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Natural tricks to save time in bean breeding

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CGIAR meta data: Saving agrobiodiversity, Reducing hunger and malnutrition; reach: global excluding (sub-) artic regions

Bean breeding

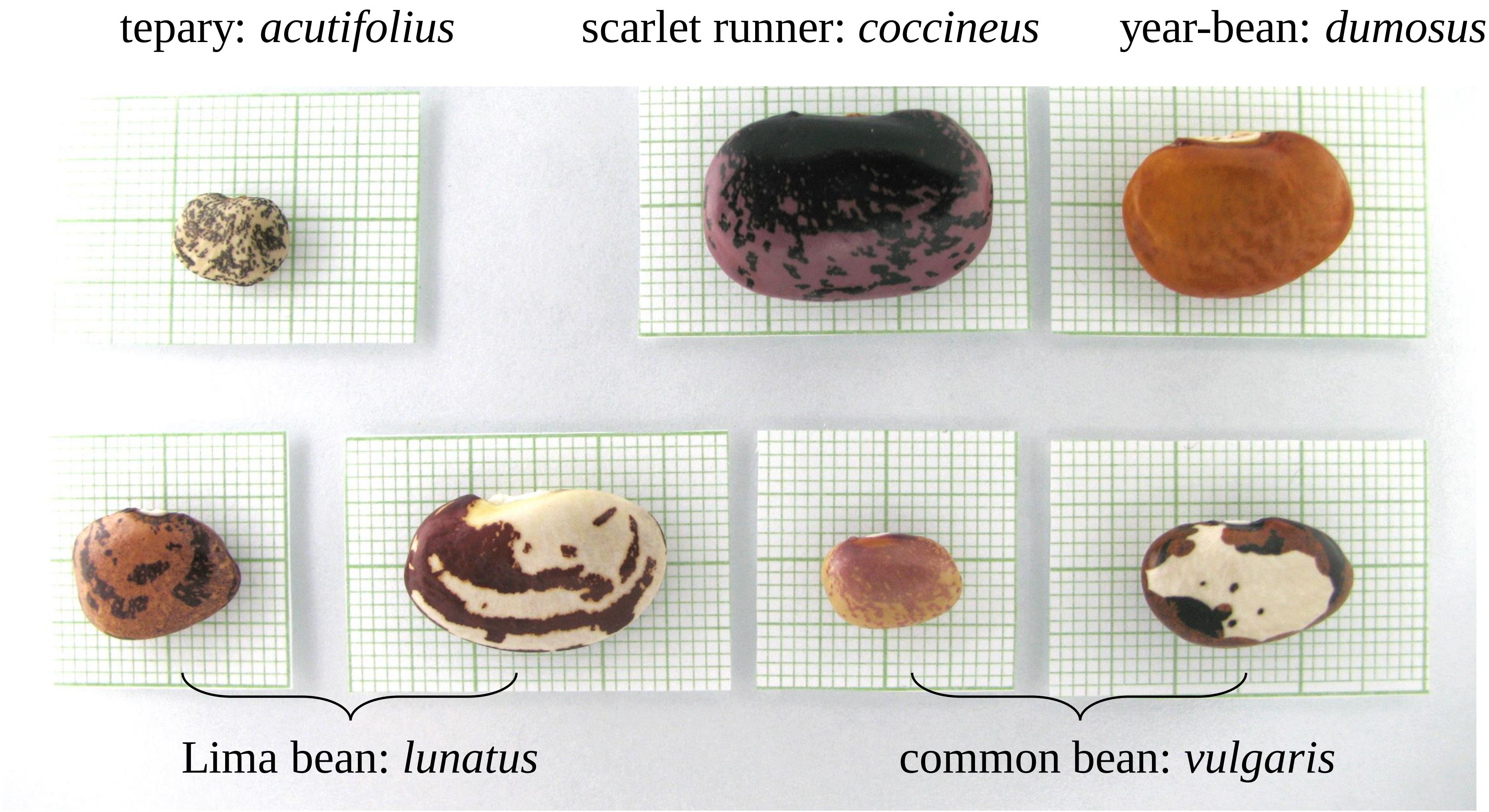
The purpose: to combine into a productive variety the traits that meet the needs of the farmer and the consumer, and reduce production costs and environmental footprint at the original location.

The question: can we shorten the process?

meiosis = creation of variants → mitosis = development of individuals + testing

additional reading: Hickey et al. 2019; Miklas et al. 2006

Rare event in the plant kingdom: 7 crops for breeding in one genus



sources: Bitocchi et al. 2017; Debouck & Smartt 1995; Delgado-Salinas et al. 1998

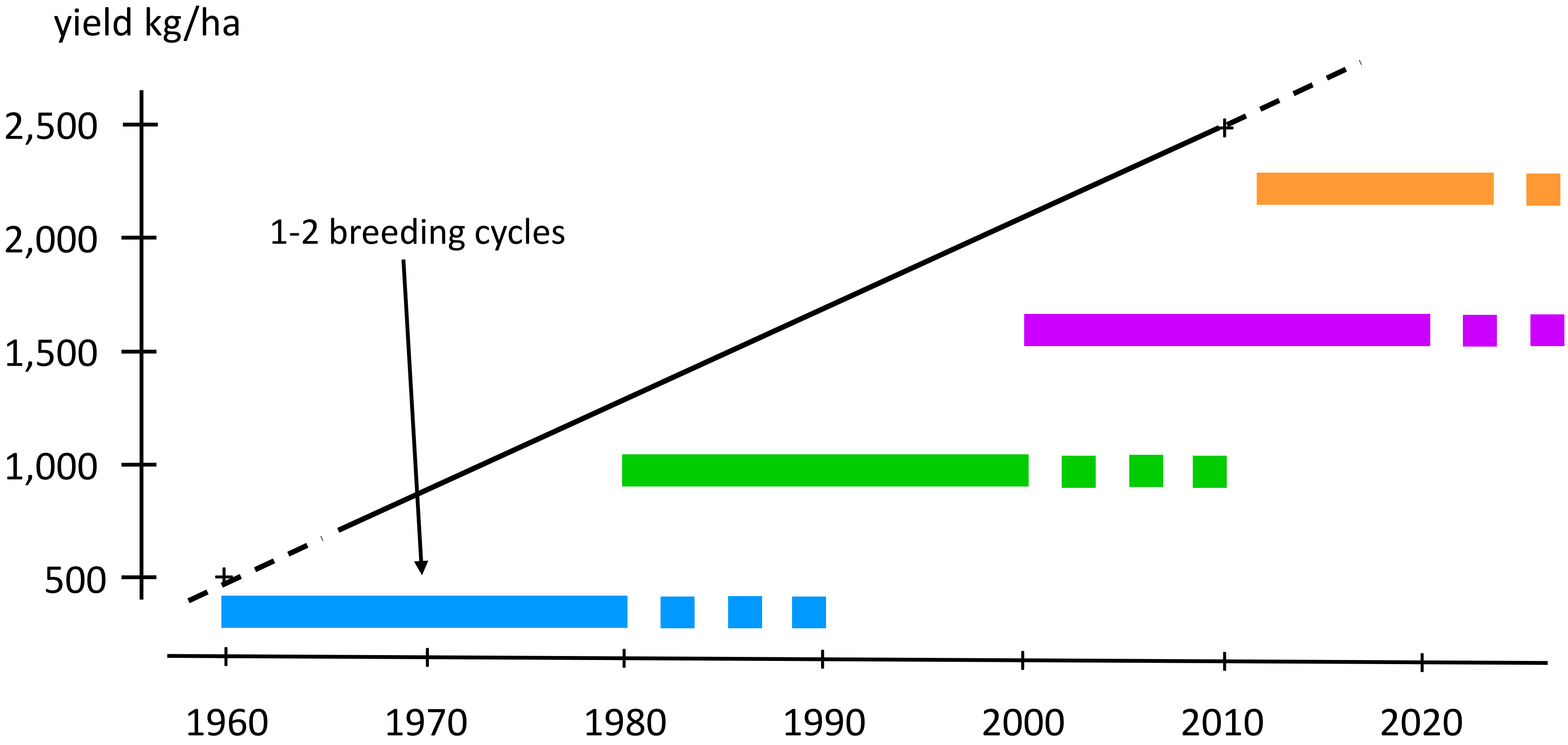
Natural trick no. 1:

pick up the right bean crop for your target producer and consumer conditions (farm and market)

(producing and breeding a crop against its original ecology has a tremendous cost)

anticipate problems in 2022-30: heat, drought, low phosphorus, acid soils
yet at farm level diseases & pests remain highly relevant because of $$$ loss

additional reading: Assefa et al. 2019; Beebe 2012



- transfer of resistances to diseases and pests
- the former, and increase of yield *per se*: harvest index, combining ability
- the former, and nutritional quality: protein content, high iron, high zinc
- the former, and low P, and climate change: tolerance to heat, drought or flooding

adapted from Debouck et al. 2021

✓ the breeding process is <u>cumulative</u>; could take ~ 10 years, although it can be shortened

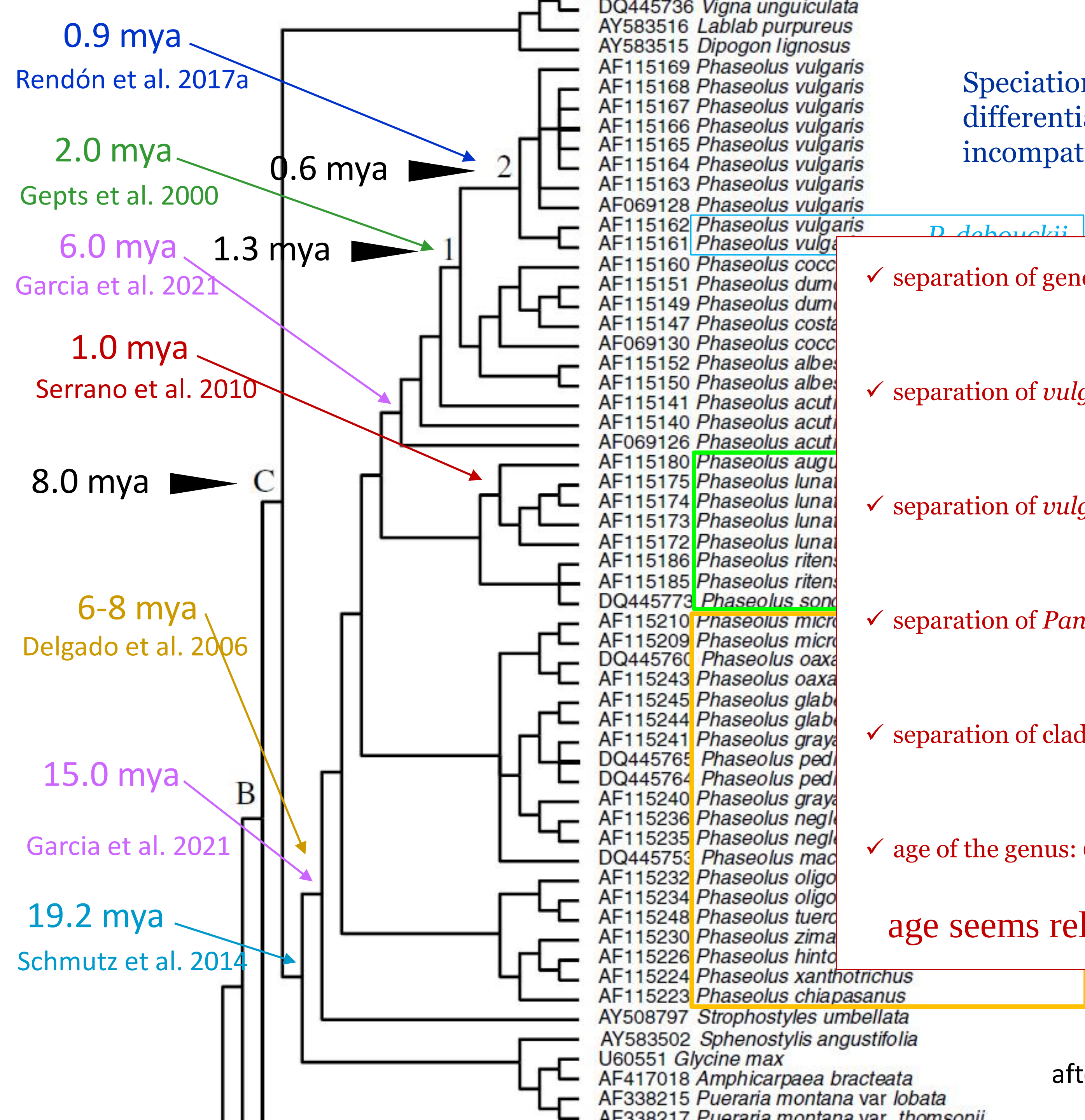
✓ if the focus has often been on methods (e.g. MAS), it should also be on <u>parental</u> materials

The current content and organization of the genus *Phaseolus*

Sections	Species	total
Clade A (8 sections)	42 species (4 widespread; 11 with intermediate range; 27 endemic)	
Not assigned to any section, nor forming any section with each other: *glabellus, microcarpus, oaxacanus*		**3**
***Bracteati* Freytag**	*macrolepis, talamancensis*	**2**
***Brevilegumeni* Freytag**	*albicarminus, angucianae, campanulatus, hygrophilus, oligospermus, tuerckheimii*	**6**
***Chiapasana* Delgado**	*chiapasanus*	**1**
***Digitati* Freytag**	*albiflorus, albiviolaceus, altimontanus, neglectus, trifidus*	**5**
***Minkelersia* (Mart. & Gal.) Maréchal,Mascherpa,Stainier**	*amabilis, amblyosepalus, anisophyllus, nelsonii, parvulus, pauciflorus, perplexus, plagiocylix, pluriflorus, tenellus*	**10**
***Pedicellati* (Benth.) Freytag**	*dasycarpus, esperanzae, grayanus, laxiflorus, pedicellatus, polymorphus, purpusii, texensis*	**8**
***Revoluti* Freytag**	*leptophyllus*	**1**
***Xanthotricha* Delgado**	*esquincensis, gladiolatus, hintonii, magnilobatus, xanthotrichus, zimapanensis*	**6**
Clade B (6 sections)	39 species (12 widespread; 7 with intermediate range; 20 endemic)	
***Acutifolii* Freytag**	*acutifolius, montanus*	**2**
***Coriacei* Freytag**	*maculatus, novoleonensis, reticulatus, ritensis, venosus*	**5**
***Falcati* Freytag**	*leptostachyus, macvaughii, micranthus*	**3**
***Paniculati* Freytag**	*albinervus, augusti, jaliscanus, juquilensis, lignosus, lunatus, maculatifolius, marechalii, mollis, nodosus,, polystachyus, rotundatus, salicifolius, scrobiculatifolius, sinuatus, smilacifolius, sonorensis, viridis, xolocotzii*	**19**
***Phaseoli* DC**	*albescens, coccineus, costaricensis, debouckii, dumosus, persistentus, vulgaris*	**7**
***Rugosi* Freytag**	*angustissimus, carterae, filiformis*	**3**
Total (no. sections): 14. Total (no. species): 81		

updated from Porch et al. 2013

additional reading: Debouck 2021; Debouck et al. 2020; Rendón-Anaya et al. 2017b

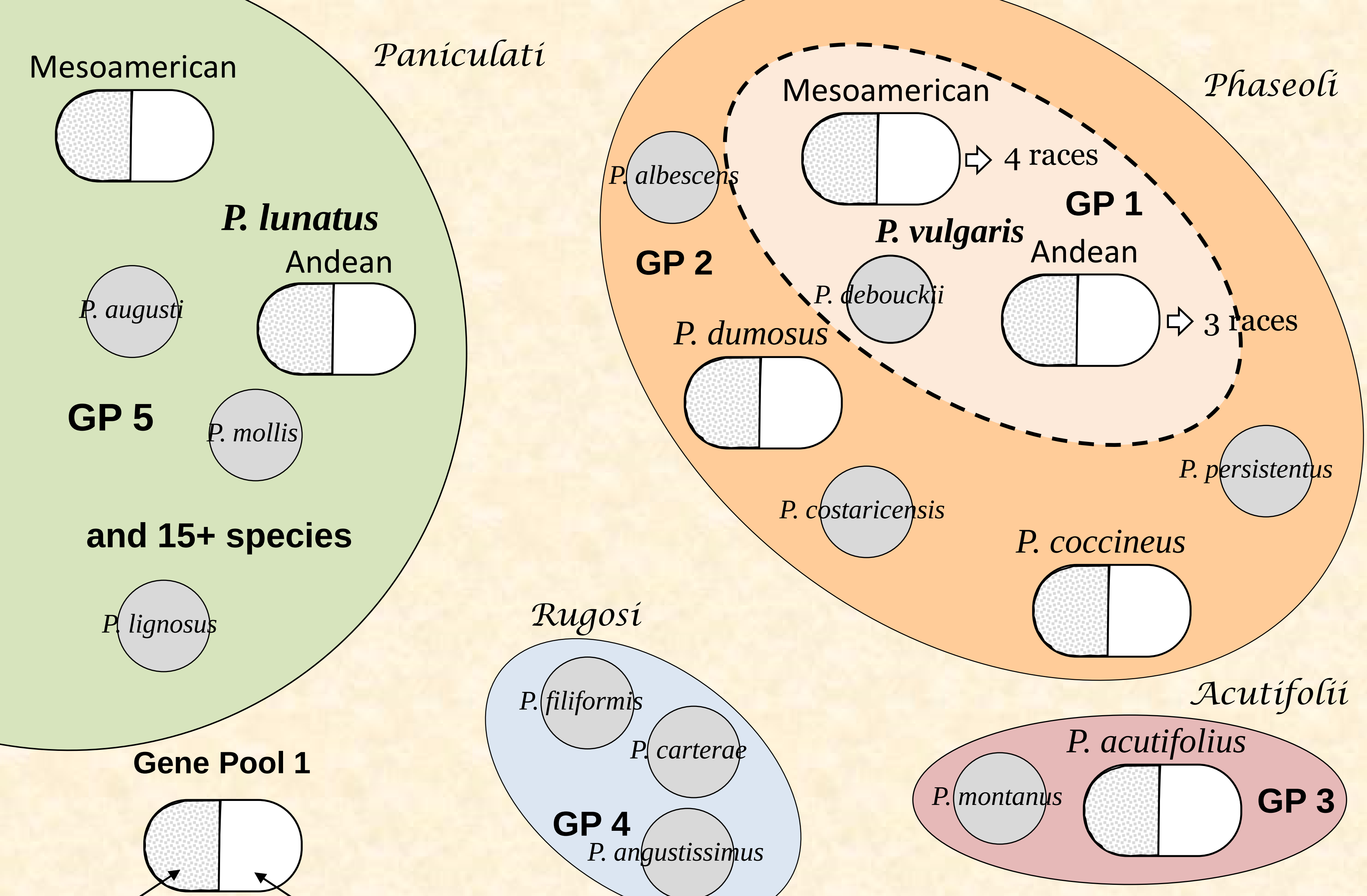


Speciation: range expansion, genetic differentiation, genetic incompatibility, isolation

- ✓ separation of gene pools in *vulgaris*: 0.16 mya
- ✓ separation of *vulgaris/ debouckii*: 0.9 mya
- ✓ separation of *vulgaris/* sister species: 2 mya
- ✓ separation of *Paniculati/ Phaseoli*: 6 mya
- ✓ separation of clades A-B: 6-8 mya
- ✓ age of the genus: 6-15 mya

age seems related to crossability

after Chacón-Sánchez et al. 2007



adapted from Debouck 1999

additional reading: Debouck 2021; Delgado-Salinas et al. 2006; Freytag & Debouck 2002

Results from interspecific hybridizations

around the Phaseoli (common bean)

vulg x *angu*	embryo did not grow	Belivanis & Doré 1986
vulg x *angu*	12,72 I + 3,45 II + 0,45 III + 0.18 IV	Balasubramanian et al. 2005
vulg x *filif*	5,69 I + 8,08 II + 0,04 III	Maréchal & Baudoin 1978
vulg x *filif*	12,14 I + 4,71 II + 0,14 III	Balasubramanian et al. 2005
vulg x *acut*	6,0 I + 8,0 II	Katanga & Baudoin 1990
vulg x *dumo*	0,88 I + 10,56 II	Schmit et al. 1992
vulg x *cocci*	0,32 I + 10,84 II	Maréchal 1971

around the Paniculati (Lima bean)

vulg x *luna*	embryo did not grow	Kuboyama et al. 1991
luna x *jali*	2,06 I + 9,97 II	Katanga & Baudoin 1990
luna x *polys*	10,0 I + 6,0 II	Dhaliwal et al. 1962
luna x *macu*	2,31 I + 9,70 II + 0,03 III + 0,06 IV	Le Marchand et al. 1976
luna x *rite*	1,95 I + 10,02 II	Katanga & Baudoin 1990
luna x *sali*	3,61 I + 9,19 II	Katanga & Baudoin 1990

Wide crossing going on in common bean with taxa of *Acutifolii* and *Phaseoli*

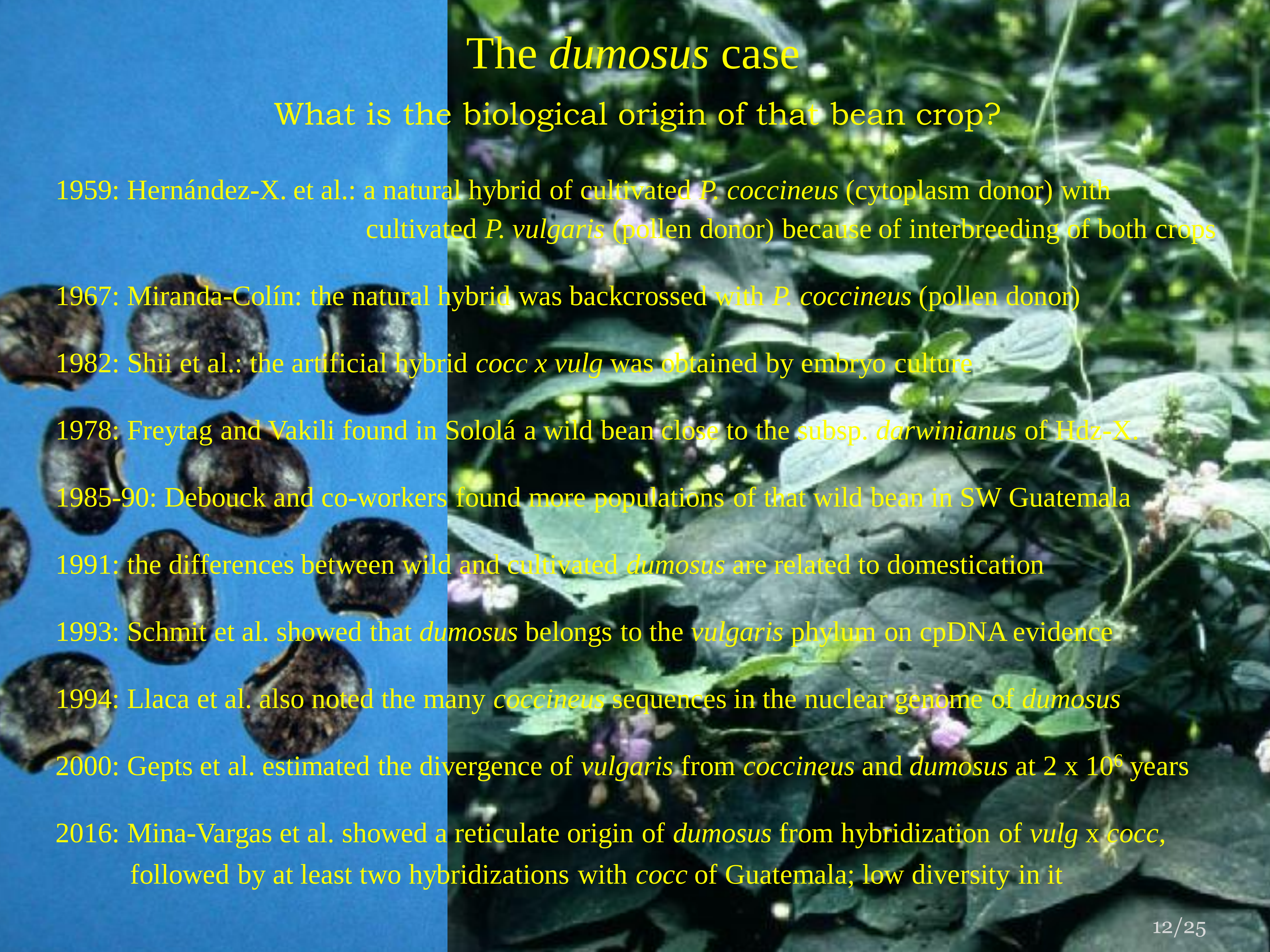
Target trait	reference
Cross with *acutifolius*	
resistance to common bacterial blight	Singh et al. 2001
resistance to *Acanthoscelides* bruchid	Kusolwa & Myers 2011
tolerance to drought	Thomas & Waines 1982; Rao et al. 2013
tolerance to high temperatures	Suárez et al. 2020
tolerance to sub-zero temperatures	Souter et al. 2017
Cross with *coccineus*	
resistance to common bacterial blight	Park & Dhanvantari 1984
resistance to anthracnose	Mahuku et al. 2002
resistance to root rot *Fusarium solani*	Hucl & Scoles 1985
resistance to angular leaf spot	Mahuku et al. 2003
resistance to white mold	Singh et al. 2014
resistance to Bean Yellow Mosaic Virus	Baggett 1956
tolerance to aluminium	Butare et al. 2011, 2012

Wide crossing going on in common bean with taxa of *Acutifolii* and *Phaseoli*

Target trait	reference
Cross with *costaricensis*	
resistance to white mold	Singh et al. 2013
Cross with *dumosus*	
resistance to angular leaf spot	Mahuku et al. 2003
resistance to anthracnose	Mahuku et al. 2002
resistance to *Ascochyta* blight	Garzón et al. 2011
high iron in seed	Klaedtke et al. 2012

Successes but not up to the level of achievements in tomato or potato breeding in spite of early attempts (Fermond 1855; Mendel 1865)

- if extreme temperatures: breed tepary *per se*, OR gene editing (CRISPR) by use of *filiformis* or *angustissimus* as models; return on time invested!
- OR can we take benefit from natural hybrids (cross + natural selection)



The *dumosus* case

What is the biological origin of that bean crop?

1959: Hernández-X. et al.: a natural hybrid of cultivated *P. coccineus* (cytoplasm donor) with cultivated *P. vulgaris* (pollen donor) because of interbreeding of both crops

1967: Miranda-Colín: the natural hybrid was backcrossed with *P. coccineus* (pollen donor)

1982: Shii et al.: the artificial hybrid *cocc x vulg* was obtained by embryo culture

1978: Freytag and Vakili found in Sololá a wild bean close to the subsp. *darwinianus* of Hdz-X.

1985-90: Debouck and co-workers found more populations of that wild bean in SW Guatemala

1991: the differences between wild and cultivated *dumosus* are related to domestication

1993: Schmit et al. showed that *dumosus* belongs to the *vulgaris* phylum on cpDNA evidence

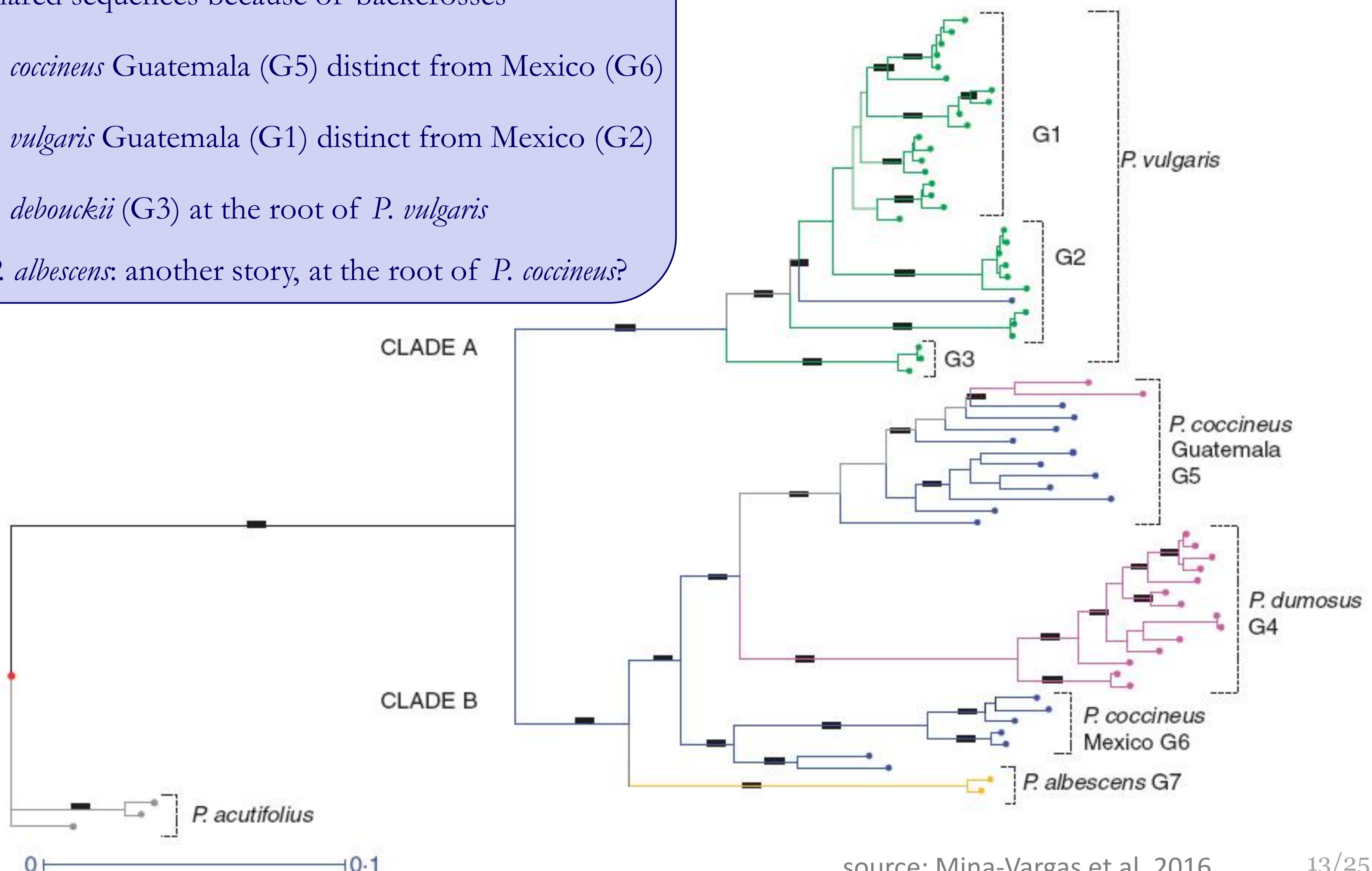
1994: Llaca et al. also noted the many *coccineus* sequences in the nuclear genome of *dumosus*

2000: Gepts et al. estimated the divergence of *vulgaris* from *coccineus* and *dumosus* at 2 x 10^6 years

2016: Mina-Vargas et al. showed a reticulate origin of *dumosus* from hybridization of *vulg* x *cocc*, followed by at least two hybridizations with *cocc* of Guatemala; low diversity in it

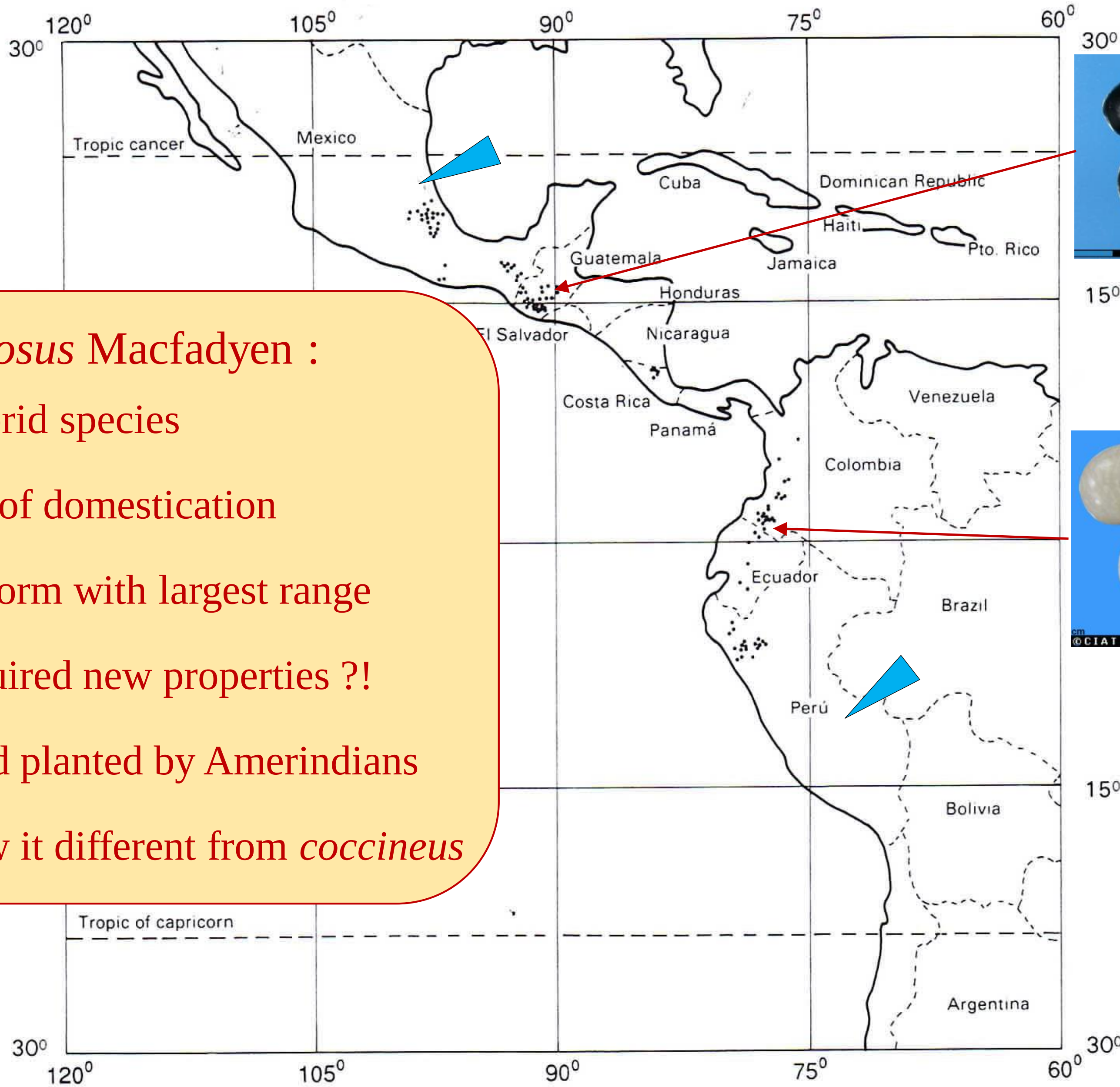
Neighbor-joining dendrogram of polymorphisms in 4,208 DArT markers of genomic DNA

- *P. dumosus* (G4) close to *cocc* (G5) (pollen donor) shared sequences because of backcrosses
- *P. coccineus* Guatemala (G5) distinct from Mexico (G6)
- *P. vulgaris* Guatemala (G1) distinct from Mexico (G2)
- *P. debouckii* (G3) at the root of *P. vulgaris*
- *P. albescens*: another story, at the root of *P. coccineus*?



source: Mina-Vargas et al. 2016

The year-bean: a less known bean crop



P. dumosus Macfadyen :

- sole hybrid species
- 5th case of domestication
- weedy form with largest range
- has acquired new properties ?!
- used and planted by Amerindians
- they saw it different from *coccineus*

Alta Verapaz

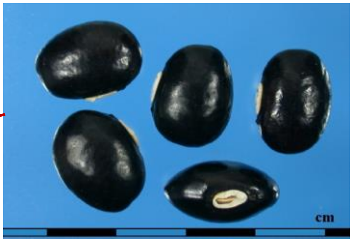


photo: CIAT 2022

Sibundoy

photo: CIAT 2022

map adapted from Schmit & Debouck 1991

Natural trick no. 2:

save years by using natural hybrids, most if

you breed common or year-bean for

fungi diseases, low phosphorus, mineral content

note: they have been/are being tested in the wild

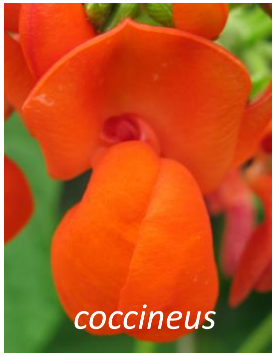
they are cheap!

keep in mind that *P. vulgaris* is the most drought tolerant of the *Phaseoli*!

it means that at the lower cost you will find resistances to foliar/ root fungi diseases

additional reading: Assefa et al. 2019; Beebe 2012; Cortés et al. 2013

The early separations in the *Phaseoli*

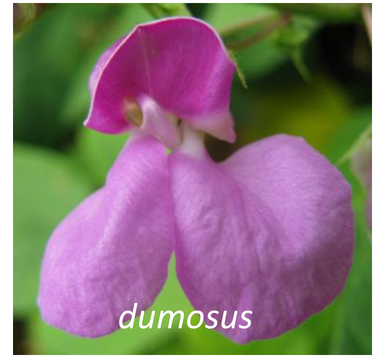


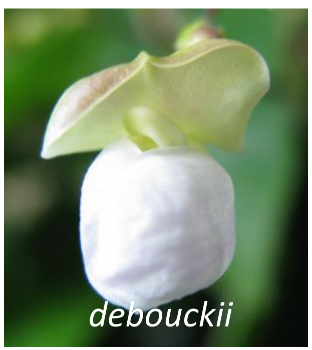
ancestor of

vulgaris

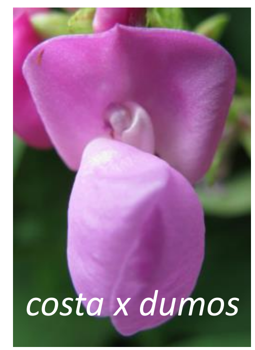
extinct?

An ancient hybrid taxon





The hybridizations under way



vulg x *cocc*: occurs in El Progreso, GTM, 1987

vulg x *dumo*: occurs in Tolima, CLB, 1990

vulg x *costa*: occurs in Cartago, CRI, 2006

dumo x *cocc*: occurs in Nariño, CLB, 1985

costa x *cocc*: occurs in Alajuela, CRI, 2018

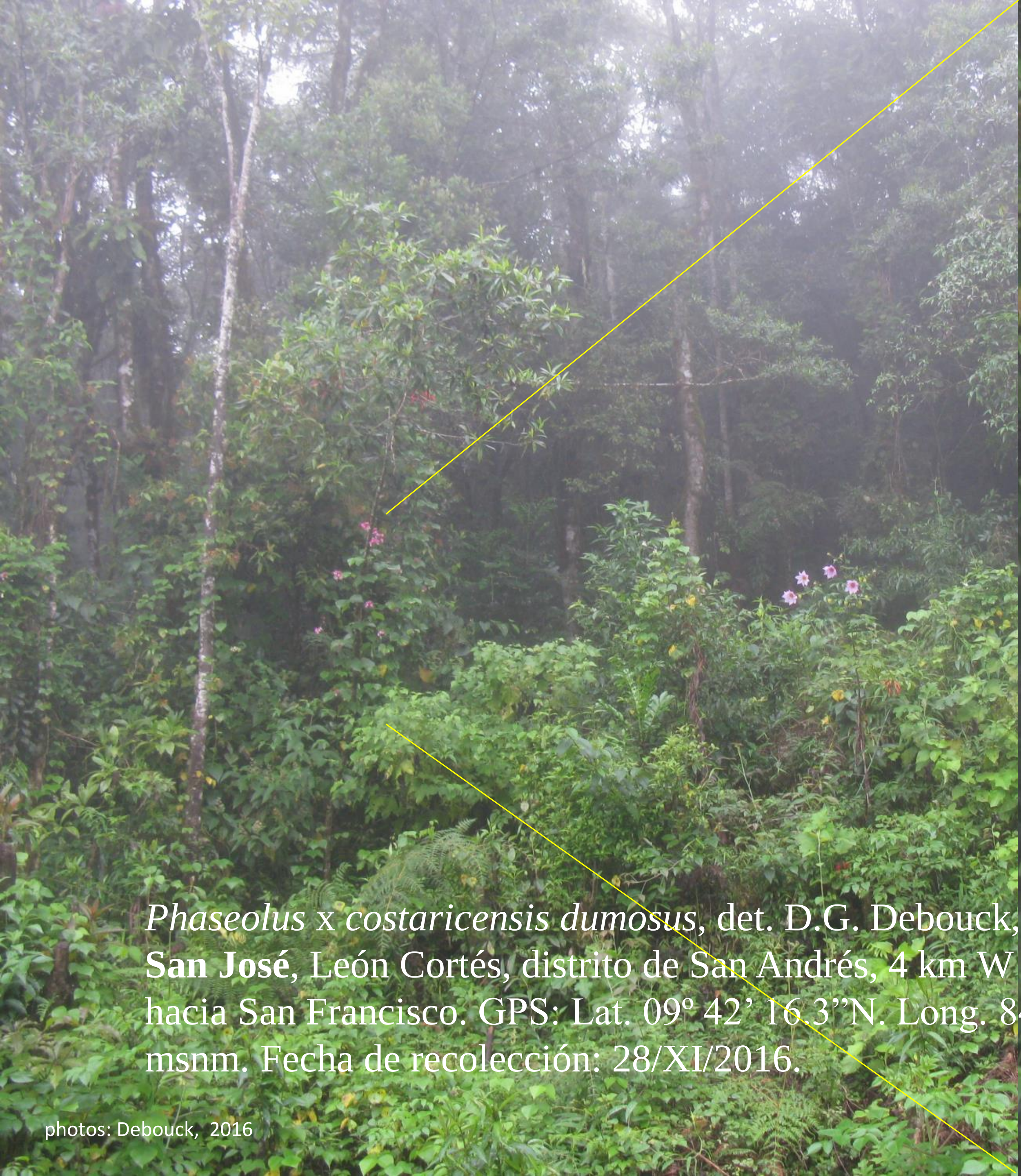
costa x *dumo*: occurs in Cartago, CRI, 2003

photos: Debouck, various dates

Traits of interest for common bean breeding in GP 2

Donor species	trait	source
P. coccineus	anthracnose	Mahuku et al. 2002
	ascochyta blight	Schmit & Baudoin 1992
	Fusarium root rot	Wallace & Wilkinson 1965
	virus BGYMV	Osorno et al. 2007
	white mold	Abawi et al. 1978
	aluminum toxicity	Butare et al. 2011
	low temperatures seedling	Rodiño et al. 2007
P. dumosus	angular leaf spot	Mahuku et al. 2003
	anthracnose	Hubbeling 1957
		Mahuku et al. 2002
	ascochyta blight	Schmit & Baudoin 1992
		Hanson et al. 1993
	bean fly	Schmit & Baudoin 1987
	white mold	Hunter et al. 1982
	high iron in seeds	Beebe 2012

photos: Debouck, various dates



Phaseolus x *costaricensis dumosus*, det. D.G. Debouck, 28/XI/2016. COSTA RICA, **San José**, León Cortés, distrito de San Andrés, 4 km W de intersección de ruta 226 hacia San Francisco. GPS: Lat. 09º 42’ 16.3”N. Long. 84º 04’ 57.5”W. Alt. 2,121 msnm. Fecha de recolección: 28/XI/2016.

photos: Debouck, 2016

Final remarks

- *Phaseolus* has a breeding system of autogamy and auto-compatibility
- to survive in the wild an association with insects Hymenoptera was selected
- at this time of evolution, the association seems very active in the *Phaseoli*
- the stability of *dumosus* is puzzling, while other hybrids are generated
- once stabilized *dumosus* has colonized new humid forest habitats
- *P. dumosus* was domesticated for that ecological capacity, little found elsewhere
- for that same capacity humans distributed it in the Caribbean and the Andes

sources and additional reading: Chacón-Sánchez et al. 2021, Ellstrand & Schierenbeck 2000, Weinstein 1926

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