NST PMS 1B: Origins of modern agriculture

Prof. Jim Haseloff (jh295)

Lecture 1. **Plant breeding and transformation**

(i) Crop domestication, with maize as an example

(ii) Modern agriculture, hybrid maize and the rise of agribusiness

(iii) Green Revolution

(iv) Agrobacterium mediated plant transformation

Lecture 2. **From genotype to phenotype**

(i) Designing synthetic plant genes

(ii) Single gene traits: pest and herbicide resistance

(iii) Reporter genes

(iv) Microscopy

Lecture 3. **New tools for engineering future crop traits**

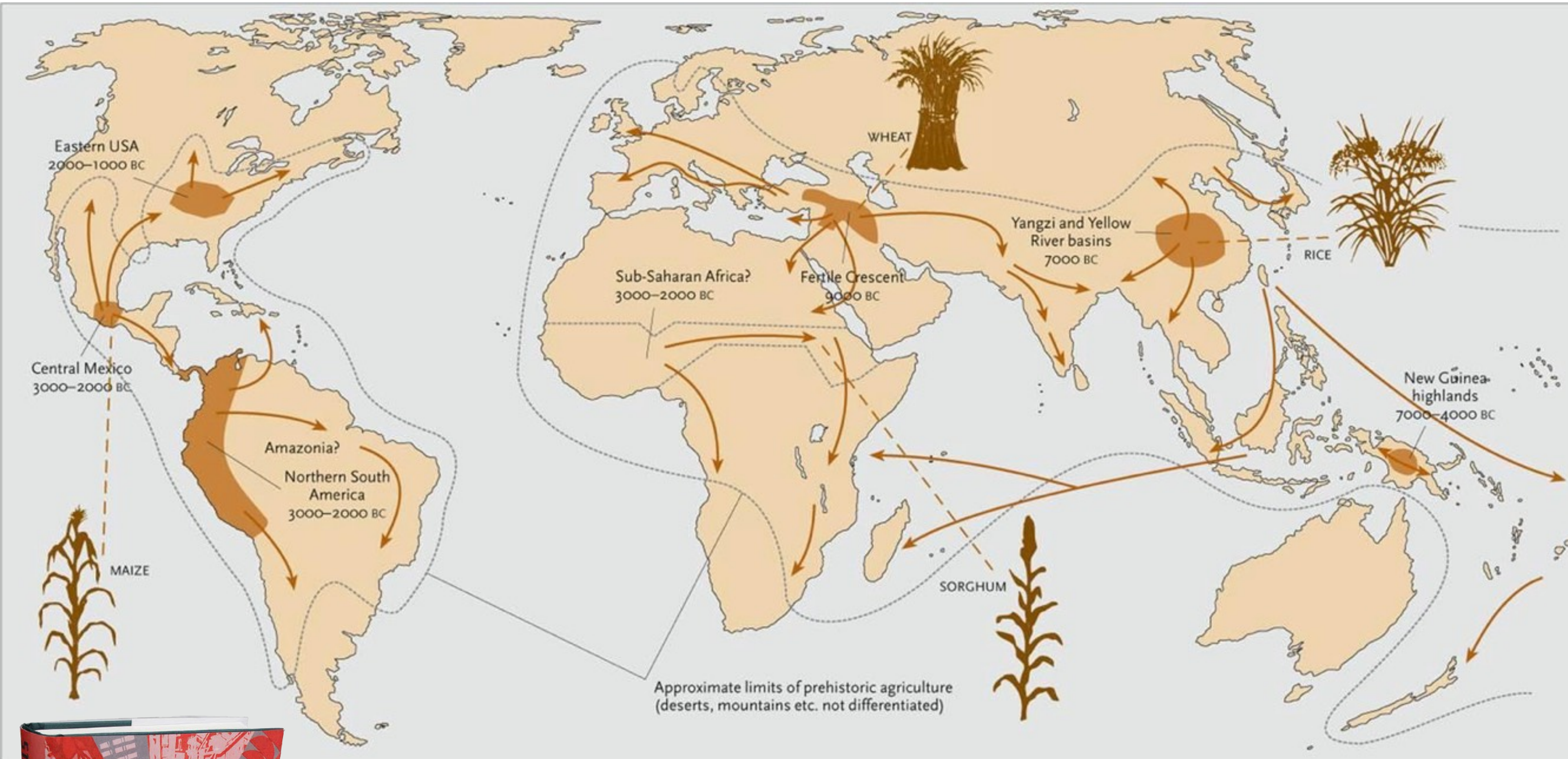
(i) Complex traits and breeding

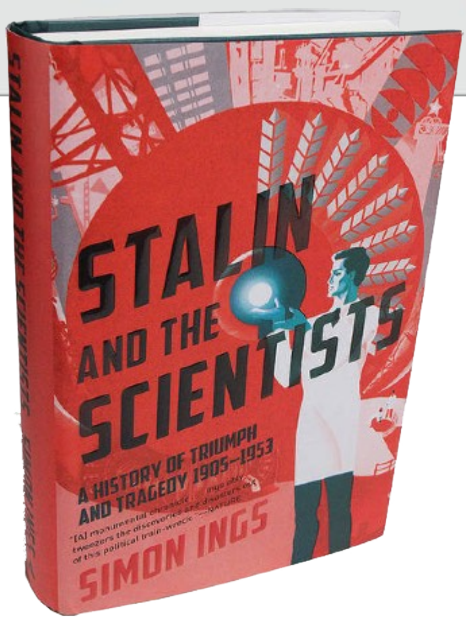
(ii) Reprogramming regulatory networks

- Engineering new metabolic pathways
- Loss-of-function e.g. for reduced pod shatter
- Re-wiring networks e.g. modification of tomato plants
- Selective amplification of pathways e.g. expansion of structural tissues

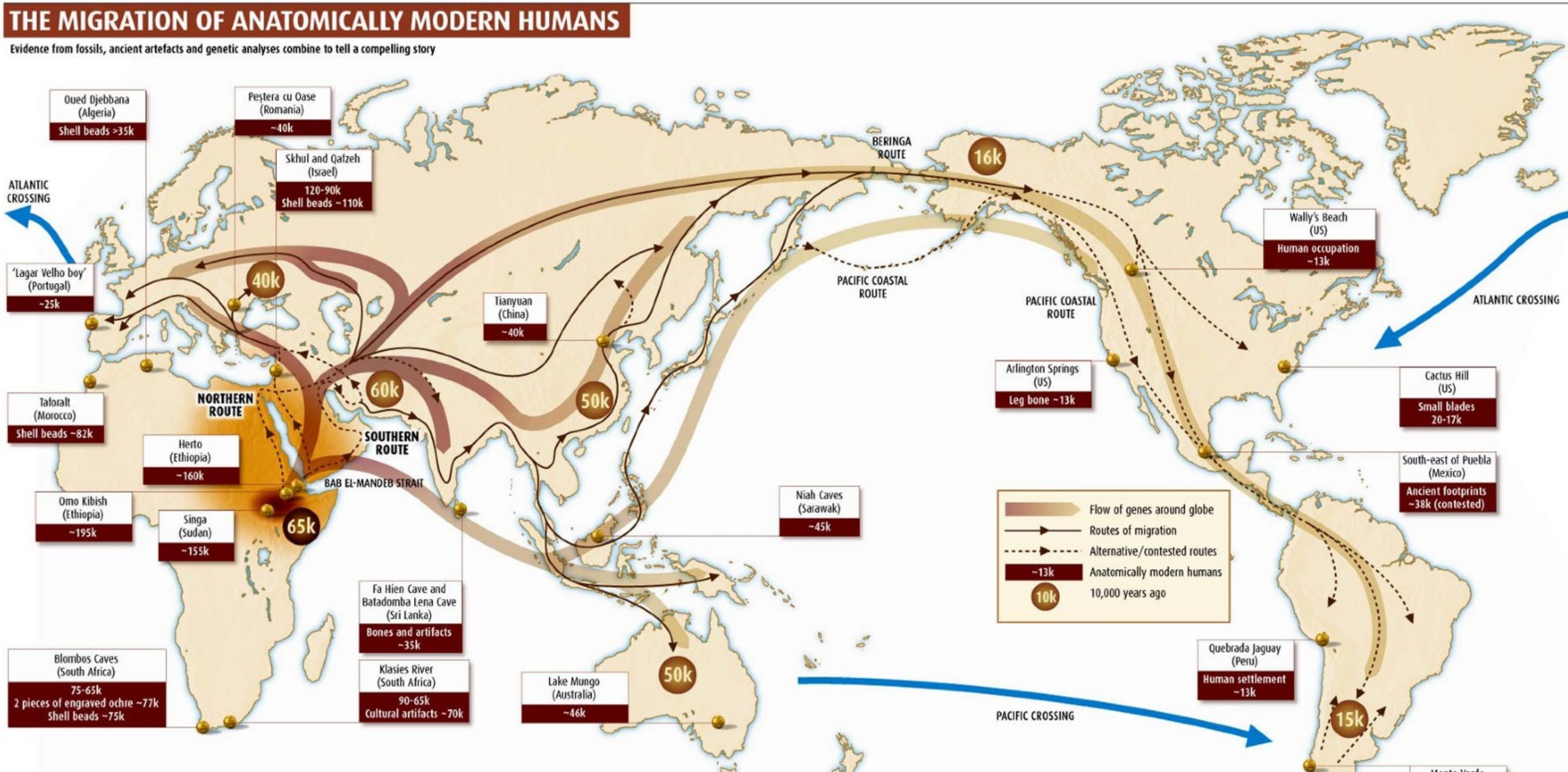
Lecture 1
Plant breeding and transformation

Origins of world crops





Nikolai Vavilov



Two routes jump out as prime candidates for the human exodus out of Africa. A northern route would have taken our ancestors from their base in eastern sub-Saharan Africa across the Sahara desert, then through Sinai and into the Levant. An alternative southern route may have charted a path from Djibouti or Eritrea in the Horn of Africa across the Bab el-Mandeb strait and into Yemen and around the Arabian peninsula. The plausibility of these two routes as gateways out of Africa has been studied as part of the UK's Natural Environment Research Council's programme "Environmental Factors in the Chronology of Human Evolution & Dispersal" (EFCHED).

During the last ice age, from about 80,000 to 11,000 years ago, sea levels dropped as the ice sheets grew, exposing large swathes of land now submerged under water and connecting regions now separated by the sea. By reconstructing ancient shorelines, the EFCHED team found that the Bab el-Mandeb strait, now around 30 kilometres wide and one of the world's busiest shipping lanes, was then a narrow, shallow channel.

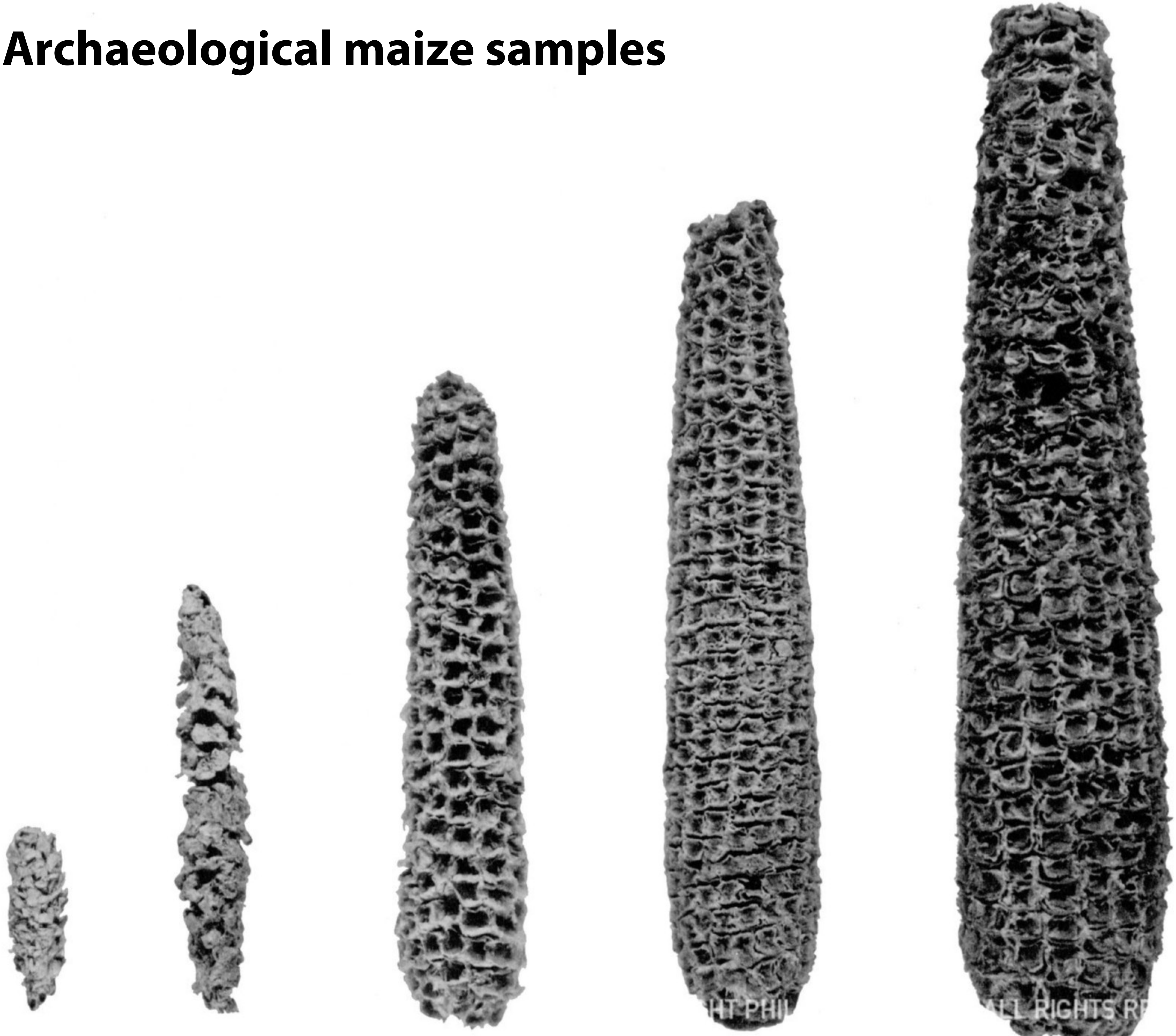
Early humans may have taken this southern route out of Africa. The northern route appears easier, especially given the team's finding that the Suez basin was dry during the last ice age. But crossing the Sahara desert is no small matter. EFCHED scientist Simon Armitage of the Royal Holloway University of London has found some clues as to how this might have been possible. During the past 150,000 years, North Africa has experienced abrupt switches between dry, arid conditions and a humid climate. During the longer wetter periods huge lakes existed in both Chad and Libya, which would have provided a "humid corridor" across the Sahara.

Armitage has discovered that these lakes were present around 10,000 years ago, when there is abundant evidence for human occupation of the Sahara, as well as around 115,000 years ago, when our ancestors first made forays into Israel. It is unknown whether another humid corridor appeared between about 65,000 and 50,000 years ago, the most likely time frame for the human exodus. Moreover, accumulating evidence is pointing to the southern route as the most likely jumping-off point.

Human migration and establishment of population centres

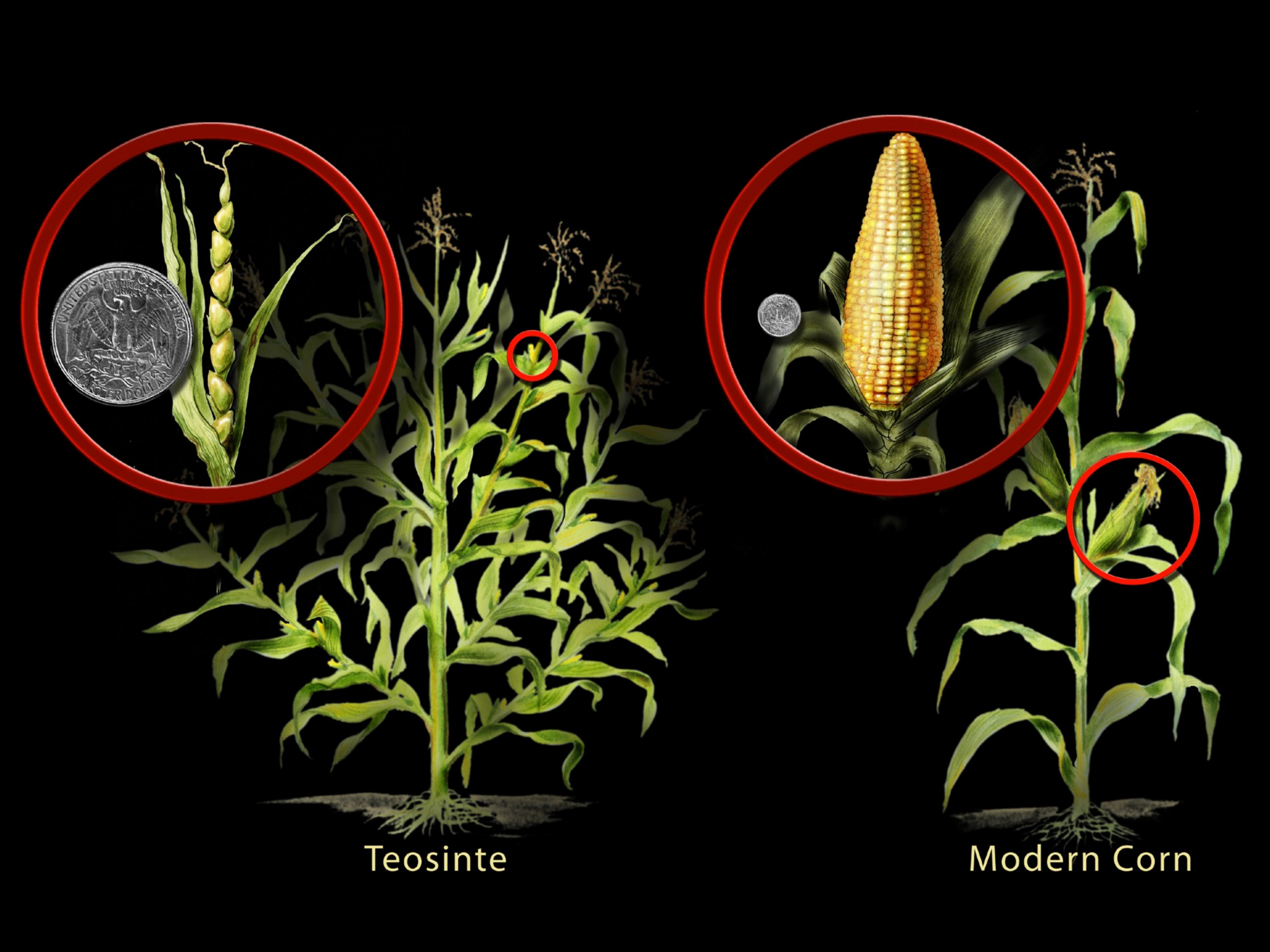
Recreation of an Aztec market as seen by first Europeans

Archaeological maize samples

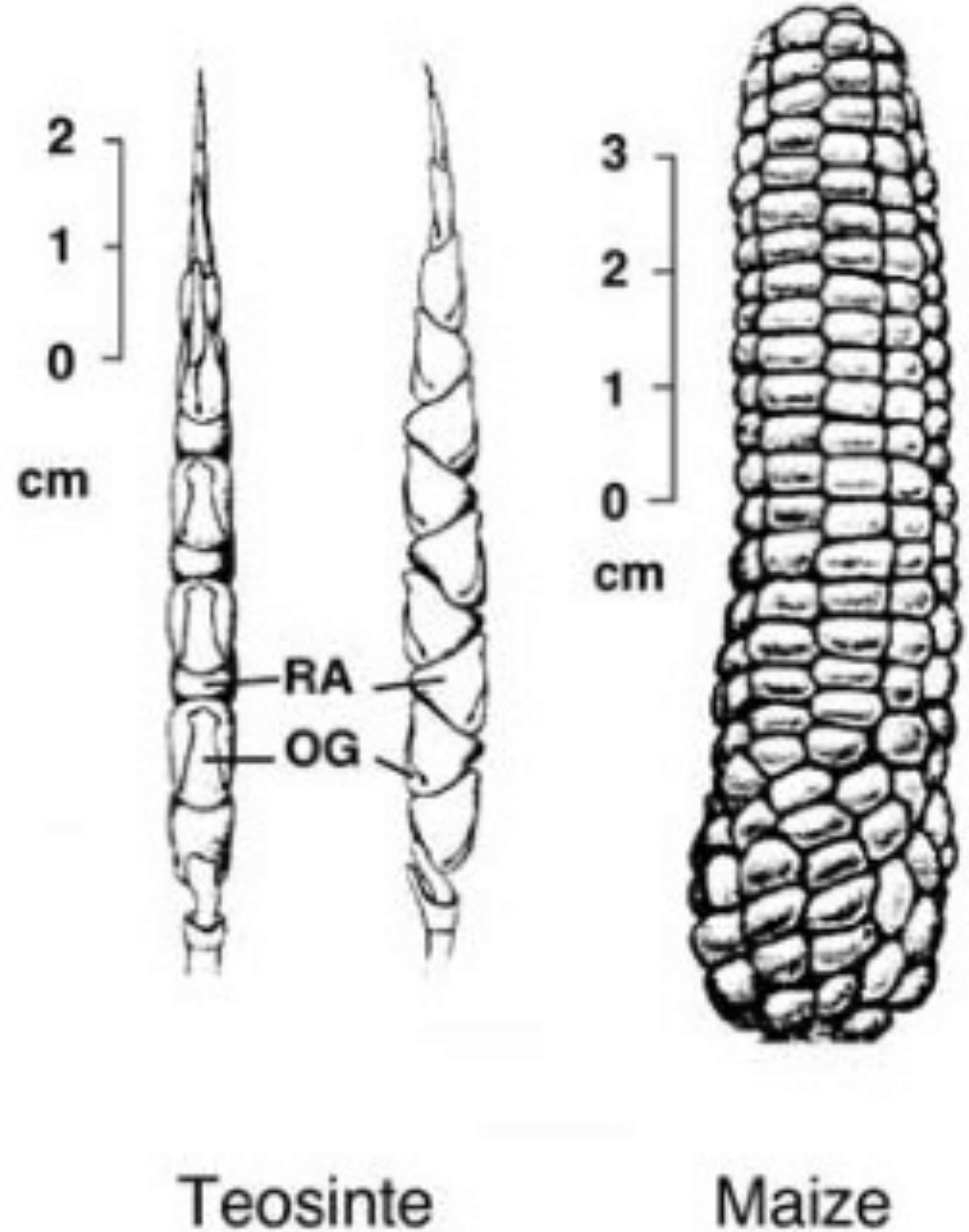


Domestication of maize

Figure 1. Domestication of corn. The upper image shows the mature inflorescence, or "ear" of teosinte (*Zea mays* ssp. *mexicana*), the probable wild progenitor of modern corn (or maize, *Zea mays* ssp. *mays* L.), shown in the lower image. The teosinte inflorescence has no cob, allowing the seed to separate and disperse easily when they are mature. Selection over time by early agriculturalists resulted in types that retained their seed on the ear, leading to the development of the cob. Modern breeding has greatly increased the size and number of seed per ear. (Courtesy J. Doebley, University of Wisconsin)

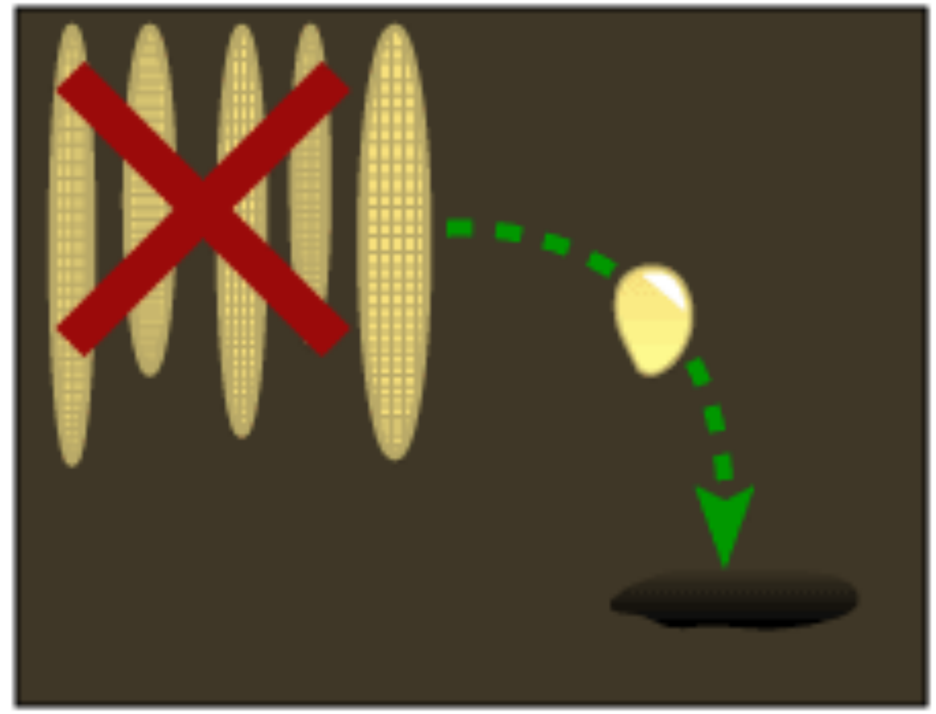


Teosinte
Modern Corn

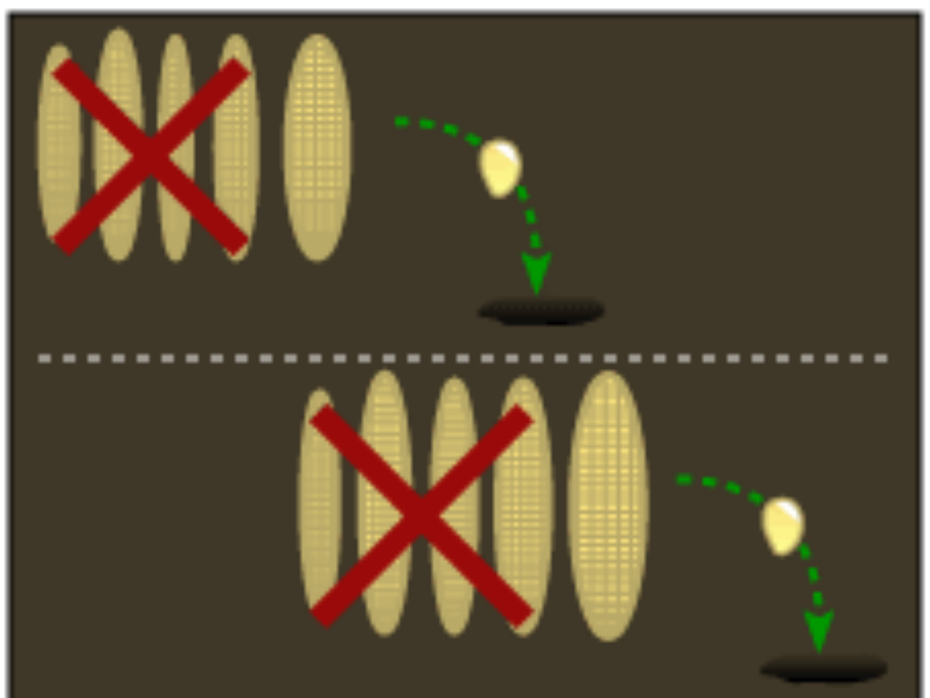

2
1
0
cm
RA
OG
3
2
1
0
cm
Teosinte
Maize

Maize breeding

1. Natural variation occurs in the wild population.



2. Seeds for the next generation are chosen only from individuals with the most desirable traits.



3. Repeat this process for several generations.

4. Over time, the quality of the crop increases.

Image from University of California Museum of Paleontology, Understanding Evolution - www.evolution.berkeley.edu

Examples of some of the 59 native Mexican maize landraces.

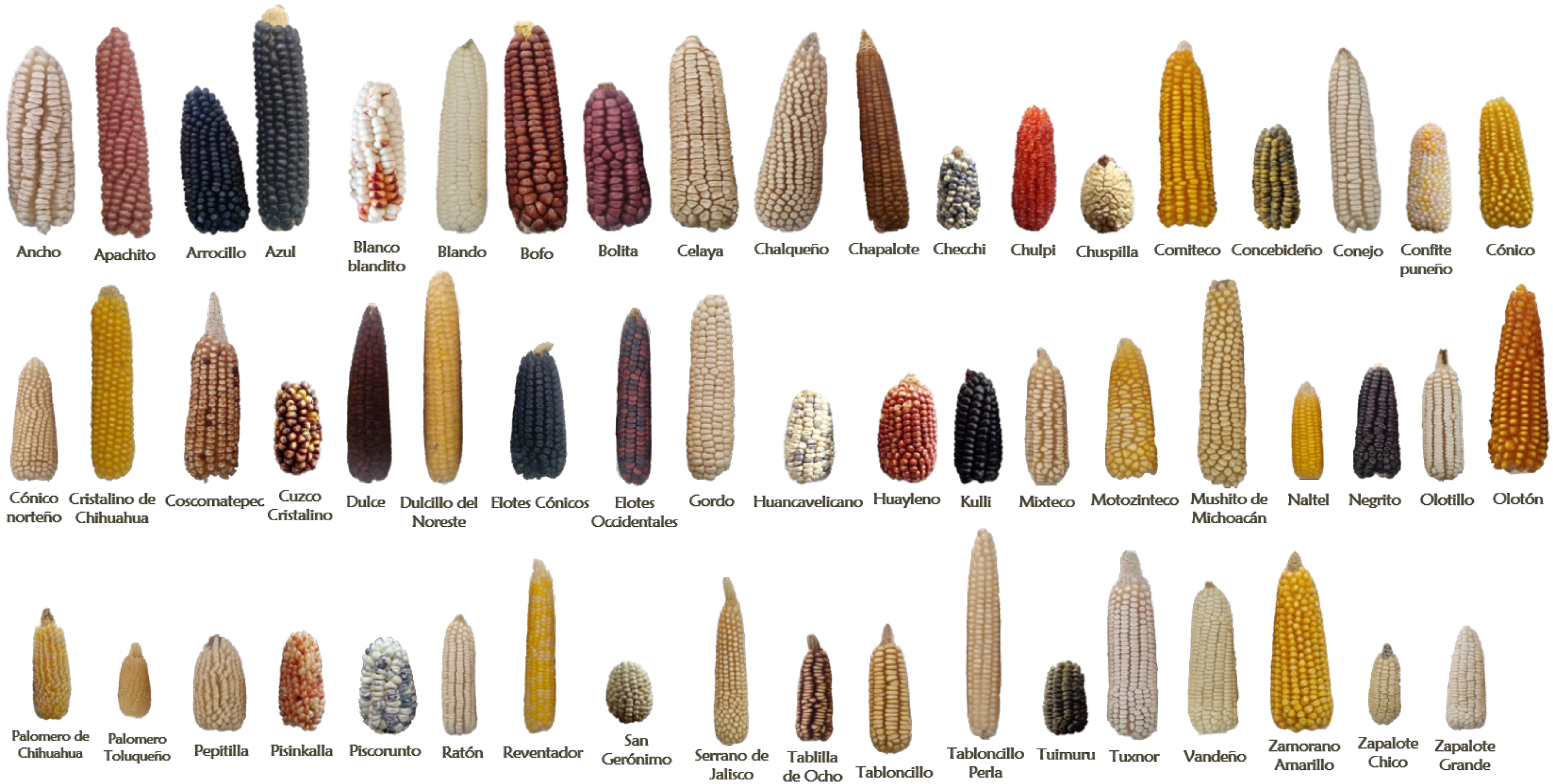
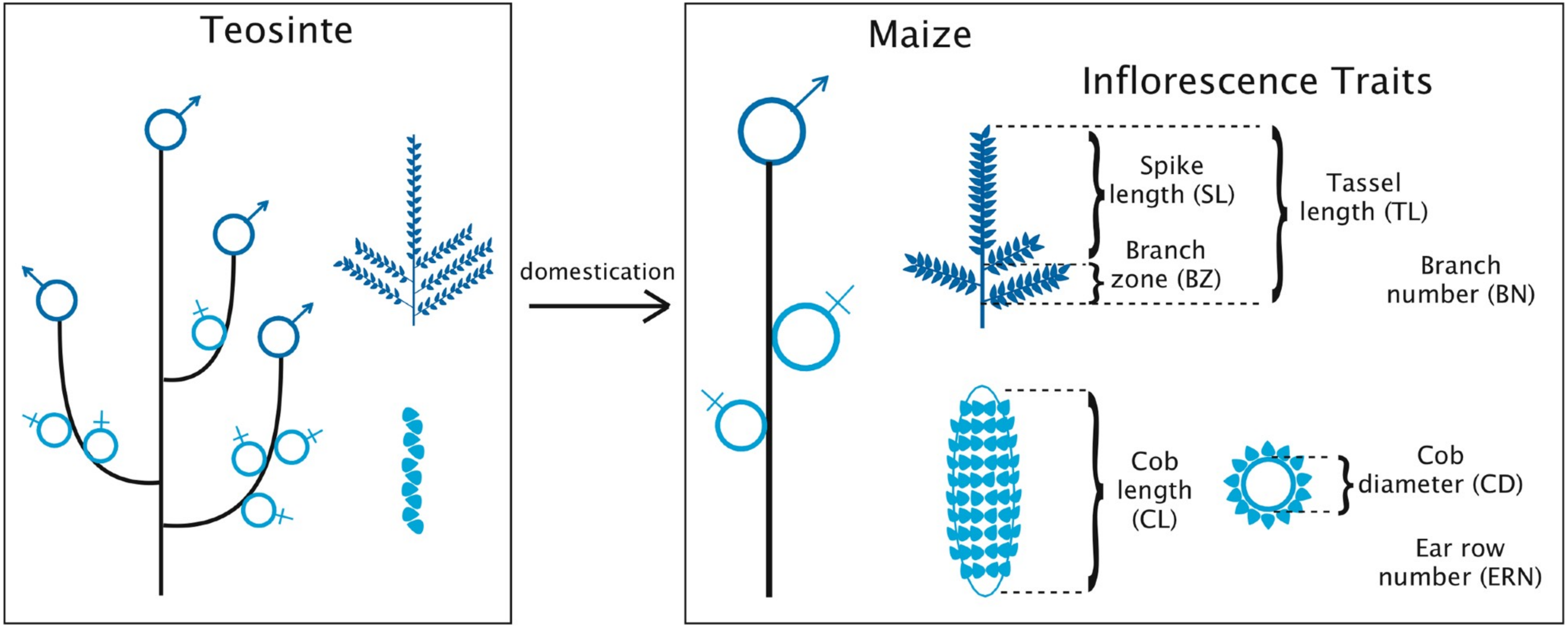
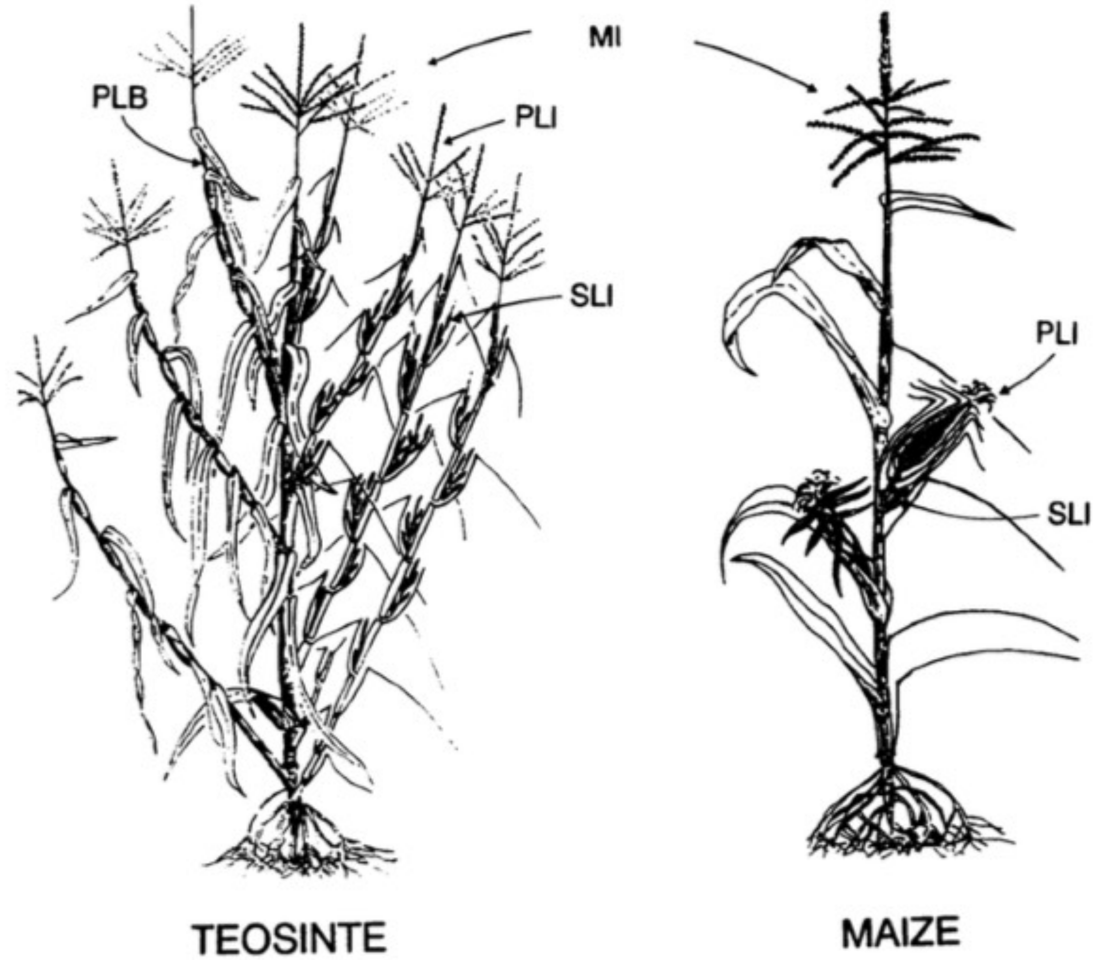
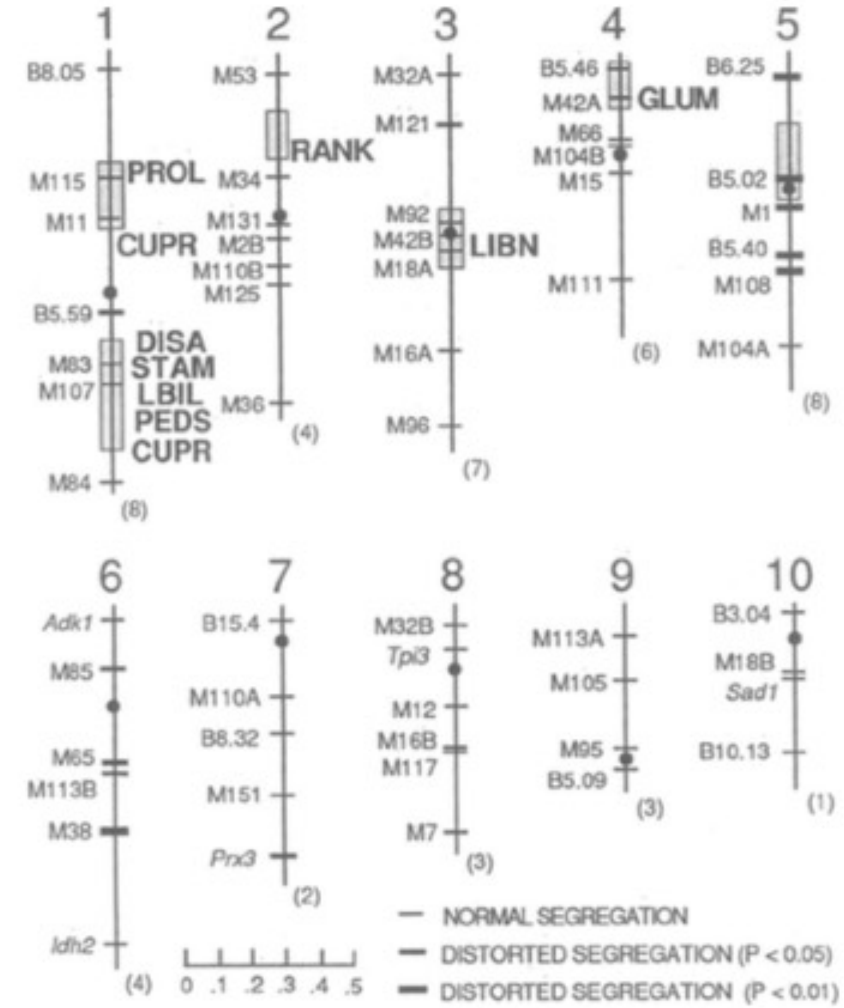


Photo courtesy of CIMMYT Maize Germplasm Bank



Maize domestication was accompanied by modification of many plant traits related to agronomy, growth and yield





Major differences between maize and teosinte map to few loci

Table 1. List of principal traits distinguishing maize and teosinte

Trait	Description
CUPR (cupules per rank)	Number of cupules in a single rank
DISA (disarticulation score)	Tendency of ear to shatter (1–10 scale)
GLUM (glume score)	Hardness and angle of outer glume (1–10 scale)
LBIL (lateral branch internode)	Average length of internodes on the primary lateral branch
LIBN (branch number)	Number of branches in primary lateral inflorescence
PEDS (pedicellate spikelet score)	Percentage of cupules lacking the pedicellate spikelet
PROL (prolificacy)	Number of ears on the primary lateral branch
RANK (rank)	Number of rows of cupules
STAM (staminate score)	Percentage of male spikelets in primary lateral inflorescence

Doebley *et al*., PNAS (USA) 87: 9888-9892 (1990)



Maize farming in the US Midwest circa 1900

Genetic crossing to produce hybrid Maize

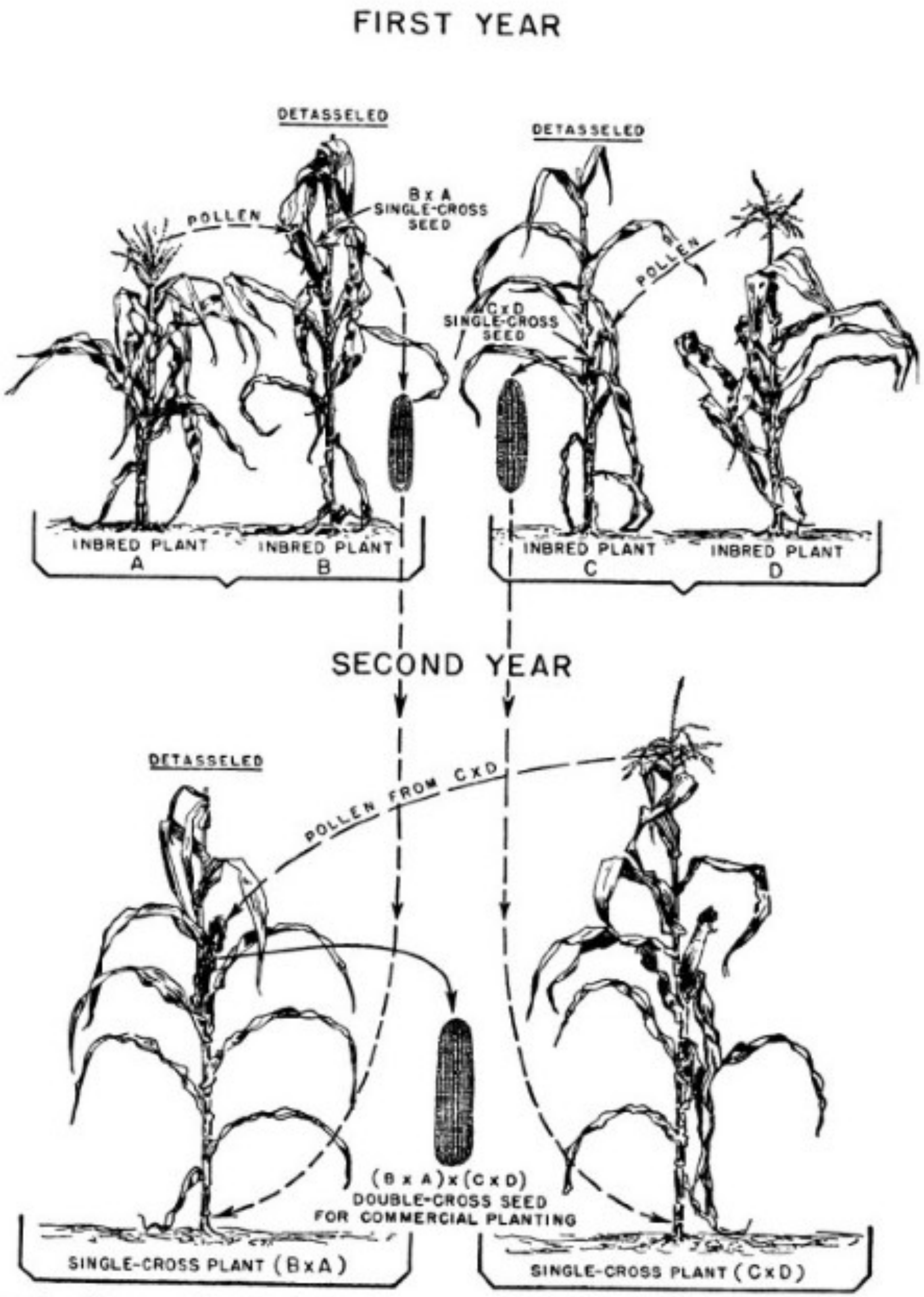
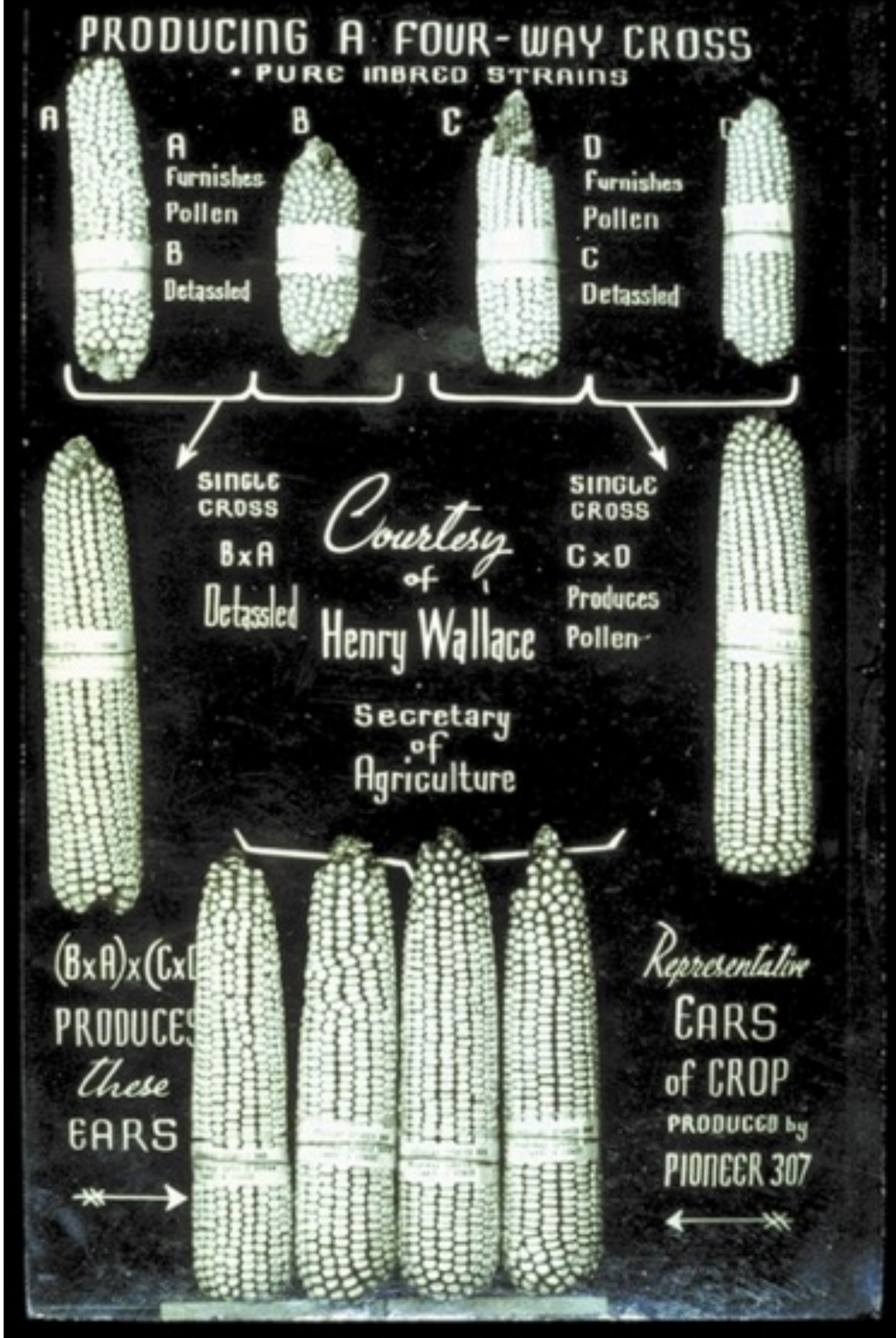


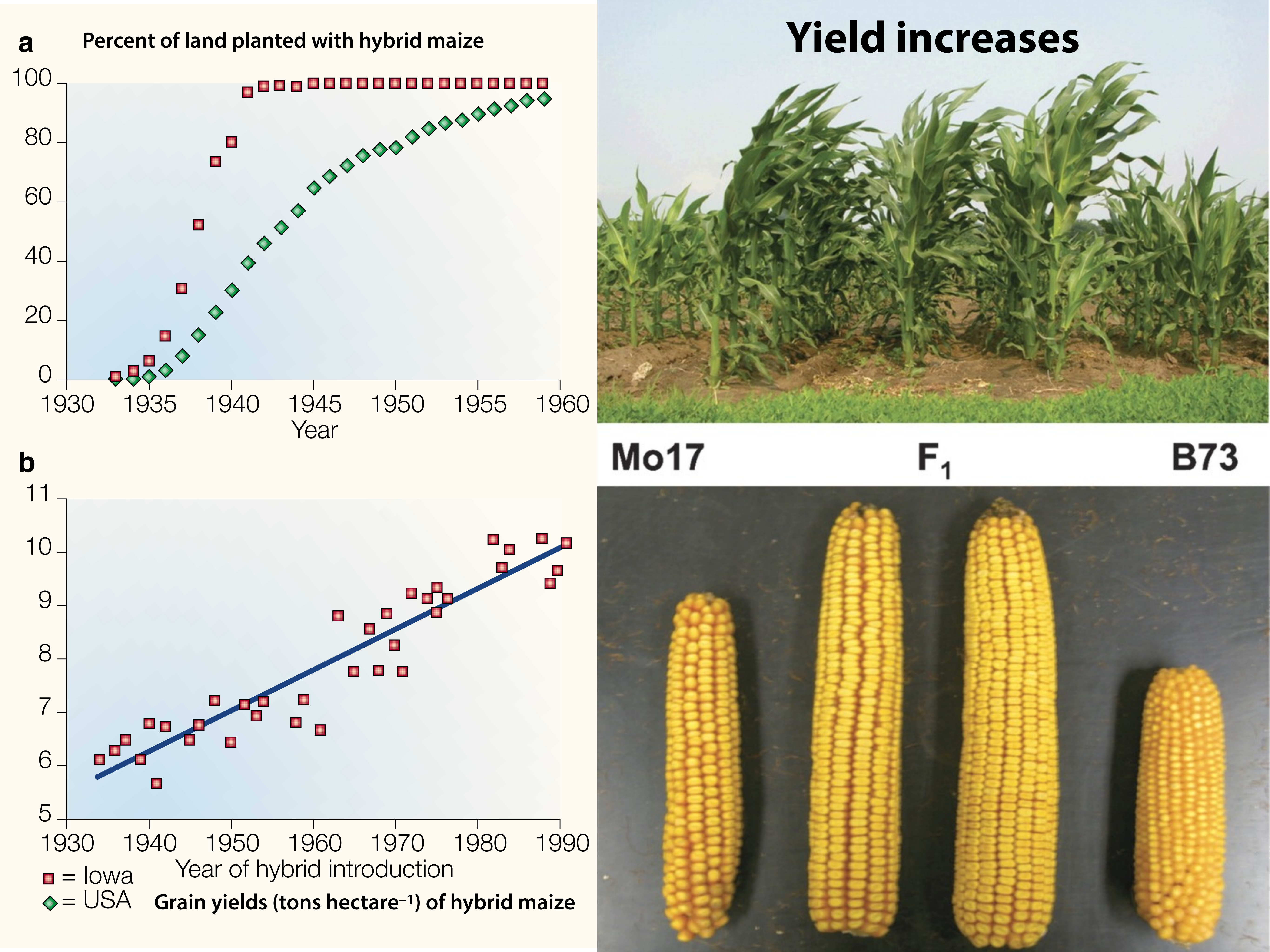
FIGURE 4.—Diagram of method of crossing inbred plants and the resulting single crosses to produce double-cross hybrid seed. A field grown from such hybrid seed is shown on the cover of this bulletin.



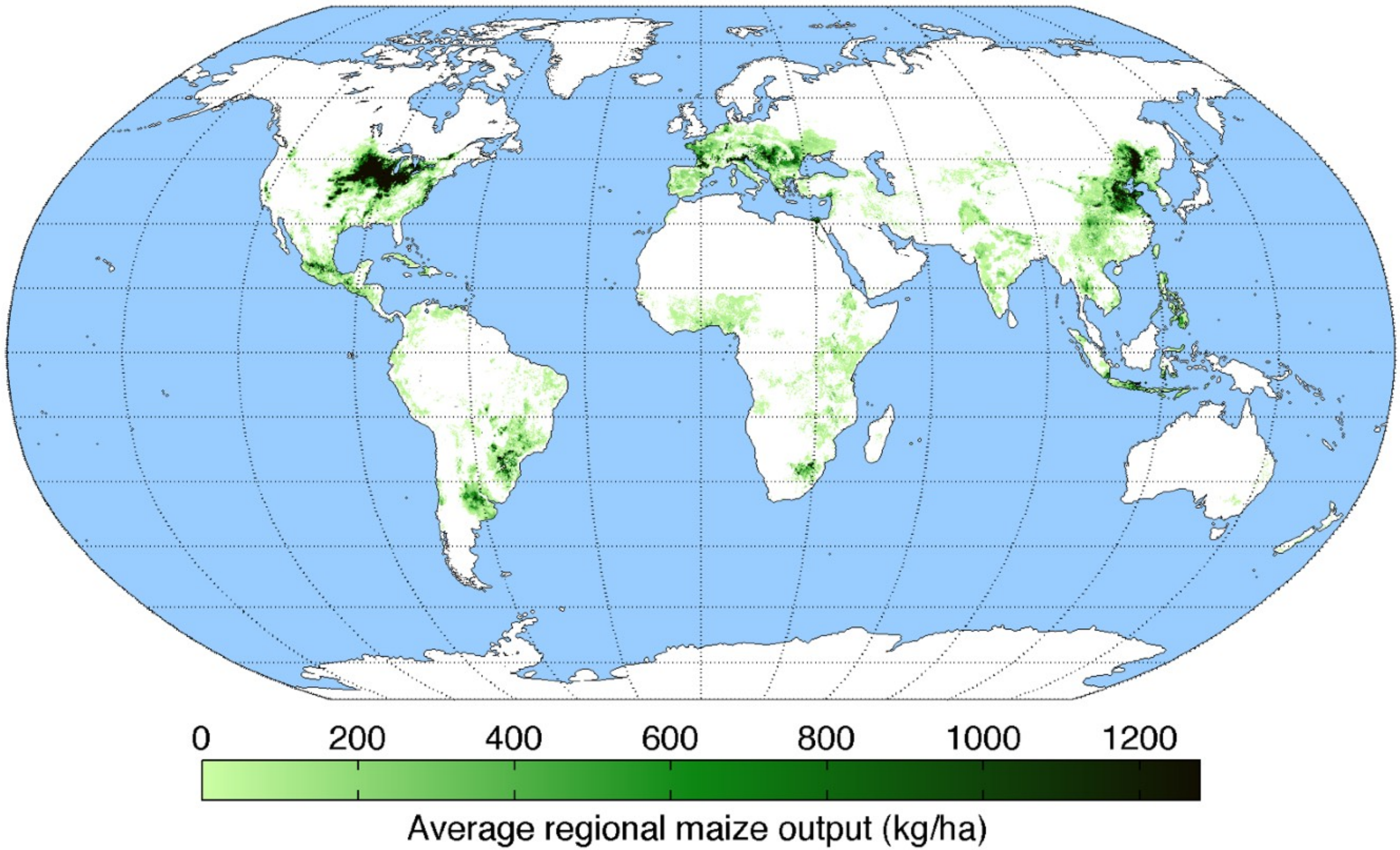
Roswell Garst: marketing and adoption of hybrid maize.

Growth of seed companies (like Garst Seed) and increasing use of fertilisers and pesticides.

Beginning of modern agriculture and integration of industrialised approaches to food production.


a
Percent of land planted with hybrid maize
100
80
60
40
20
0
1930
1935
1940
1945
1950
1955
1960
Year
b
11
10
9
8
7
6
5
1930
1940
1950
1960
1970
1980
1990
Year of hybrid introduction
= Iowa
= USA
Grain yields (tons hectare−1) of hybrid maize
Yield increases
Mo17
F1
B73

Maize is the world's most successful crop



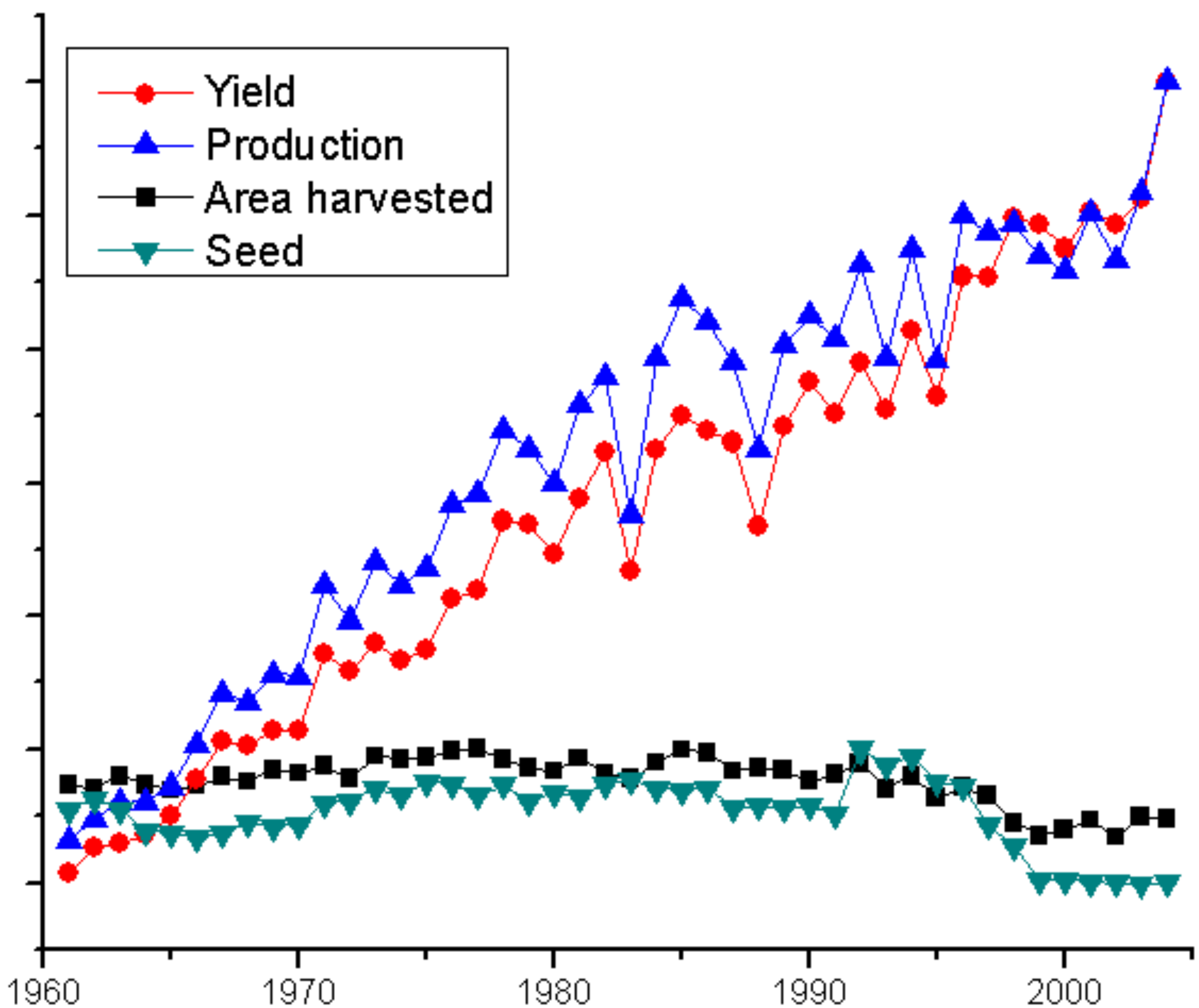

Norman
Borlaug and
the Green
Revolution

La Moisson (1874) - Léon Augustin Lhermitte


SONORA-64

The Green Revolution

Total world production of coarse grain, 1961-2004



Source: FAO

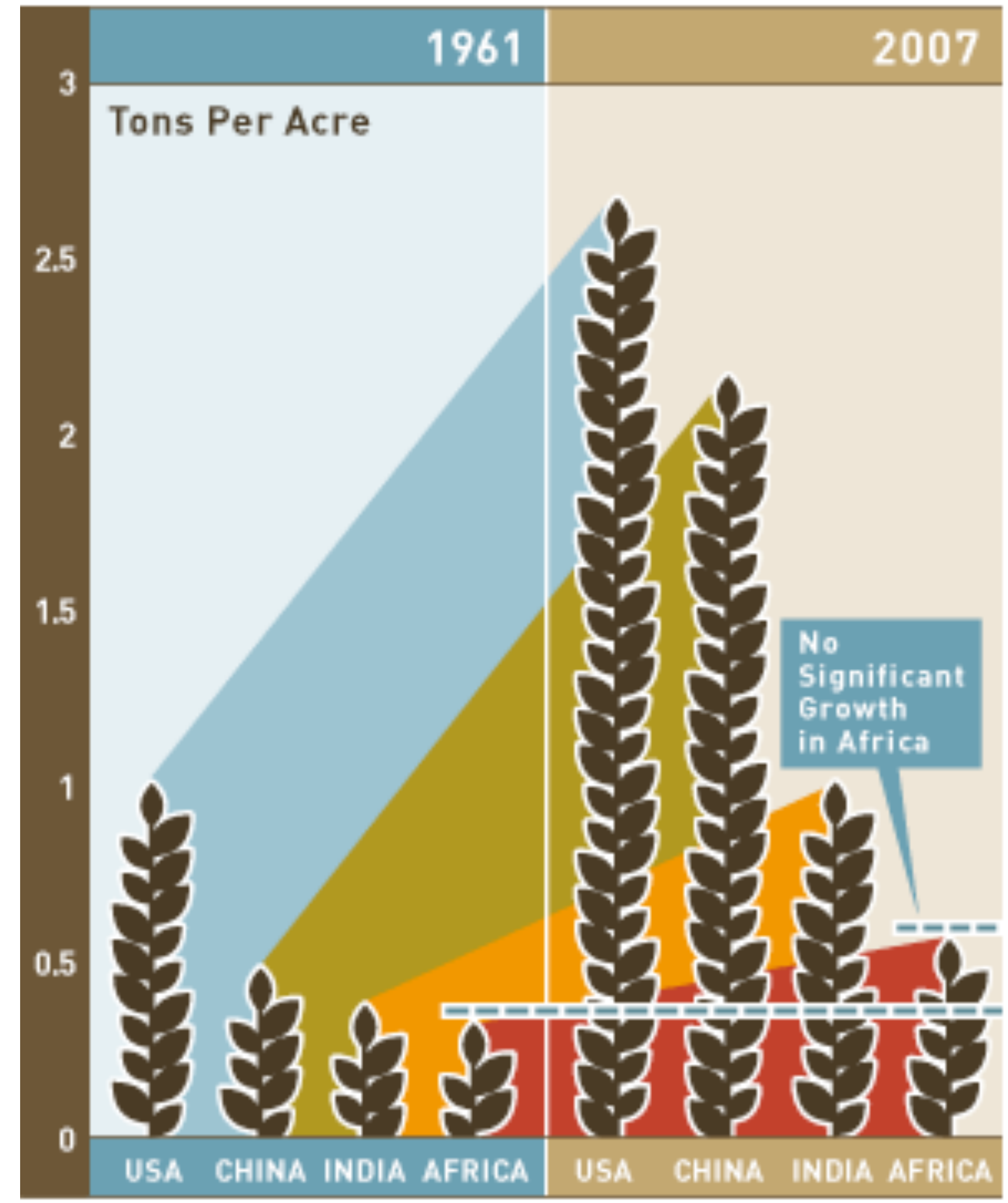
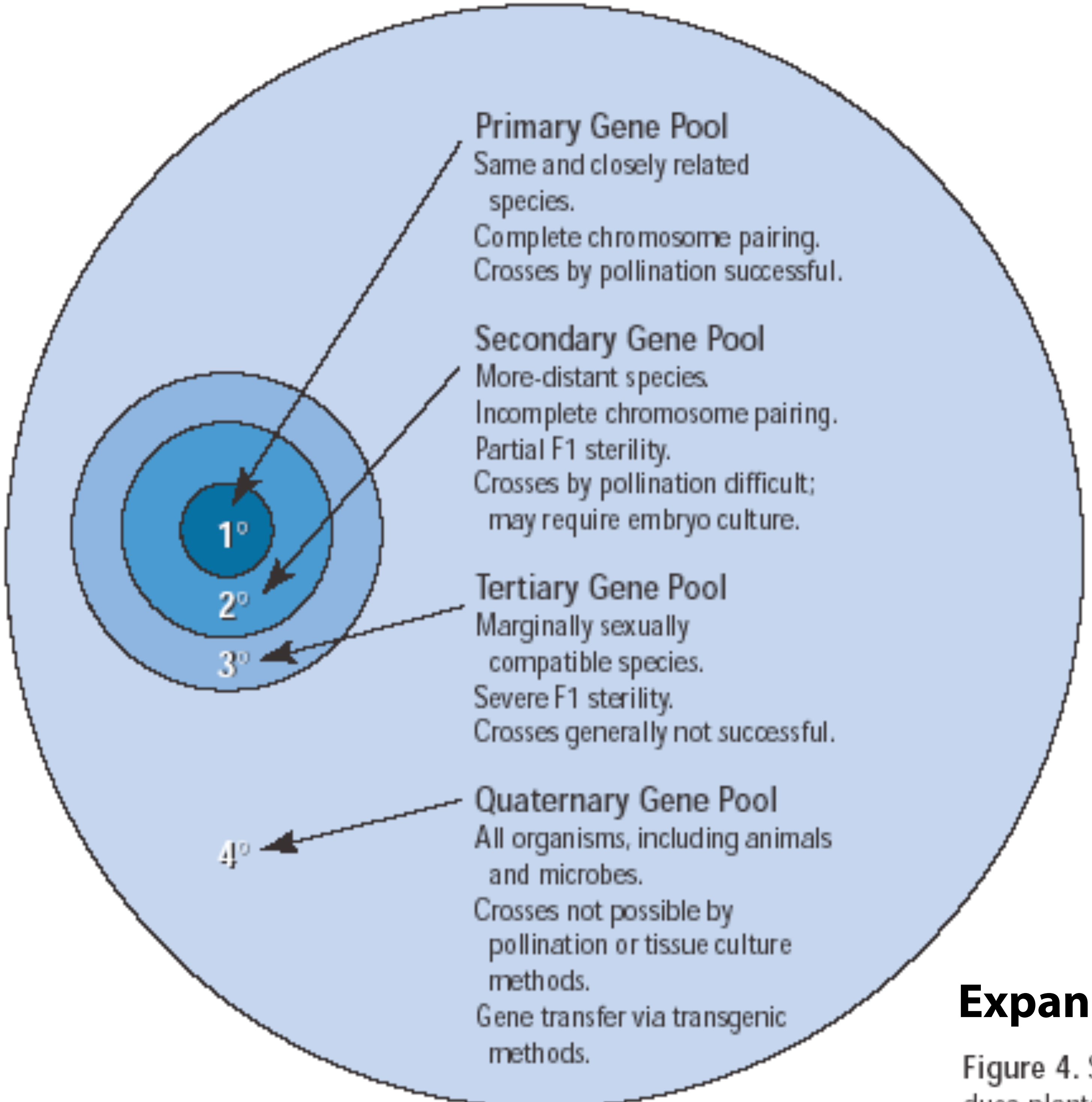


CHART 4: Africa missed out on the Green Revolution.



Expansion of the gene pool

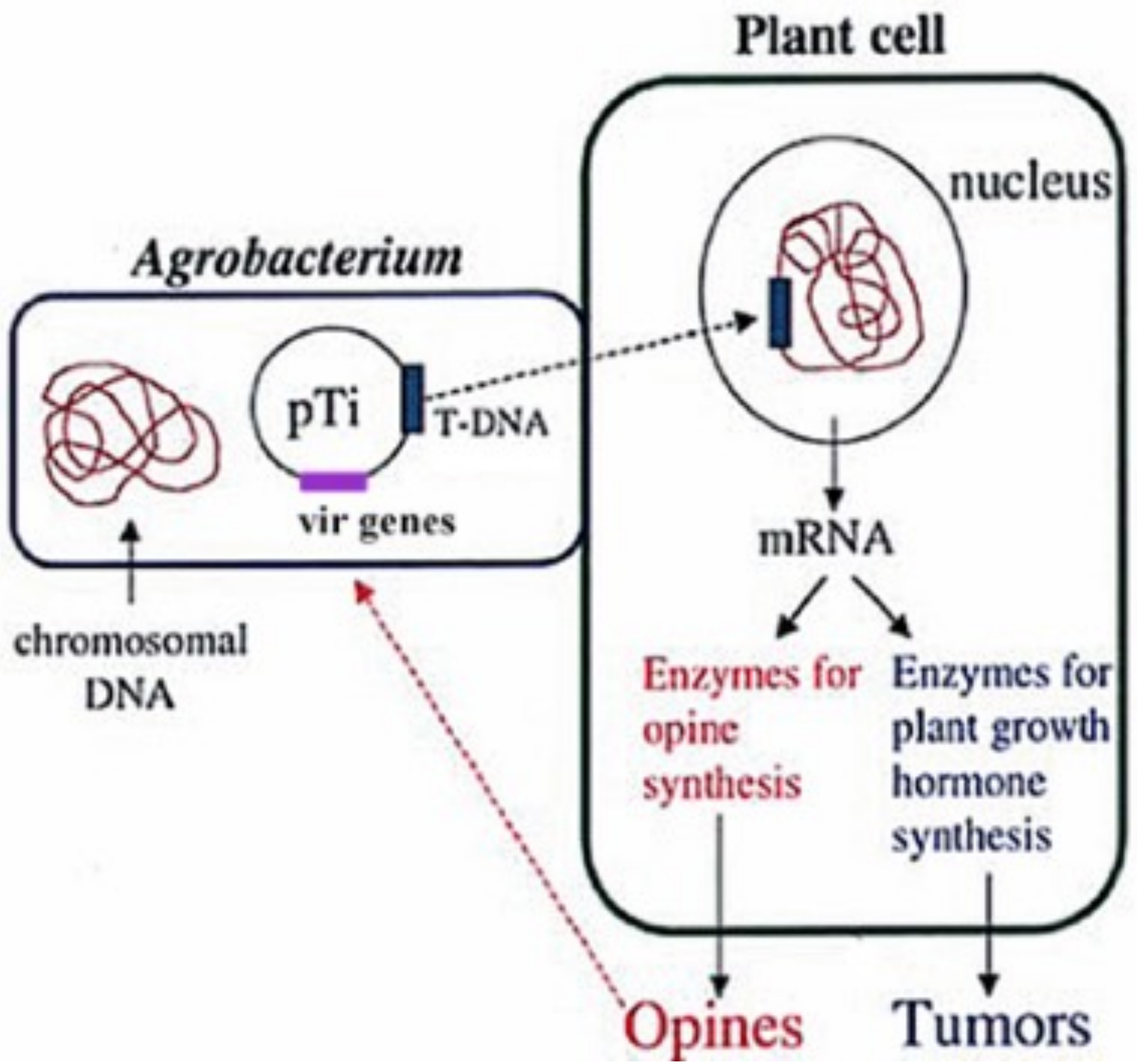
Figure 4. Sources of genetic variation for crop improvement. Breeders produce plants with improved combinations of genes by crossing (hybridization) and selection within the primary gene pool, which is comprised of a crop species and its closest related wild species. Tissue culture methods such as embryo culture are commonly used to enable genes from the secondary gene pool to be transferred into the cultivated species. Other methods such as somatic hybridization sometimes allow genes from the tertiary gene pool of more distantly related species to be transferred into crop plants. The immense gene resources of the quaternary gene pool (essentially all other organisms) can be used for crop improvement only via transgenic methods.

Plant transformation

D.I. Păcurar et al. / Physiological and Molecular Plant Pathology 76 (2011) 76–81

Fig. 1. Crown gall tumor on an oak tree.

Crown gall disease



Agrobacterium transfers genes for tumour growth and opine biosynthesis to plant cells

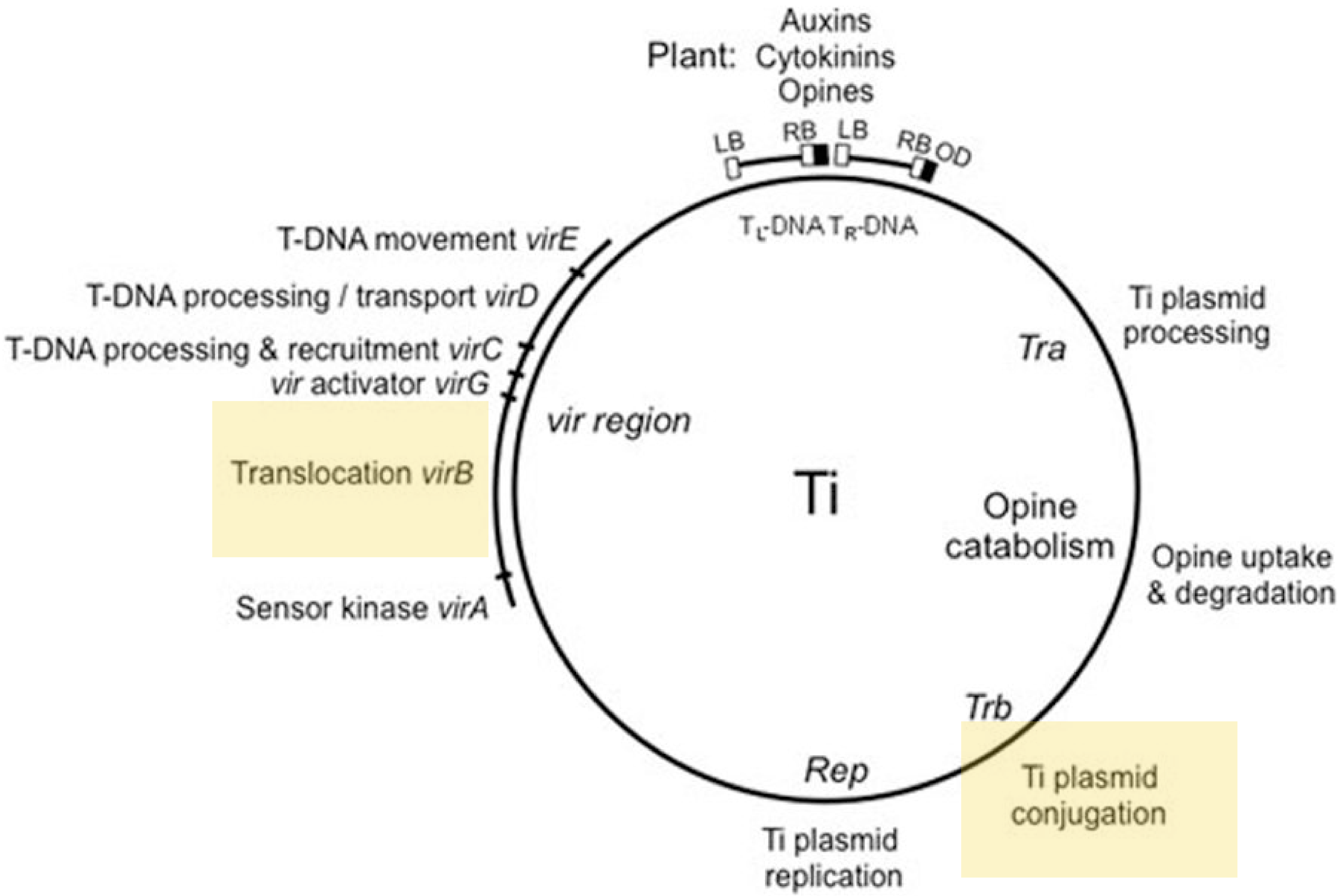
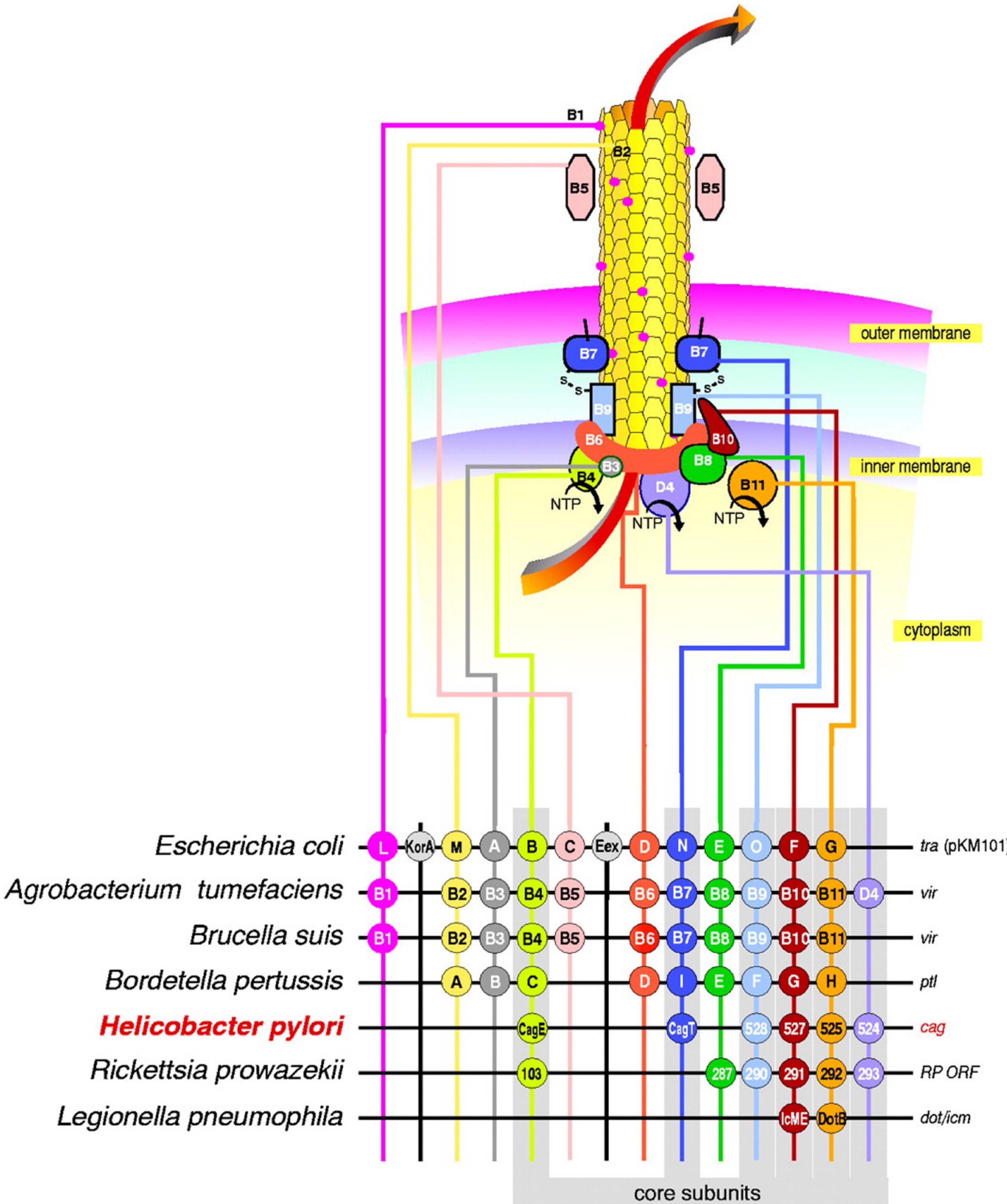
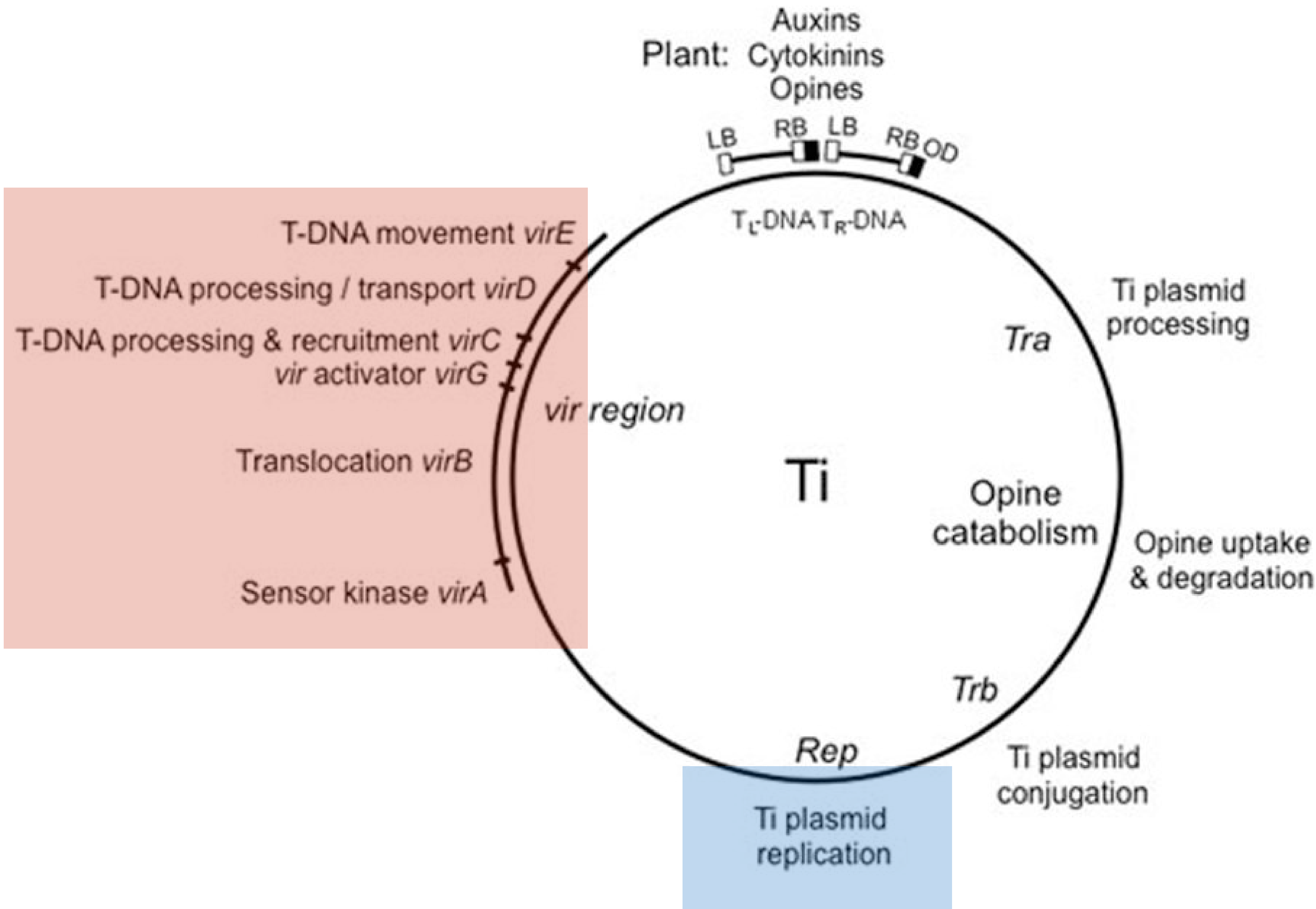


Fig. 1.

Schematic of octopine-type Ti plasmid pTiA6 showing locations of genes coding for plasmid maintenance (*rep*), infection of plant cells (*vir* region, T-DNA), cell survival in the tumor environment (opine catabolism), and conjugative transfer of the Ti plasmid to recipient agrobacteria (*tra* and *trb*). The various contributions of the *vir* gene products to T-



B1
B2
B5
B5
outer membrane
B7
B7
B9
B9
B6
B10
B8
B3
B4
D4
B11
inner membrane
NTP
NTP
NTP
cytoplasm
Escherichia coli
L KorA M A B C Eex D N E O F G
tra (pKM101)
Agrobacterium tumefaciens
B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 D4
vir
Brucella suis
B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11
vir
Bordetella pertussis
A B C D I E F G H
ptl
Helicobacter pylori
CagE CagT 528 527 525 524
cag
Rickettsia prowazekii
103 287 290 291 292 293
RP ORF
Legionella pneumophila
IcME DotB
dot/icm
core subunits



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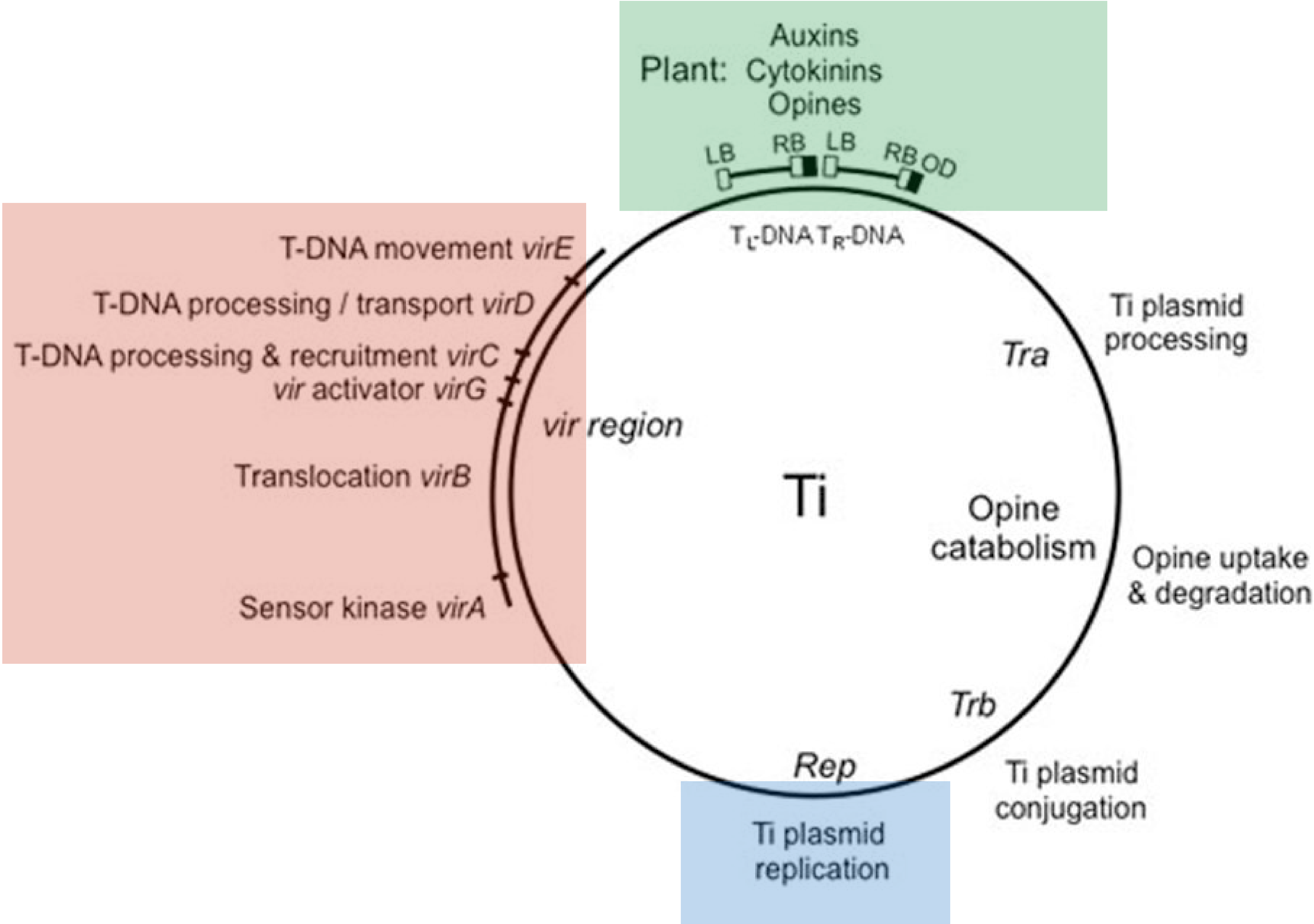

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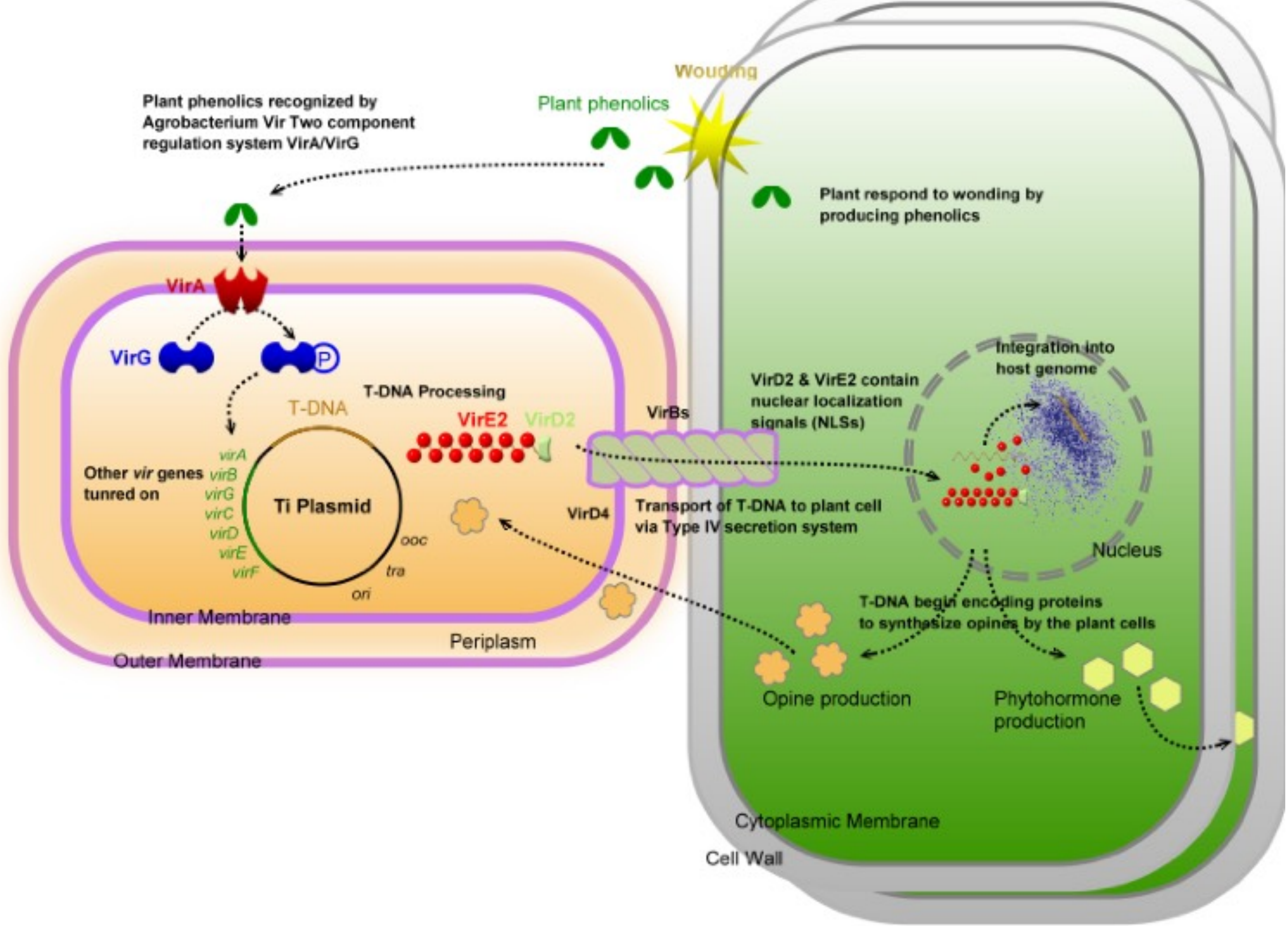
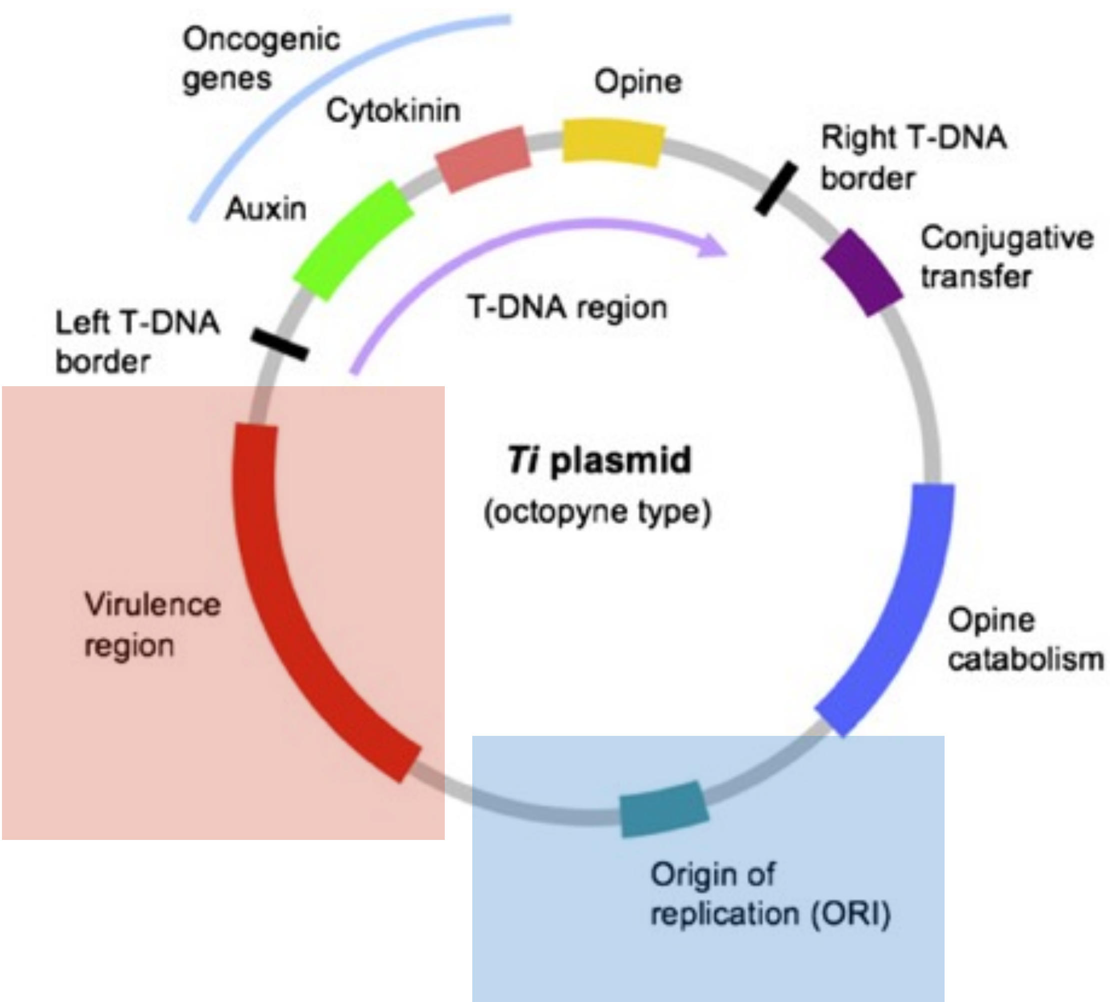
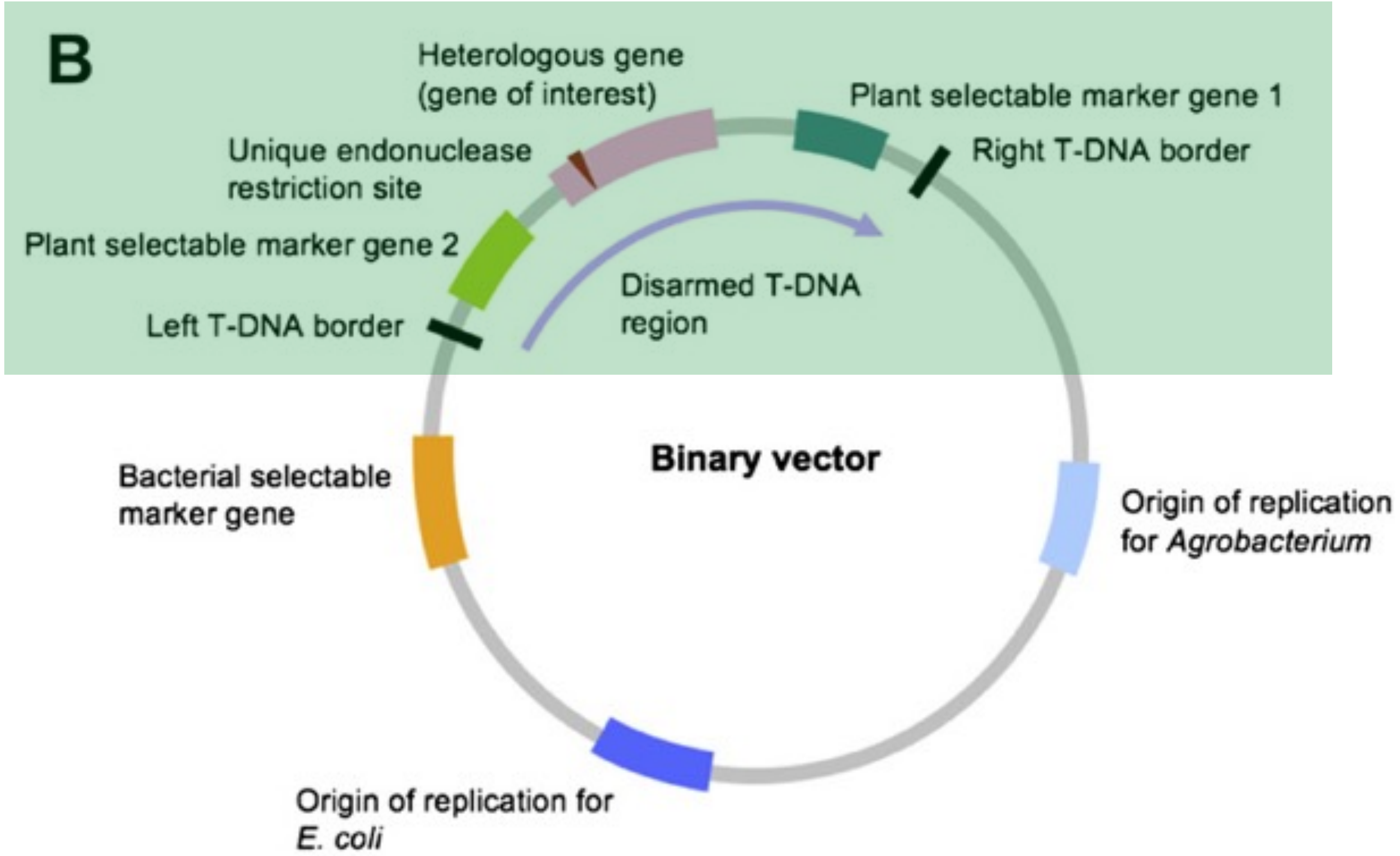
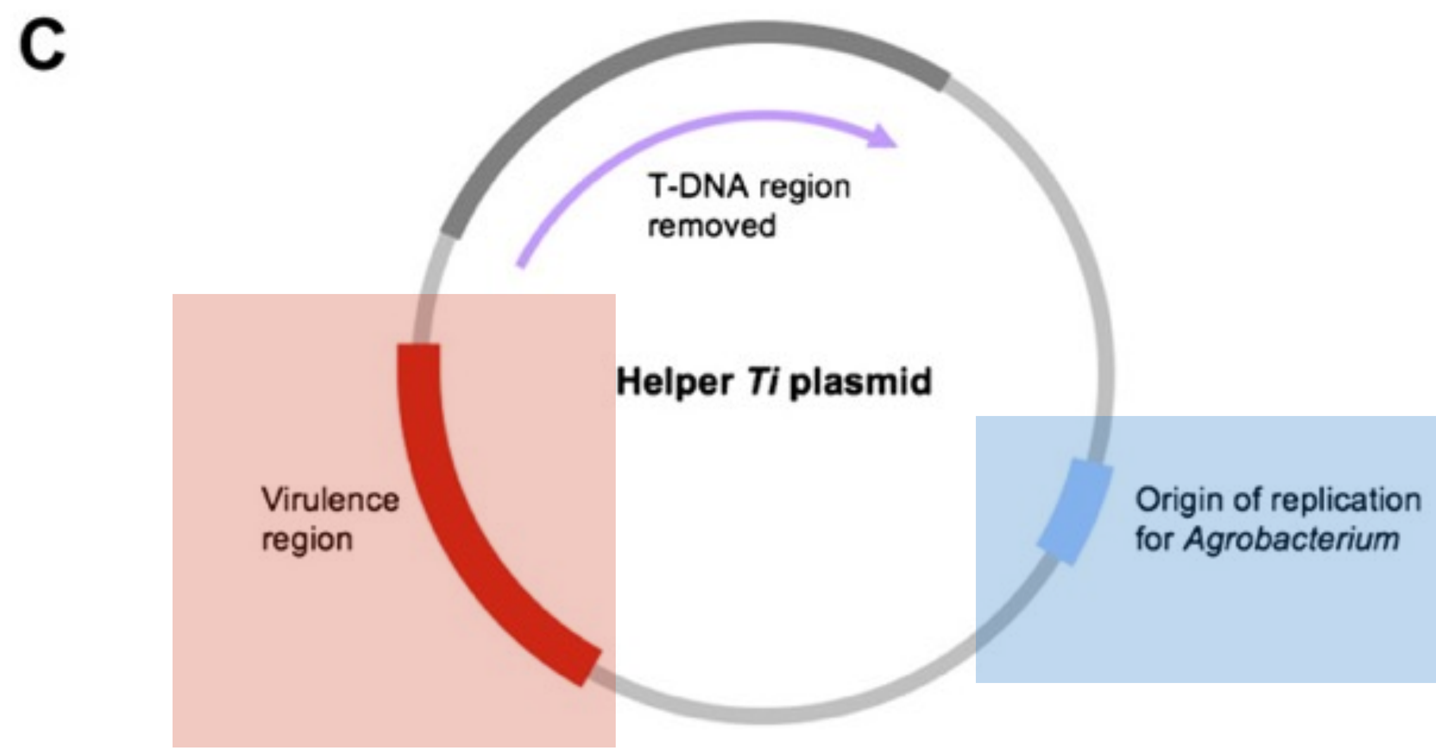


Agrobacterium transformation of plant cells is mediated by intercellular signalling, attachment, virulence protein catalysed DNA transfer to the nucleus and genome integration.

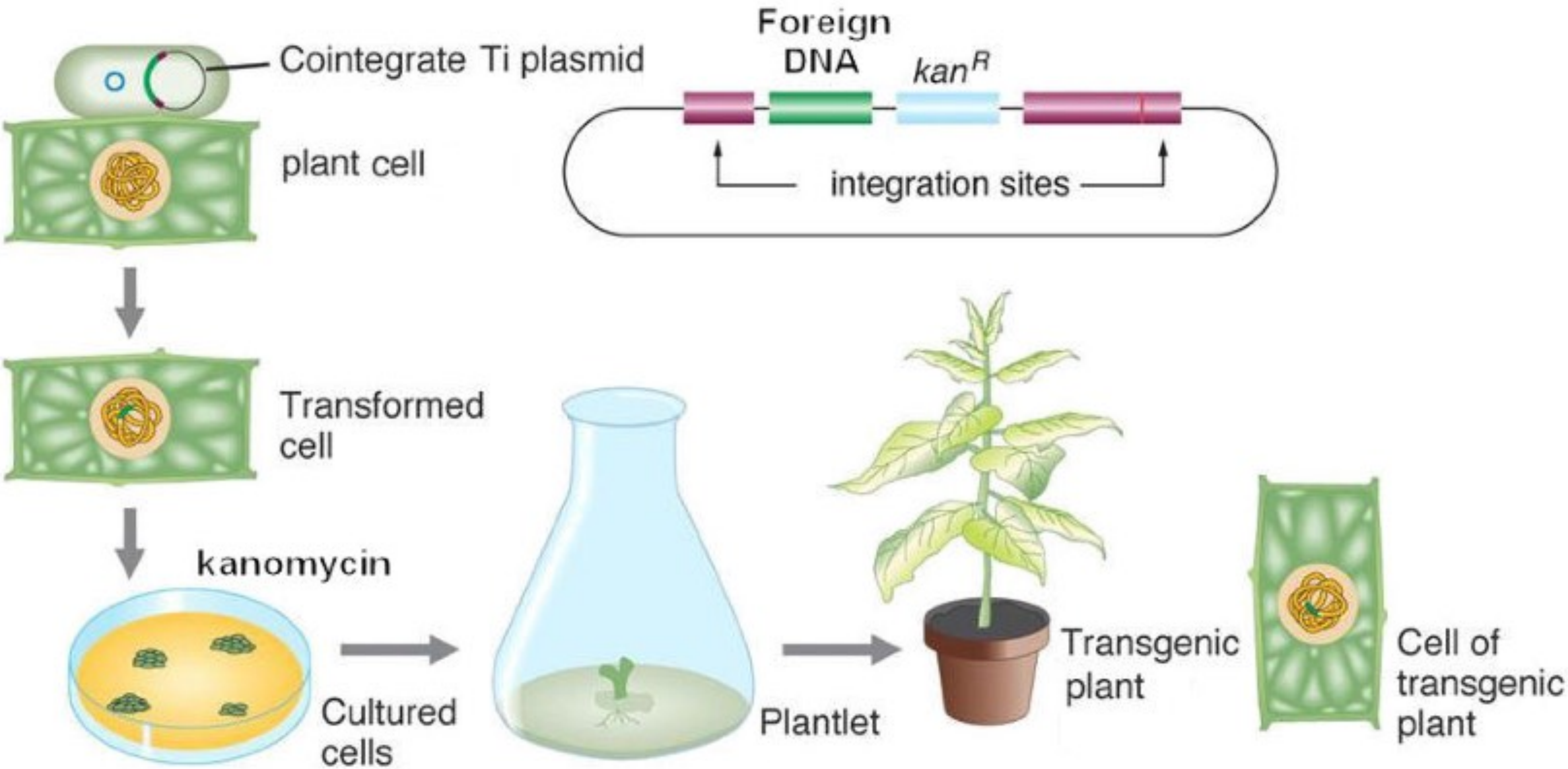
Removal of the tumour-forming genes, and separation of the virulence functions (Vir genes) on a separate "helper" plasmid allows simpler manipulation of the T-DNA and genes to be inserted into the plant genome.







"Disarmed" binary plasmids



Summary of Agrobacterium mediated gene transfer and plant regeneration

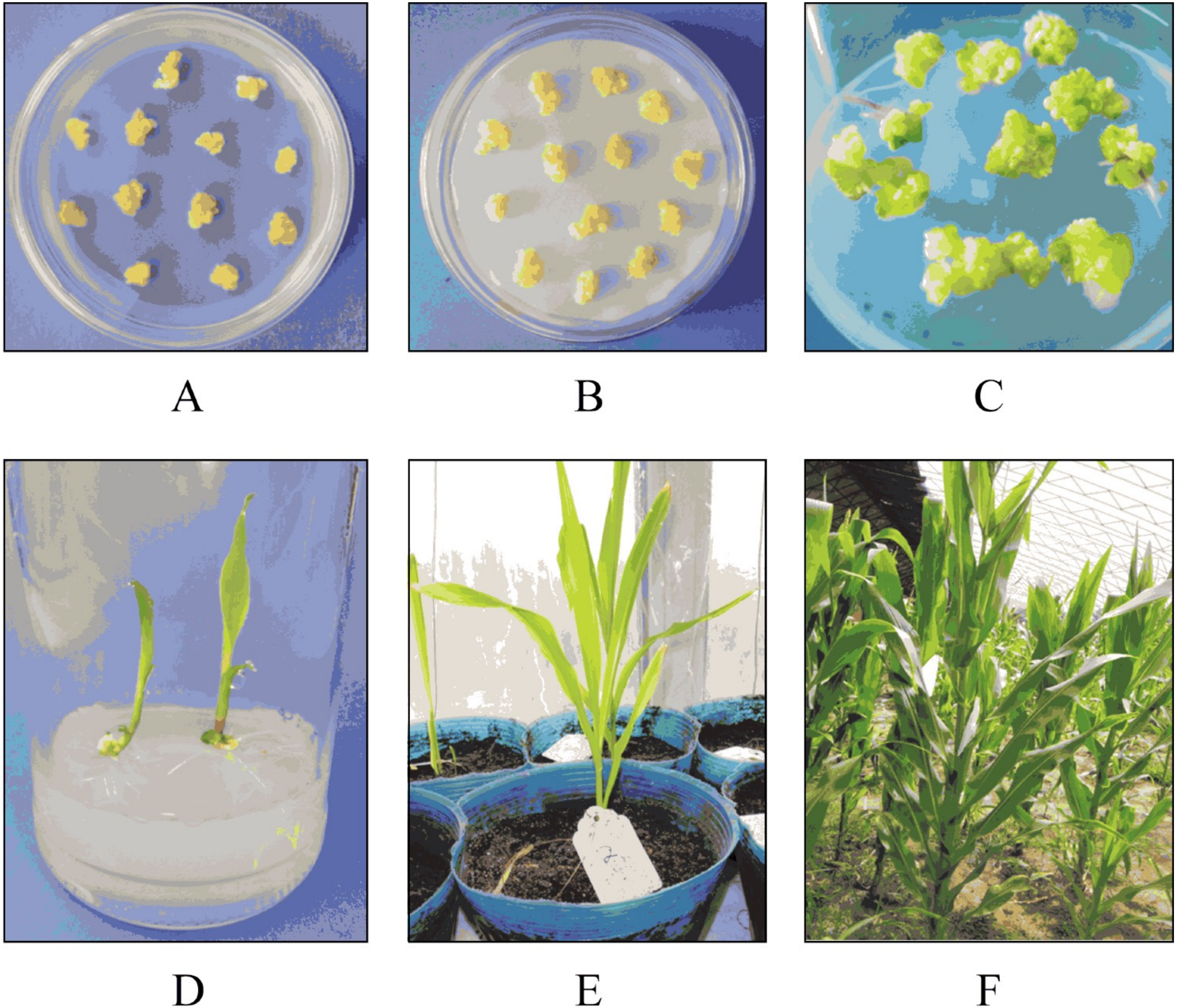
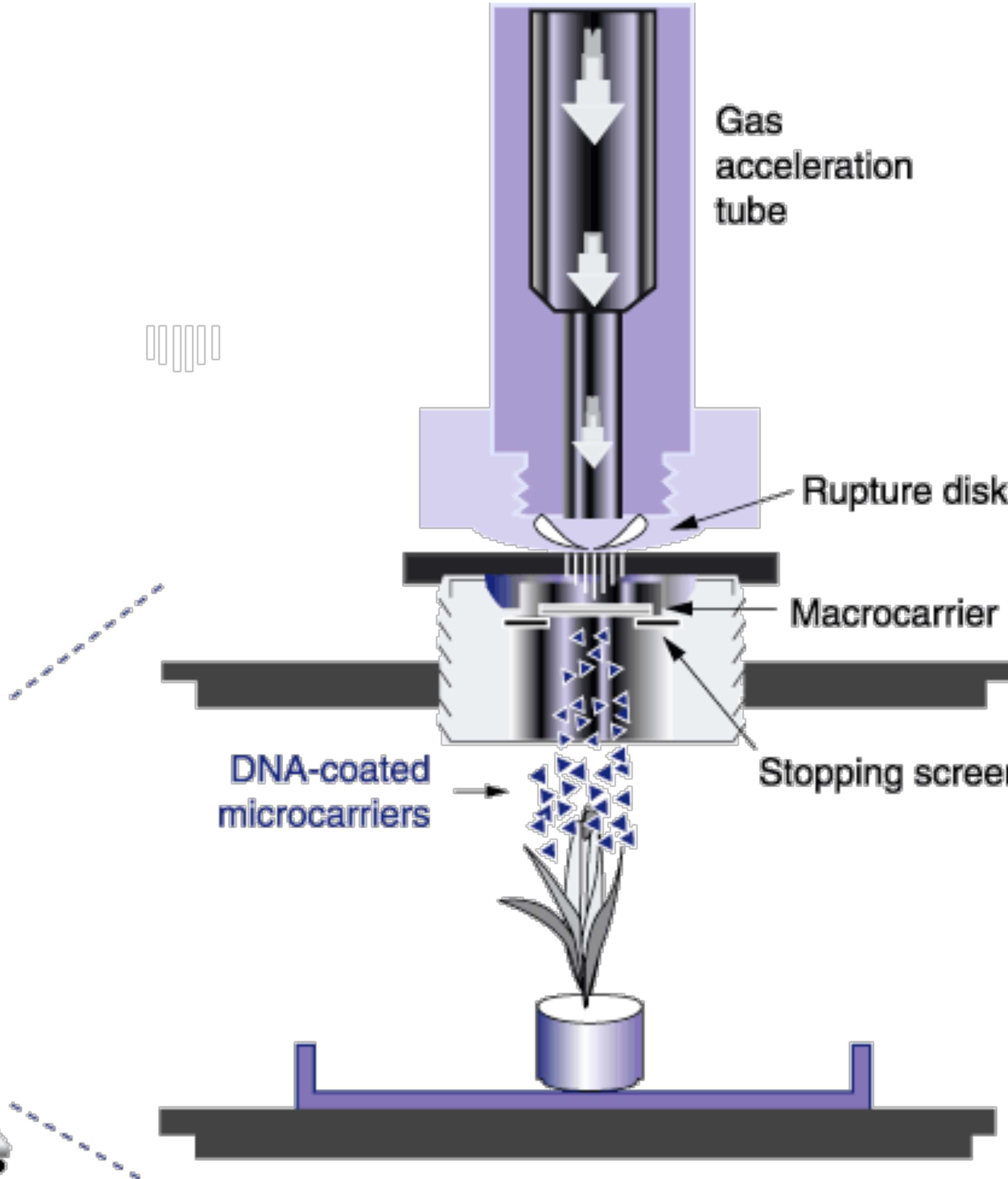
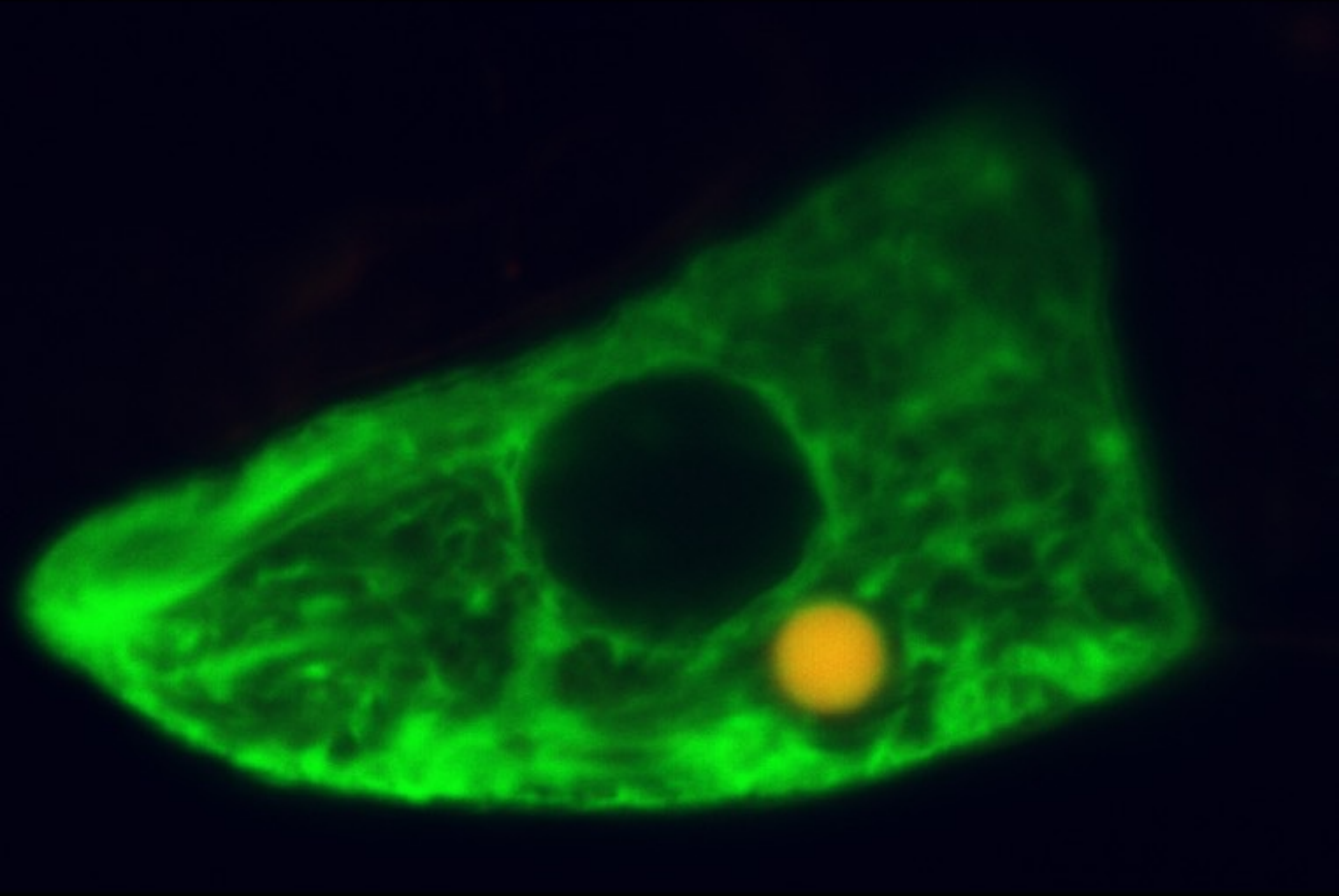


Figure 4 Regeneration of transgenic maize plants

Biolistic delivery of DNA





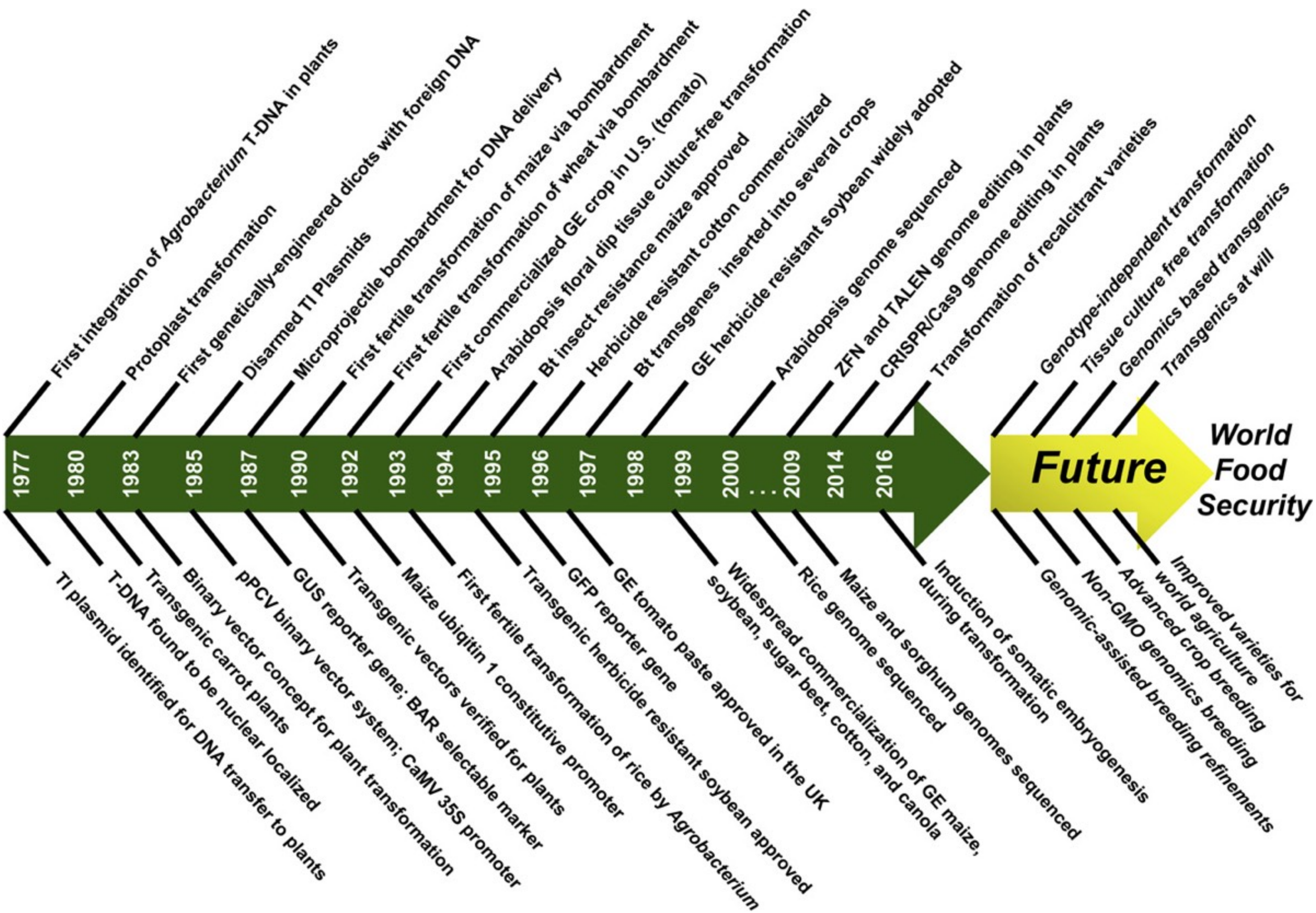


Figure 3. Important Historical Milestones in Plant Transformation.

Since its beginning in 1977, the pace of crop transformation technology development has not been linear. In recent years, the genome editing revolution begs for crop transformation improvements to enable greater food security.