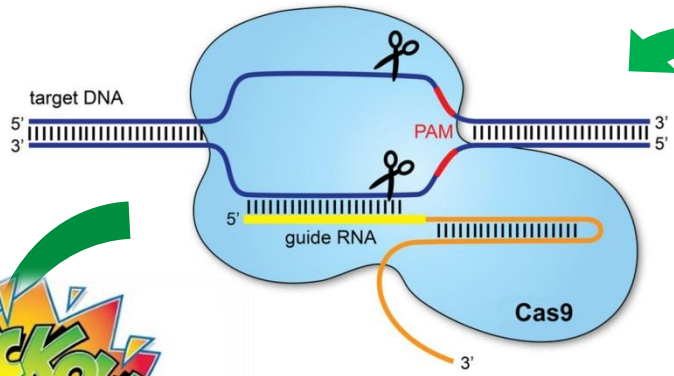
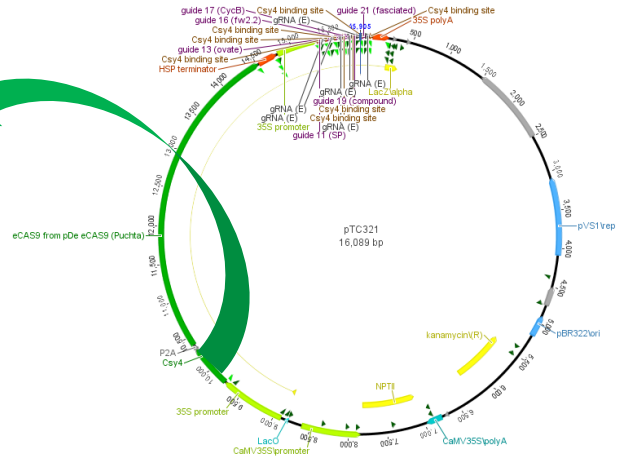
De novo domestication of wild species

Multiplex targeting of domestication genes in *S. pimpinellifolium* in one generation





SELF-PRUNING
FRUIT WEIGHT 2.2
FASCIATED
LYCOPENE BETA CYCLASE
COMPOUND INFLORESCENCE
OVATE

De novo domestication of wild species

- Growth habit (determinate)
- Flower number (+600%)
- Fruit size (+300%)
- Fruit shape (ovate)
- Lycopene content (+500%)

Wild tomato

Genome engineering

(In one generation)

New domesticate

De novo domestication of wild species

nature biotechnology

Article | Published: 01 October 2018

De novo domestication of wild tomato using genome editing

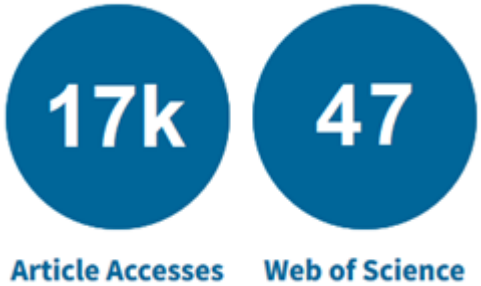
Agustin Zsögön, Tomáš Čermák, Emmanuel Rezende Naves, Marcela Morato Notini, Kai H Edel, Stefan Weinl, Luciano Freschi, Daniel F Voytas, Jörg Kudla ✉ & Lázaro Eustáquio Pereira Peres ✉

Nature Biotechnology **36**, 1211–1216 (2018)

Altmetric score (what's this?)

- Tweeted by **886**
- Blogged by **5**
- On **8** Facebook pages
- Mentioned in **1** Google+ posts
- Picked up by **29** news outlets

Show more



This Altmetric score means that the article is:

- in the 99th percentile (ranked 337th) of the 263,314 tracked articles of a similar age in all journals
- in the 95th percentile (ranked 2nd) of the 47 tracked articles of a similar age in *Nature Biotechnology*

De novo domestication of wild species

MENU nature
International journal of science

EDITORIAL · 02 OCTOBER 2018

Super-tomato shows what plant scientists can do

A better-tasting tomato highlights problems with Europe's outdated approach to gene editing.

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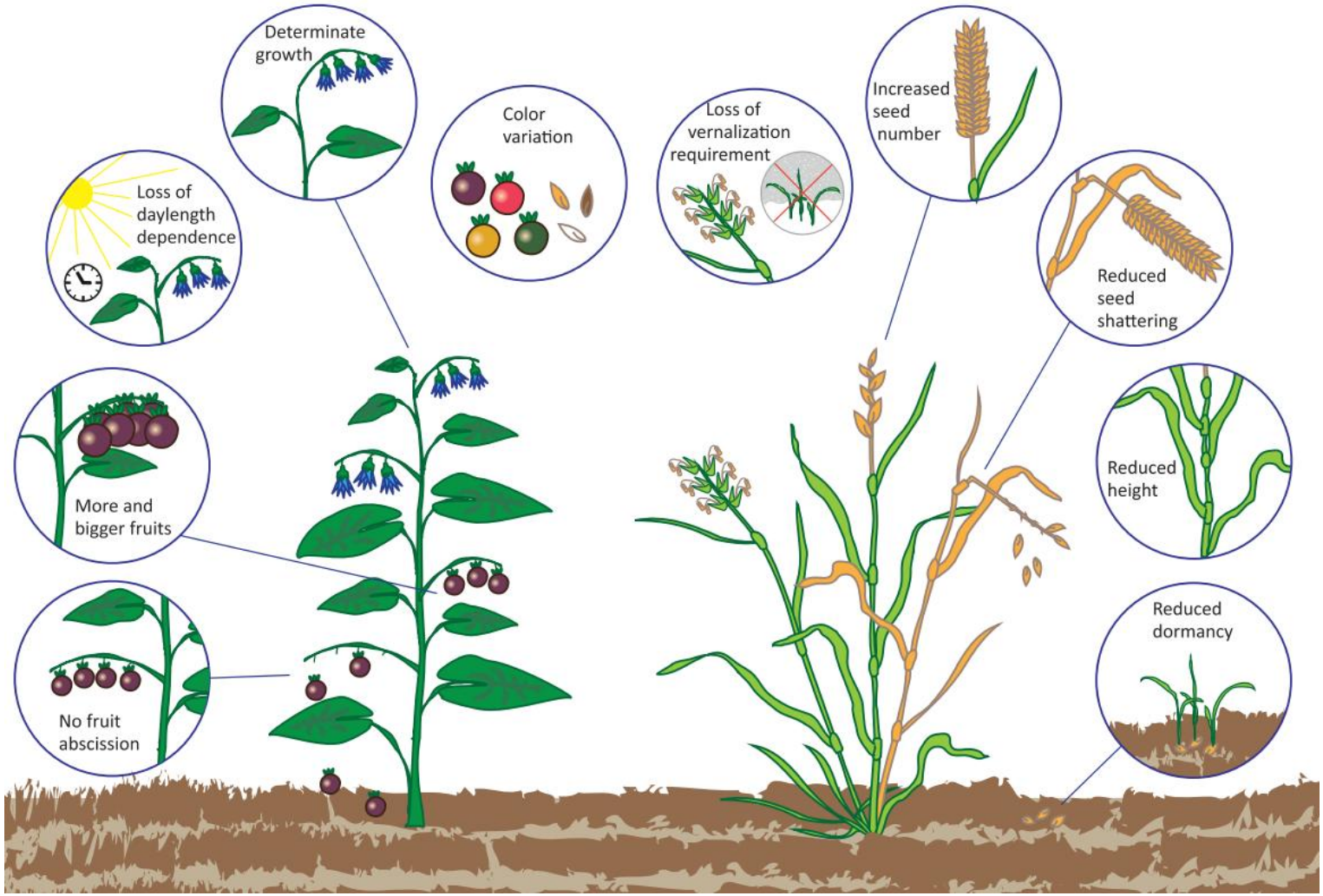
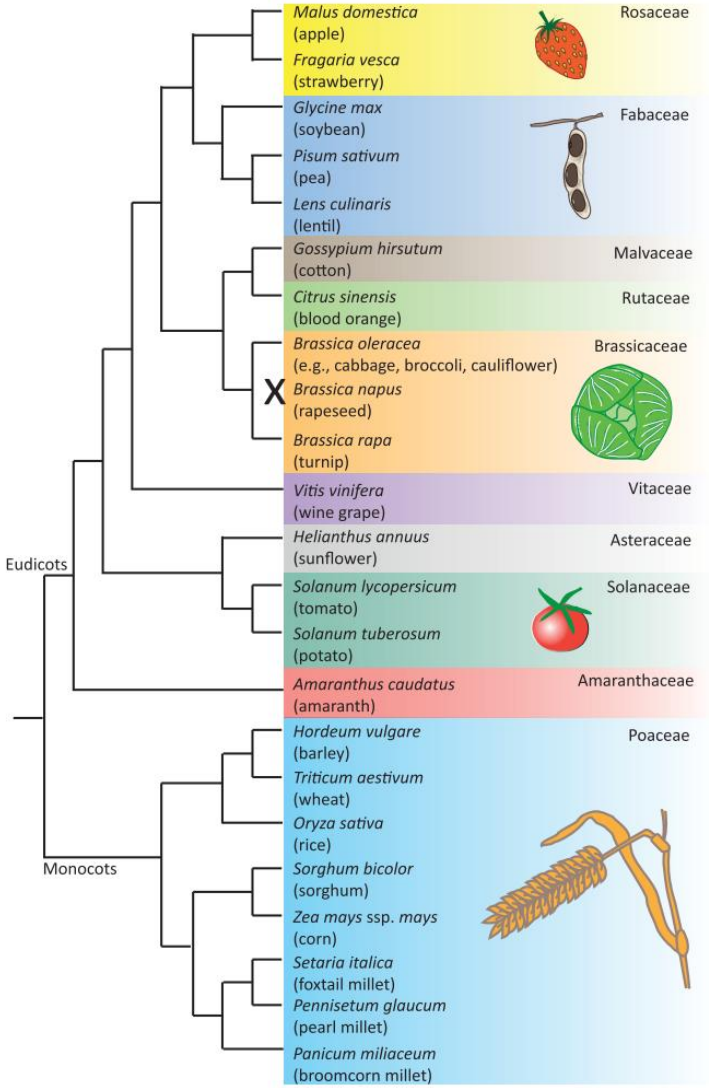
Convergent crop domestication facilitates gene discovery



Lenser & Theissen (2013) TIPS 18: 704-714

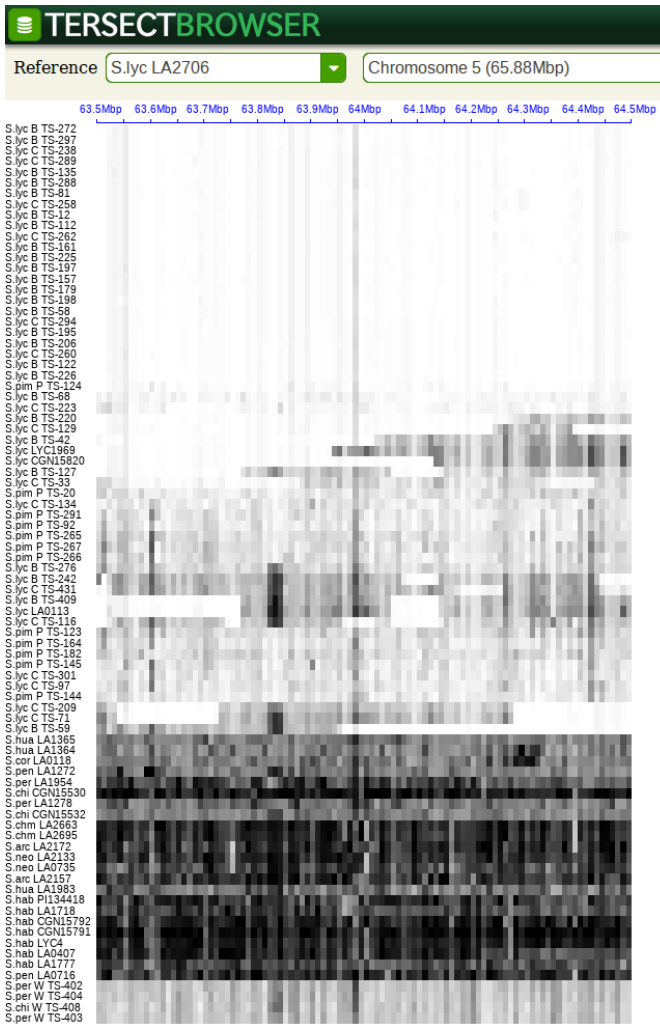
Convergent crop domestication facilitates gene discovery



- Use of closely related model species
- Genes in ‘simple’ pathways or with reduced pleiotropic effects
- Bioinformatics to find homologous genes or equivalent nodal positions

Lenser & Theissen (2013) TIPS 18: 704-714

Convergent crop domestication facilitates gene discovery



- A genetic diversity browser
- Blazing fast, highly flexible, customizable

Kurowski & Mohareb (2019) Bioinformatics

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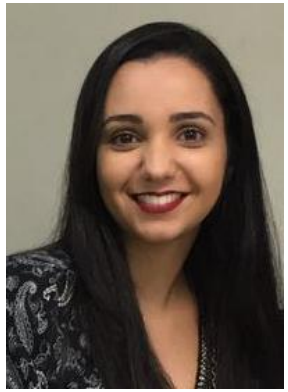
1- Ideotype breeding and *de novo* domestication are conceptually different to conventional breeding

2- They help avoid founder effect, linkage drag and reduced recombination rates

3- They could provide a fast pathway for increased resilience and nutritional content in crops

4- Both require a deeper understanding of the genes underlying key agronomic traits

Lab members



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João Victor Abreu Cerqueira - PhD
Emmanuel Rezende Naves - PhD
Bruno Luan Rosa - PhD

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www.fisiologiavegetal.ufv.br