



Unique Challenges in Breeding Specialty and Perennial Crops

Presentation for Advanced Plant Breeding Symposium
September 7 2021



MARS

Advanced Research Institute

**We spark discoveries
in emerging science
and technology to create the
world we want tomorrow.**

Carl Jones PhD Plant Sciences Director
Mars Advanced Research Institute

Global Crops, Global Challenges

A hard crop,

A really hard crop,

Why a single trait can be hard even in an easy crop.



There are over

5

million
smallholder farmers

95%

of cocoa is grown
by smallholder
farmers

Mars depends on

400K

farming
families

Cocoa is essential to the livelihoods of
40-50 million people worldwide.

For most of them, cocoa is their **main source of income.**

Cocoa is produced in 13 countries

1	Côte d'Ivoire	39%
2	Ghana	17%
3	Indonesia	13%
4	Nigeria	6%
5	Cameroon	6%
6	Brazil	5%
7	Ecuador	4%
8	Peru	2%
9	Dominican Republic	2%
10	Colombia	1%
11	Papua New Guinea	1%
12	Uganda	1%
13	Mexico	1%



Global Cocoa Production (2017)



Côte d'Ivoire produces nearly

40%

of the world's cocoa

Four West African countries produce

70%

of the world's cocoa

The top four producers

- Côte d'Ivoire
- Ghana
- Indonesia
- Nigeria

Are in the bottom half of nations GDP per capita



Challenges in Cacao Production

30-40% of production is lost to 5 major pest and diseases each year

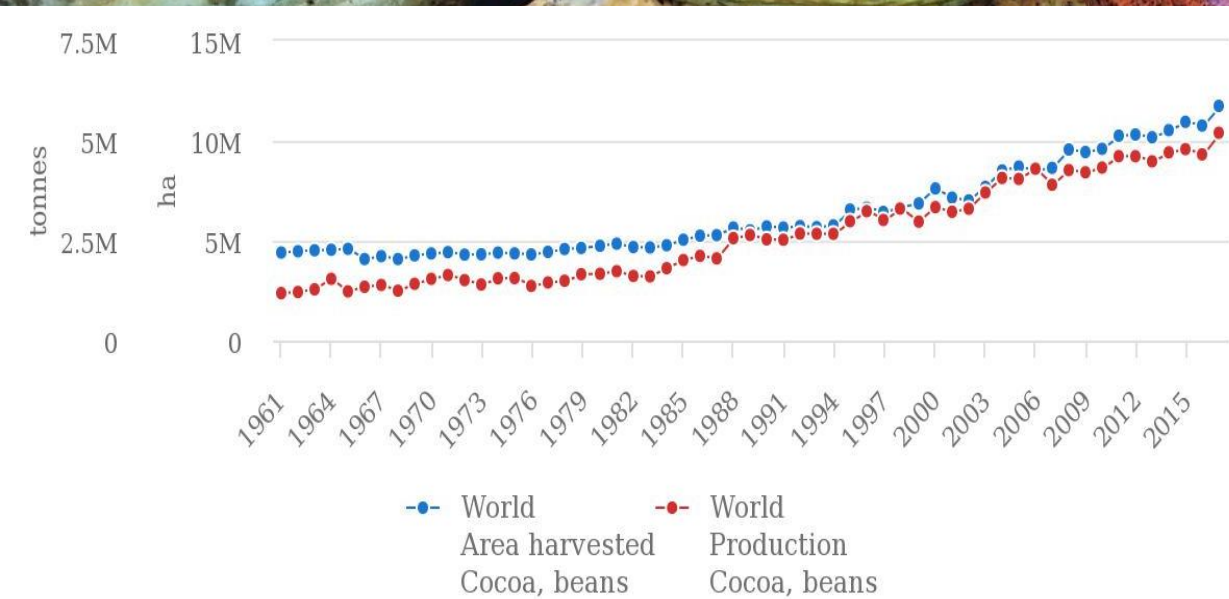
- Black Pod (Phytophthora spp.)
- Frosty Pod (Moniliophthora roreri)
- Cacao Swollen Shoot Virus
- Vascular Streak Dieback
- Witches Broom Disease



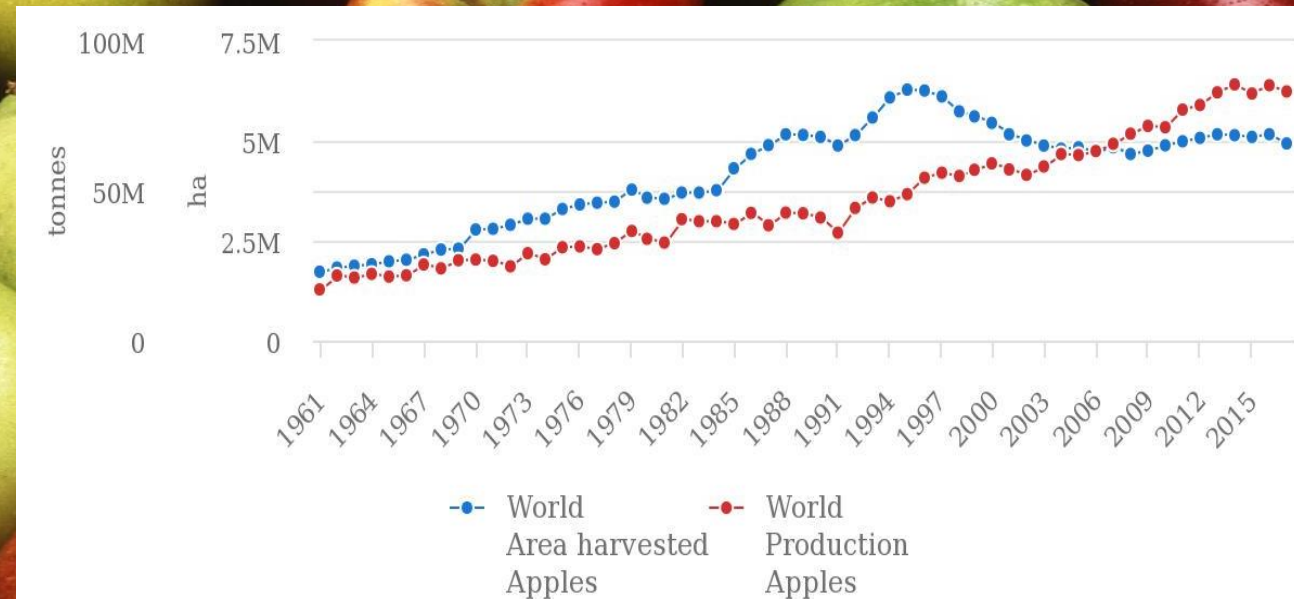
Increased production as a result of expansion - not efficiency

1990 : 443 kg/ha
2017: 442 kg/ha

1990 : 8 T/ha
2017: 16.8T/ha



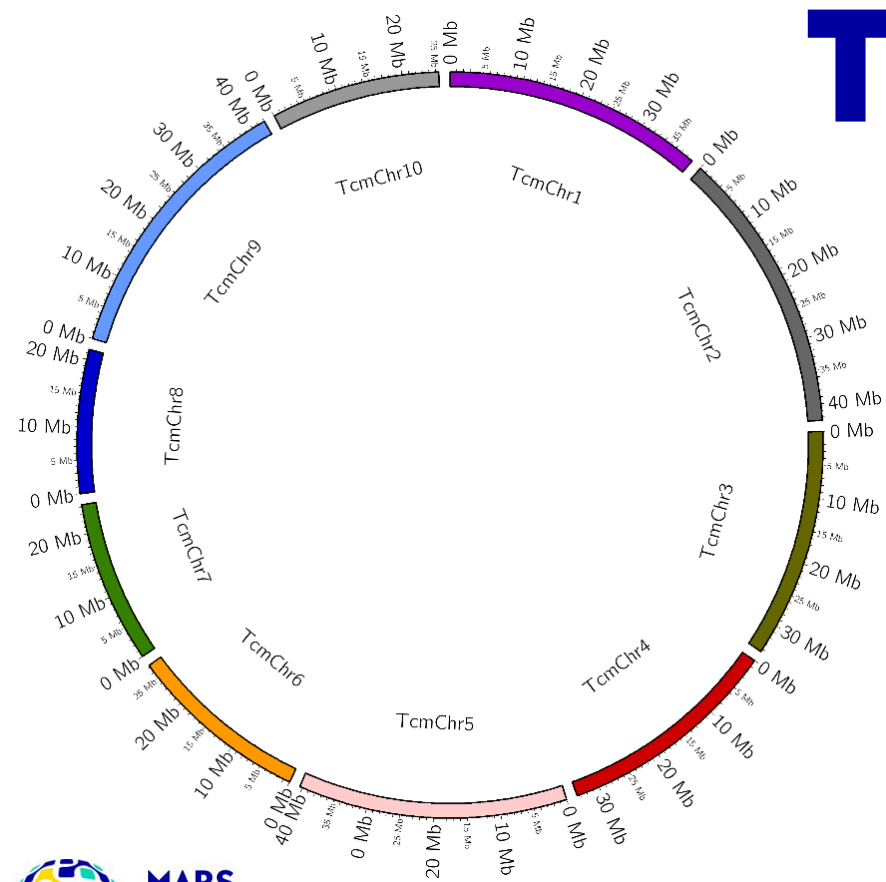
Source: FAOSTAT (May 11, 2019)



Source: FAOSTAT (May 11, 2019)



THE GENETIC TOOLKIT



Historically, Three Groups Recognized

Two subspecies based on morphological traits and geographic origins, and a third that arose from their hybridization (Cheeseman 1944; Cuatrecasas 1964)

“**Forastero**” (*Theobroma cacao* subsp. *sphaerocarpum*)

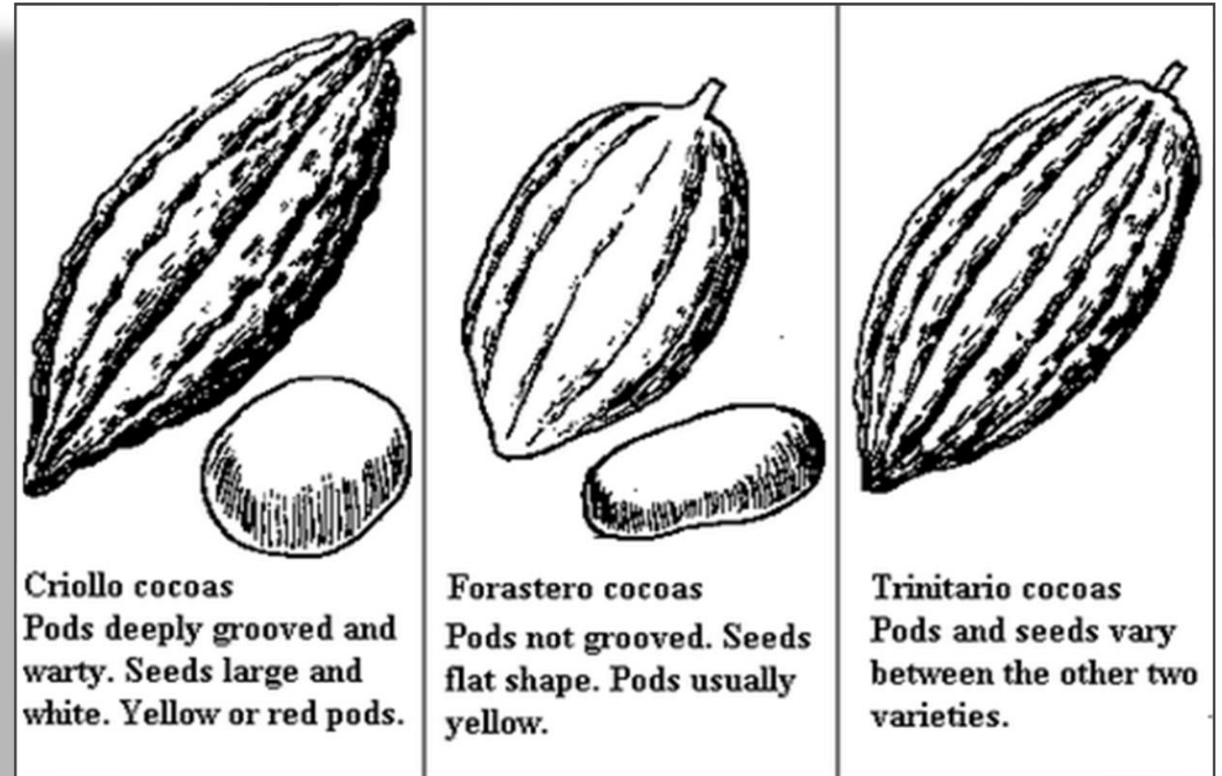
- Amazonian
- Broader genetic diversity base

“**Criollo**” (*Theobroma cacao* subsp. *cacao*)

- Mesoamerican domestication
- Highly homozygous
- Fine flavor characteristics but highly susceptible to diseases

“**Trinitario**”

- Spontaneous hybrid when other types were brought to plantations in Trinidad



Geographic and Genetic Population Differentiation

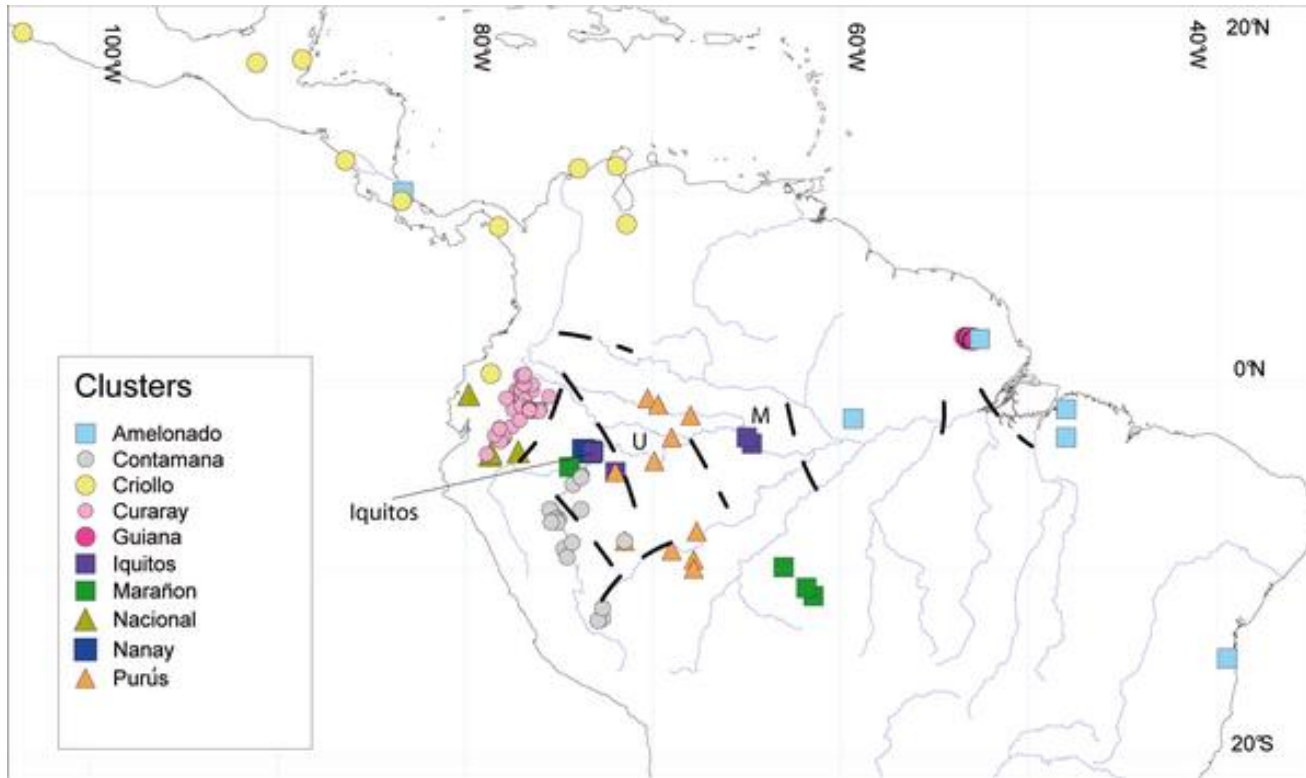
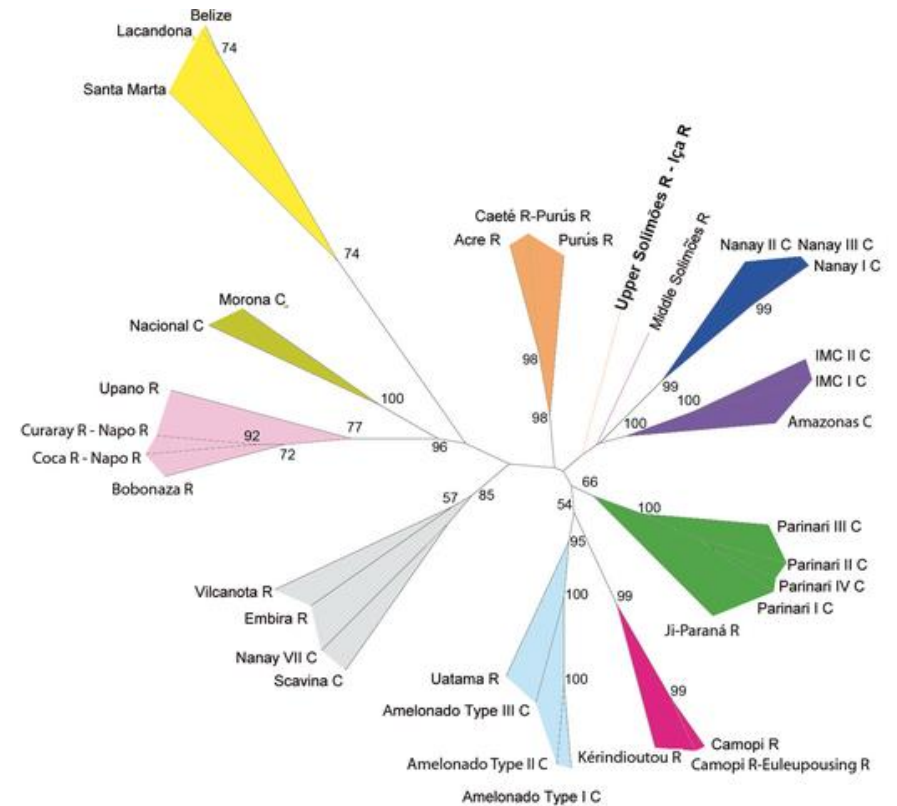


Figure 1. Localization of the origin of individuals analyzed; colors indicate the inferred genetic cluster to which they belong.

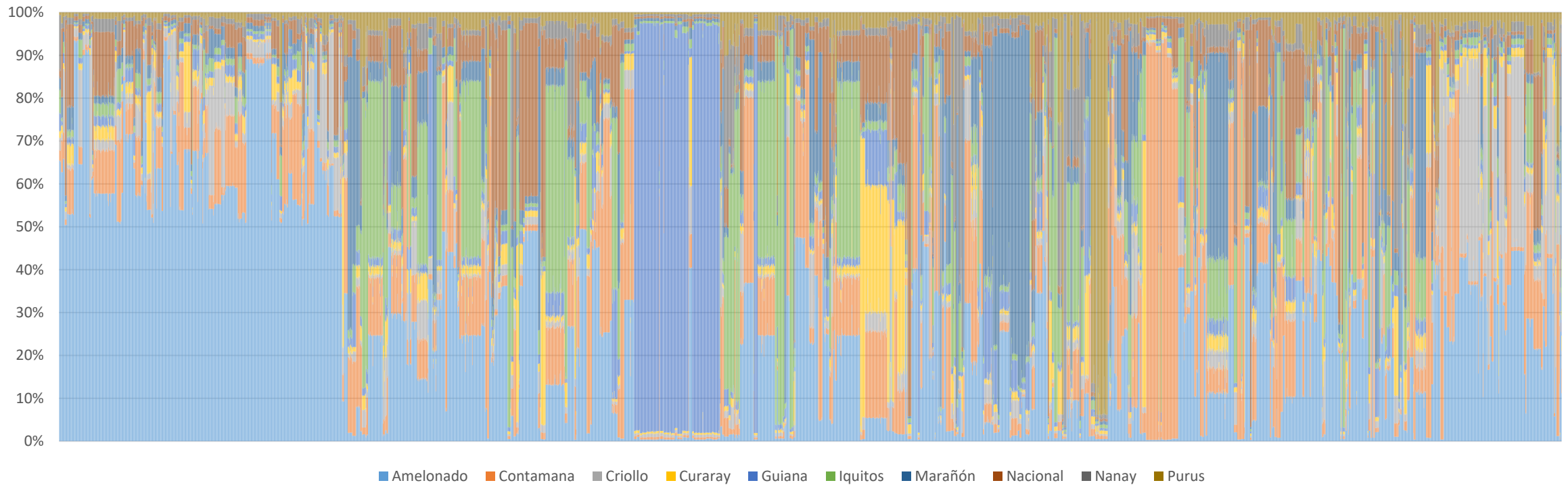


Colors indicate the inferred genetic cluster to which the subcluster belongs: Marañon (●), Guiana (●), Contamana (●), Curaray (●), Nanay (●), Iquitos (●), Nacional (●), Purús (●), Criollo (●), and Amelonado (●), (C=Clones; R=River).

Figure 2. Neighbor joining tree from Cavalli-Sforza and Edwards genetic distance [16] matrix among the 36 subclusters identified using Structure (559 clones).

Genetic Diversity in Cacao

Structure analysis of 700 cacao germplasm accessions



Implications for Breeding

Understand ancestry sources of production and resistance traits

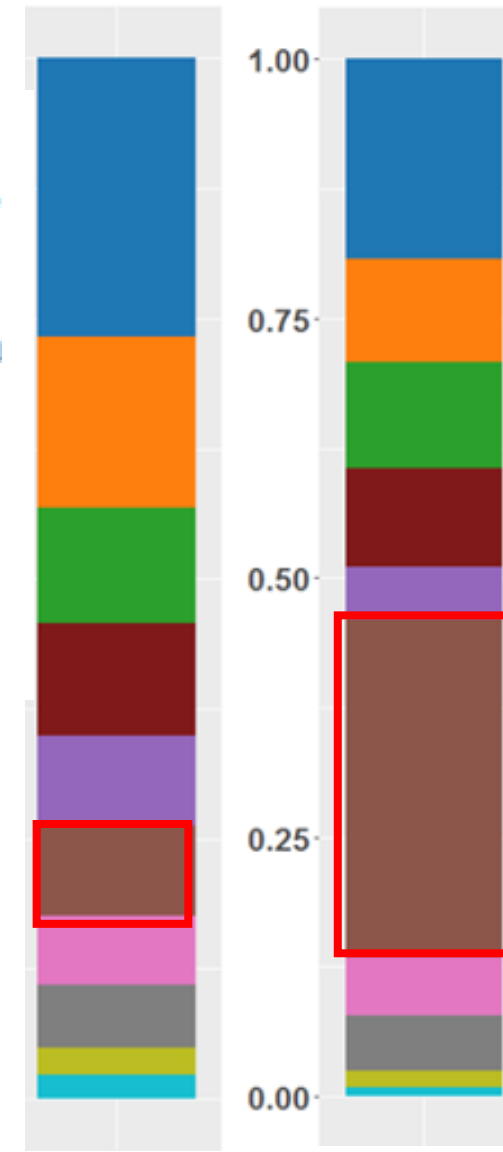
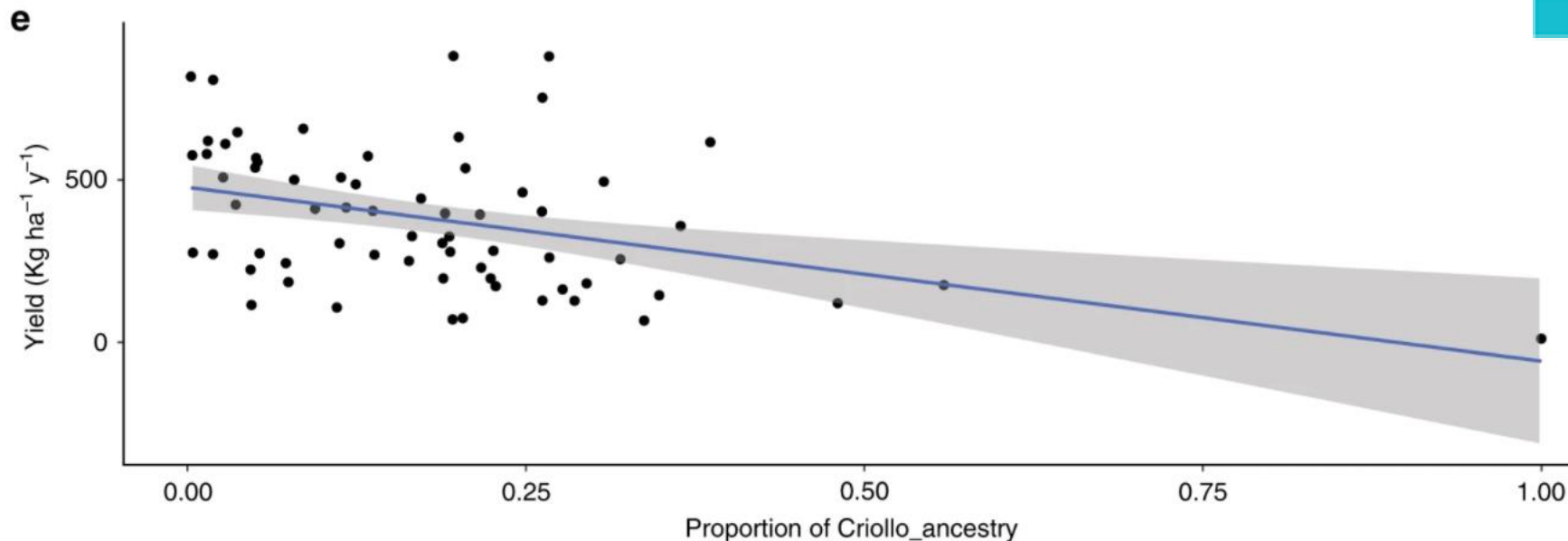
Exploit heterosis, avoid inbreeding depression

Better estimations of heritability

Population structure to correct for GWAS

Ancestry

- Amelonado
- Criollo
- Iquitos
- Contamana
- Nacional
- Guiana
- Nanay
- Maranon
- Purus
- Curaray



Using molecular tools for detection of Off-types

Prevalence of off-types in Cacao collections

COLLECTION/TRIAL	% OFFTYPES	REFERENCE
HYBRID	5.9%-8.6%	Dadzie et al., 2013
HYBRID	11.8%	Cervantes-Martinez et al., 2006
HYBRID	30%	Schnell et al., 2013
HYBRID	54.5%	Padi et al., 2015
CLONAL	0-100%	Padi et al., 2015
CLONAL	35%	Olasupo et al., 2017
CLONAL	6.9%	Romero Navarro et al., 2017
CLONAL	15-44%	Sounigo et al., 2001
CLONAL	20-100%	Padi et al., 2015
CLONAL	46.4%	Aikpokpodion et al., 2009
CLONAL	57.4-78%	Olasupo et al., 2017

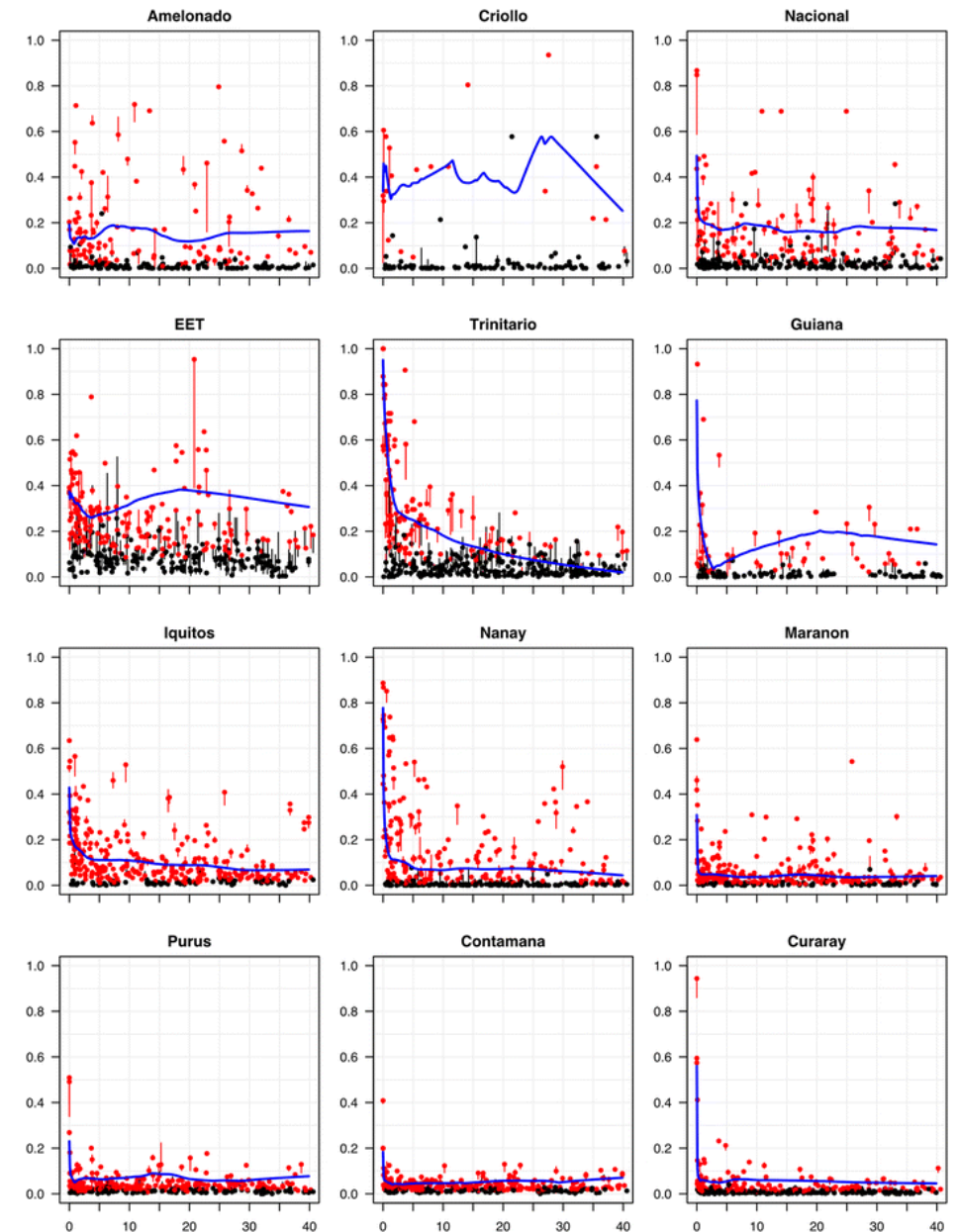


LD in cacao genetic groups

Linkage Disequilibrium is effectively a measure of historical recombination.

We care about this because we need to “observe” recombination to find where important traits are in the genome.

Recombination only occurs each reproductive cycle (7 years)



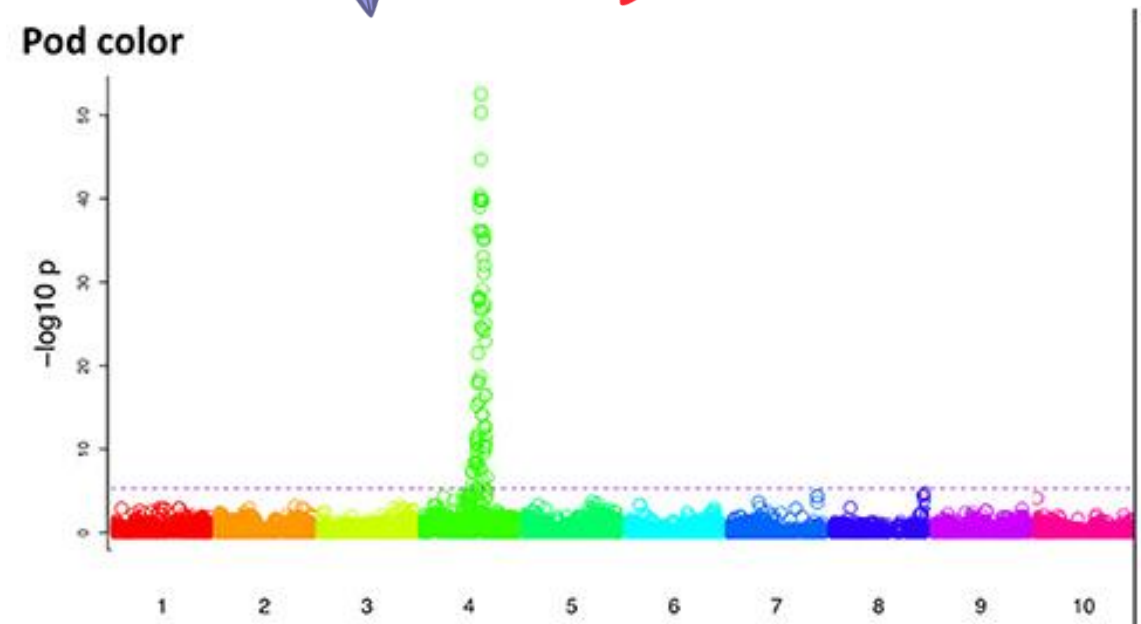
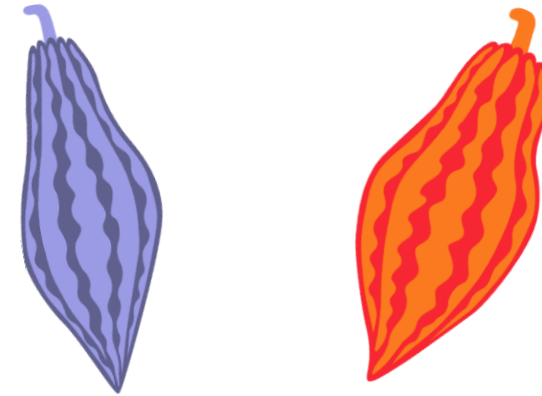
[Assessing microsatellite linkage disequilibrium in wild, cultivated, and mapping populations of Theobroma cacao L. and its impact on association mapping | SpringerLink](#)

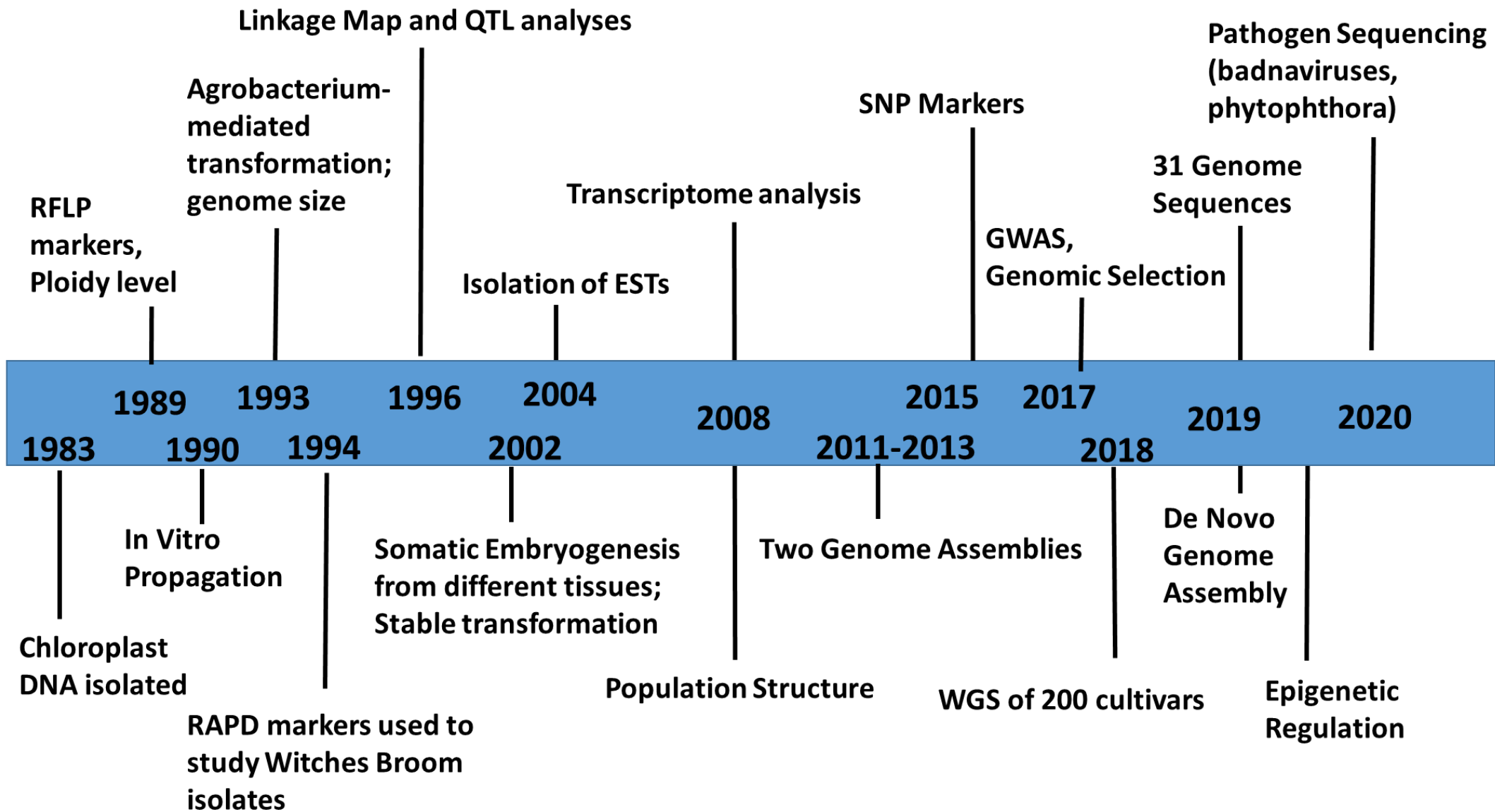
Genome Wide Association Study

Uses diverse individuals to look for regions contributing to trait expression

TcMYB113 gene on chromosome 4 associates strongly with pod color (Motamayor et al., 2013)

Transcription factor with homologues regulating fruit color in Rosaceae, Solanaceae





Breeding for Multiple Traits



Yield



Pod Index



Fat Content



Self-Compatibility



Resistance

Ceratocystis



Resistance

Witches' Broom



Resistance

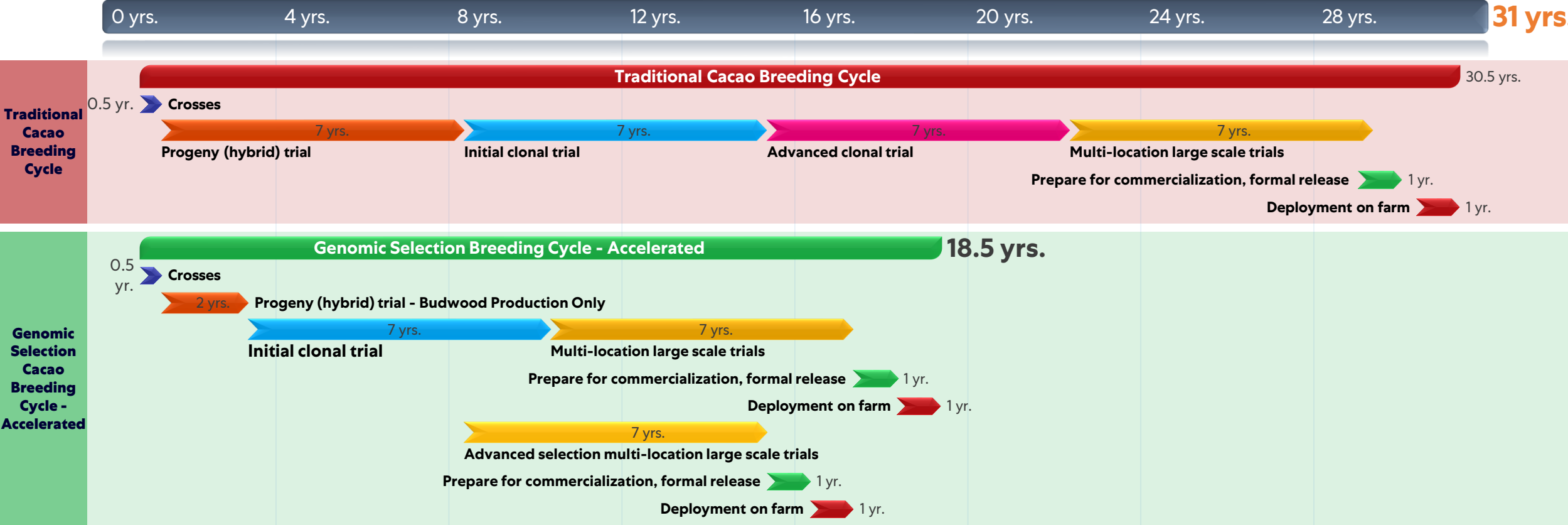
Black Pod



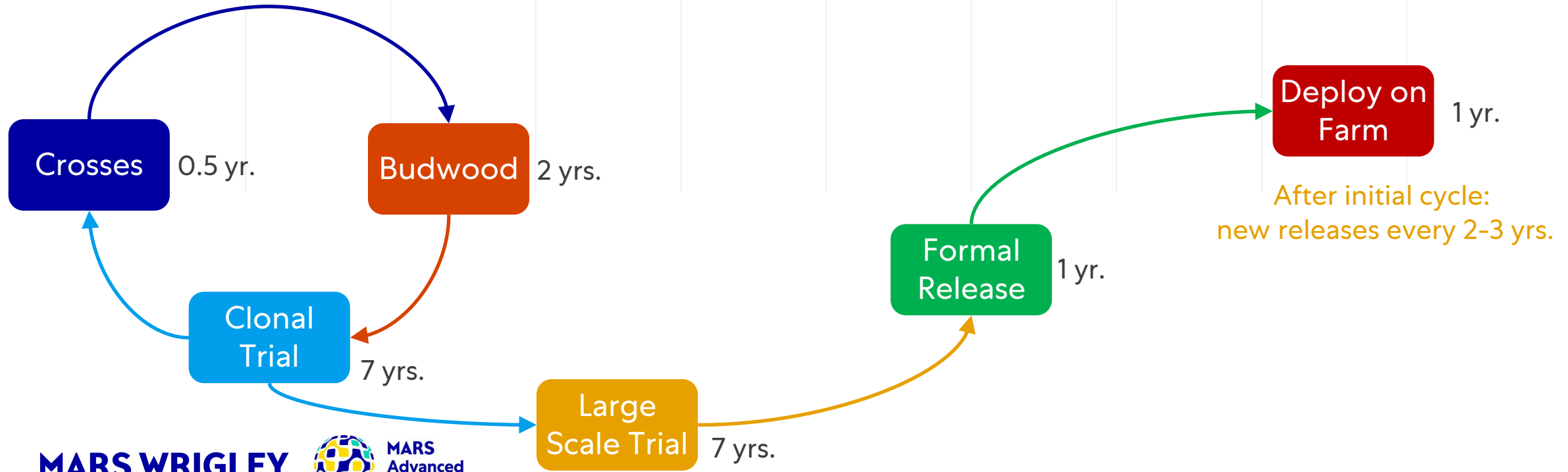
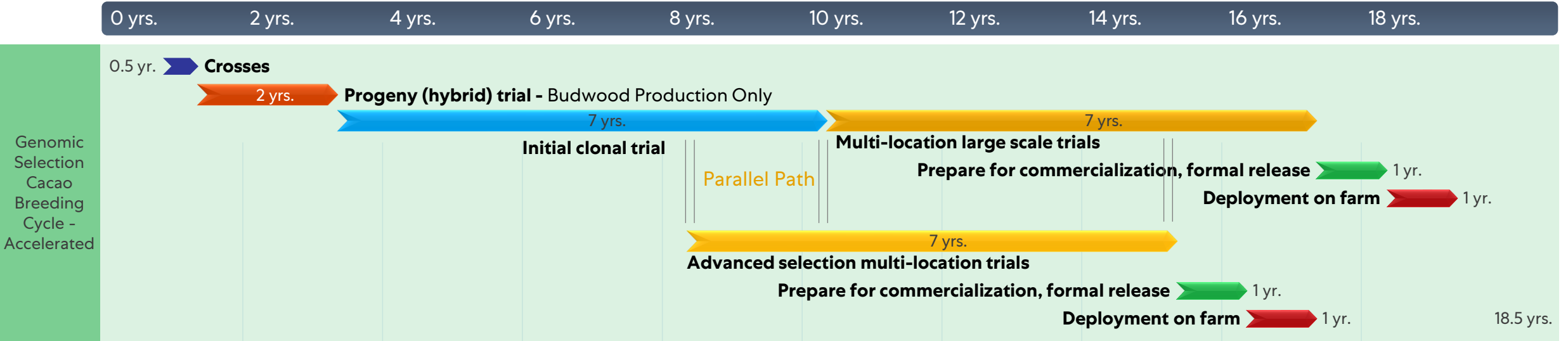
Resistance

Frosty Pod

Cacao Breeding Cycle Timeline



Breeding is cyclical



Mint

Mint oil is a key source of natural flavors for gum, candy, perfumes, cosmetics and health care products.

Industry based on a few number of cultivars

Peppermint [*Mentha x piperita* L.]

Native **Spearmint** [*Mentha x spicata* L.]

Scotch **Spearmint** [*M. x gracilis* Sole]

Corn Mint [*Mentha Arvensis*]

Susceptible to pests


Asexual plant reproduction

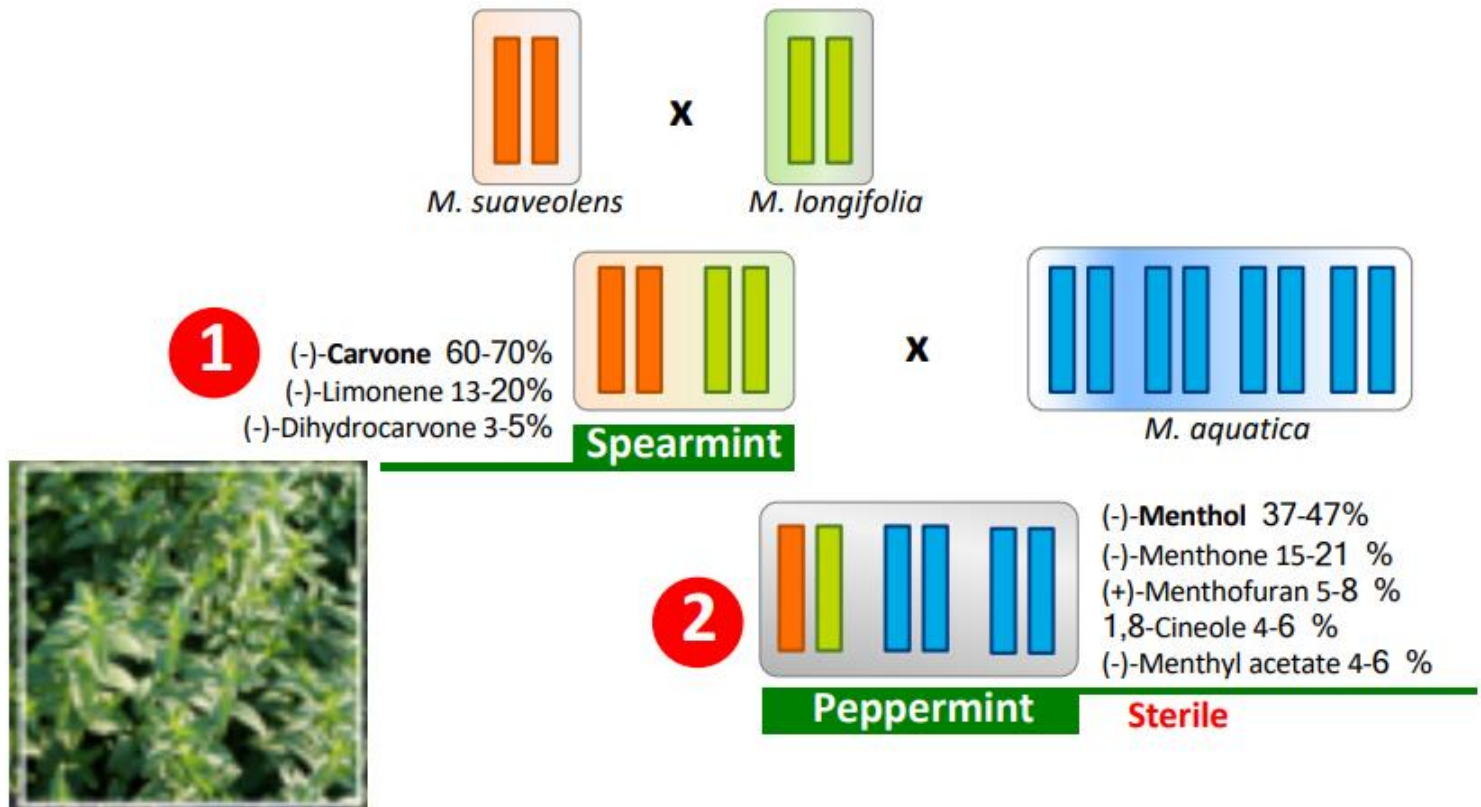
Limited genetic information



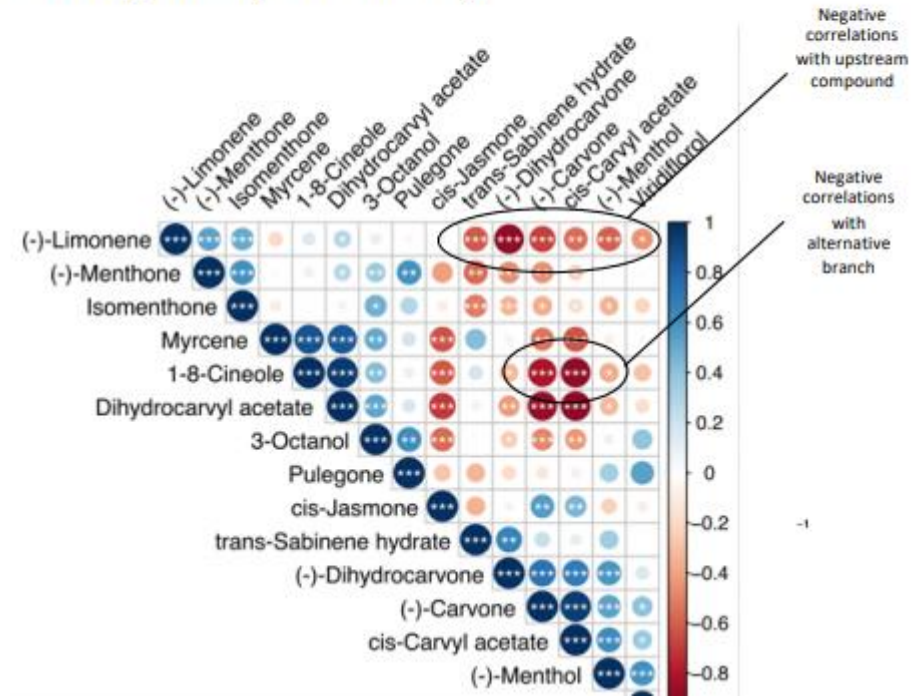
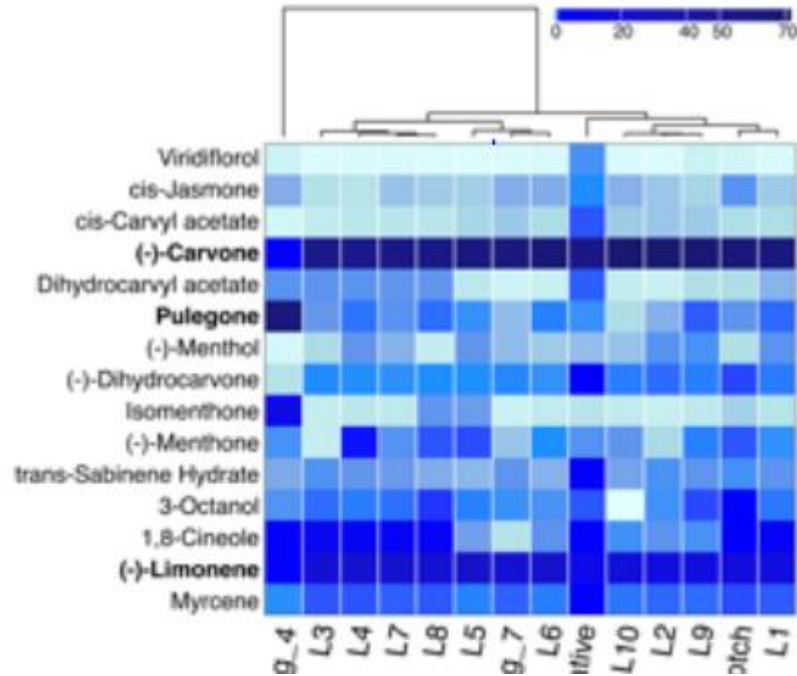
Black Mitcham [ploidy: 6X]

Origins of cultivated mints

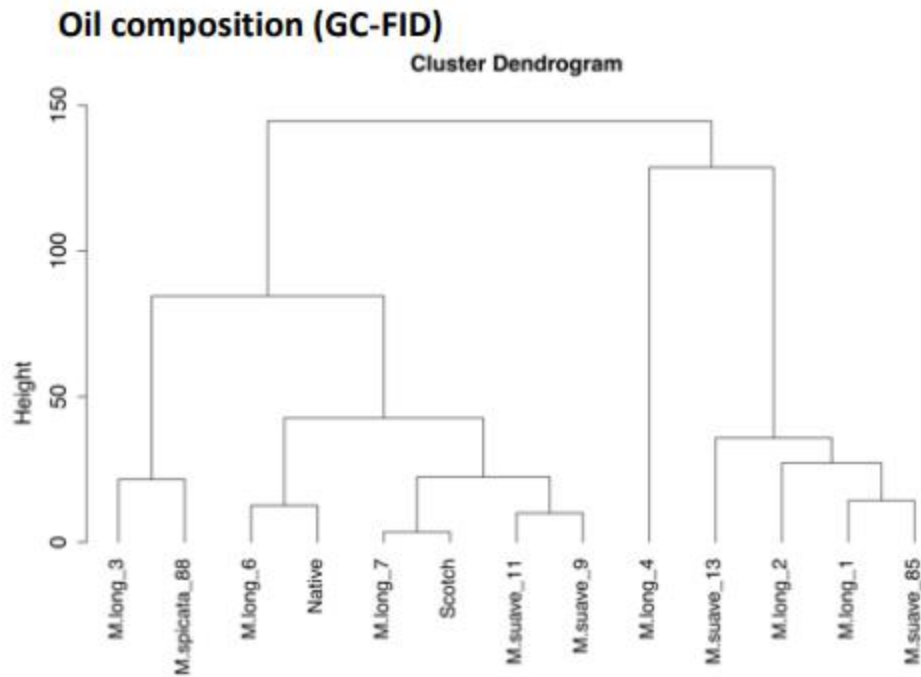
 = 12 chromosomes



Diploid progenies flavor composition analysis (GC-FID)

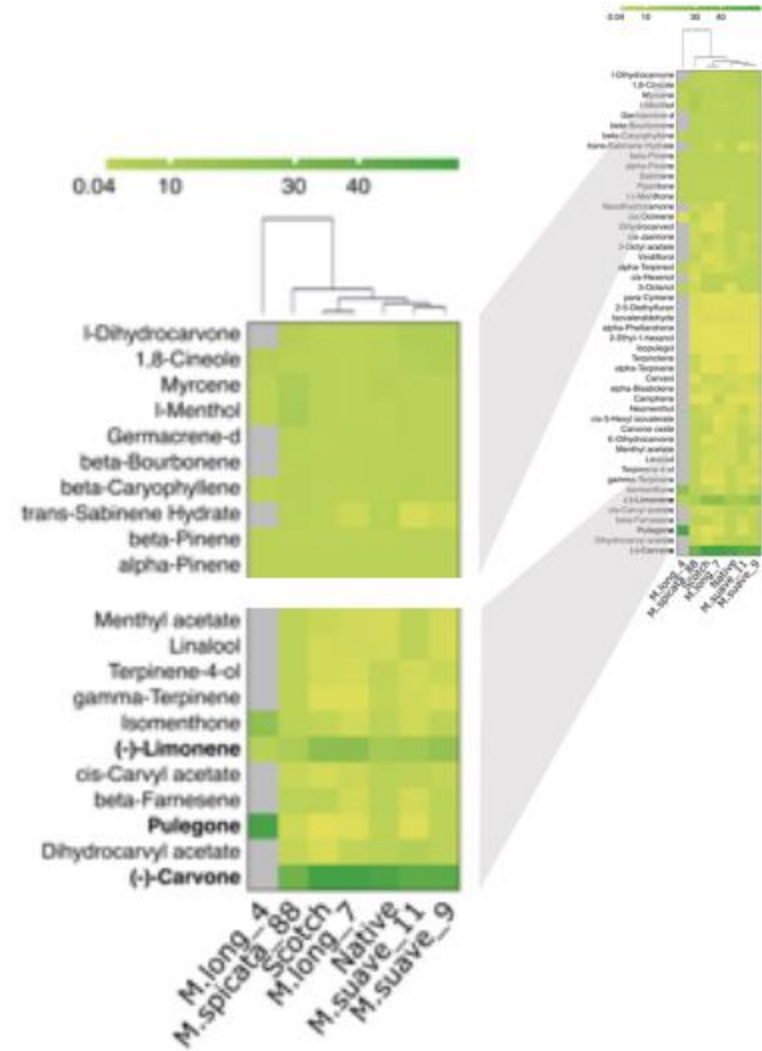


Mint diploid relatives are highly diverse



Oil composition does not correlate with genetic similarities

Spearmint type-like profiles are present in diploid species

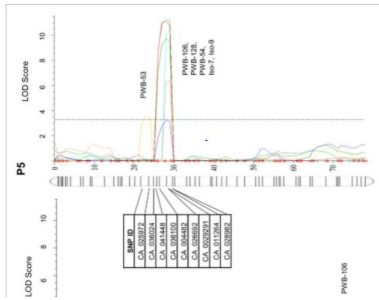


Pepper *Phytophthora* Resistance – A 50 year journey from discovery to product

1965
Resistance discovered in Landrace pepper CM334



Breeders and scientists struggle for years to combine meaningful resistance with acceptable commercial qualities



Public and private QTL mapping identify a strong QTL on chromosome 5 2010-2014

<https://doi.org/10.3835/plantgenome2014.03.0011> Rehrig 2014



Work at Seminis discovers key modifying loci

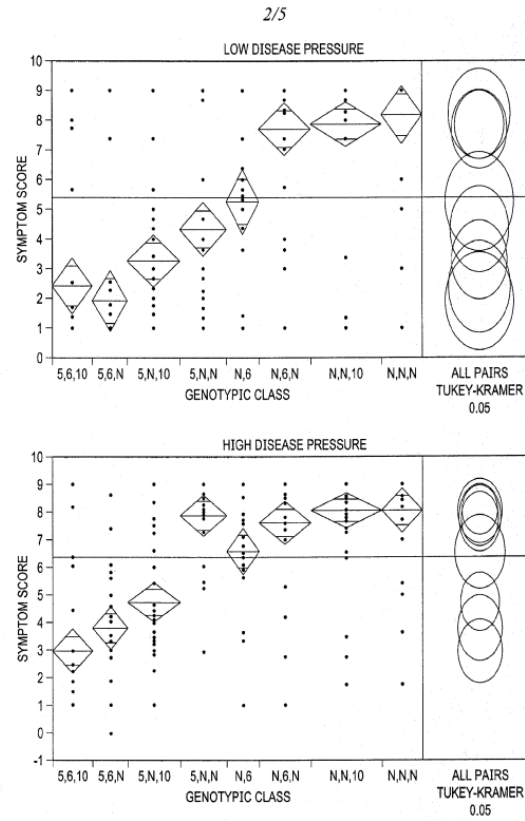


FIG. 2

PEPPER PLANTS WITH IMPROVED DISEASE RESISTANCE US Patent App 20210102219

Years of additional work finally create key recombination events and Identify AIG1 gene 2018

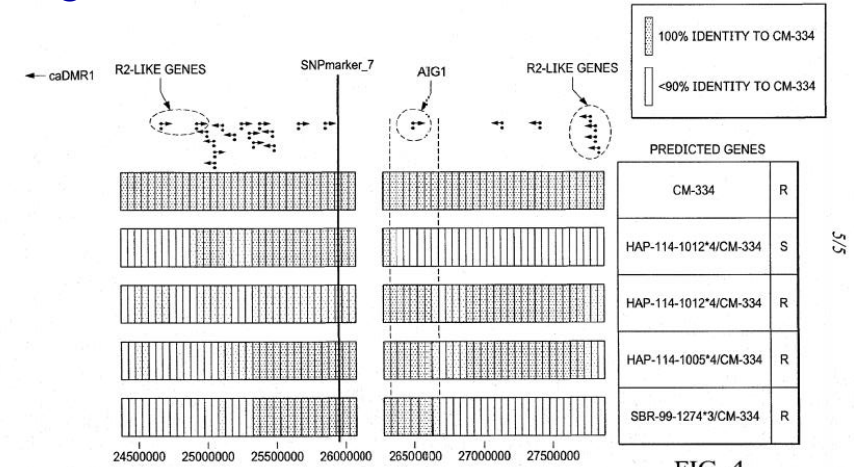


FIG. 4

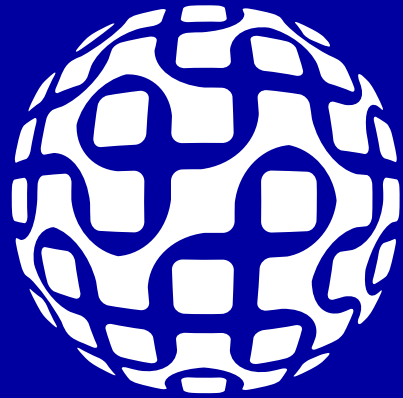
Products start hitting markets 2020



Profile
United States / Northeast / Open Field Fresh Market / Fresh Market
Tarpon is a main-season hybrid with X10R® Technology and Intermediate Resistance to *Phytophthora* blight in the Northeast and Midwest United States and Eastern Canada. Tarpon has a compact plant and produces dark green, smooth blocky fruit.

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