



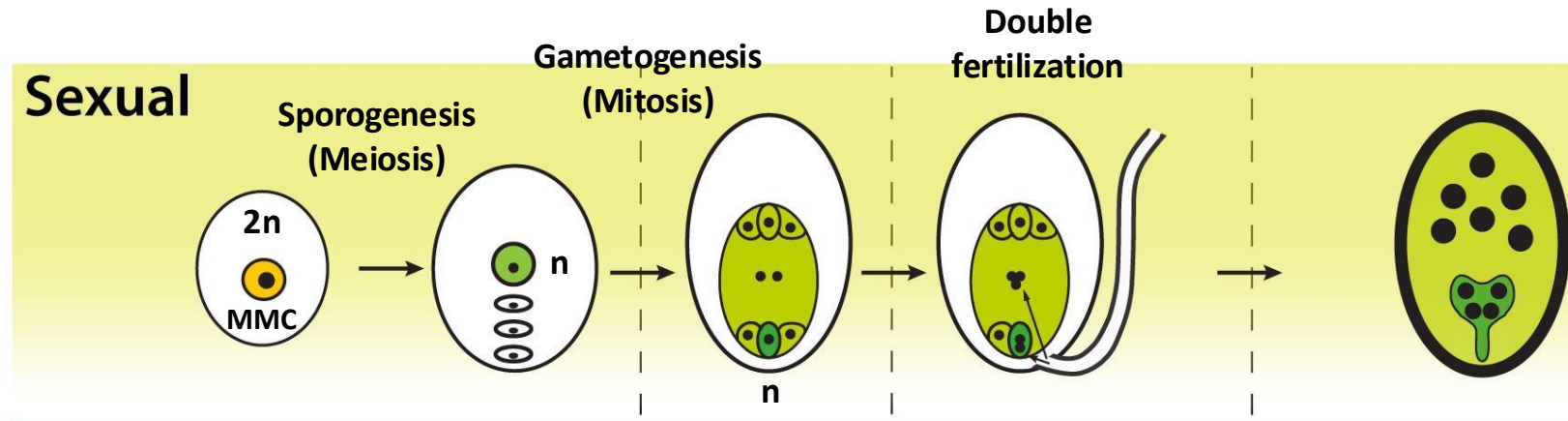
Meiosis: Apomixis



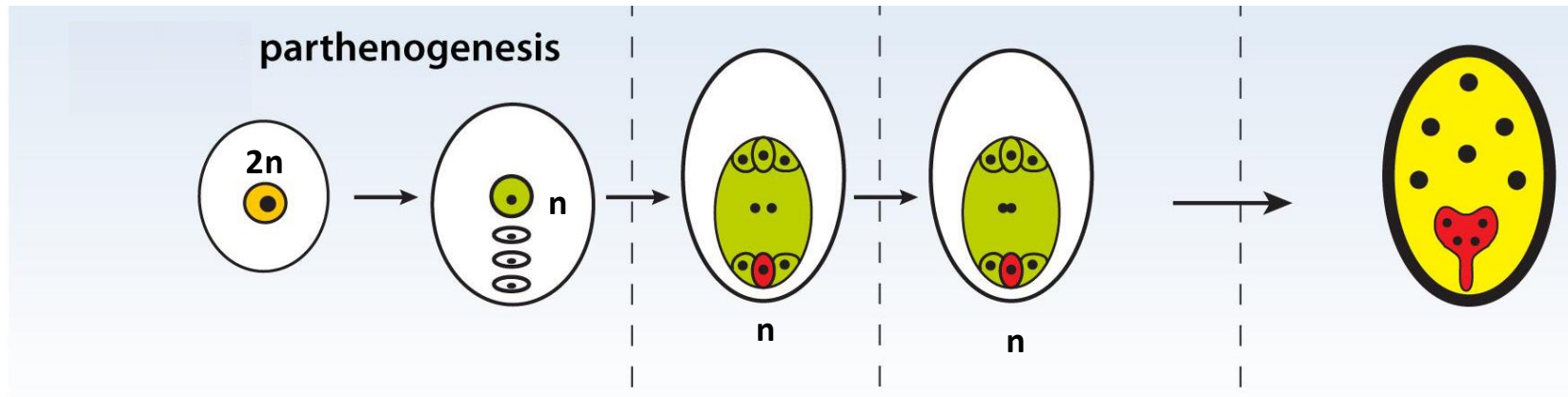
Section IV-F

Review

Hojsgaard and Hörandl, 2019

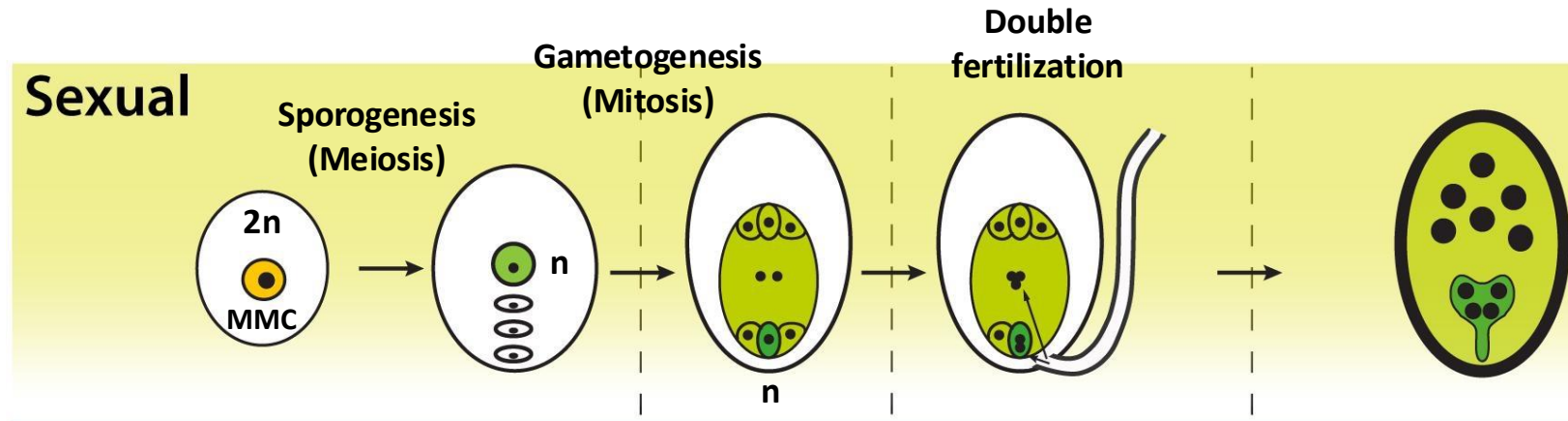


- Parthenogenesis: Embryogenesis without fertilization.



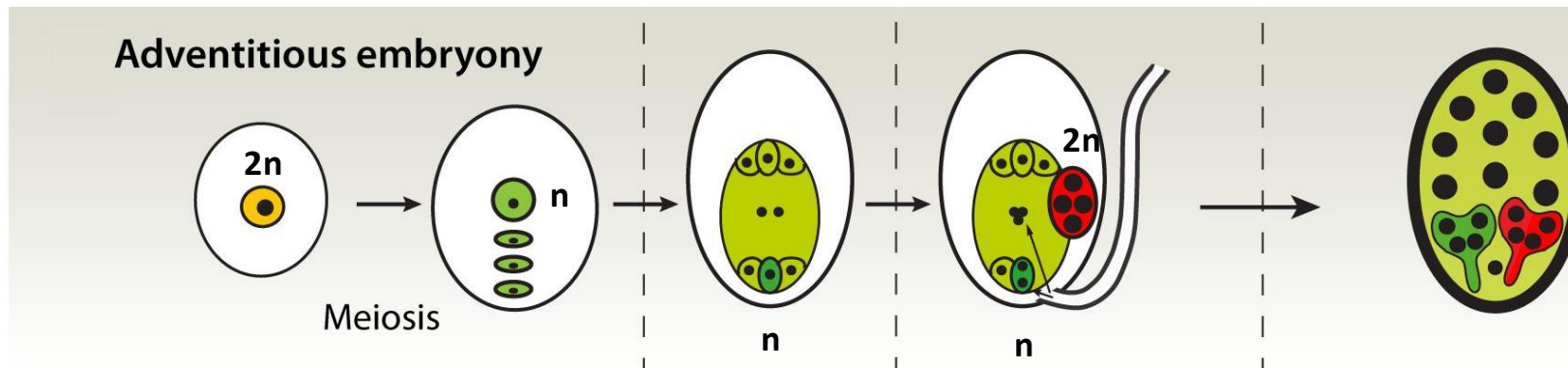
Review

Hojsgaard and Hörandl, 2019



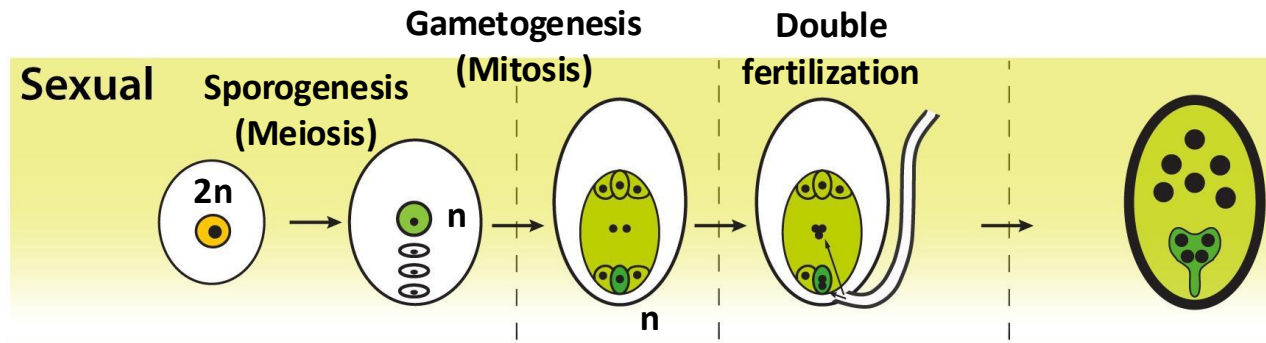
Endosperm: 3C (2m:1p)
Embryo: 2C (1m:1p)

- Adventitious embryony (Sporophytic apomixis).



Endosperm: 3C (2m:1p)
Embryo (sexual): 2C (1m:1p)
Embryo (apomictic): 2C (2m)

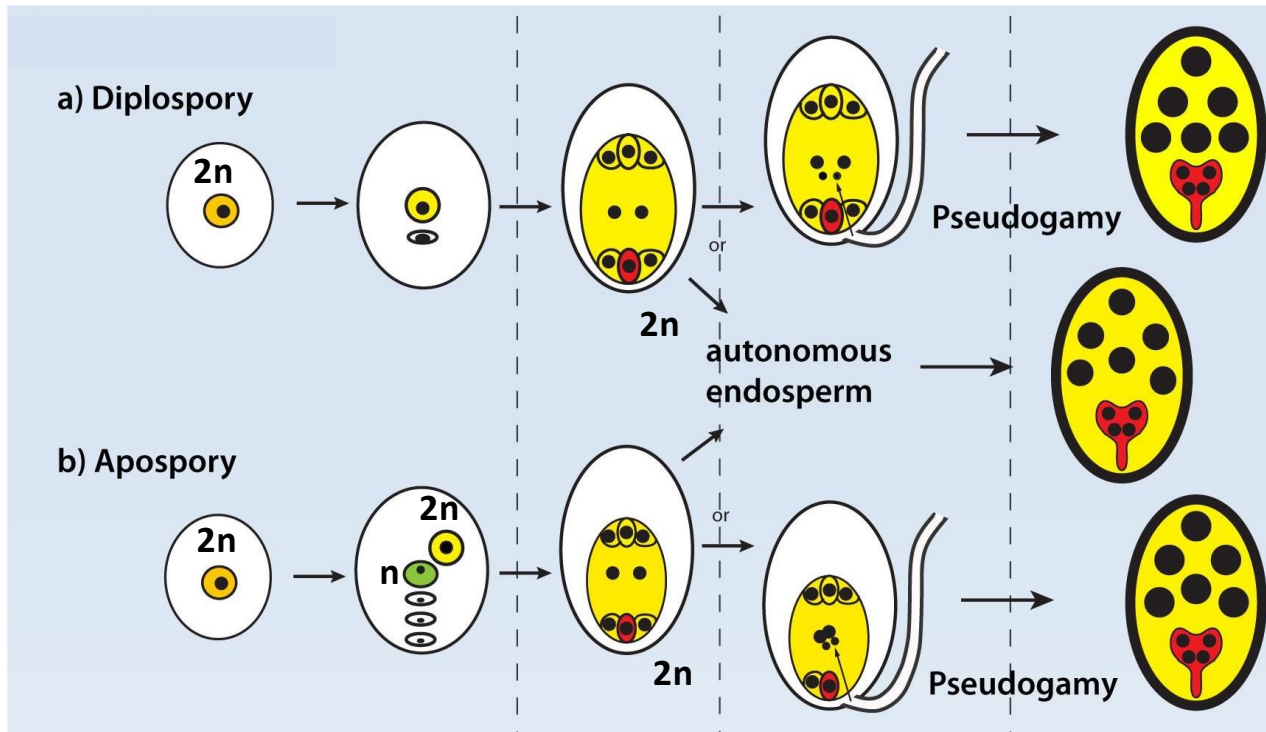
Review



Hojsgaard and Hörandl, 2019

Endosperm: 3C (2m:1p)
Embryo: 2C (1m:1p)

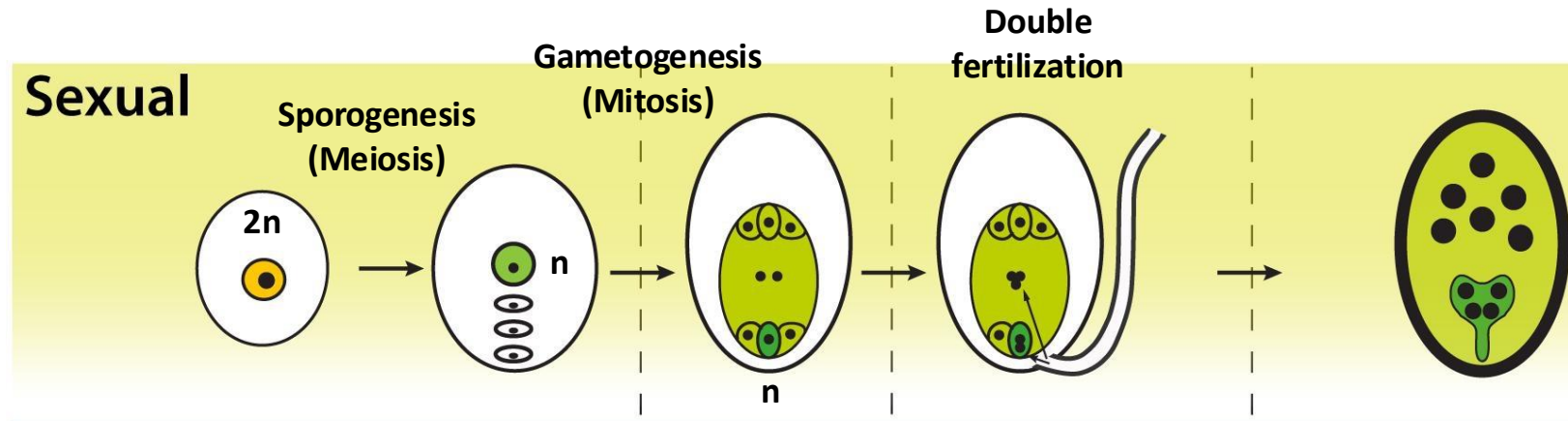
- Gametophytic Apomixis: Apomictic embryo is formed from an unreduced gametophyte (Apomeiosis + parthenogenesis).



Endosperm (pseudogamous): 5C (4m:1p)
OR
Endosperm (autonomous): 4C (4m)
Embryo (apomictic): 2C (2m)

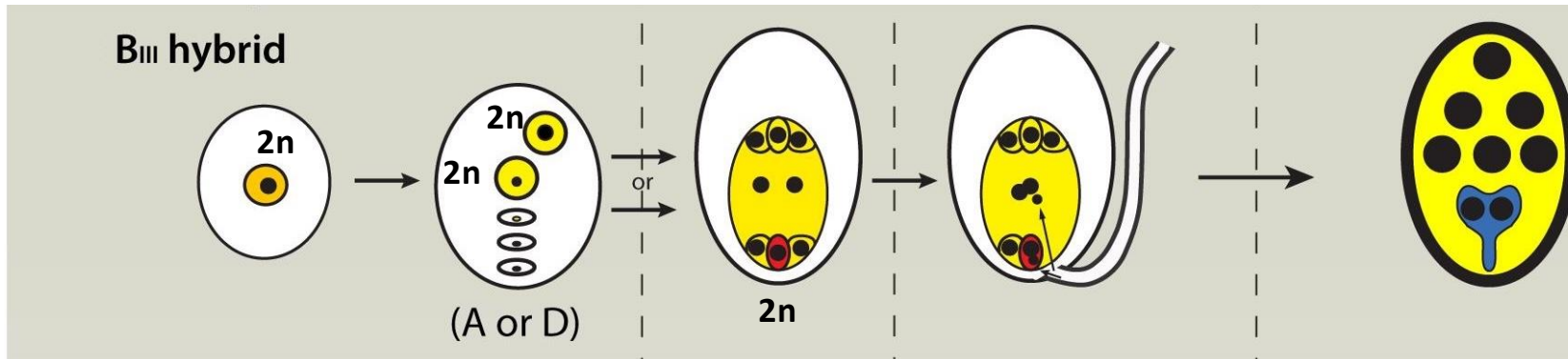
BIII hybrid

Hojsgaard and Hörandl, 2019



Endosperm: 3C (2m:1p)
Embryo: 2C (1m:1p)

- BIII hybrid: Unreduced egg-cell is fertilized by reduced sperm.



Endosperm: 5C (4m:1p)
Embryo (sexual): 3C (2m:1p)

•

•

•

•



A circular phylogenetic tree of angiosperms, with branches colored by order. The tree is rooted at the bottom and branches outwards. Major orders are labeled around the perimeter, including:

- Asparagales** (bottom left, green)
- Commelinales** (bottom left, purple)
- Zingiberales** (bottom left, blue)
- Poales** (bottom, yellow)
- Ceratophyllales** (bottom, orange)
- Ranunculales** (bottom, red)
- Proteales** (bottom, pink)
- Buccharidales** (bottom, light pink)
- Quinquefoliales** (bottom, light blue)
- Saxifragales** (bottom right, dark blue)
- Violales** (bottom right, purple)
- Geraniales** (bottom right, pink)
- Myrtales** (bottom right, red)
- Saxifragales** (bottom right, dark blue)
- Crossosomales** (bottom right, orange)
- Sapindales** (bottom right, yellow)
- Huerteales** (bottom right, green)
- Malvales** (bottom right, red)
- Brassicales** (bottom right, orange)
- Zygophyllales** (bottom right, yellow)
- Fabales** (bottom right, red)
- Rosales** (bottom right, orange)
- Fagales** (bottom right, red)
- Cucurbitales** (bottom right, green)
- Oxalidales** (bottom right, blue)
- Celastrales** (bottom right, green)
- Malpighiales** (top right, pink)
- Santalales** (top right, green)
- Berberidopsidales** (top right, red)
- Caryophyllales** (top, orange)
- Cornales** (top, green)
- Ericales** (top, blue)
- Aquiforiales** (top left, red)
- Escalloniales** (top left, orange)
- Asterales** (top left, blue)
- Brinales** (top left, green)
- Dipsacales** (top left, blue)
- Apiales** (top left, blue)
- Isocarinales** (top left, blue)
- Menyanthes** (top left, blue)
- Gentianales** (top left, blue)
- Boraginales** (top left, blue)
- Vahiales** (top left, blue)
- Solanales** (top left, green)
- Lamiales** (top left, red)
- Amborellales** (top left, blue)
- Nymphaeales** (top left, blue)
- Austrobaileyales** (top left, blue)
- Chloranthales** (top left, blue)
- Cannellales** (top left, blue)
- Piperiales** (top left, blue)
- Magnoliales** (top left, blue)
- Laureles** (top left, blue)
- Acorales** (top left, blue)
- Alismatales** (top left, green)
- Petrosaviales** (top left, green)
- Dioscoreales** (top left, orange)
- Pandanales** (top left, blue)
- Liliales** (top left, blue)

 The tree shows a high degree of branching, with many families represented by small dots or short branches. The colors are consistent across the tree, allowing for easy identification of the order to which each family belongs.

Apomixis: role in evolution

Occurrence

- **Darlington, 1939:** "Apomixis is an escape from sterility, but an escape into a blind alley of evolution."
- However, this view has been found to be incorrect:
 -
 -
 -



Dandelions (*Taraxacum* spp.)
Insideecology.com



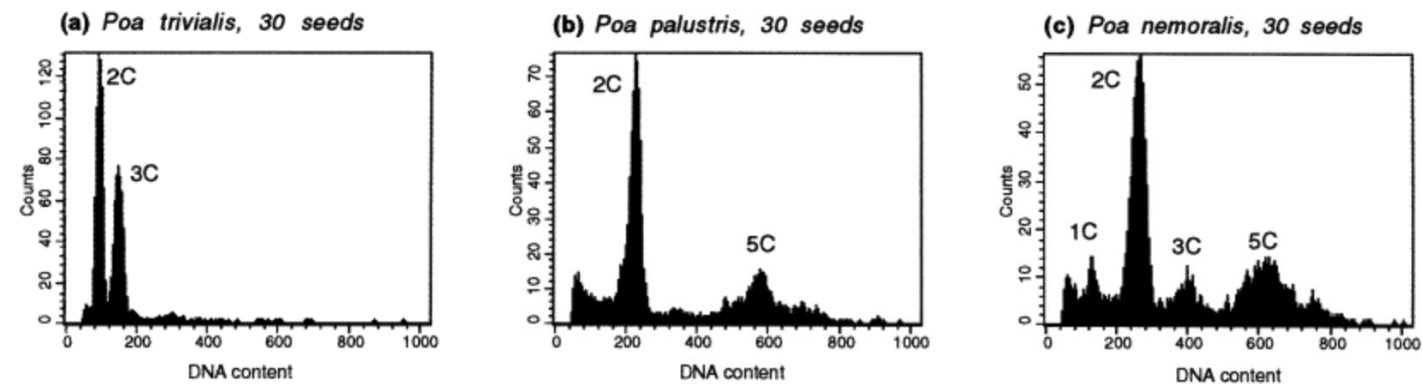
Kentucky bluegrass (*Poa prantensis*)
thespruce.com

Indicators of Apomixis

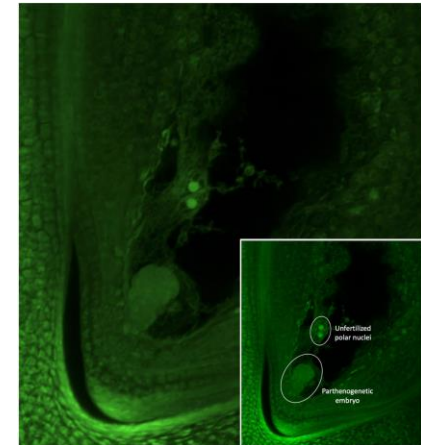
Occurrence

-
-
-
-
-
-

Matzk et al, 2001



Sidhu et al. 2022



Genetic control of Apomixis

Ozias-Akins & Van Dijk, 2007

Species	Apomixis type	Loci	Genotype	Suppression of recombination
<i>Brachiaria brizantha</i>	Apospory, pseudogamous endosperm	1	Aaaa	—
<i>Cenchrus ciliaris</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Erigeron annuus</i>	Diplospory, mitotic, autonomous endosperm	2	D/dd*) Fff	+ —
<i>Hieracium caespitosum</i>	Apospory, autonomous endosperm	2	Aaaa Pppp	— +
<i>Panicum maximum</i>	Apospory	1	Aaaa	+
<i>Paspalum notatum</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Paspalum simplex</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Pennisetum squamulatum</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Poa pratensis</i>	Apospory	2	Aaaa Pppp	—
<i>Ranunculus auricomus</i>	Apospory, pseudogamous endosperm	1	Aaaa	??
<i>Taraxacum officinale</i>	Diplospory, meiotic, autonomous endosperm	3	Ddd Ppp	— +
<i>Tripasium dactyloides</i>	Diplospory, mitotic, pseudogamous endosperm	1?	Dddd	+

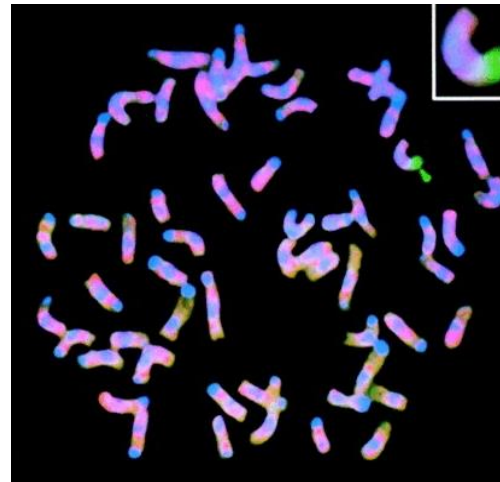
A: apospory, D: diplospory, P: parthenogenesis, F: fertilization factor

Genetic control of Apomixis

- Apomictic loci usually have suppressed recombination.



- Difficulties in genetic mapping and introgression.



Goel et al. 2003. ASGR in *Pennisetum squamulatum* ($2n = 8X = 56$). Mitotic spread. ASGR is ~50 Mb long (almost $\frac{1}{4}$ of the chromosome).

Ozias-Akins & Van Dijk, 2007

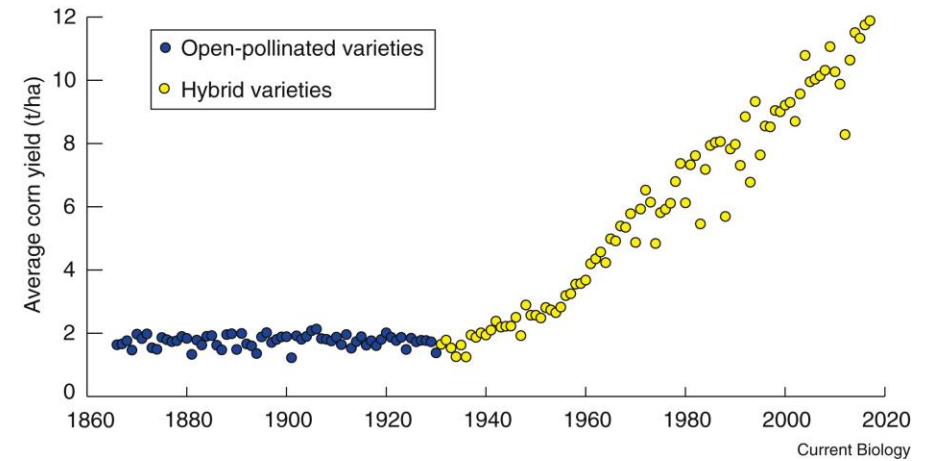
Species	Apomixis type	Loci	Genotype	Suppression of recombination
<i>Brachiaria brizantha</i>	Apospory, pseudogamous endosperm	1	Aaaa	—
<i>Cenchrus ciliaris</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Erigeron annuus</i>	Diplospory, mitotic, autonomous endosperm	2	D/dd*) Fff	+ —
<i>Hieracium caespitosum</i>	Apospory, autonomous endosperm	2	Aaaa Pppp	— +
<i>Panicum maximum</i>	Apospory	1	Aaaa	+
<i>Paspalum notatum</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Paspalum simplex</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Pennisetum squamulatum</i>	Apospory, pseudogamous endosperm	1	Aaaa	+
<i>Poa pratensis</i>	Apospory	2	Aaaa Pppp	—
<i>Ranunculus auricomus</i>	Apospory, pseudogamous endosperm	1	Aaaa	??
<i>Taraxacum officinale</i>	Diplospory, meiotic, autonomous endosperm	3	Ddd Ppp	— +
<i>Tripasacum dactyloides</i>	Diplospory, mitotic, pseudogamous endosperm	1?	Dddd	+

A: apospory, D: diplospory, P: parthenogenesis, F: fertilization factor

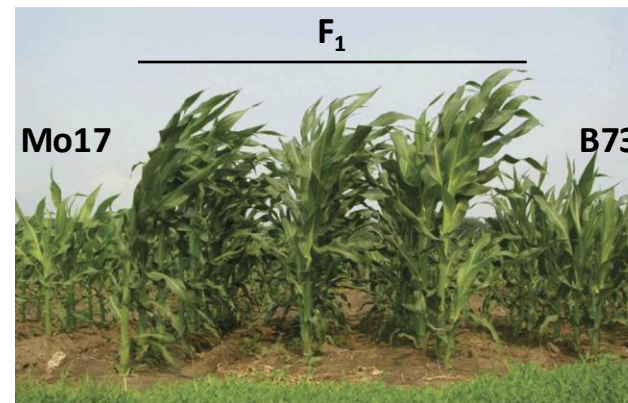
Why we care about Apomixis?

Hybrids

Hochholdinger and Baldauf, 2018

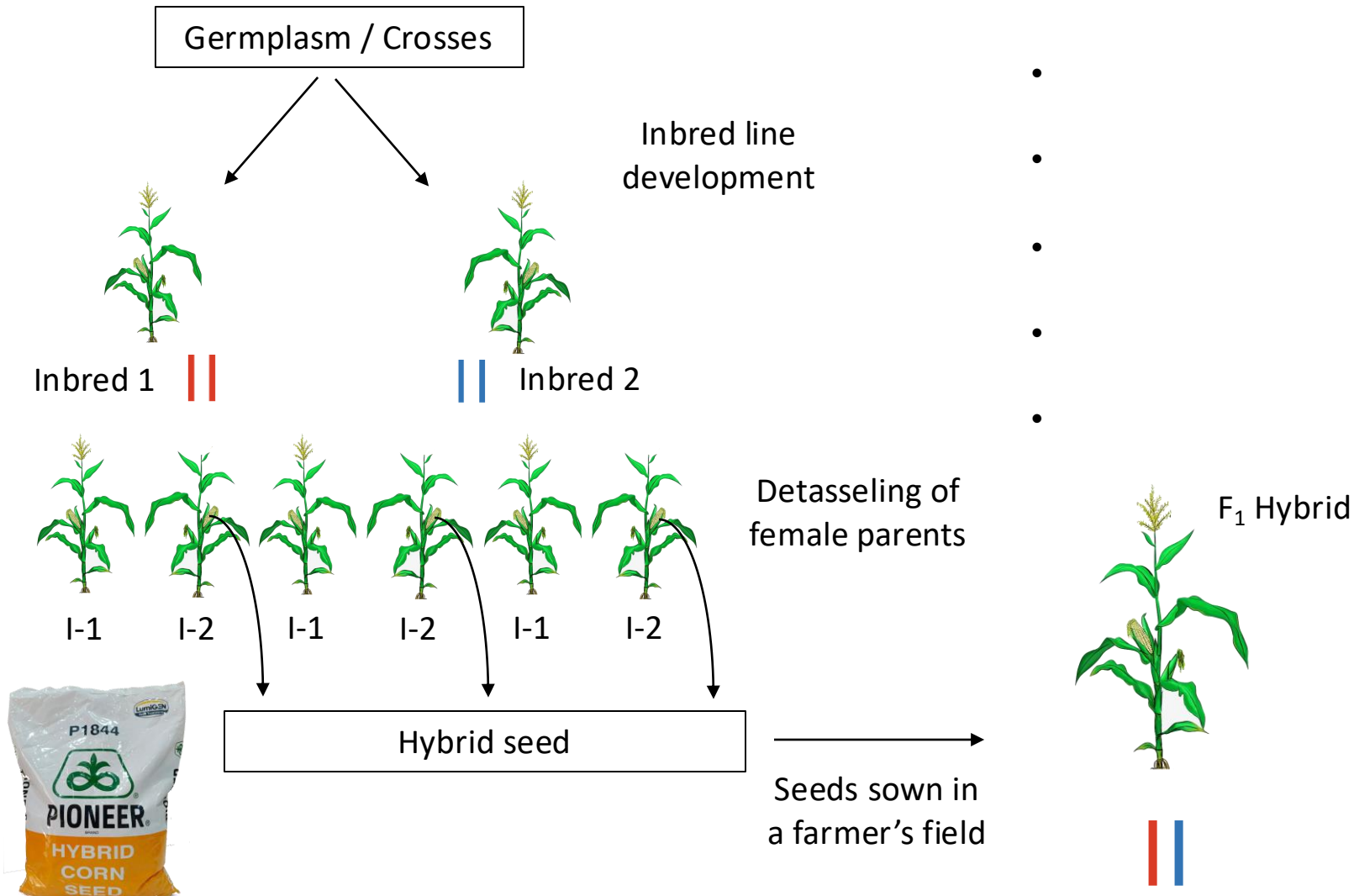


Springer and Stupar, 2007



Why we care about Apomixis?

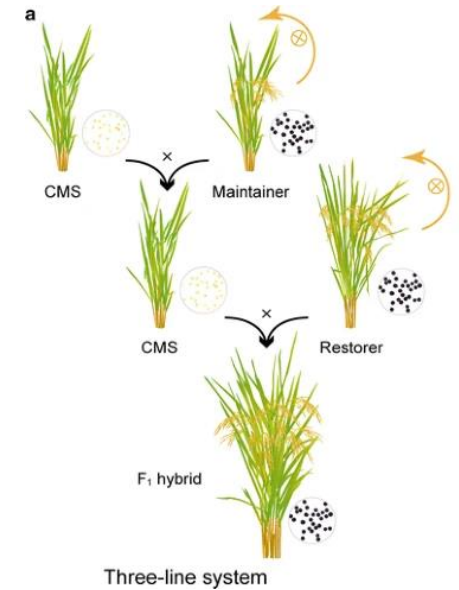
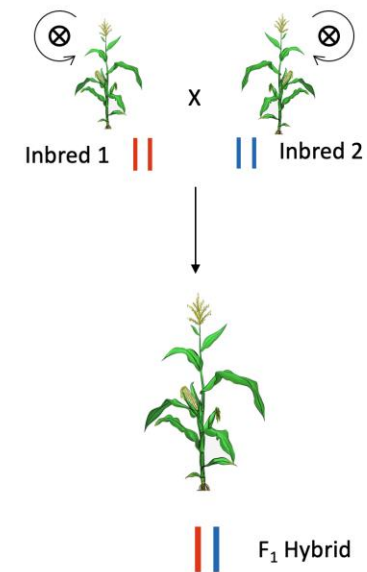
Hybrid seeds are expensive!



Why we care about Apomixis?

Benefits Hanna, 1987

-
-
-
-
-
-
-
-
-
-



Fan and Zhang, 2017

Country ->	China	India
Total area under rice cultivation	30 m ha	45 m ha
Rice production (2020 – 21)	210 m tons	120 m tons
%age Hybrid rice	> 50 %	< 10 %

Data source: National Food Security Mission, India & National Bureau of Statistics, China

Breeding for Apomixis

Introgression from related species

Savidan, 2000; Sokolov and Khatyapova, 2001

Tripsacum dactyloides X *Zea mays*



Carman et al. 1985

Elymus rectisetus X *Triticum*



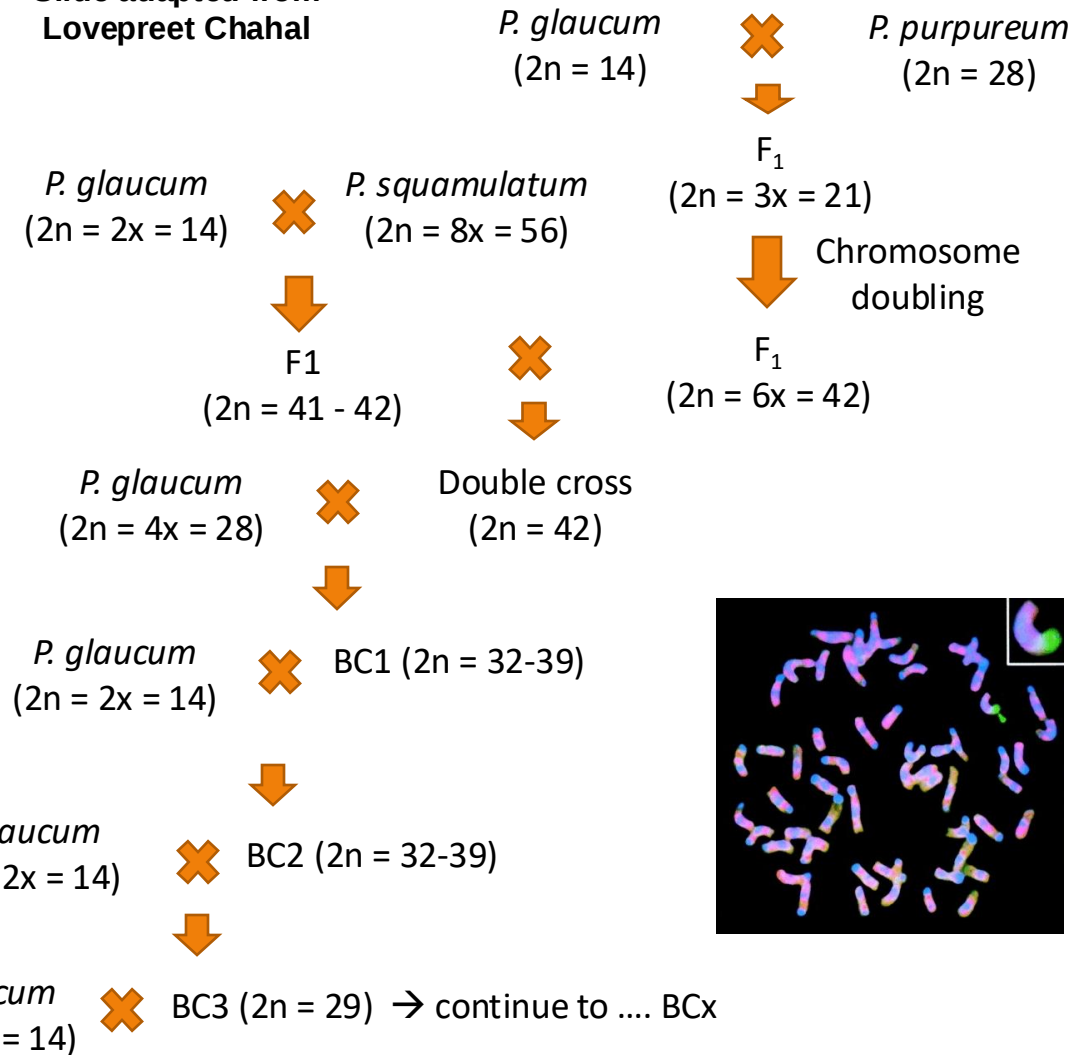
Hanna, 1987; Dujardin & Hanna, 1983 – 1989, Kaushal et al. 2010

Pennisetum squamulatum X *Pennisetum glaucum*



Wayne Hanna

Slide adapted from
Lovepreet Chahal



Morgan et al. 1998

•

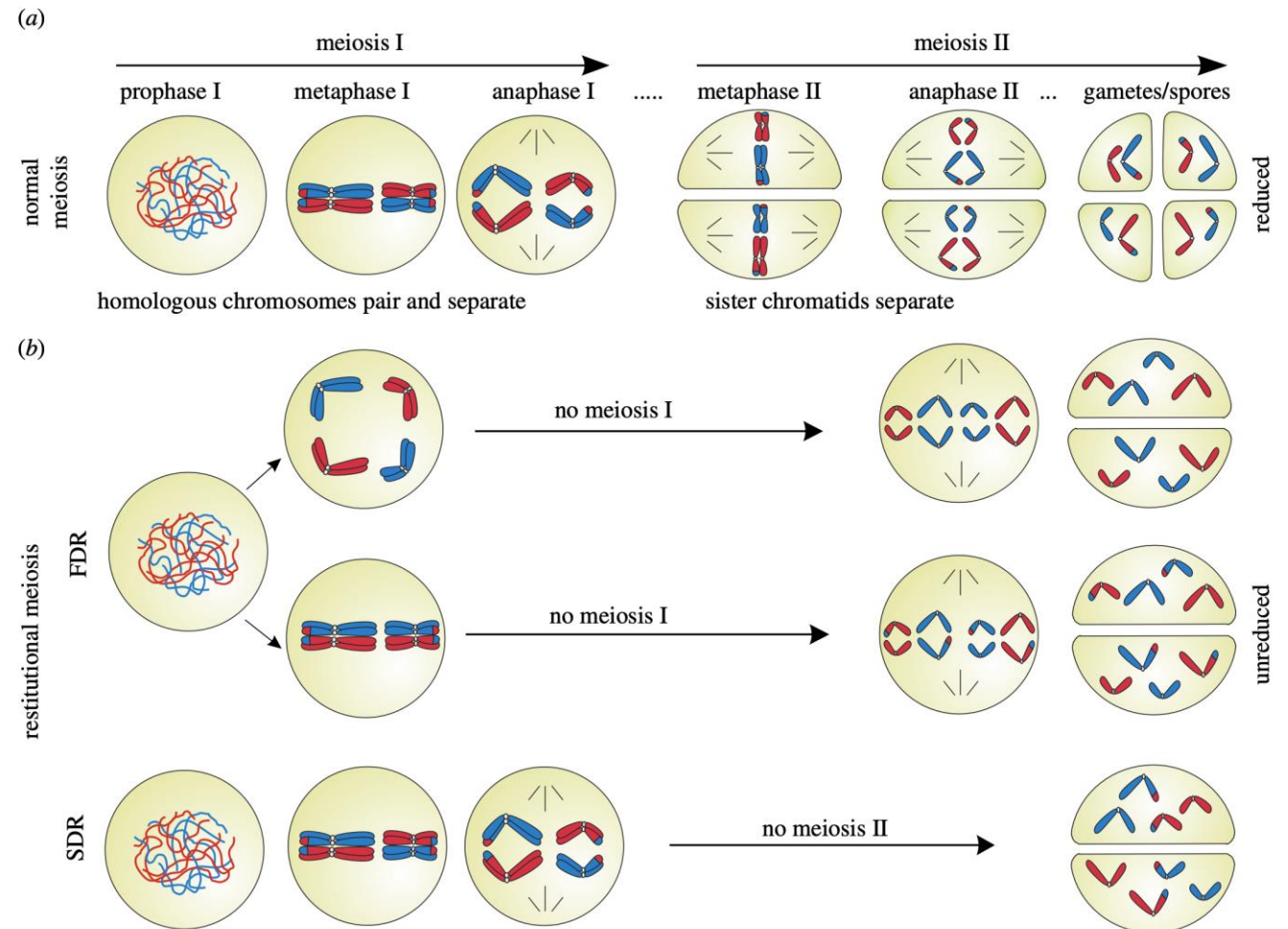
•

•

Meiosis vs mitosis

-
-
-

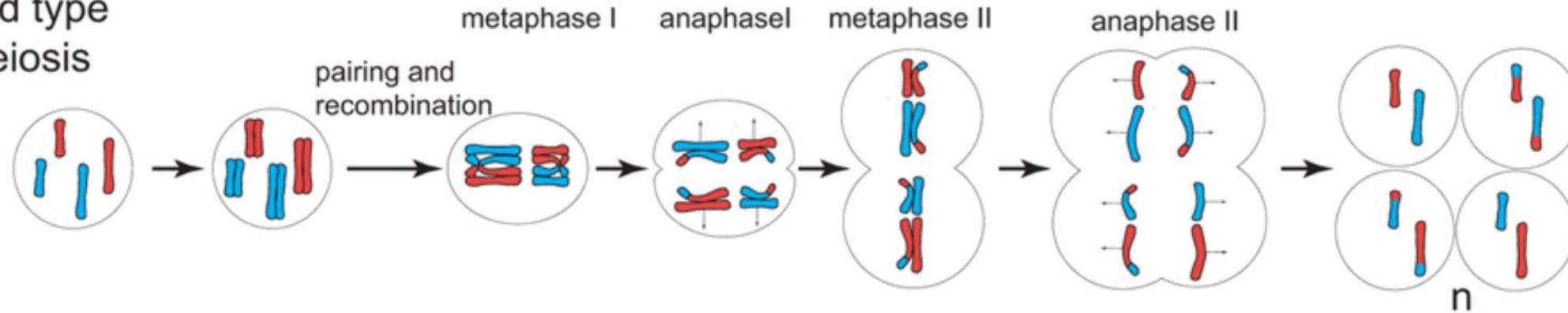
Mirzaghaderi and Horandl. 2016



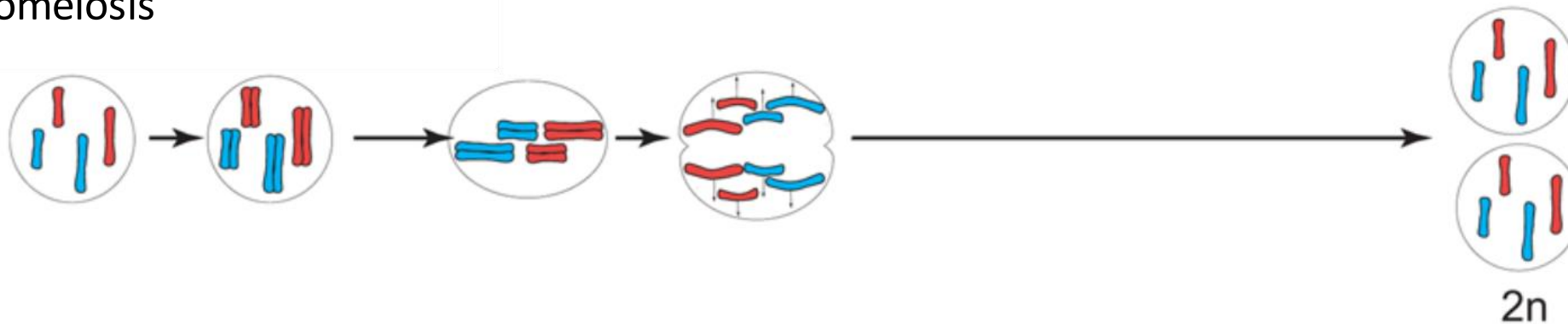
Engineering Apomeiosis.

d'Erfurth et al. 2009

Wild type
meiosis



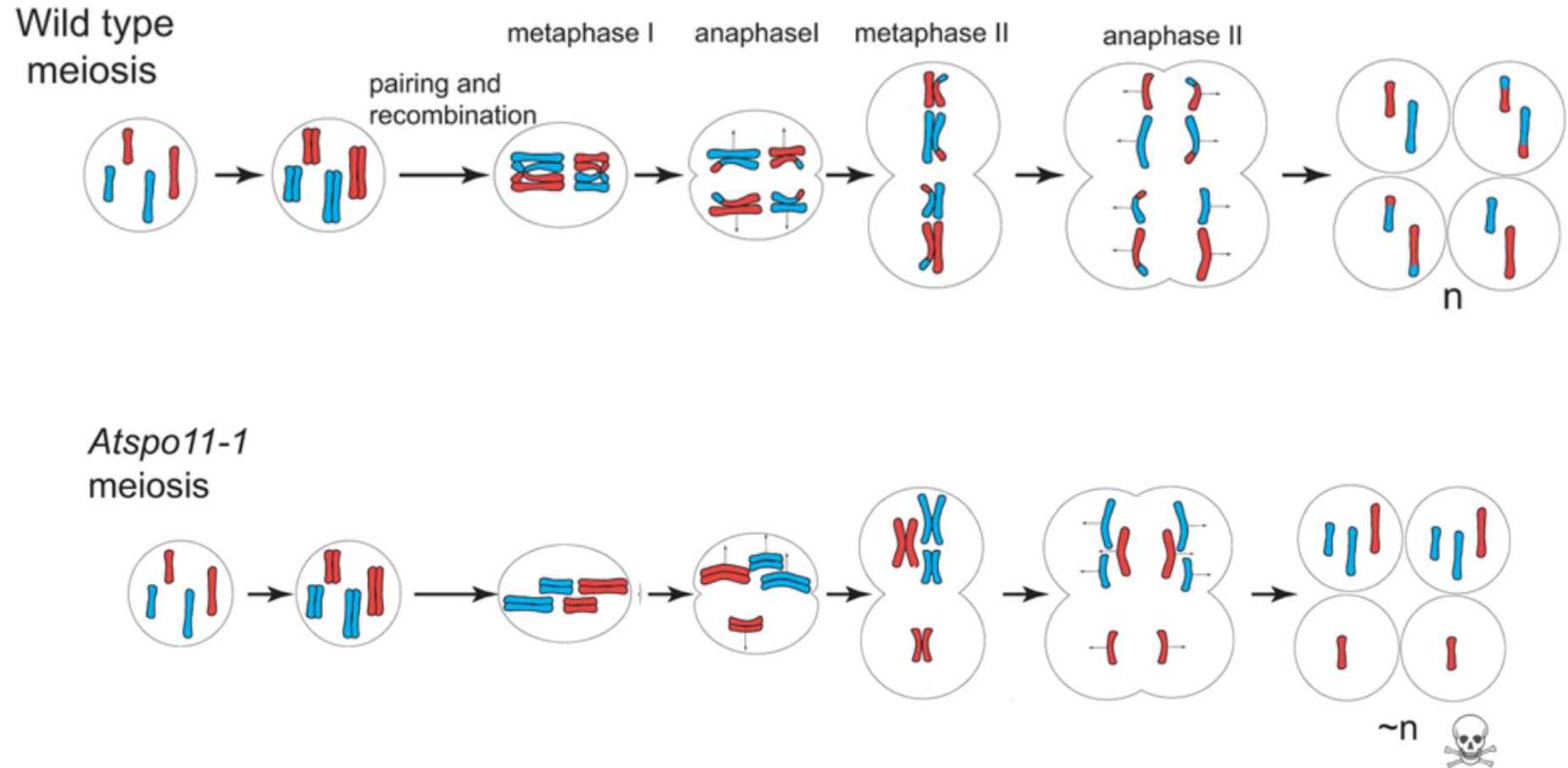
Apomeiosis



Raphaël Mercier

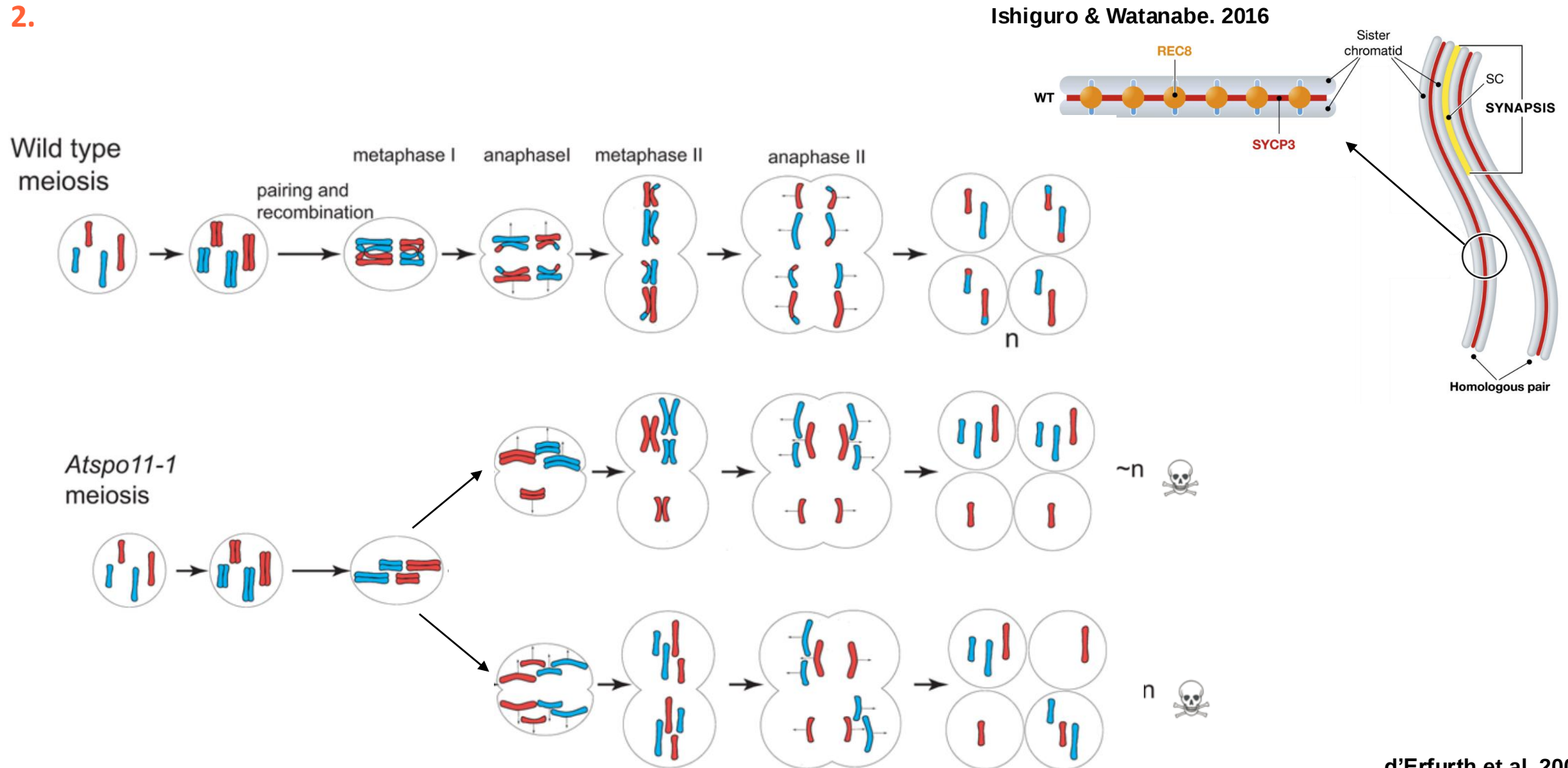
Engineering Apomeiosis.

1.



Engineering Apomeiosis.

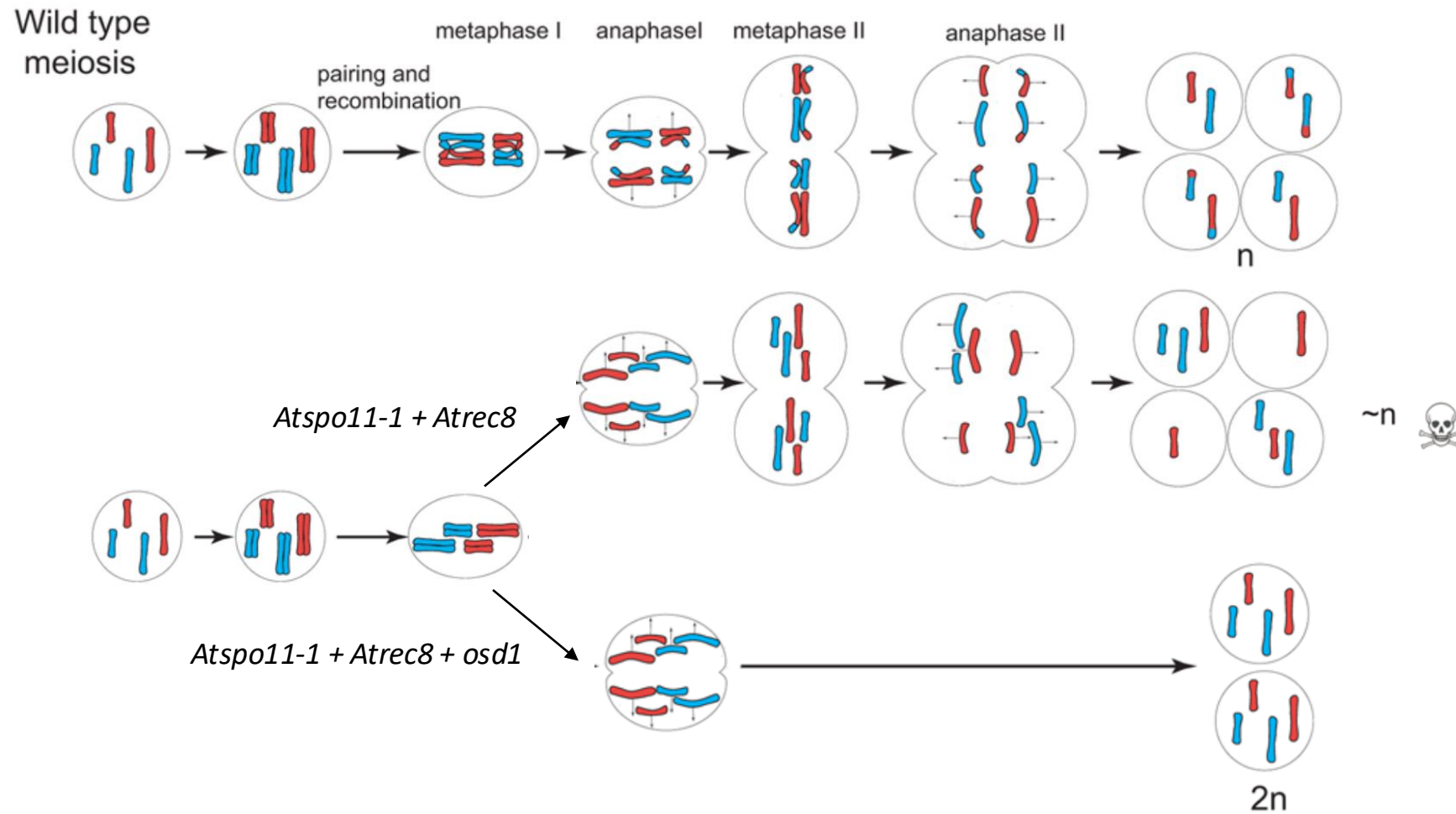
2.



d'Erfurth et al. 2009

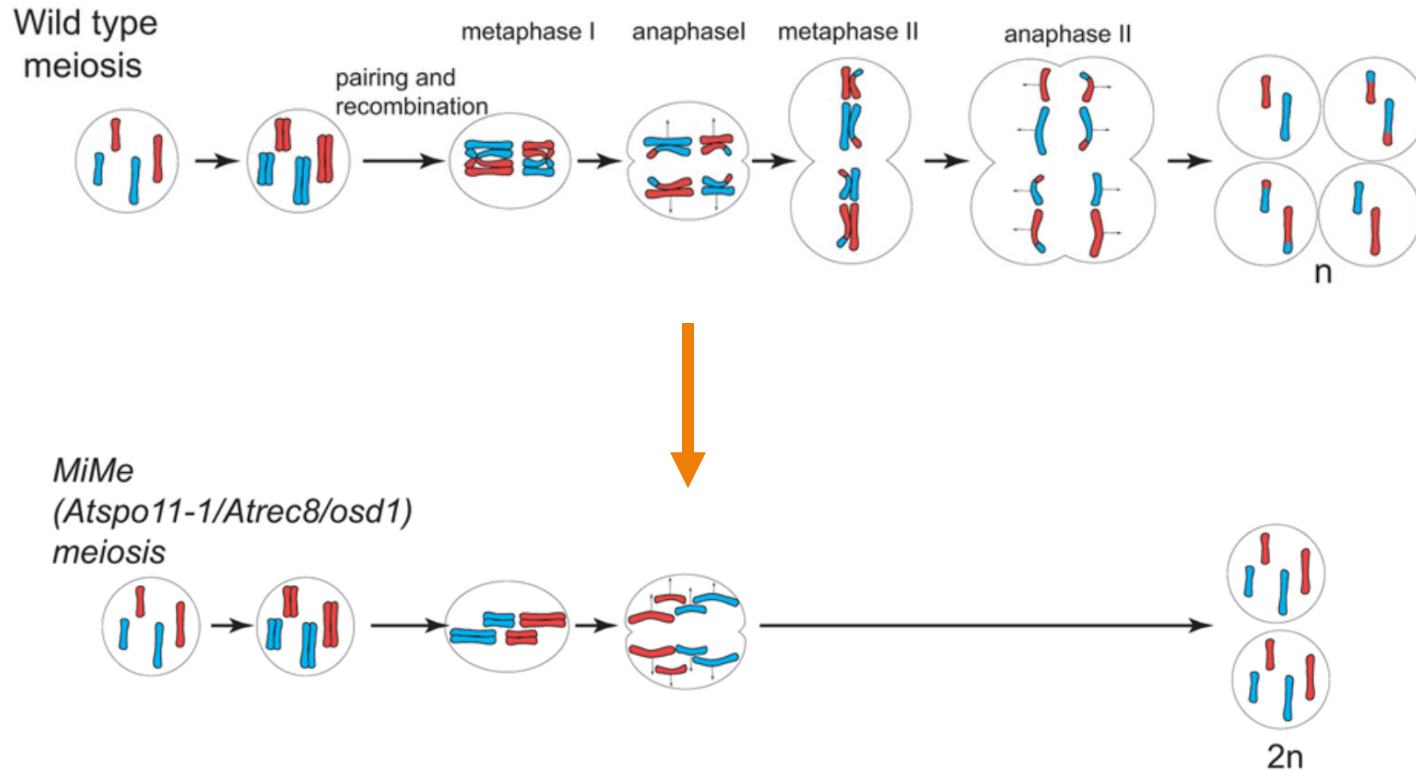
Engineering Apomeiosis.

3.



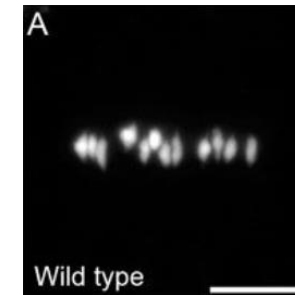
Engineering Apomeiosis.

d'Erfurth et al. 2009



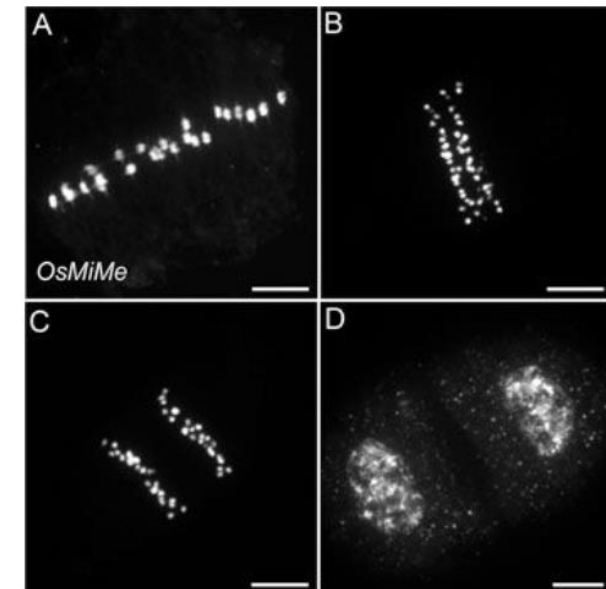
Mieulet et al., 2016

- Engineering *MiMe* in rice with CRISPR.



Wild type rice
($2n = 2X = 24$)

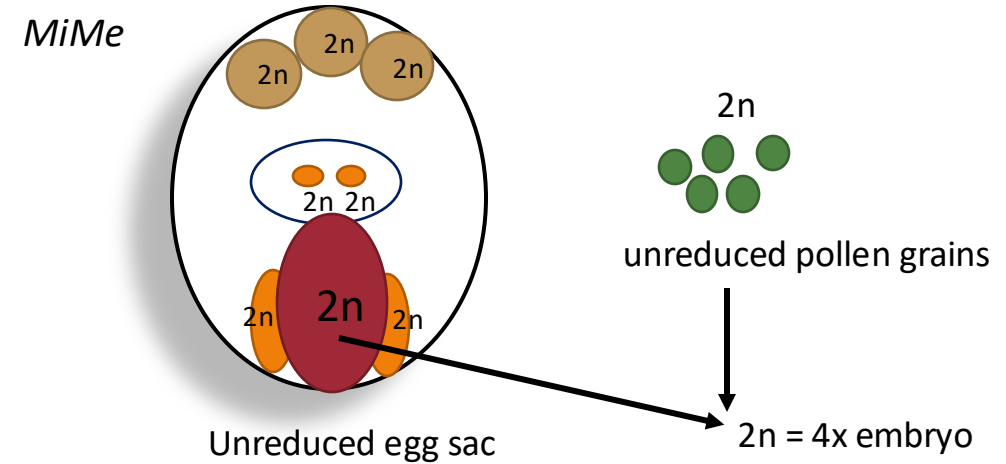
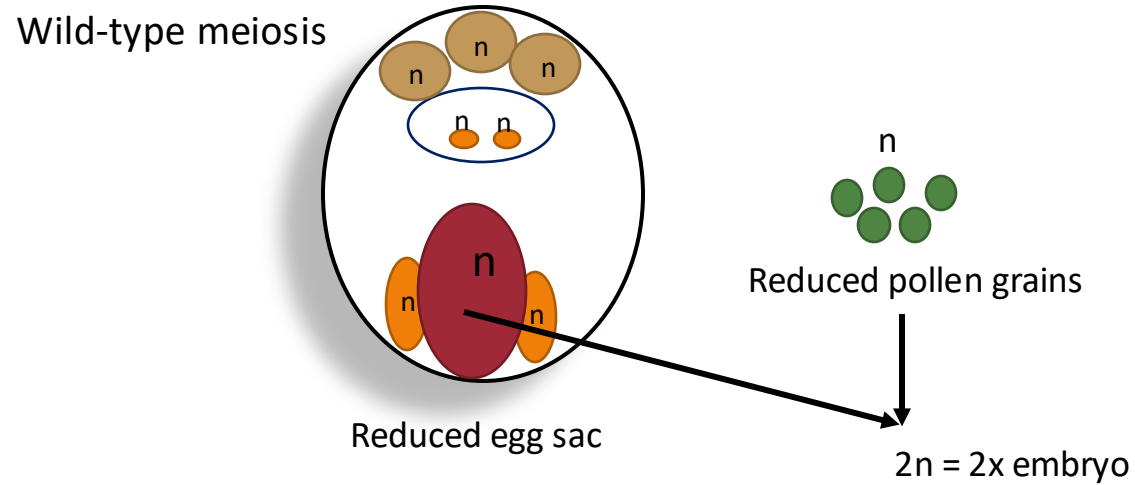
MiMe rice



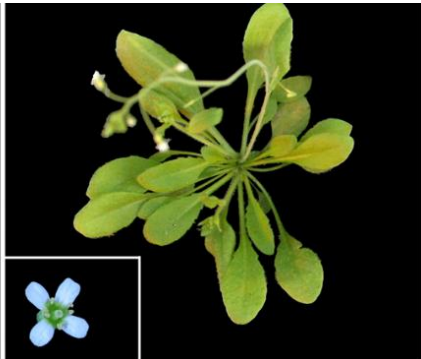
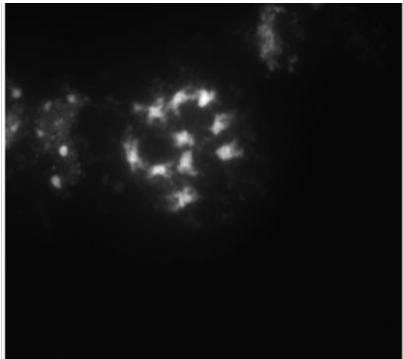
MiMe alone ?

Graphics by Lovepreet Chahal

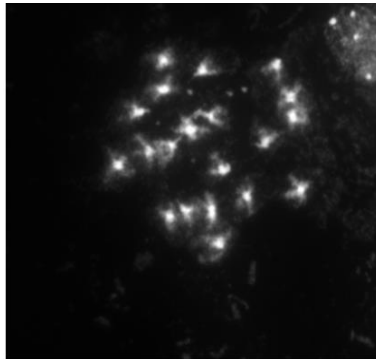
d'Erfurth et al. 2009



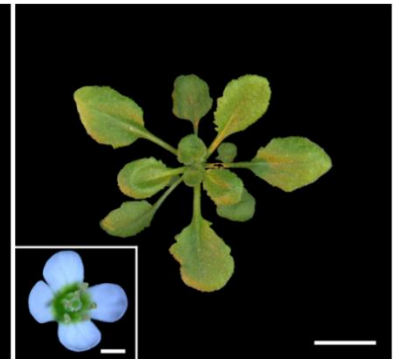
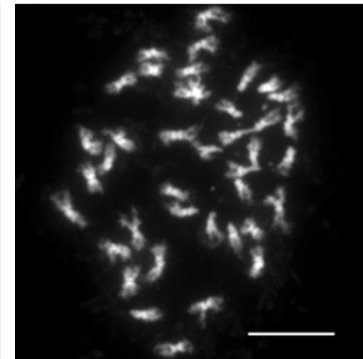
$T_0: 2n = 2x = 10$



$T_1: 2n = 4x = 20$

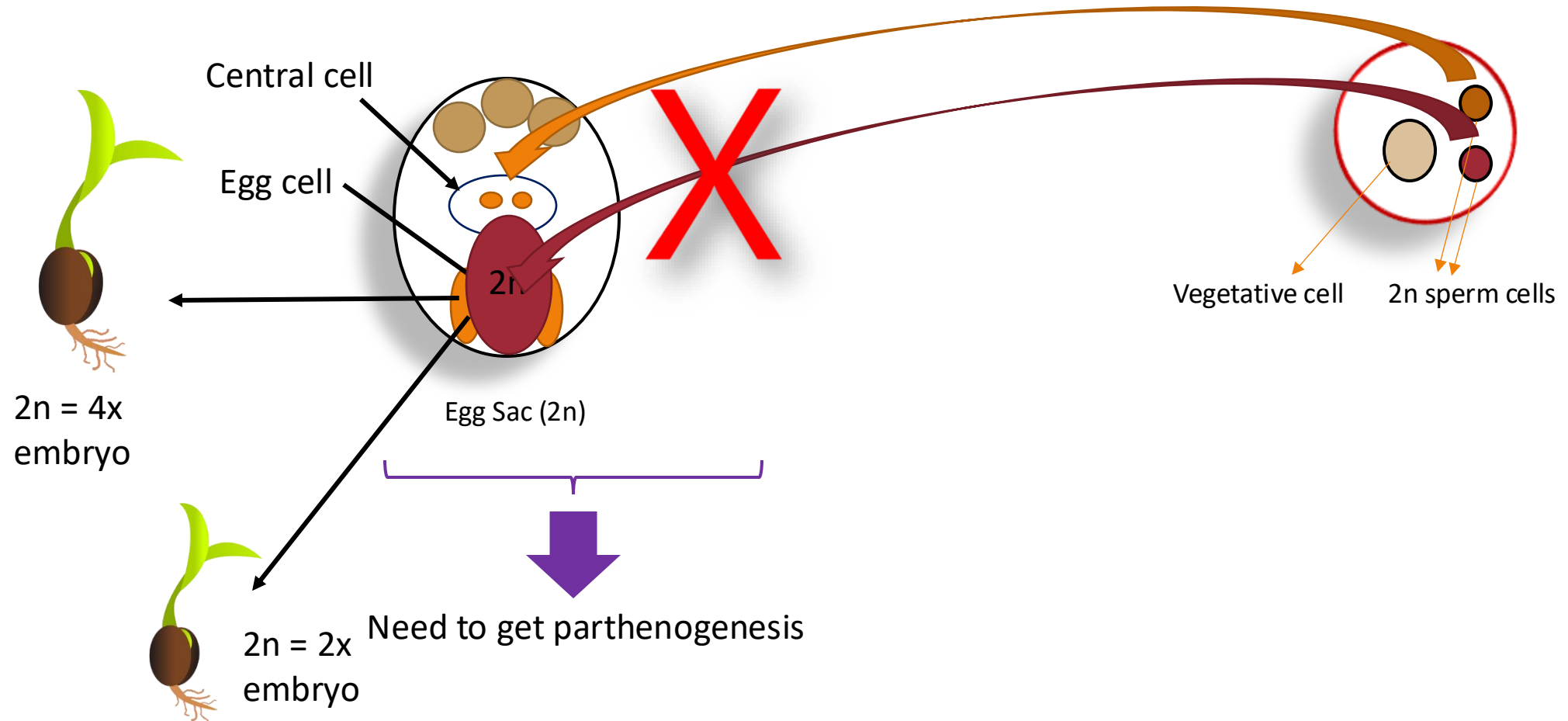


$T_2: 2n = 8x = 40$



MiMe + Parthenogenesis

Slide by Lovepreet Chahal



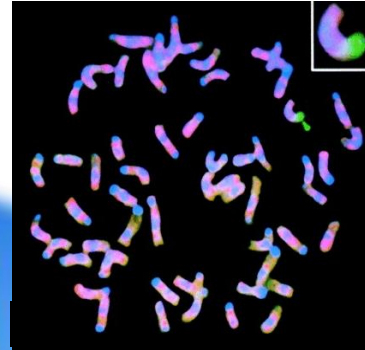
PsASGR-BBML can induce parthenogenesis

Conner et al. 2015

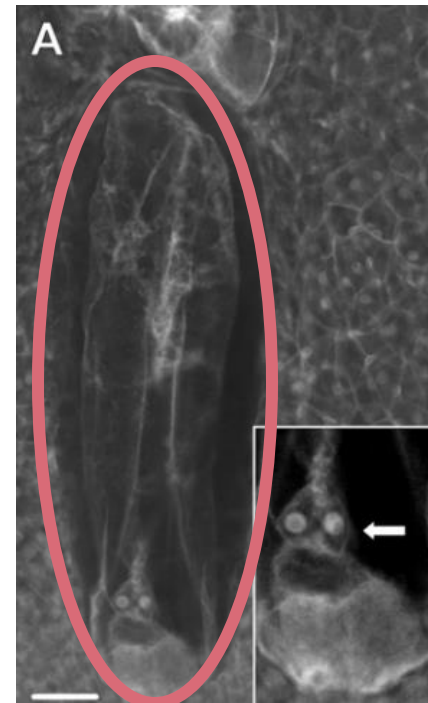
Slide by Lovepreet Chahal



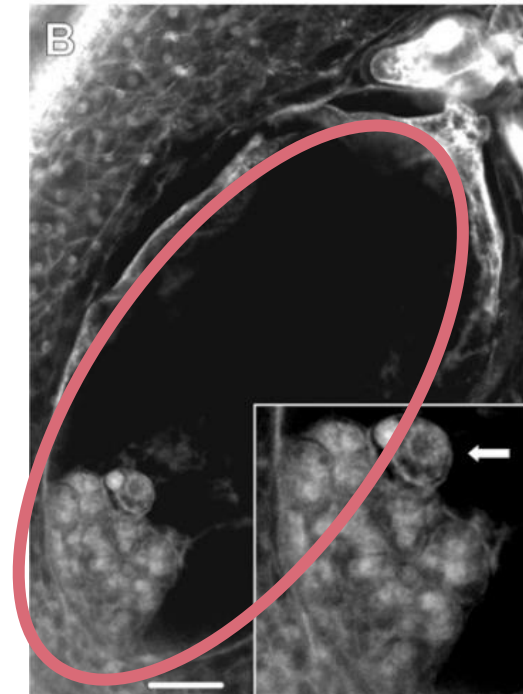
Pennisetum squamulatum *Pennisetum glaucum*



Without fertilization



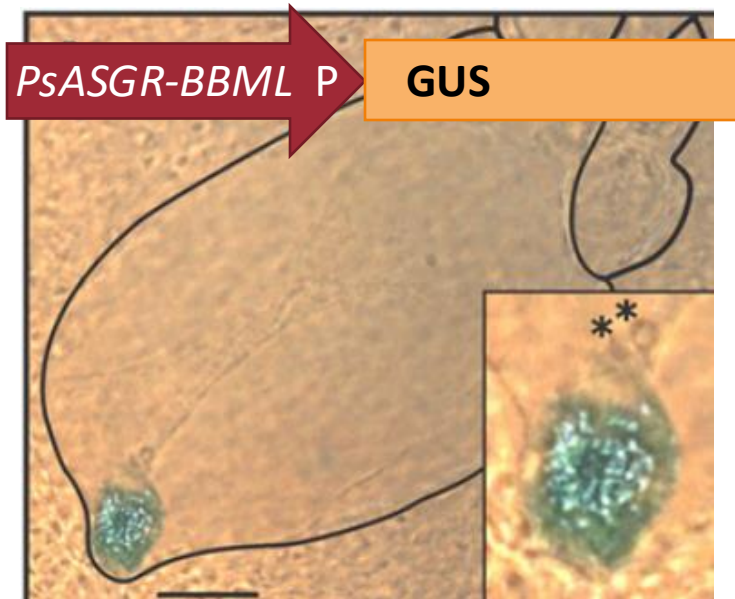
Wild type



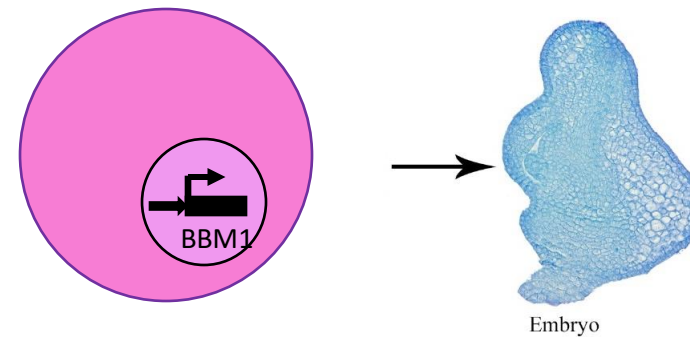
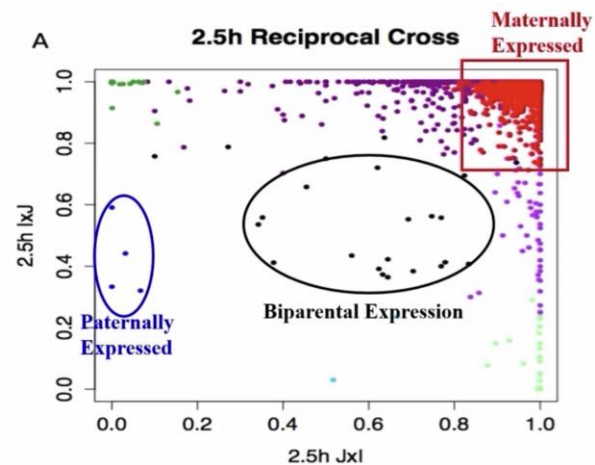
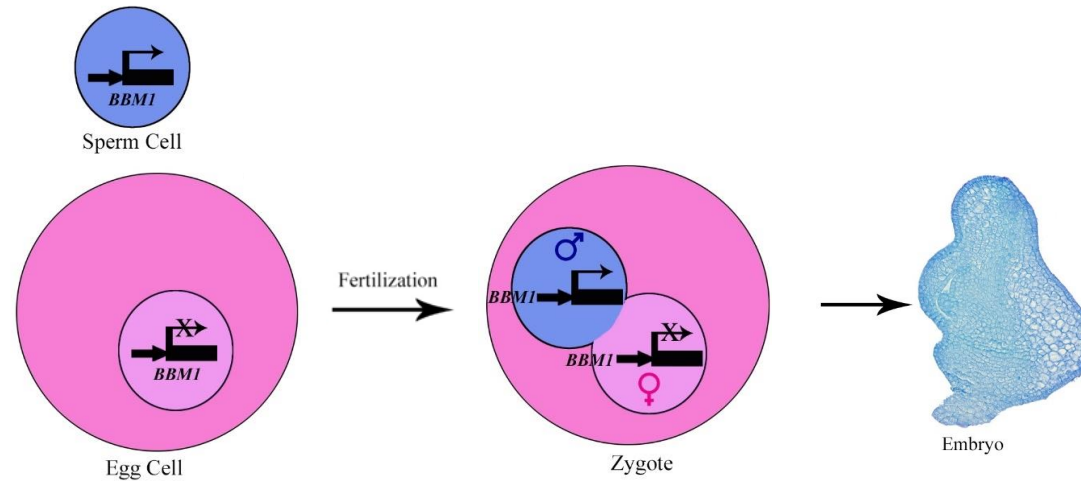
PsASGR-BBML

Baby boom like genes

Conner et al. 2015

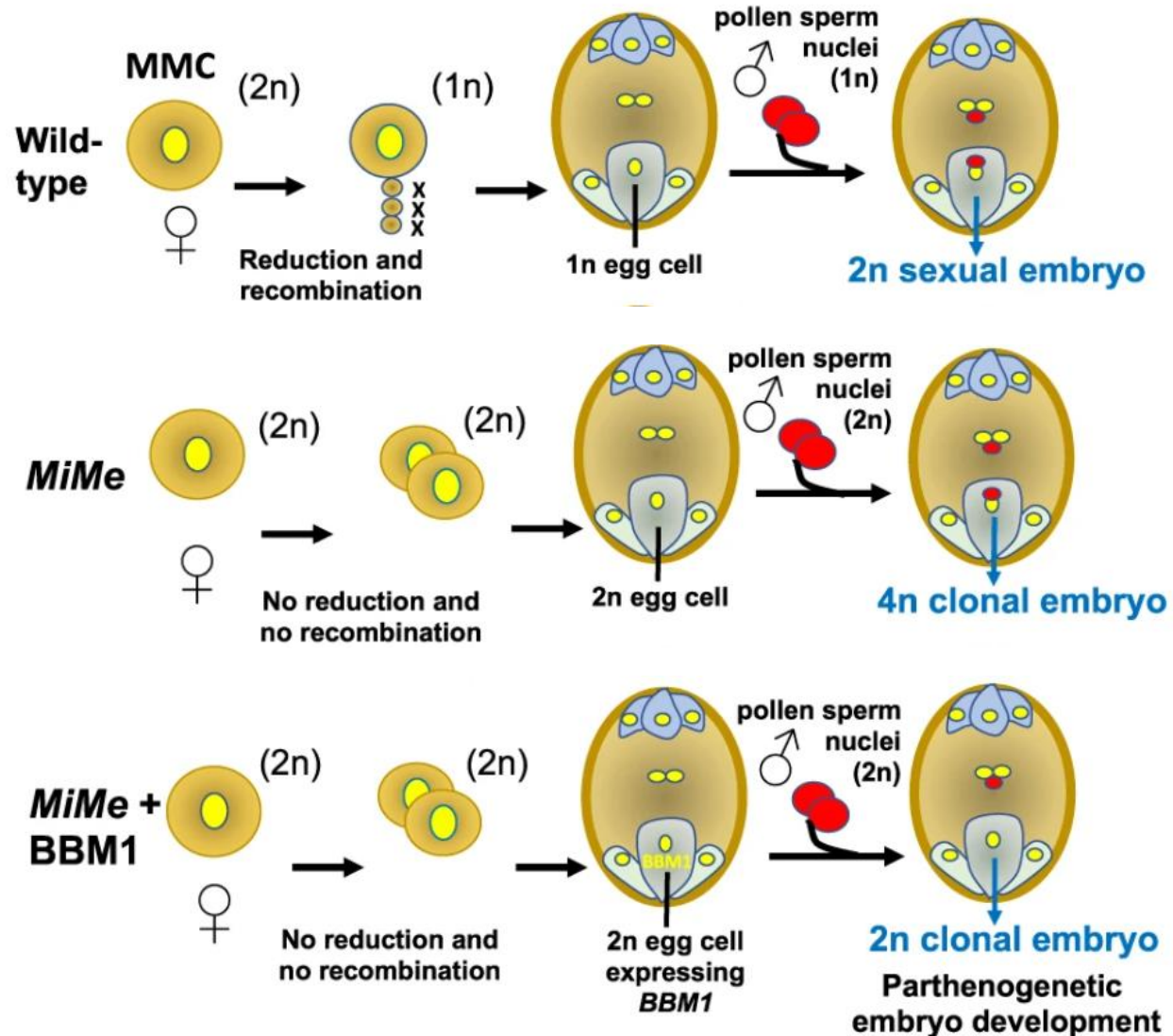


Khanday et al, 2019

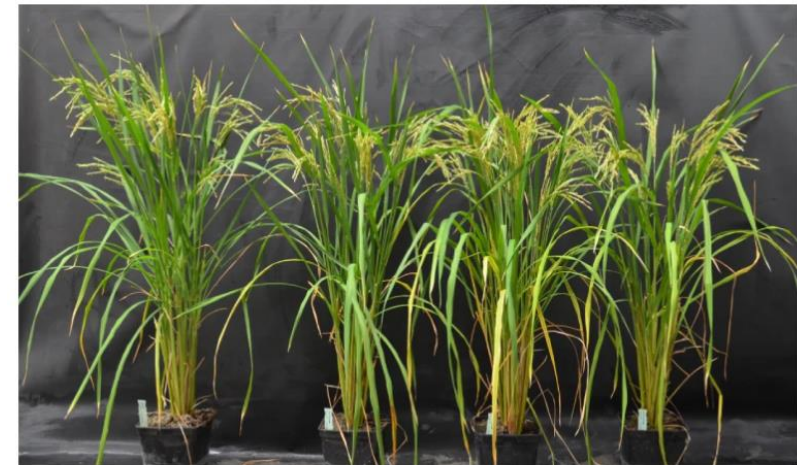


Synthetic apomixis in Rice

Khanday et al, 2019; Vernet et al, 2022



F1 ————— F2 progeny —————



F1 ————— T1 apomictic progeny —————