


BIO 235
Plants & People
Evolution &
Domestication
of Crops







Lecture 6
Hybridization, Polyploidy & Crop Domestication II –

- Strawberry
- Wheat
- Banana
- Potato
- Sugarcane
- Oil Seed Rape / Canola

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Lecture 5 - Serendipitous Backyard Hybridization & the Origin of Crops – Conclusions

Disturbed sites such as backyards, kitchen middens, and informal orchards are important sites for spontaneous hybridisation, where otherwise isolated plant species were brought into sympatry following cultivation.

For Guajes, Nopales & Maguey – three of the dominant perennial plants cultivated in south-central Mexico - predomestication cultivation has resulted in extensive artificial sympatry, and a complex series of geographically dispersed hybrids and polyploids.

In each case, there is evidence to suggest that the most prominent species in cultivation – *Leucaena leucocephala*, *Opuntia ficus-indica*, and *Agave tequilana*, have had hybrid origins most likely following cultivation.

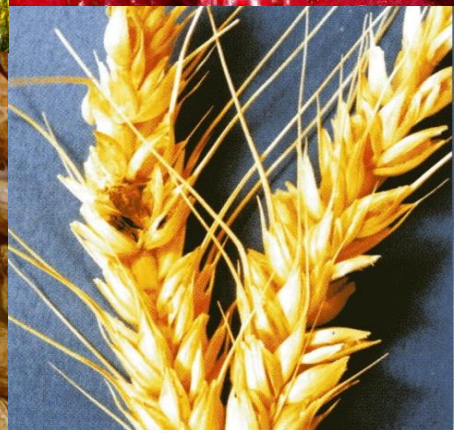
The simple step of bringing species together, casually or consciously in dump heaps and informal orchards has played a key role in domestication of these crops.

Incipient or semi-domesticates like these can provide powerful insights into the early stages of domestication





Polyploidy & Crops

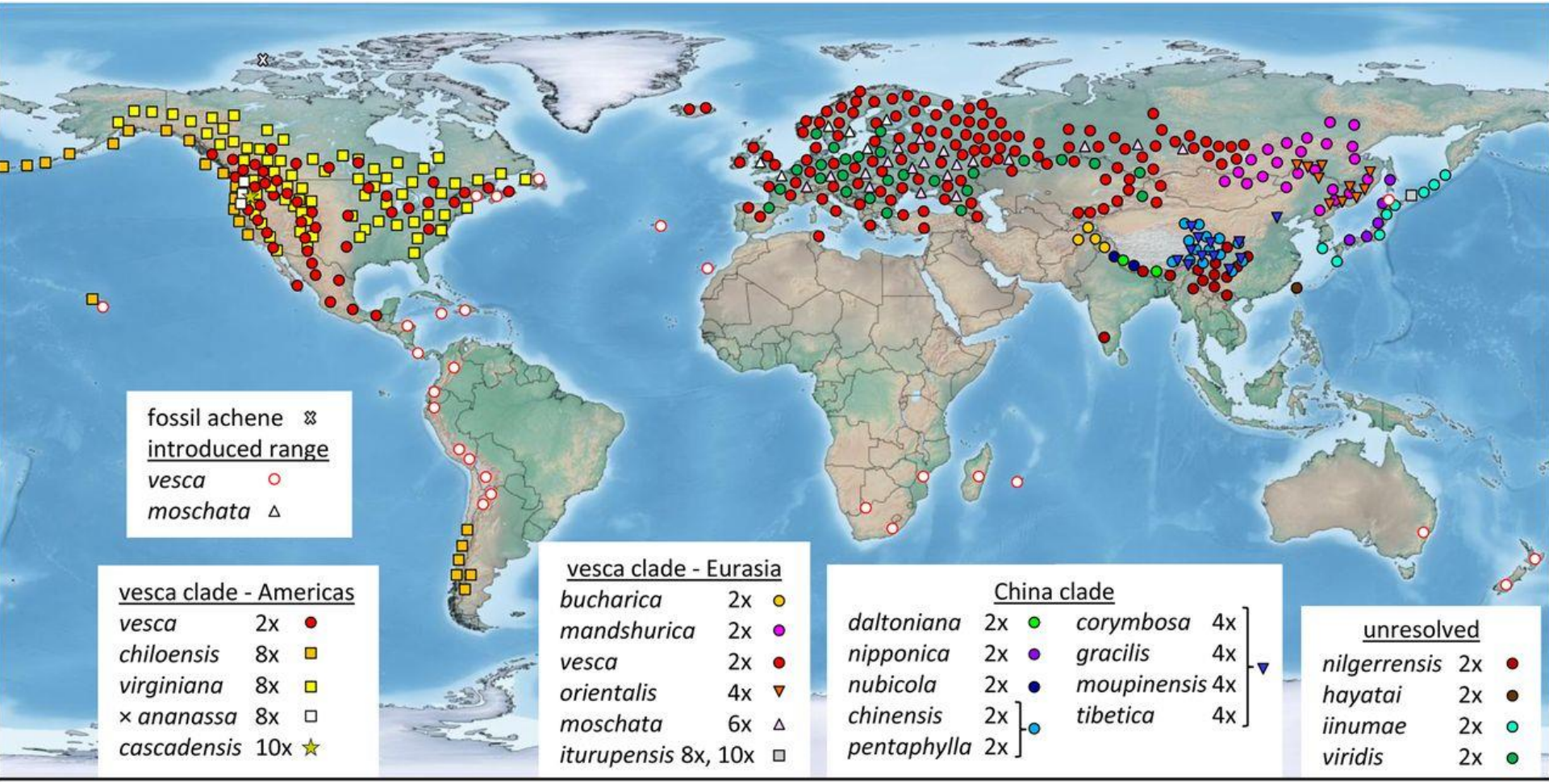




Wild
Strawberries

Fragaria
Rosaceae

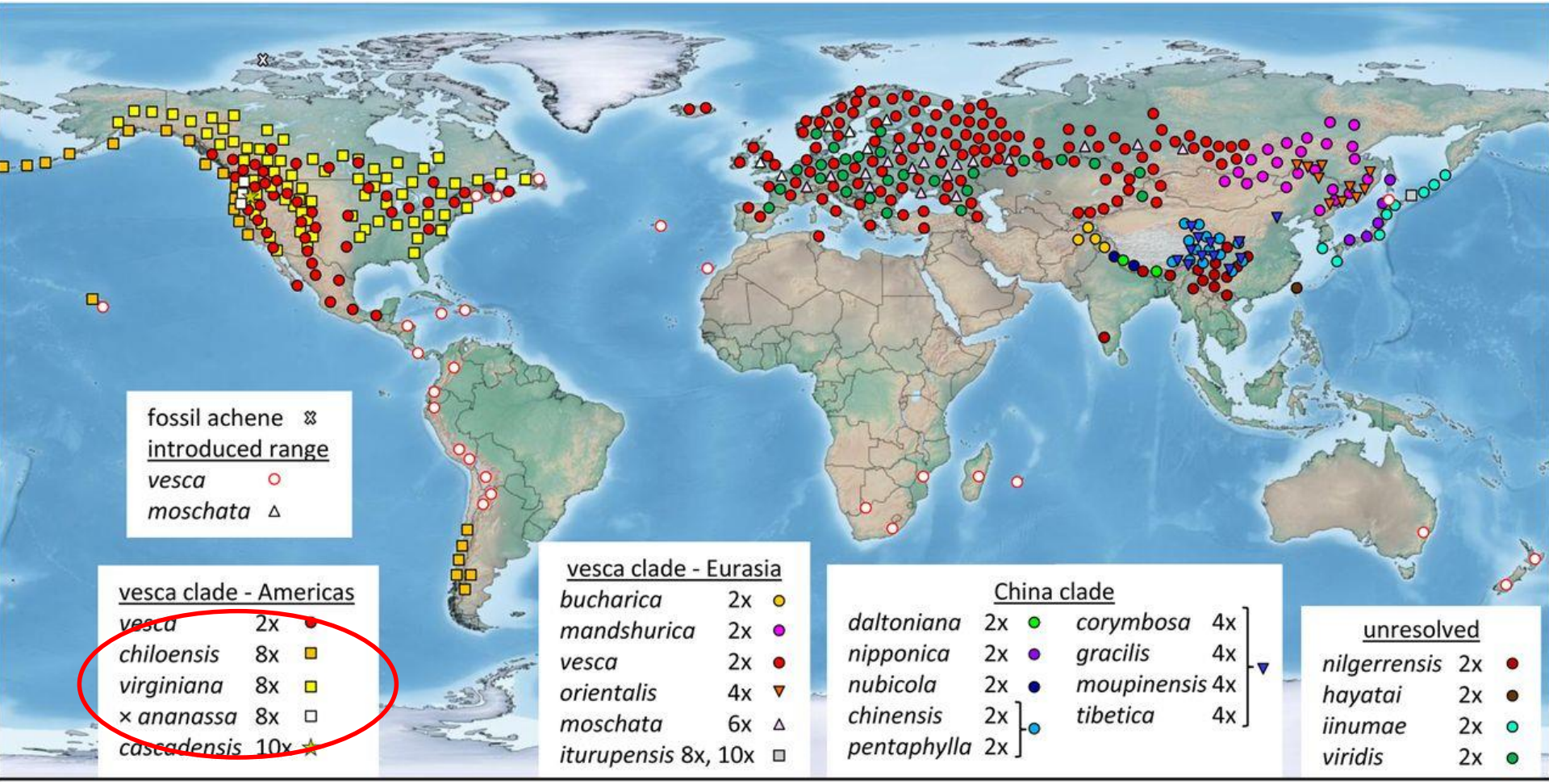
F. vesca
F. moschata
F. viridis

Polyploidy & Geography of *Fragaria*



Liston *et al.* (2014)

Polyploidy & Geography of *Fragaria*



Liston *et al.* (2014)

Strawberry
Fragaria - Rosaceae

F. chiloensis (Chile) 2n=8x=56

×

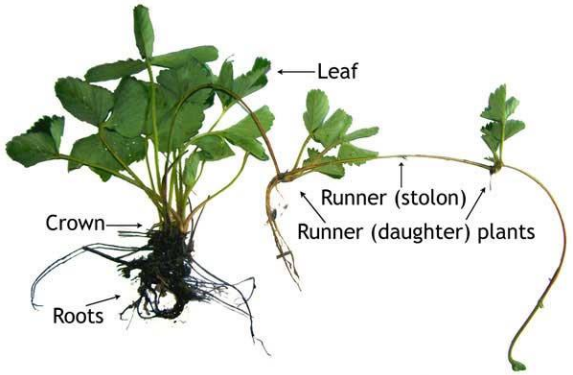
F. virginiana (USA) 2n=8x=56

↓

F. ×ananassa (Europe) 2n=8x=56

Dioecious – separate male and female plants

Vegetative Propagation



Strawberry - Fragaria – Rosaceae

- *F. vesca* cultivated in Roman & Greek times
- 1300s – *F. vesca*, *F. viridis* & *F. moschata* grown widely in Europe
- *F. chiloensis* – cultivated by native Mupache Indians in Chile
- 1714 - *F. chiloensis* - introduced from Chile to Europe by Frezier a French army spy
- 1600s – *F. virginiana* introduced to Europe & rose to importance in 1700s
- *F. virginiana* and *F. chiloensis* initially grown separately and only female plants of *F. chiloensis* introduced, but later pollinated by male *F. virginiana* plants
- 1750 – first *F. ×ananassa* hybrids arose spontaenously where Frezier's female *F. chiloensis* interplanted with males of *F. virginiana*.

F. chiloensis (Chile) 2n=8x=56

×

F. virginiana (USA) 2n=8x=56

↓

F. ×ananassa (Europe) 2n=8x=56

Wheat - In 2007 world production of 607 million tonnes; second only to rice as main human food crop and ahead of maize, after allowing for use in animal feeds. Globally, wheat is the leading source of vegetable protein in human food, with a higher protein content than maize or rice.

PNAS

Archaeobotanical evidence reveals the origins of bread 14,400 years ago in northeastern Jordan

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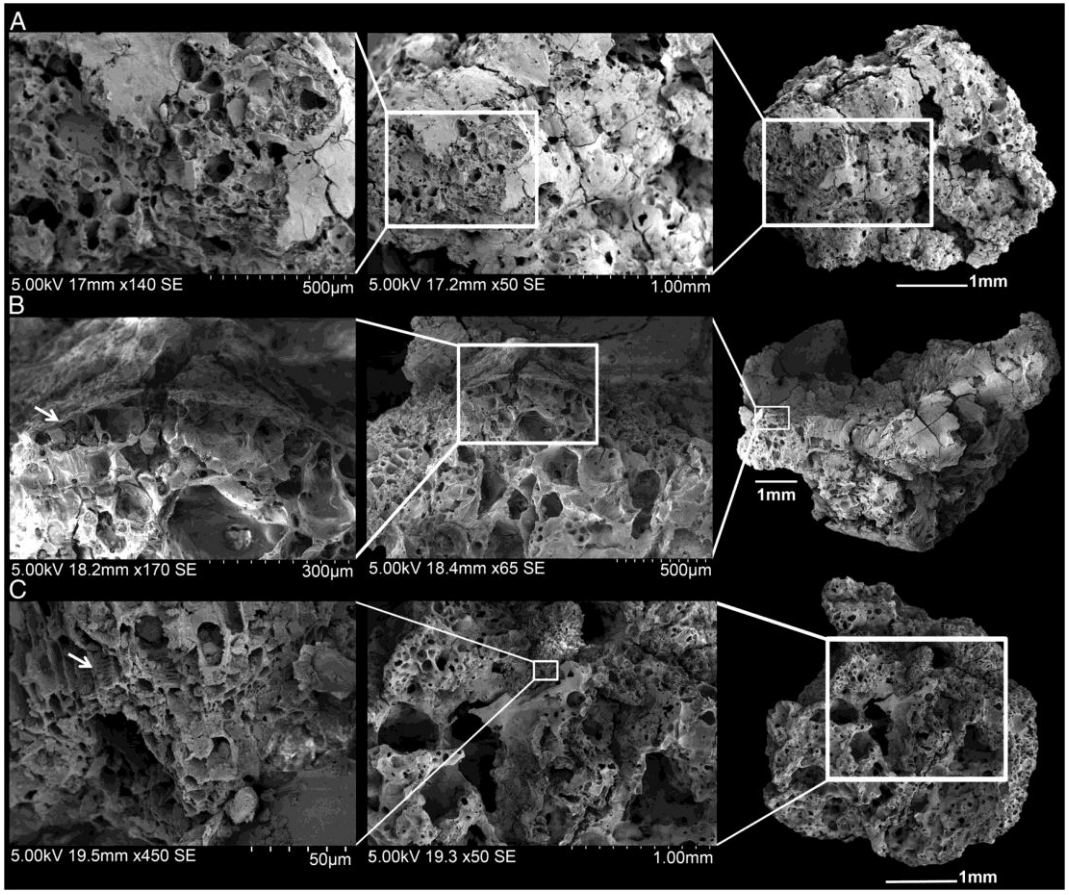
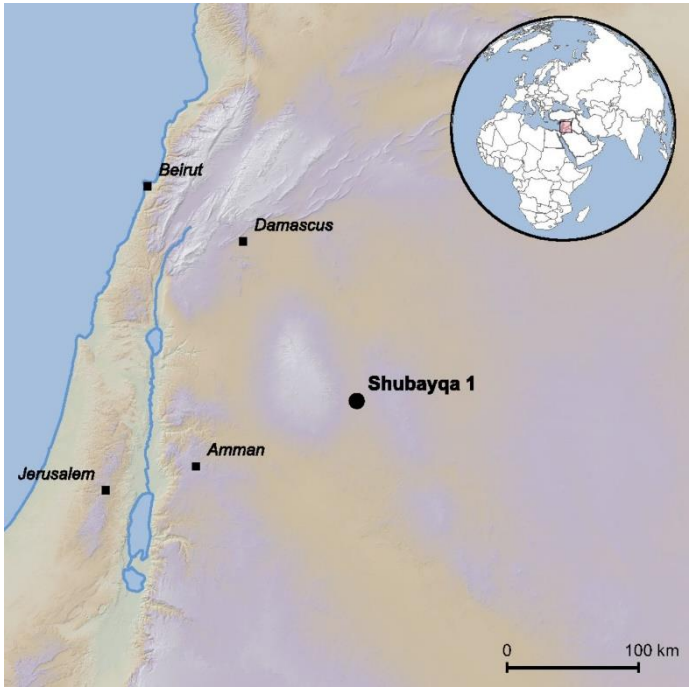
Edited by Dolores R. Piperno, Smithsonian Institution, Washington, DC, and approved June 12, 2018 (received for review January 19, 2018)

The origins of bread have long been associated with the emergence of agriculture and cereal domestication during the Neolithic in southwest Asia. In this study we analyze a total of 24 charred

phases at the center of Structure 1. The oldest fireplace is a large (approximately 1 m in diameter) circular structure made of flat basalt stones (Fig. 2). The contents of the fireplace were left





Arranz-Otaegui et al. (2018)

Triticum – 6 species, Middle East and trans-Caucasus

T. monococcum **= diploid *AA* = Einkorn wheat – wild & domesticated**

T. urartu = diploid *AA* – only wild – never domesticated

T. turgidum **= tetraploid *AABB* = emmer (durum / pasta) wheat – wild & domesticated**

T. timopheevii = tetraploid *AAGG* – wild & domesticated

T. aestivum **= hexaploid *AABBDD* = bread wheat or common wheat – only domestciated – no wild populations** (sometimes called *T. vulgare*)

T. zhukoskyi = hexaploid *AAAAGG* – only domesticated – no wild populations

Aegilops

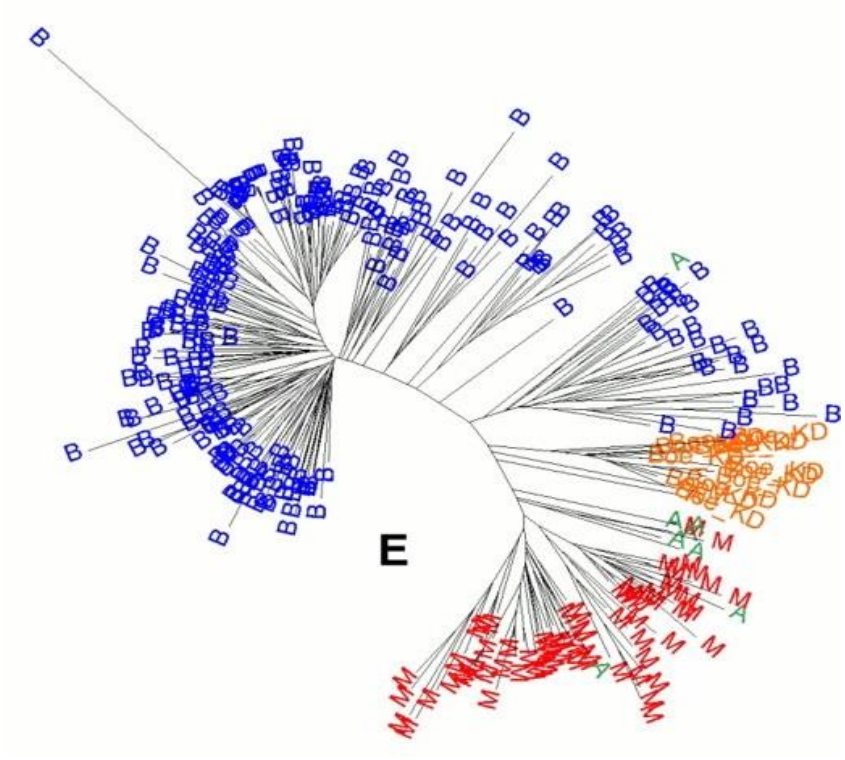
A. tauschii **= diploid DD wild goat grass**

Origins of Einkorn Wheat – Genetic Data

M = Domesticated Einkorn wheat *Triticum monococcum* subsp. *monococcum* – the earliest culivated wheat – monophyletic suggesting a single origin

B = Wild progenitor *T. monococcum* subsp. *boeoticum*

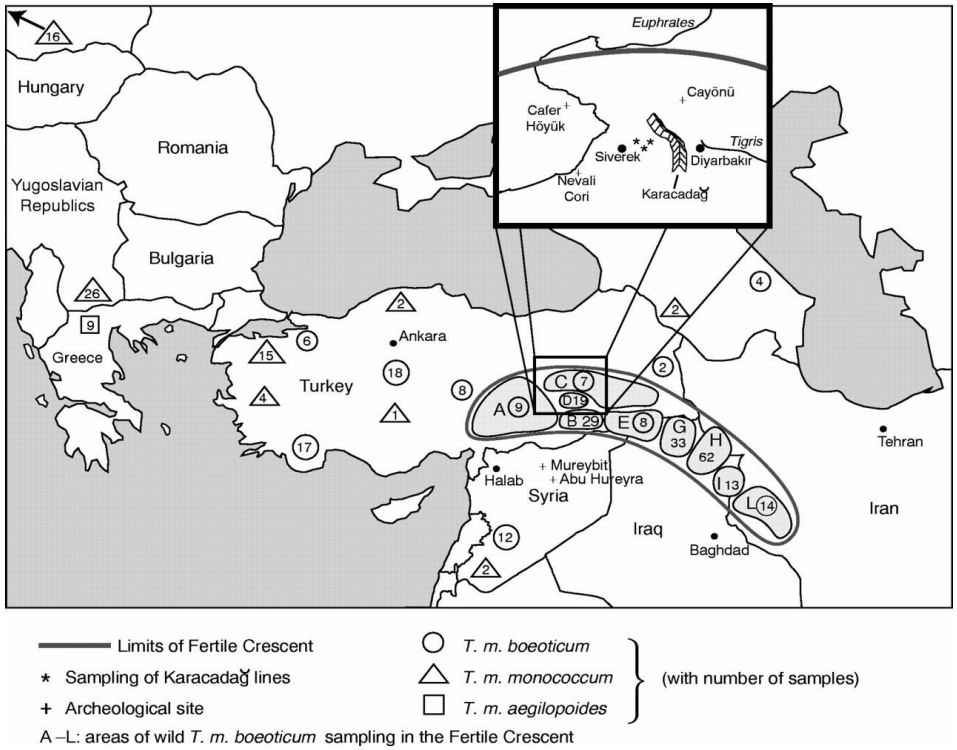
KD = *boeoticum* accessions from the Karacadag Mtns of SE Turkey



Heun et al 1997 Science

Origins of Einkorn Wheat – Archaeological Data

Abu Hureyra in NE Syria where the earliest evidence of farming domesticated einkorn around 9,500 BP has been found lies just 200km from Karacadag area where genetic data suggest einkorn wheat was first domesticated.



Heun et al 1997 Science

Ploidy in Wheat

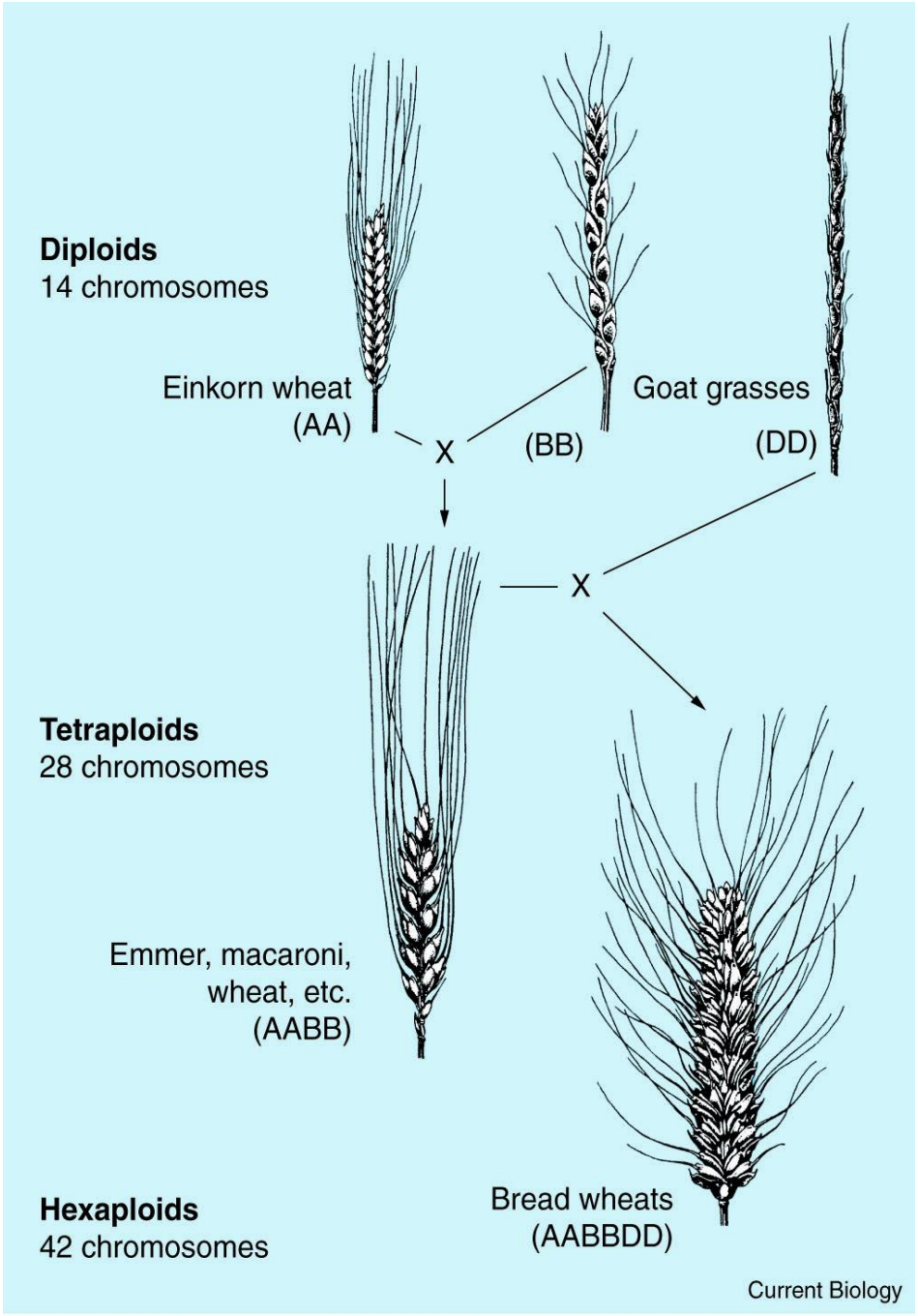
The ploidy levels of domesticated wheat species range from diploid, 2n=14, to hexaploid, 6n=42.

Wheats of all ploidy levels have been domesticated:

- Diploid einkorn *AA* – the earliest primitive, but now relic wheat, *T. monococcum* derived from wild *T. boeticum*

- Tetraploid emmer *AABB* – the durum wheats used to make pasta, semolina and couscous, *T. turgidum* & *T. dicoccum* derived from *T. dicoccoides*

- Hexaploid bread wheats *AABBDD*, *T. aestivum* (*T. vulgare*), including spelt, *T. spelta*.



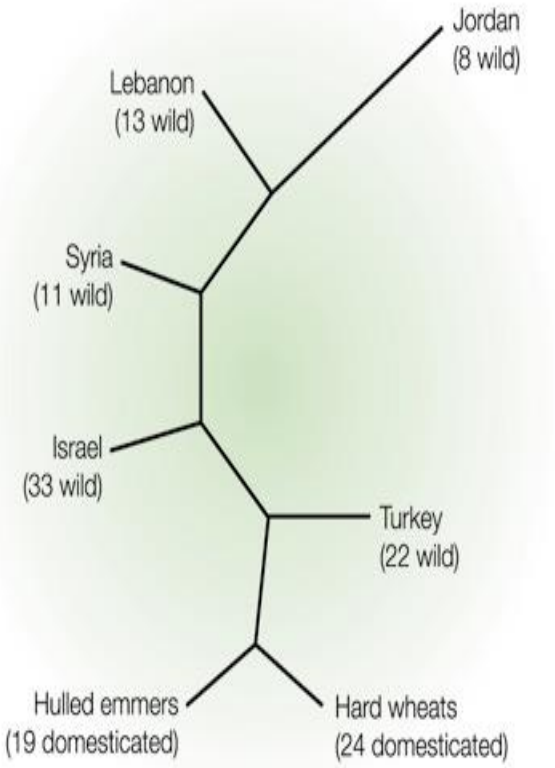
The Near East & the Core Area of the Fertile Crescent

Archaeobotanical remains of 7 crops

Wild populations of einkorn & emmer wheat, pea, lentil & chickpea

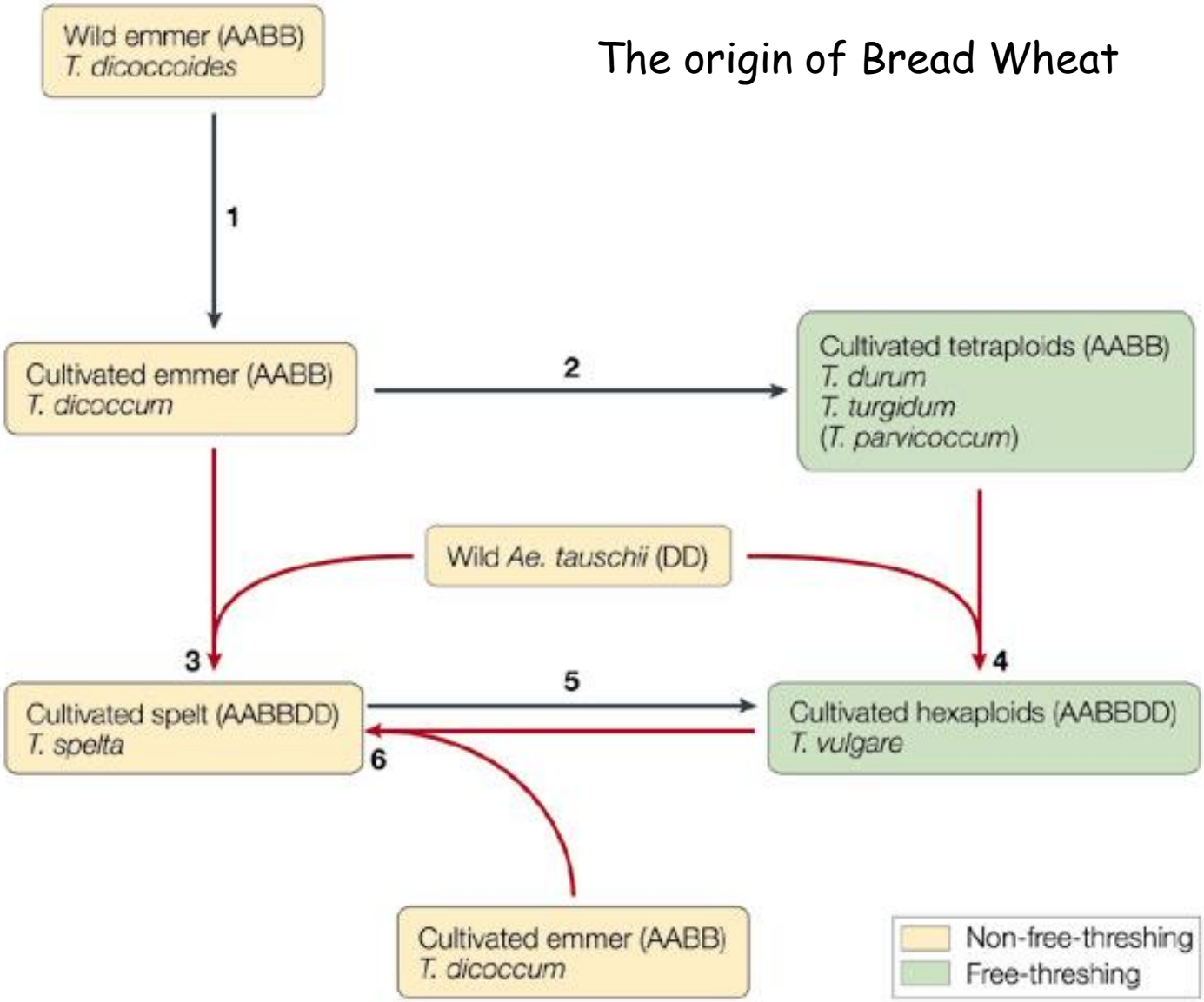
Salimini et al. 2002

Origin of tetraploid emmer wheat



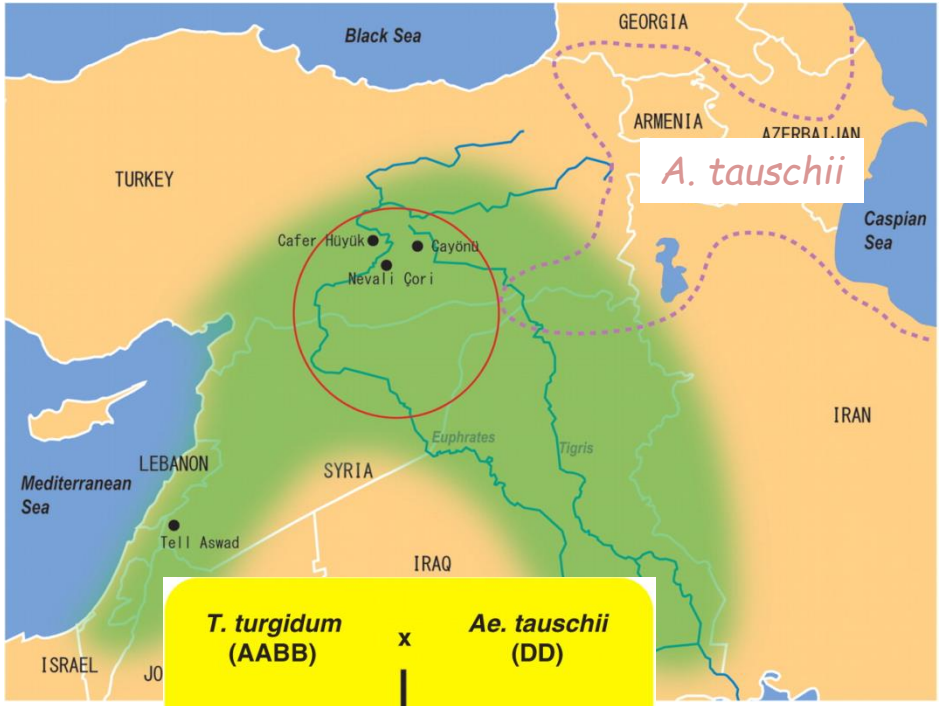
Genetic similarities (AFLPs) of cultivated tetraploid wheats *T. turgidum* (hulled emmer and hard durum wheat) to wild emmer populations from different regions, showing single origin and most closely related to wild emmer progenitors from Turkey

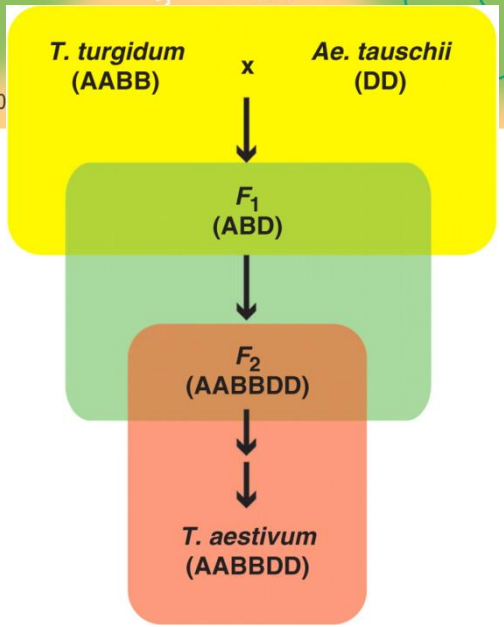
The origin of Bread Wheat



Hypothesized routes for the origin of hexaploid wheat
Black arrows = domestication events
Red arrows = hybridization events

Salimini et al. 2002





Aegilops tauschii

Triploid F1 hybrid
T. turgidum x A. tauschii

Spelt – T. aestivum subsp. spelta

Bread wheat
T. aestivum subsp. aestivum

Human-mediated range expansion of T. turgidum into range of A. tauschii
Spontaneous hyrbidization in agricultural environment
Alloployploid speciation of T. aestivum


BANANALAND
BANANAS · SWEET · SATISFYING · SIMPLE TO SERVE

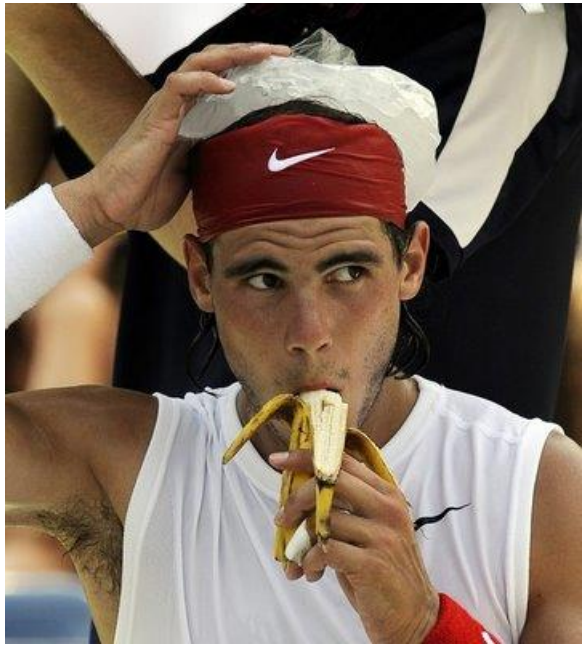
Banana – *Musa* – Monocots, Zingiberales

c.50 species in S.E. Asia
Giant 3m tall herbs on edge of rainforests
Propagated by suckers
Centre of origin in New Guinea - Malaysia – Indonesia
Fourth most important crop in developing countries
Plantains are an important staple crop in the tropics

Sweet, satisfying & simple to serve

& good for you!


OLEX

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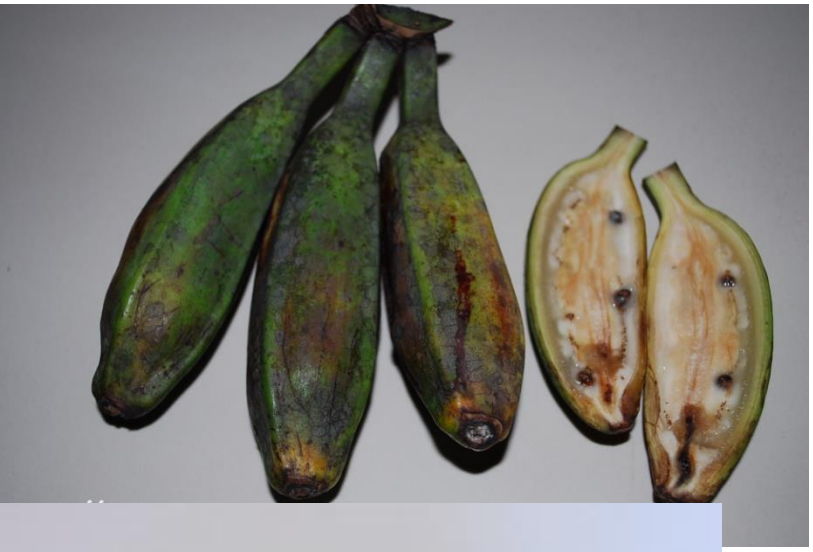
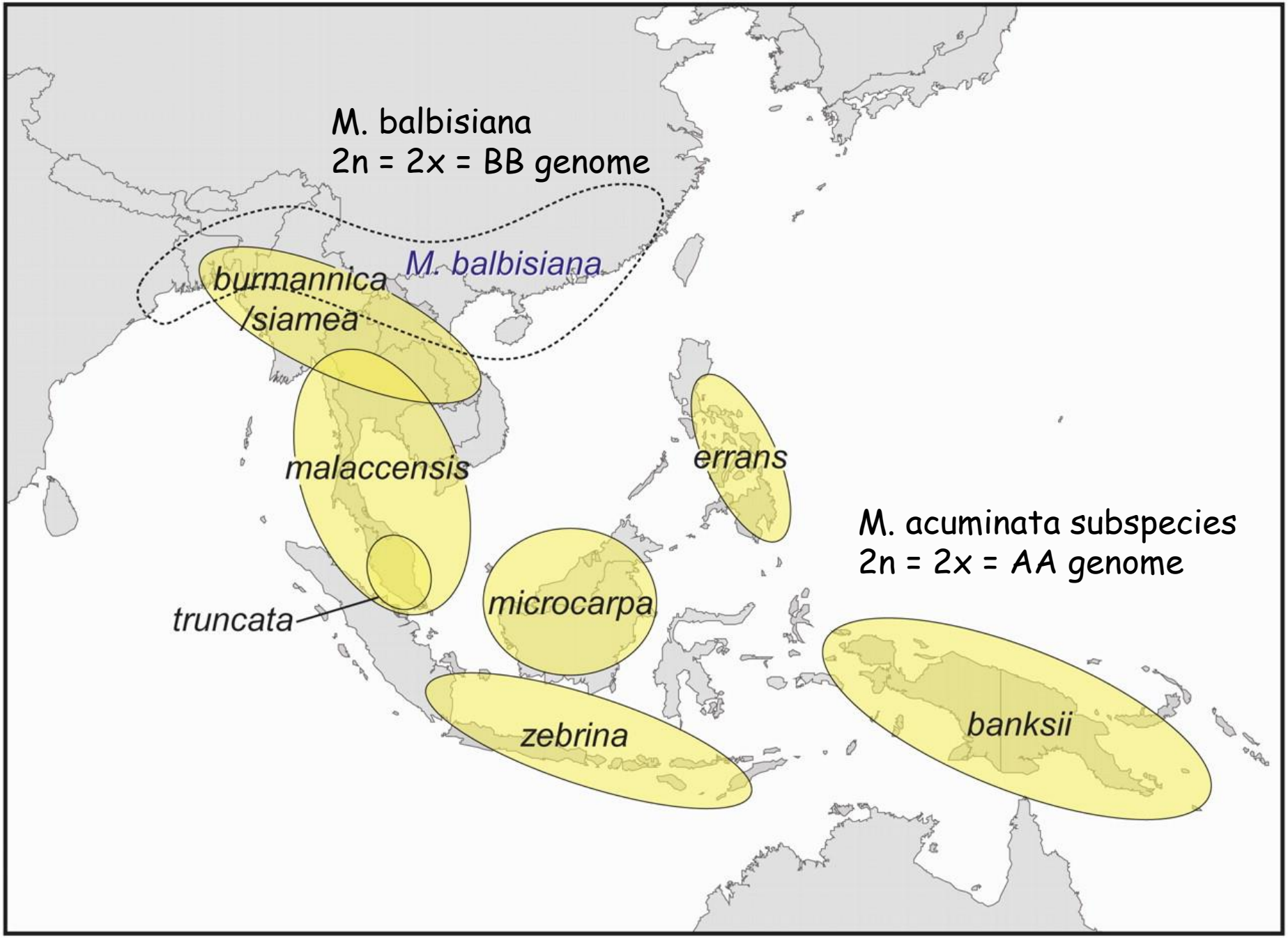
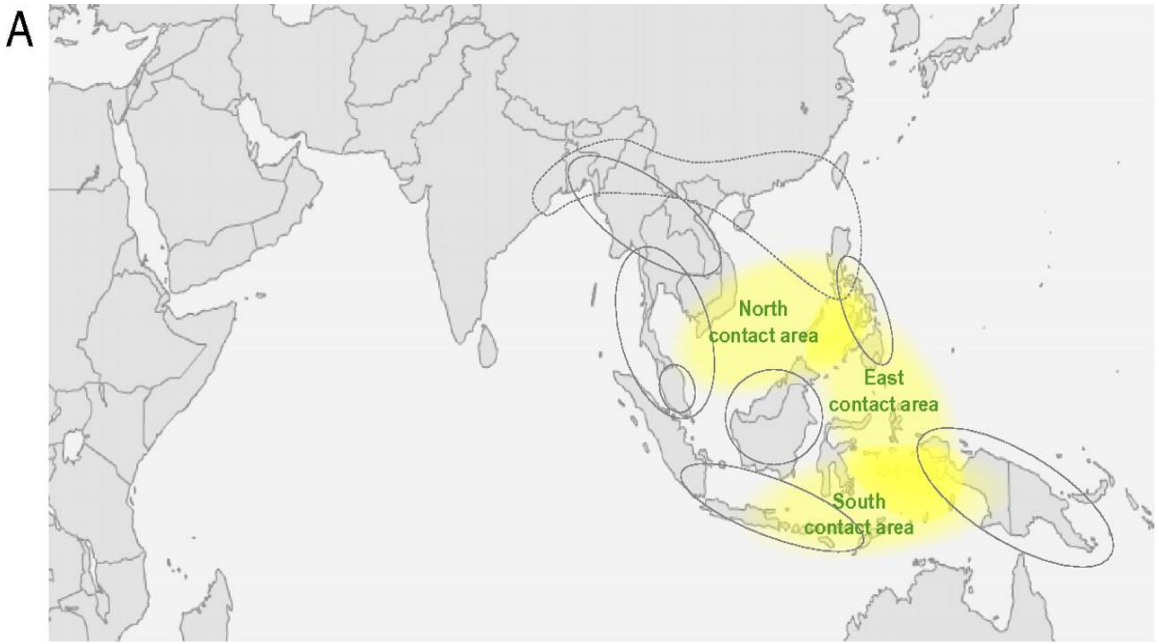
Wild Bananas

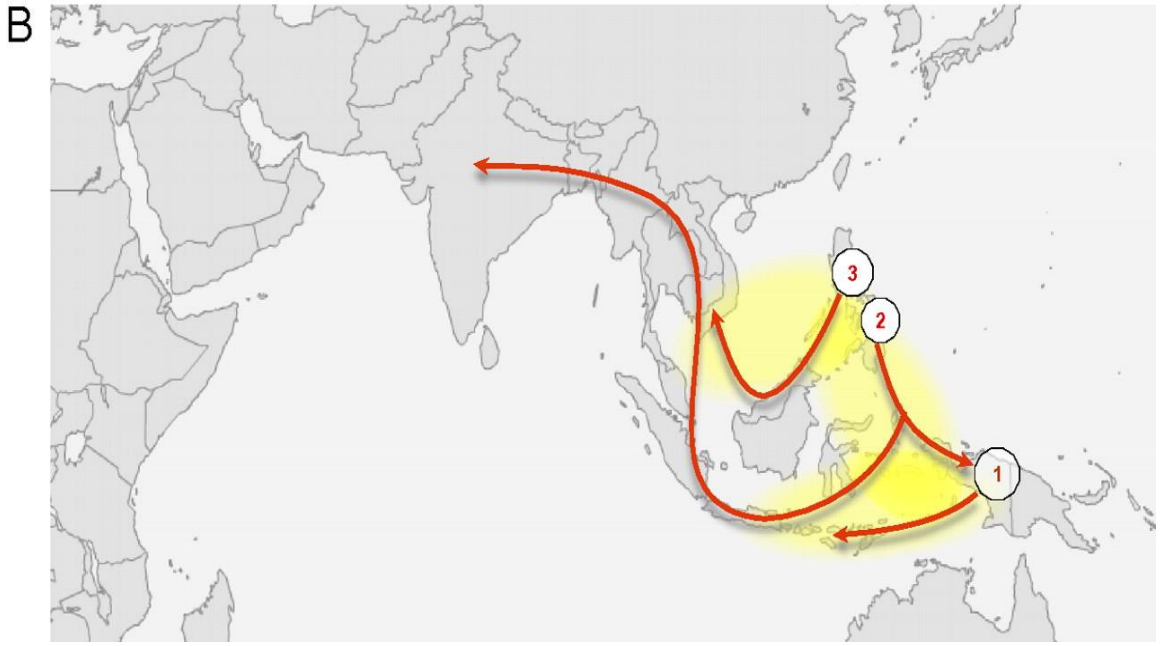


Wild diploid bananas *M. acuminata* 2n=2x=22 AA, and *M. balbisiana* 2n=2x=22 BB have seedy fruit with little starch and very little fleshy pith and no value as crops. Cultivated hybrids are seedless & parthenocarpic (i.e. fruit develops without seed development or pollination / fertilization). Domestication involved seed suppression, sterility and vegetative propagation



Perrier et al. 2011





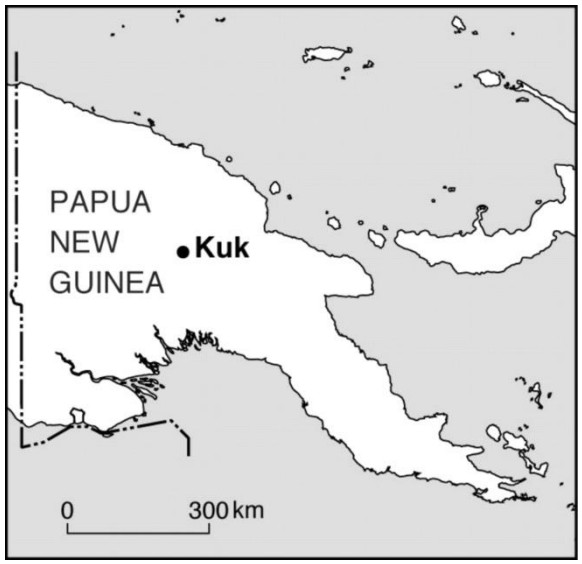
Perrier et al. 2011

Three contact zones where AA subspecies hybrids arose

Most cultivars are wild collections made by farmers of spontaneously occurring mutants with parthenocarpic fruit production which were brought into cultivation and then multiplied and distributed by suckers.

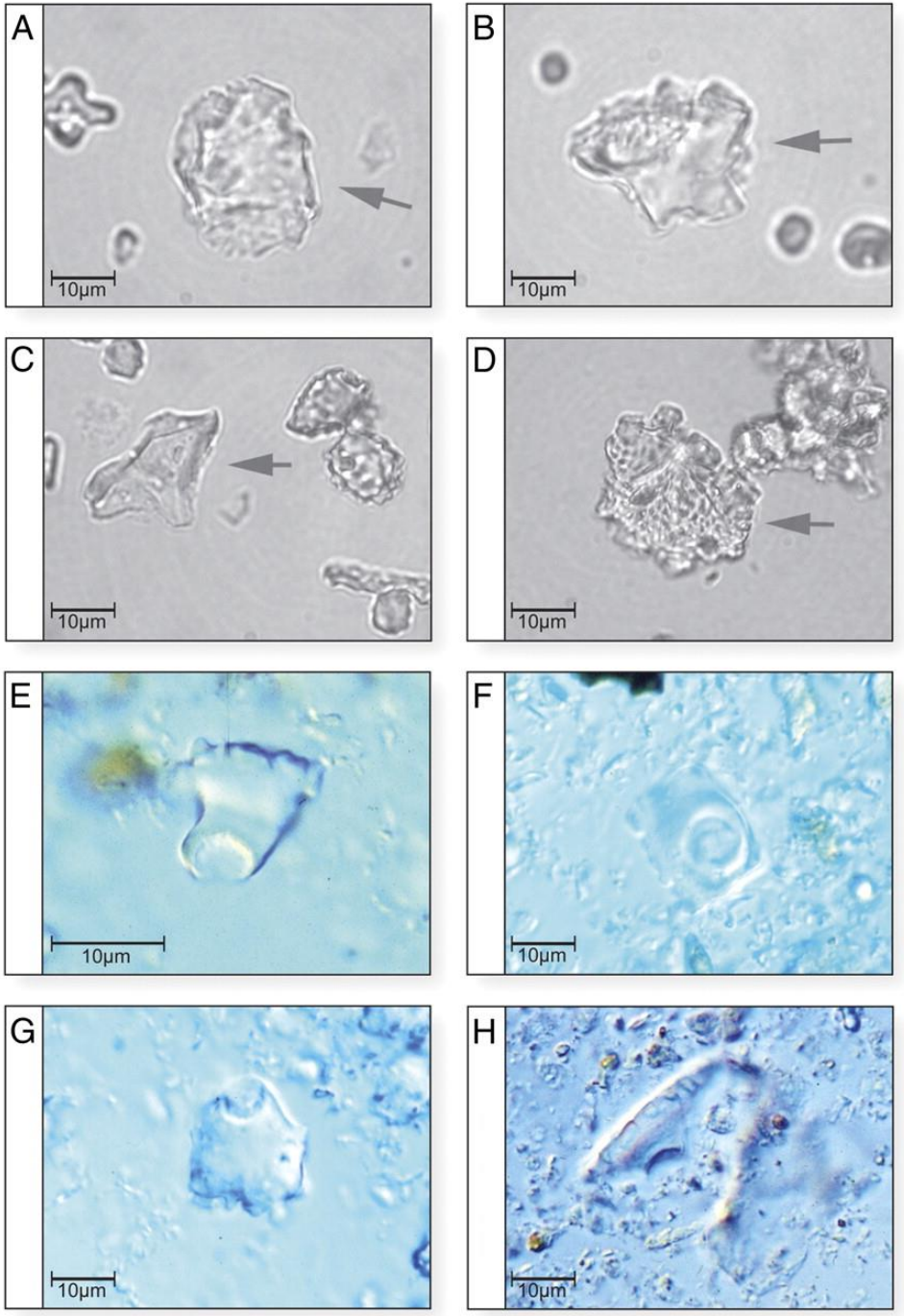
Hybridization events and mutations giving rise to the seedless parthenocarpic characters have occurred many 100s of times and spontaneous hybridization continues to produce new diversity.

Archaeological Evidence



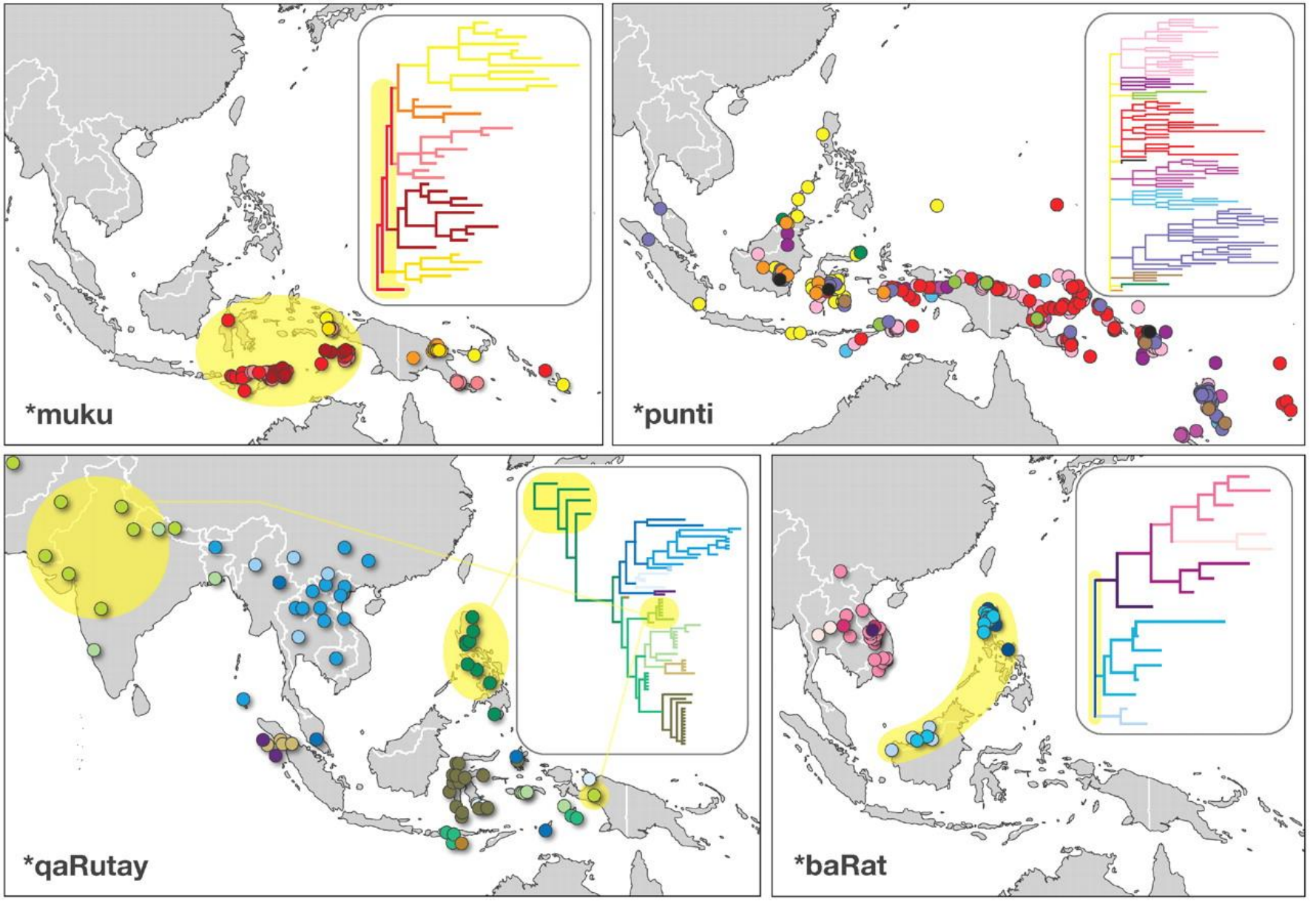
Leaf phytoliths matching *M. acuminata* subsp. *banksii* from archaeological excavations at Kuk Swamp, demonstrate that bananas were in cultivation in New Guinea 6,950-6,440 BP.

Musa leaf phytoliths from pottery remains in Nigeria in west Africa 2,790-2,300 BP, provide evidence for cultivation of exotic plantains in west Africa > 2,000 years ago.



Perrier et al. 2011

Linguistic Evidence



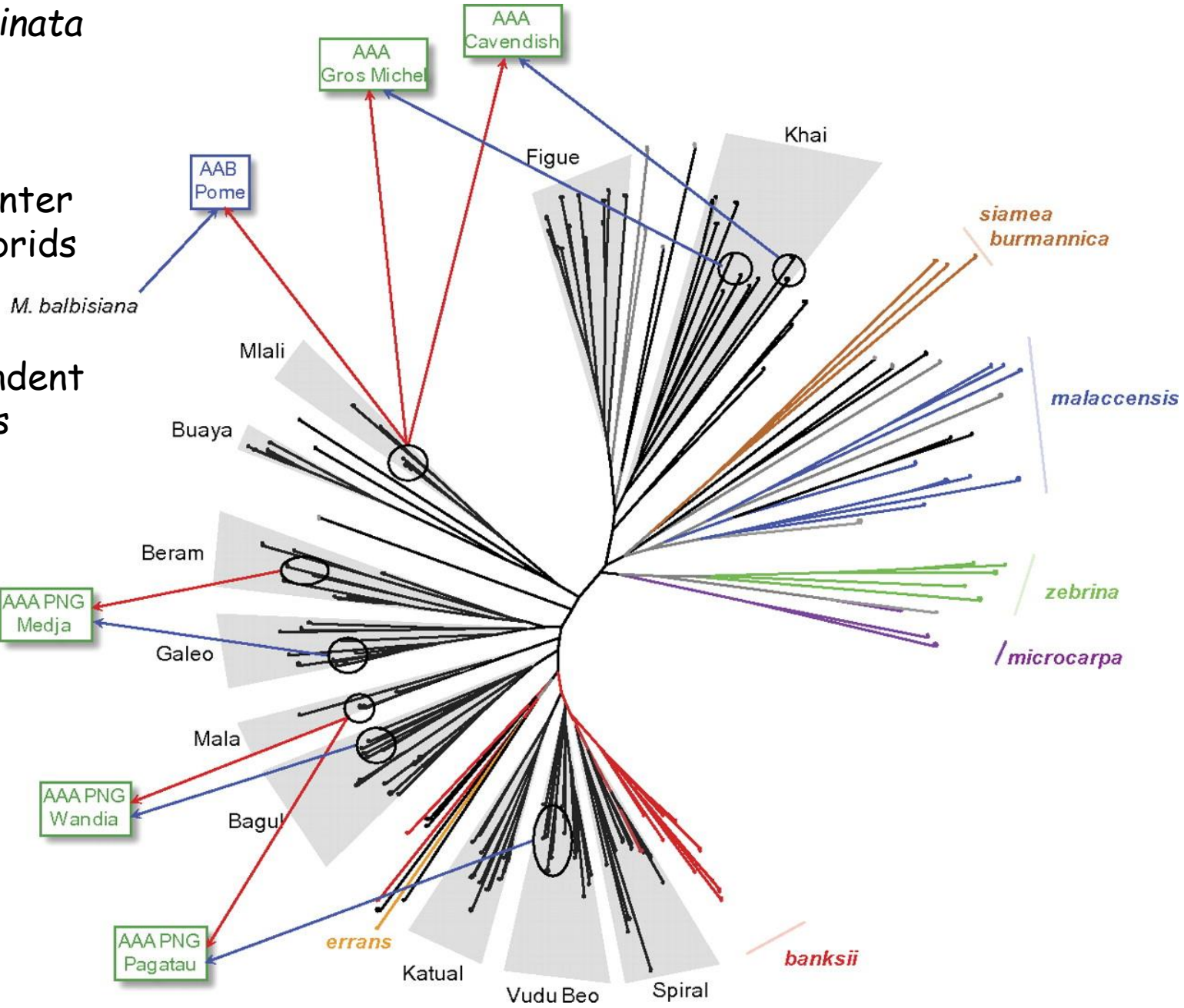
Perrier et al. 2011

-Wild *M. acuminata* subspp.

-*AA* cultivars derived from inter subspecies hybrids

- many independent domestications

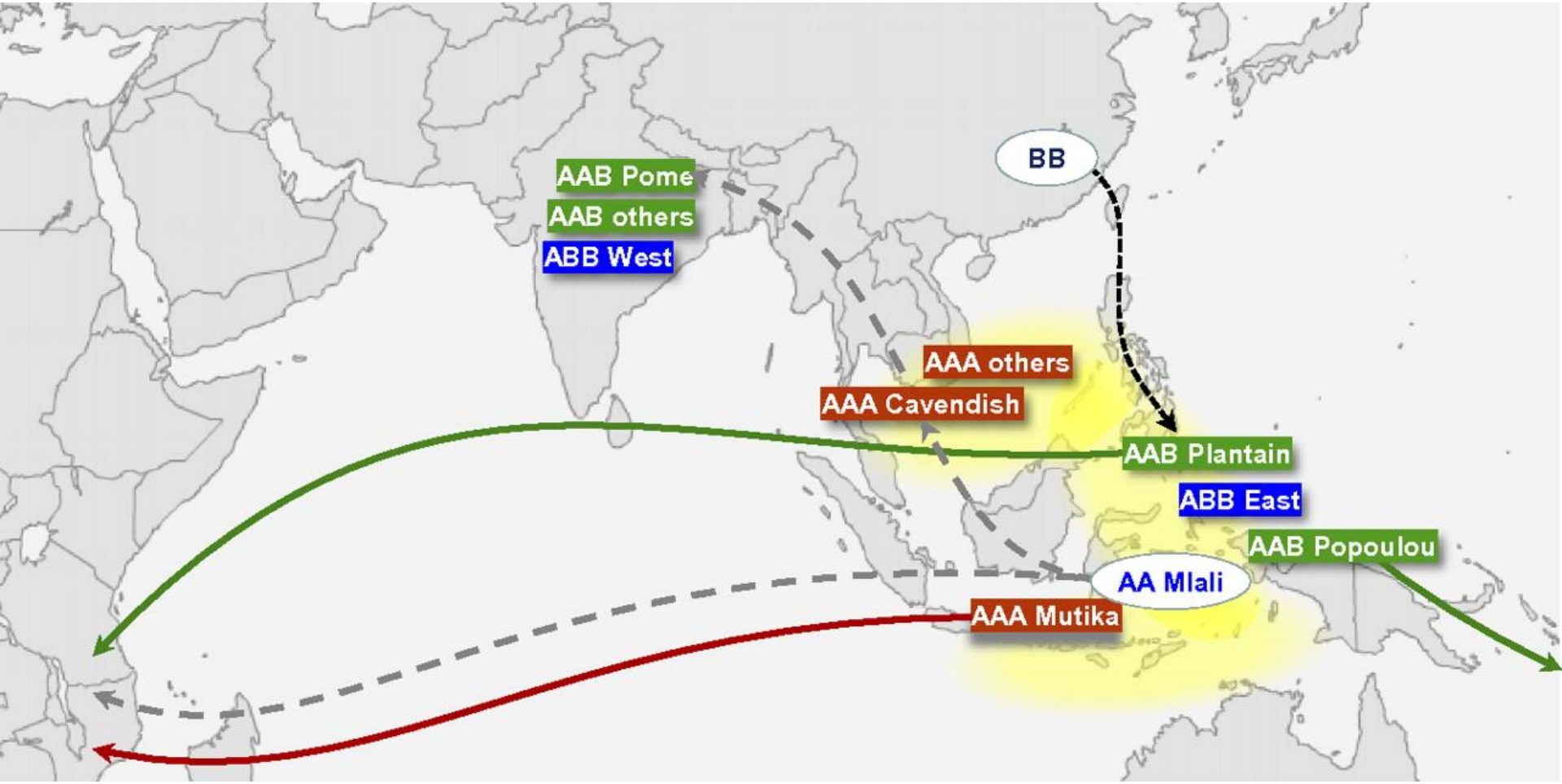
- *AAA* & *AAB* triploids



Perrier et al. 2011

Musa triploids

– three of these are remarkable because they are largely cultivated far from their regions of origin – African sweet AAA Mutika; African AAB plantains carried to Africa by Arab traders, as well as the Pacific AAB plantains



Perrier et al. 2011

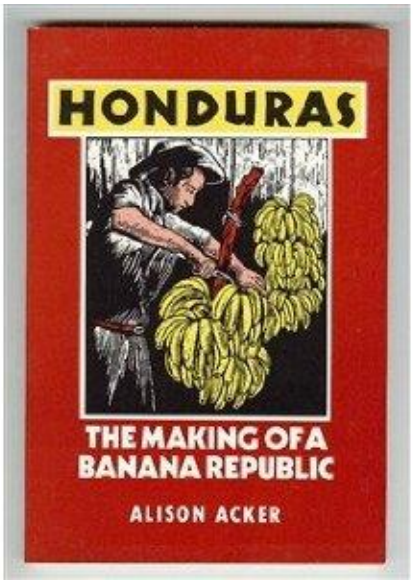
Diversity of bananas & plantains in south India

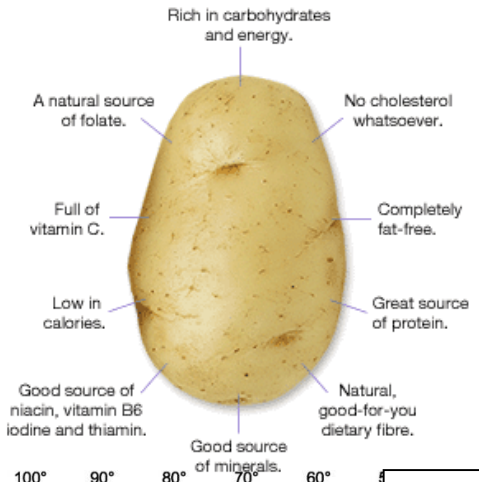
Genome compostitions:

- **a = cultivar Red = *AAA*, a prized sweet desert banana cultivar**
- b = Palayam Codan = *AAB*
- c = Njalipoovan = *AB* (unripe and ripe green and yellow) sweet desert banana with small fingers, thin skin and delicate flavour, but poor storage
- d = Robusta (Cavendish group) = *AAA* (these green bananas ripen without turning yellow when above 22C
- e = Nendran = *AAB*, plantain used for cooking and making chips
- f = Peyan = *ABB*, used as a vegetable for curries and cooked snacks
- g = Poovan = *AAB*

Heslop-Harrison & Schwarzacher (2007)

The Modern Banana in supermarkets and banana splits, is just one of numerous varieties found in the tropics – the Cavendish cultivar – genetically identical, uniform, possessing the same predictable pleasant taste and texture, and inevitably, susceptible to diseases. The previously dominant cultivar Gros Michel cultivar was decimated by a wilt fungus called Panama disease. Stuck with vegetative reproduction, disease and pest problems are especially problematic for bananas, and modern industrial scale commercial production is sustained mainly via enthusiastic applications of pesticides.

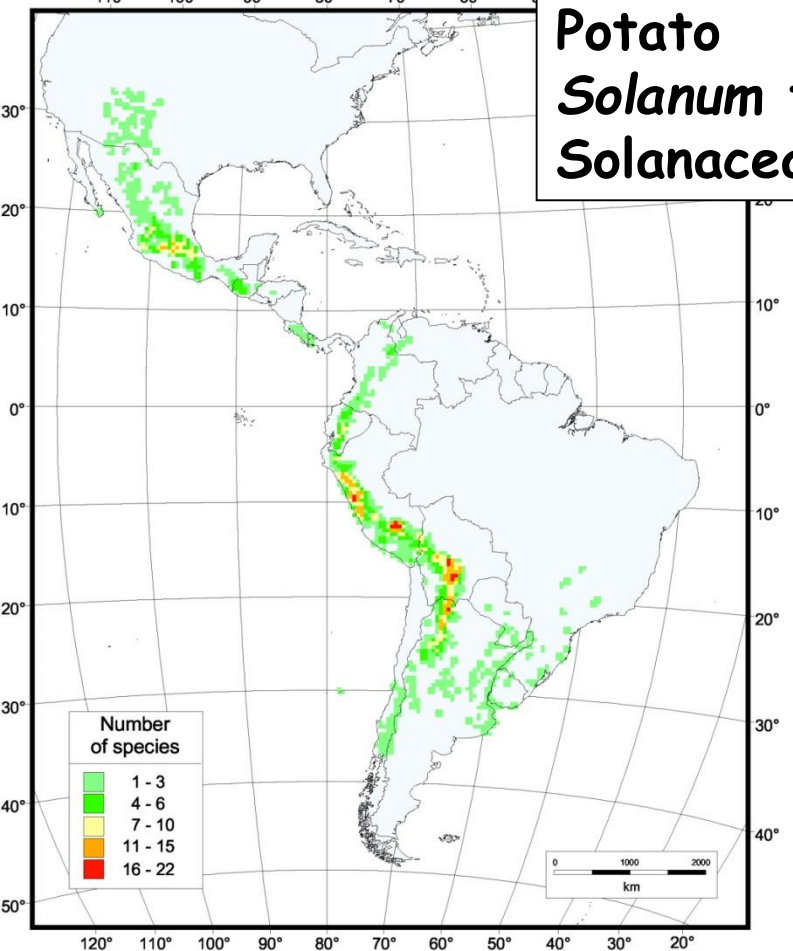




Potato

Solanum tuberosum

Solanaceae



S. brevicaule complex

↓ Selection

S. stenotosum complex X ?unknown species

2n

↓ Chromosome doubling (polyploidy)

4n

S. tuberosum – andigena group

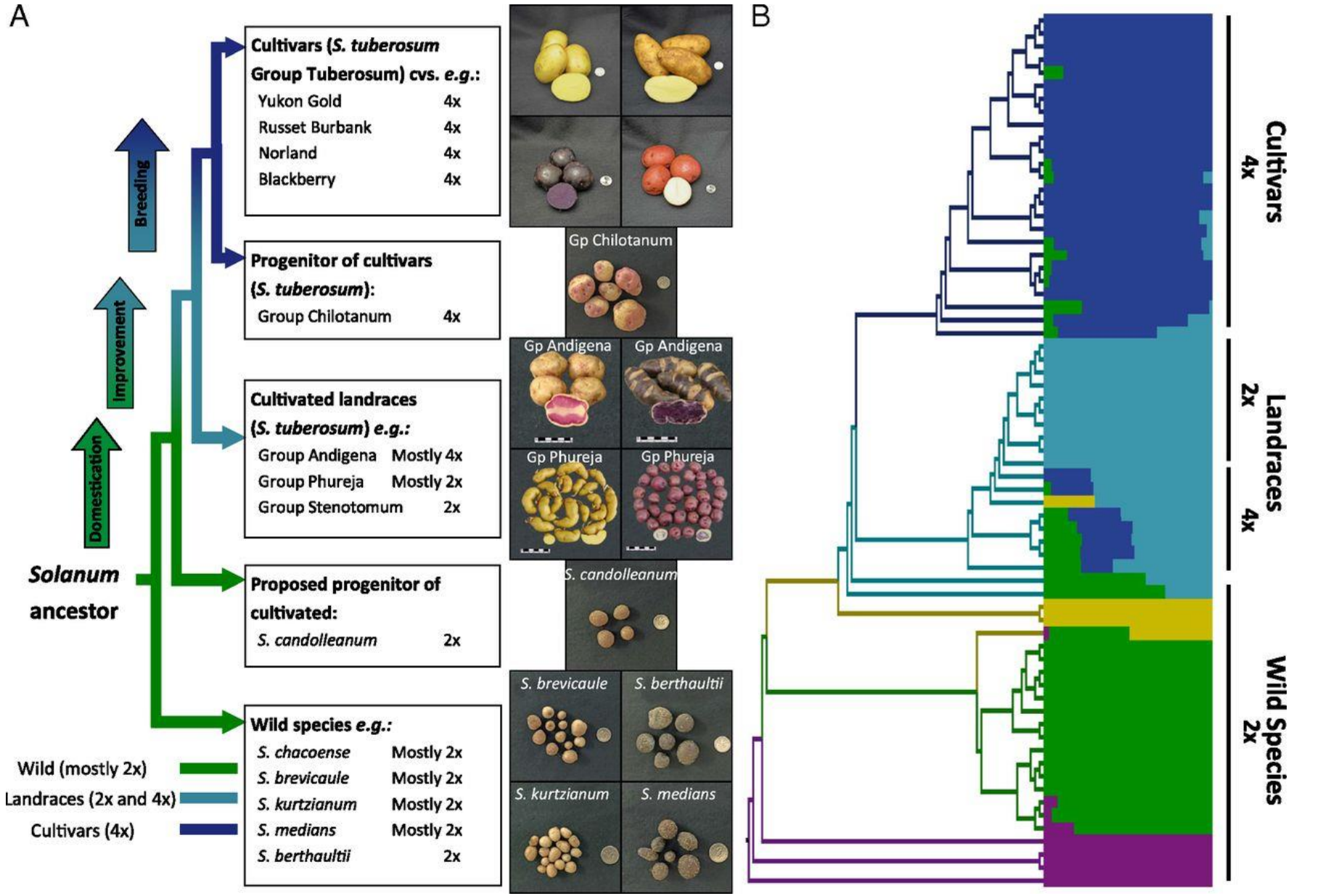
↓ Multiple backrossing (Introgression)

many diploid species X andigena group

↓

S. tuberosum subsp. tuberosum

The Complex Evolutionary History of the Potato



Hardigan et al. (2017)

PNAS

Genome diversity of tuber-bearing *Solanum* uncovers complex evolutionary history and targets of domestication in the cultivated potato

Michael A. Hardigan[a], F. Parker E. Laimbeer[b], Linsey Newton[a], Emily Crisovan[a], John P. Hamilton[a], Brieanne Vaillancourt[a], Krystle Wiegert-Rininger[a], Joshua C. Wood[a], David S. Douches[c], Eva M. Farré[a], Richard E. Veilleux[b], and C. Robin Buell[a,1]

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Edited by Esther van der Knaap, University of Georgia, and accepted by Editorial Board Member June B. Nasrallah October 5, 2017 (received for review August 21, 2017)

Cultivated potatoes (*Solanum tuberosum* L.), domesticated from wild *Solanum* species native to the Andes of southern Peru, possess a diverse gene pool representing more than 100 tuber-bearing relatives (*Solanum* section *Petota*). A diversity panel of wild species,

adopted into the global diet and is the third most important food crop for direct human consumption (faostat3.fao.org), providing food security in Asia and South America (9, 10).

The adaptability of potato to diverse growing conditions stems

(i) Autopolyploidization of early diploid land races (sections Stenotomum and Phureja) via unreduced gametes resulted in the cultivated Andean tetraploids, S. tuberosum group Andigena, 2n=4x=48, the initial Andean domesticated potatoes.

(ii) Migration south to coastal Chile resulted in long-day-adapted S. tuberosum group Chilotanum, 2n=4x=48, which provided the genetic background for commercial cultivars across the world.

(iii) A large number of the over 100 tuber-bearing wild relatives (Solanum section Petota) which ranges from the SW U.S.A. to S. Chile have contributed to the genomes of commercial potato cultivars via introgression. Including: (a) diploid Peruvian land races of S. candolleanum, S. medians, and S. raphanifolium; (b) Bolivian tetraploids, S. brevicaule, S. leptophyes, and S. microdontum; (c) Argentinian tetrploids, S. bethaultii, S. chacoense, S. gourlayi, S. kuntzianum, S. spegazzinnii and S. vernei.

Hardigan et al. (2017)

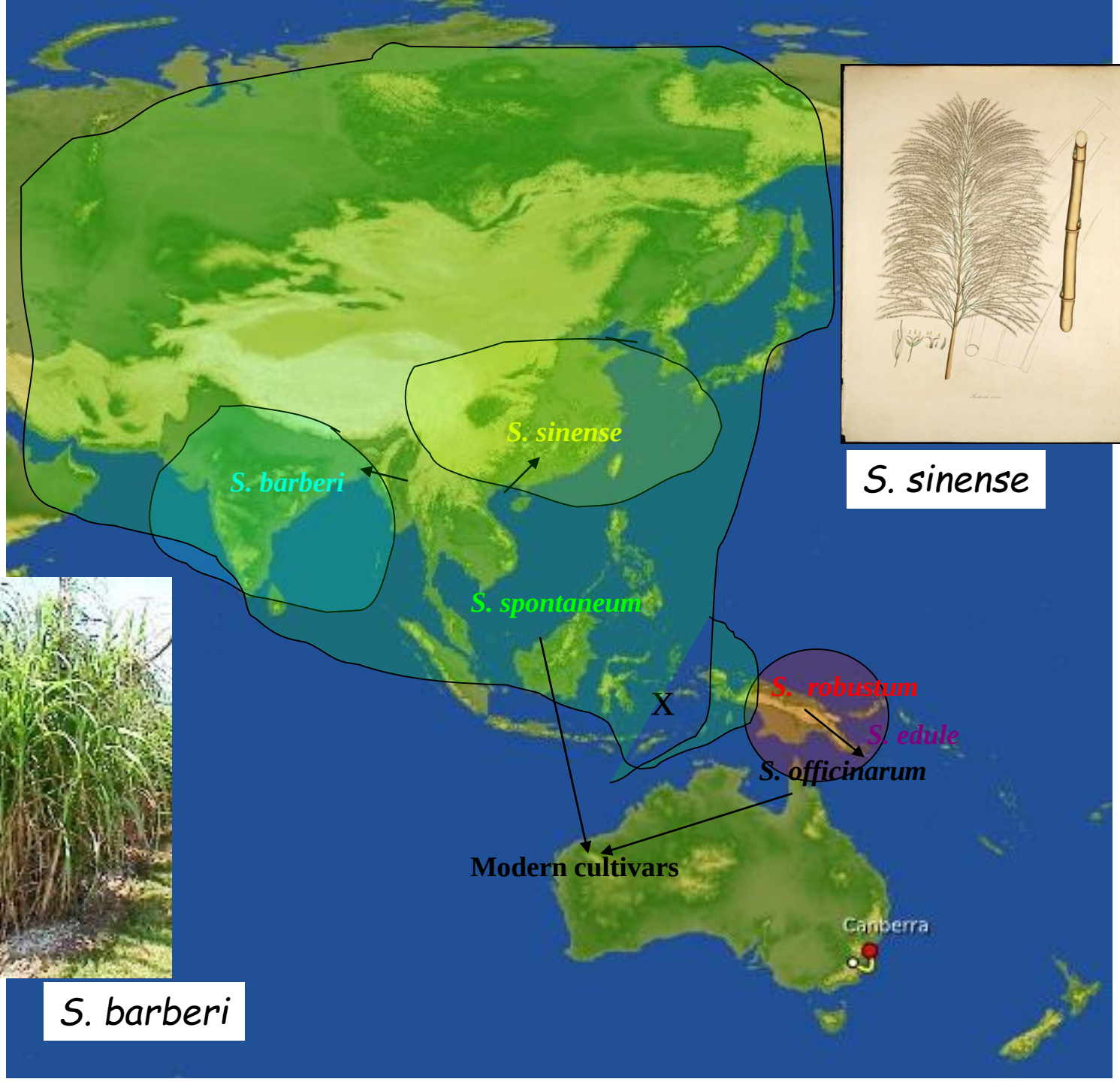
Up to five species cultivated together in fields in S Peru / Bolivia, alongside several other wild / weedy species

Highly sophisticated and complex systems of indigenous selection and use of potato varieties e.g. for drought / frost resistance to avoid risks – Andean farmers are growing (and conserving) genetic diversity

Formation of spontaneous hybrids following juxtaposition in cultivation has been vitally important in potato domestication

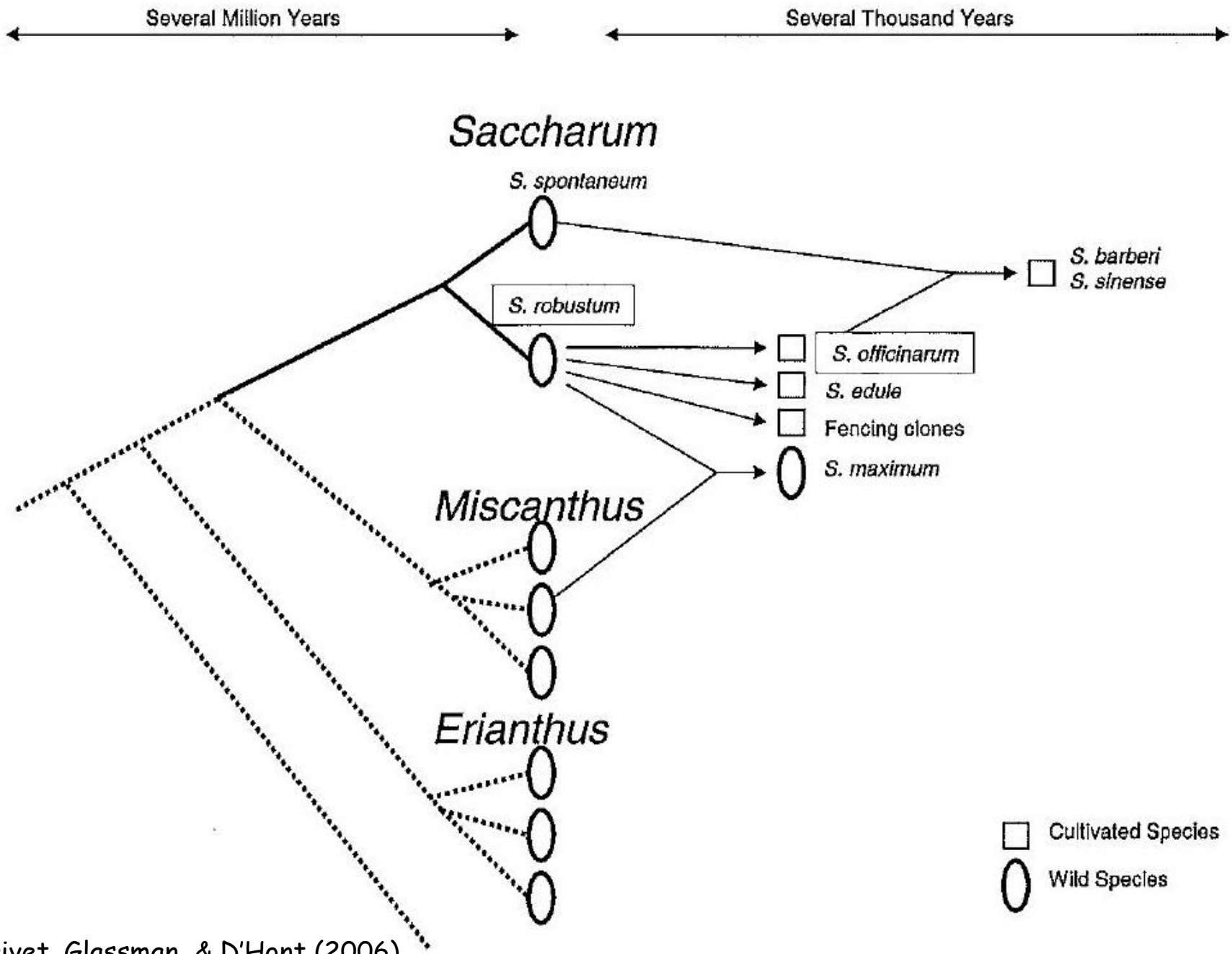
Sugarcane
Saccarum officinarum x S.spontaneum
Poaceae: Andropogoneae:

Sugar:
the 'unnecessary food'…. yet Europe imports > 1 billion tones each year



S. sinense

S. barberi

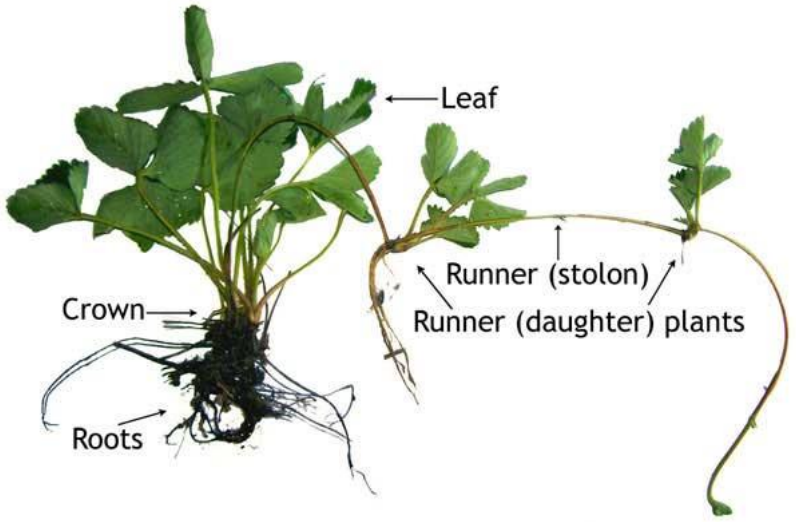


Grivet, Glassman & D'Hont (2006)

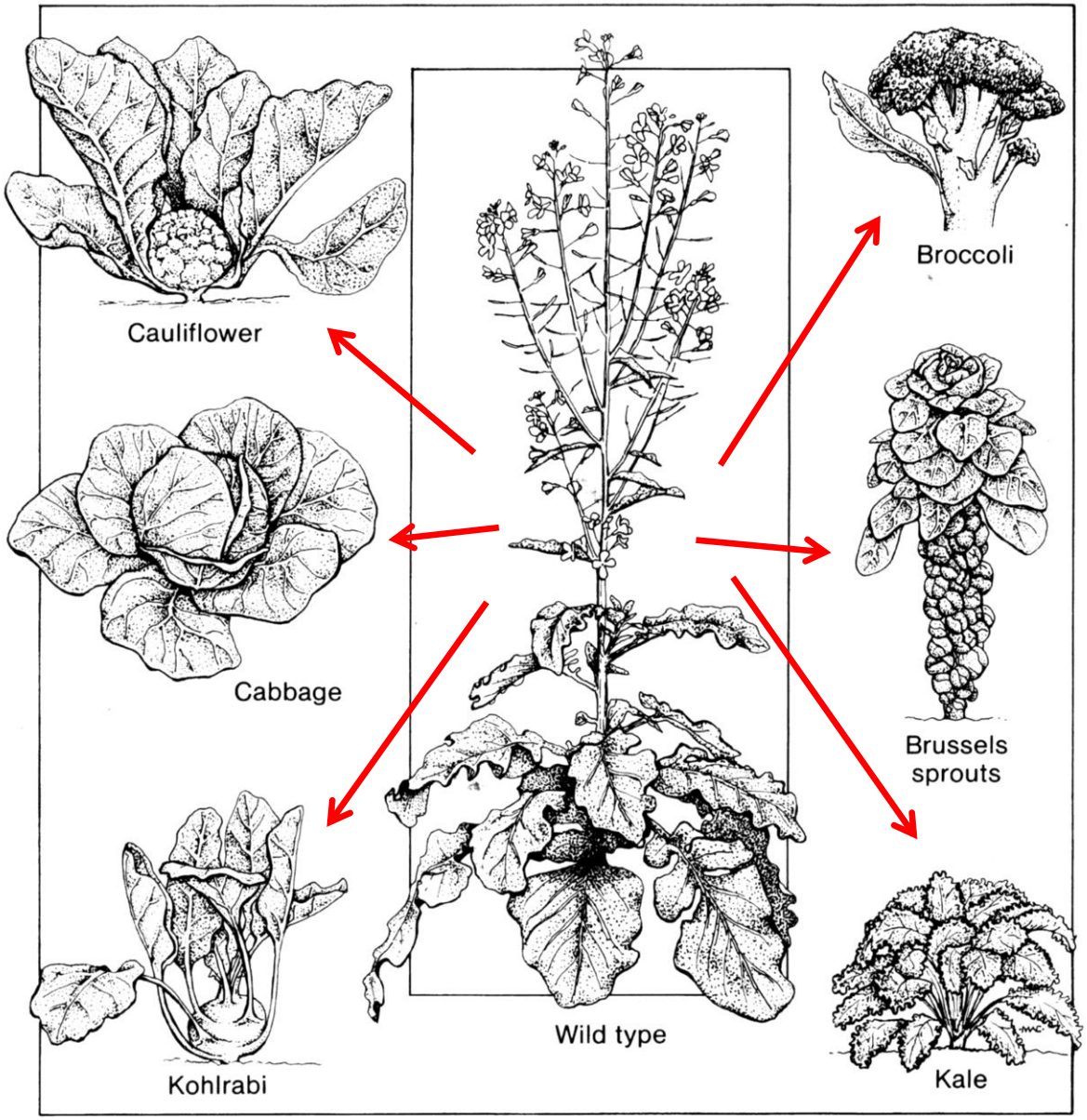
Vegetative Propagation & Polyploid Domestciates

- How does the mode of crop reproduction (ie. Clonal vs. seed setting) contribute to the genetics of domestication?

Opuntia, Agave, strawberry, potato, banana, sugarcane are all vegetatively propagated – polyploids can be immediately replicated



Crops originating from *Brassica olearacea* subsp. *oleracea* – 2n=2x=18



Brassica oleracea subsp. oleracea – native along coasts of Europe from Greece to England

Leafy kales – recorded in cultivation in Greece at least 2500 years ago

Early cabbage in Germany c.1000 years ago

Cauliflower - northern Europe c. 500 years

Broccoli – eastern Mediterranean c. 500 years

Brussels Sprouts – spontaneous mutation in France in 1750

Turnip – Brassica campestris – 2n=2x=20

- First cultivated Brassica
- Used for seed oil from as early as 4,000 BP
- Domesticated repeatedly from wild populations across Eurasia where often found as a weed in fields of wheat

Brassica & the triangle of U (1935)

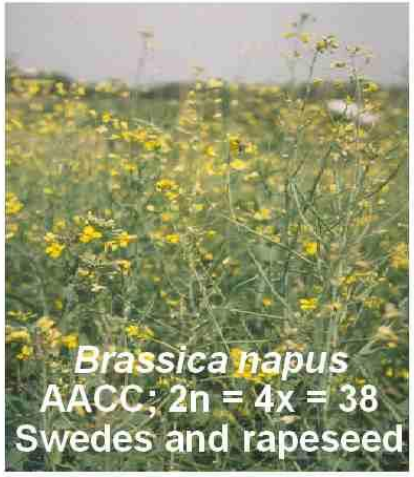
Brassica nigra
BB; 2n = 2x = 16
Black mustard

Brassica carinata
BBCC ; 2n = 4x = 34
Ethiopian mustard

Brassica juncea
AABB; 2n = 4x = 36
Brown mustard

Wild cabbage

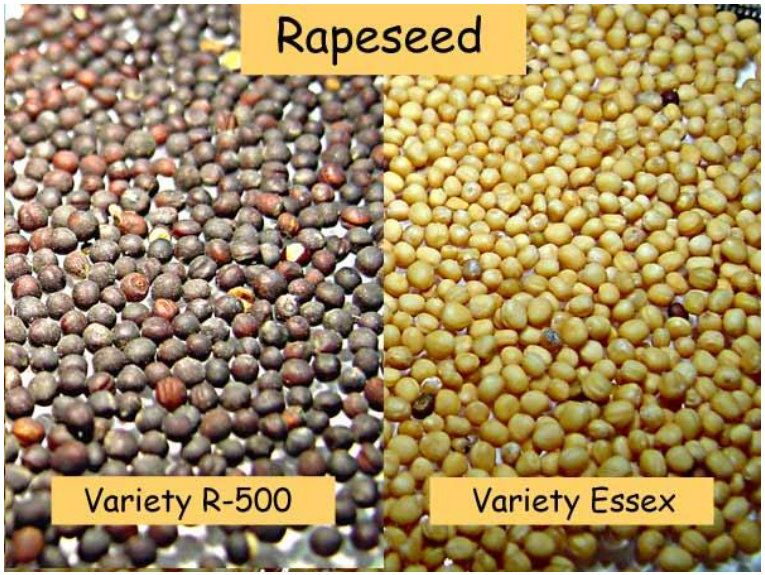
Brassica oleracea
CC ; 2n = 2x = 18
Cabbages, kale, Brussels sprout, broccoli, cauliflower



Brassica napus
AACC; 2n = 4x = 38
Swedes and rapeseed

Brassica campestris
AA ; 2n = 2x = 20
Turnip,
Chinese cabbage,
turnip rape

Oil Seed Rape / Canola – *Brassica napus*



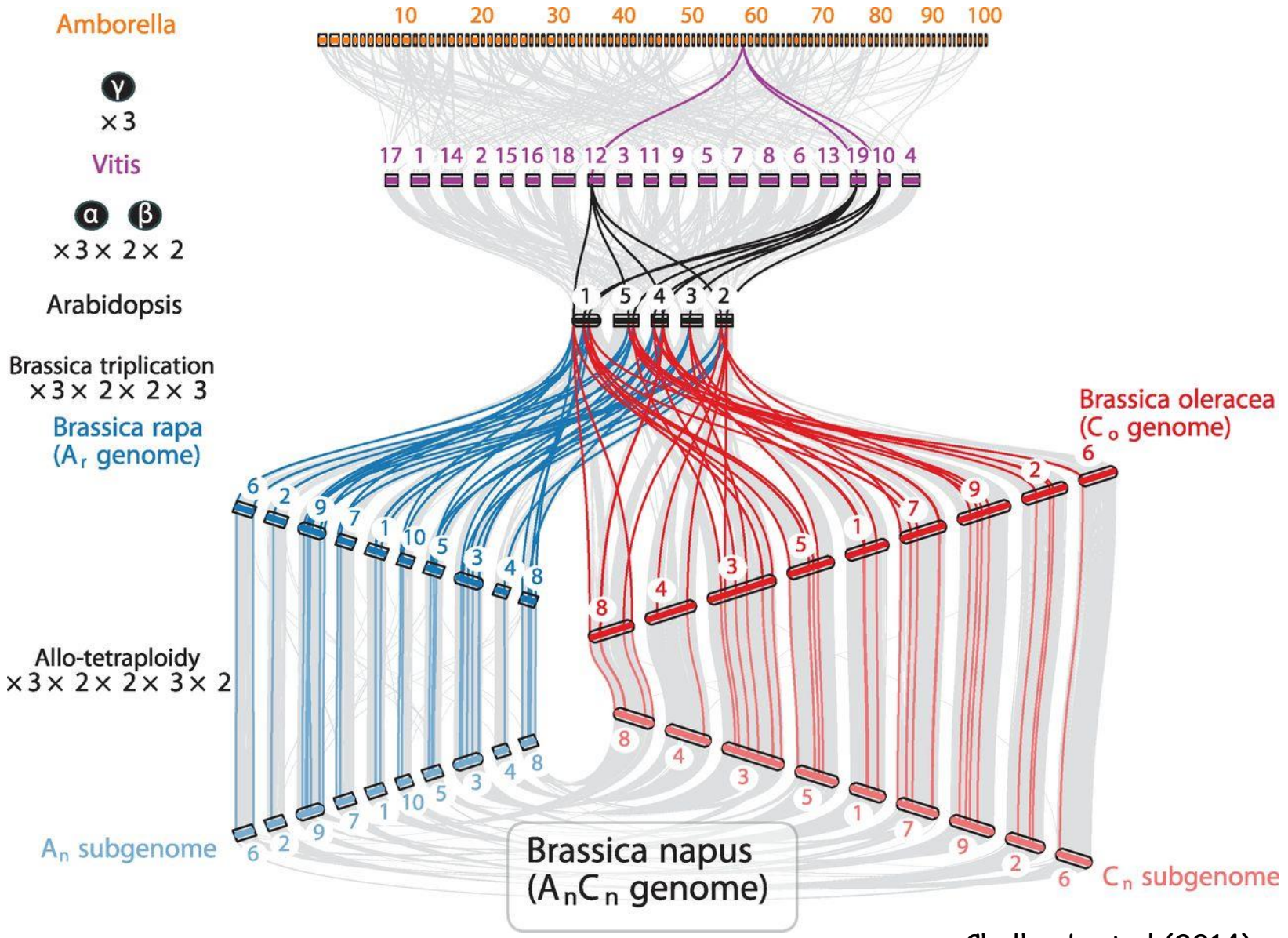
Brassica napus is a polyploid: 2n=38 *AACC*
Derived from a hybrid between:

•Kale – *B. oleracea*: 2n=18 *CC* domesticated at least 2500 years ago in Europe

•Turnip – *B. campestris*: 2n=20 *AA* – domesticated c.4000 years ago in Mediterranean

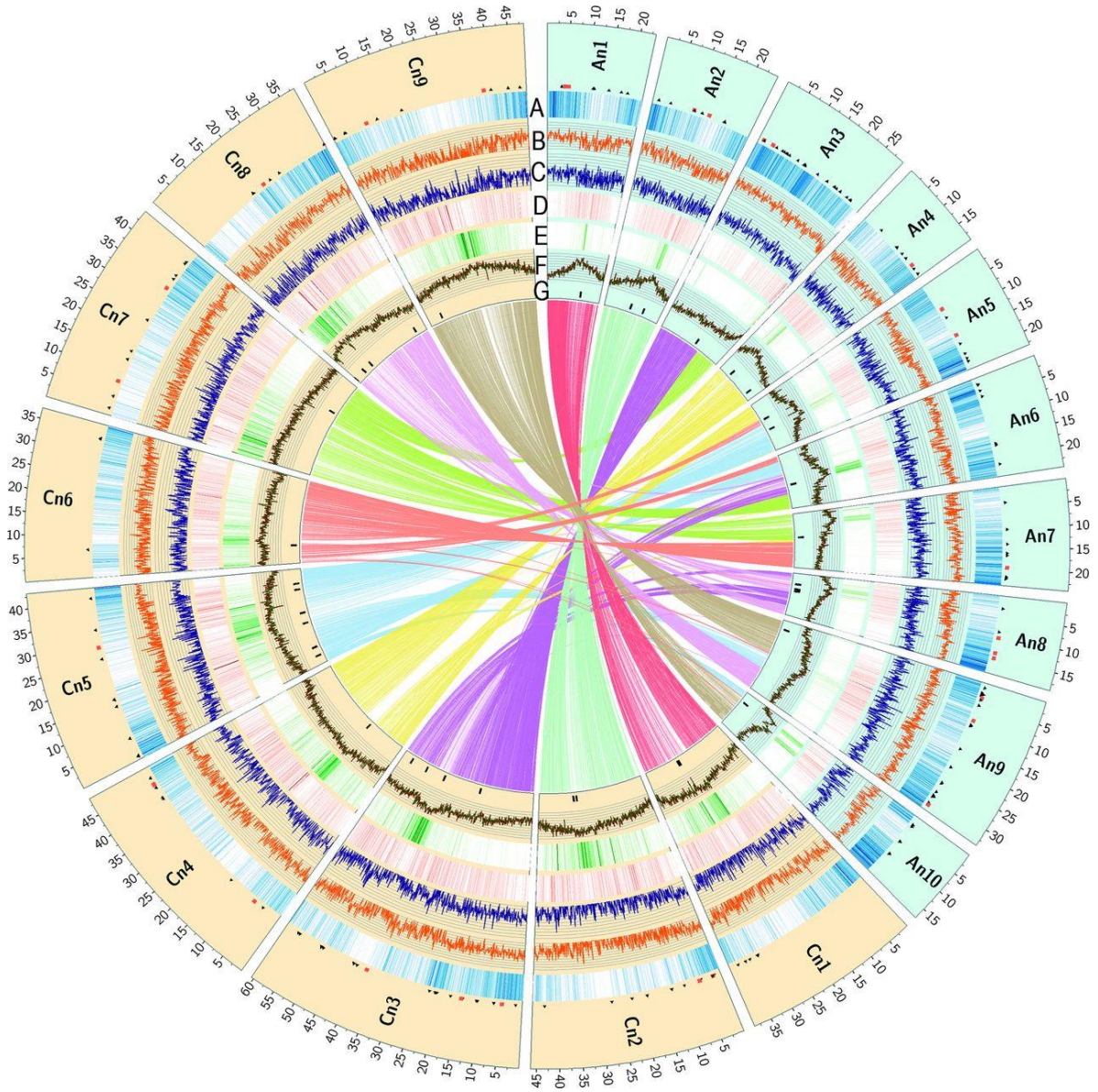
• recent introgressive hybridization between these two species and oil seed rape

The genome of the recent allopolyploid (neopolyploid) *Brassica napus*



Chalhoub et al (2014)

The genome of the recent allopolyploid (neopolyploid) *Brassica napus*



Chalhoub et al (2014)

The genome of the recent allopolyploid (neopolyploid) *Brassica napus*

Oilseed rape (*Brassica napus* L.) was formed ~7500 years ago by hybridization between *B. rapa* and *B. oleracea*, followed by chromosome doubling, i.e. via allopolyploidy.

Together with more ancient polyploidizations, this conferred an aggregate 72× genome multiplication since the origin of angiosperms and high gene content.

In the *B. napus* genome the constituent A_n and C_n subgenomes are engaged in subtle structural, functional, and epigenetic cross-talk, with abundant homeologous exchanges.

Incipient gene loss and expression divergence have begun.

Selection in *B. napus* oilseed types has accelerated the loss of glucosinolate genes, while preserving expansion of oil biosynthesis genes.

These processes provide insights into allopolyploid evolution and its relationship with crop domestication and improvement

Chalhoub et al (2014)

Hybridization, Polyploidy & Crop Domestication – Conclusions

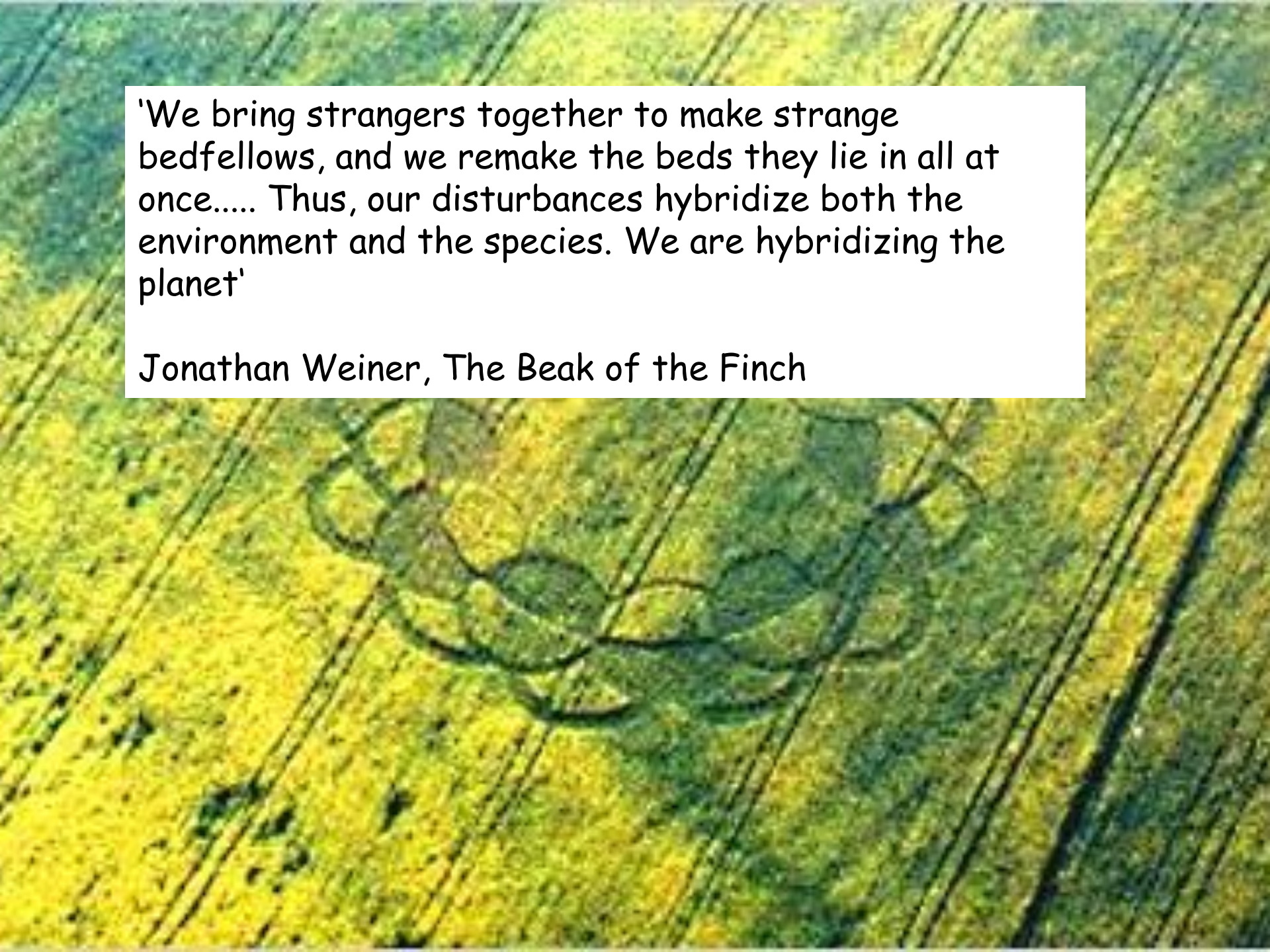
- Many of our most important crops are polyploids

- The origins in terms of where, when, how many times and from what progenitors, of several of these are highly complex, involving multiple sequential cycles of hybridization and multiple sets of wild species and early domesticates, and as yet incompletely understood – e.g. potato, banana, sugarcane

- For at least two of these – strawberry and bread wheat – there is evidence to suggest anthropogenic origins in cultivation

- For the others – potato, banana, sugarcane & canola - there is abundant circumstantial evidence that serendipitous hybridization following early cultivation, translocation and incipient domestication played an important part in generating the diversity that we see today amongst the set of important crops.

- There are many other hybrid / polyploid crops – citrus, tobacco, peanut, oca, kiwi fruit.....



'We bring strangers together to make strange bedfellows, and we remake the beds they lie in all at once..... Thus, our disturbances hybridize both the environment and the species. We are hybridizing the planet'

Jonathan Weiner, The Beak of the Finch

Announcements

Botanic Garden Fruit Market – Obstsortenmarkt
27 Oktober 2017: 11.00 - 17.00 Uhr im
Botanischen Garten der Universität Zürich
Detailed program on OLAT
www.bguz.uzh.ch

Course Assignment – *What do We Eat Today?* – 6 November 2017