Introduction: Plant Breeding and Genetics

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2024 SCST Genetics Super Workshop

February 12, 2024

Why are we here?

Knowledge of plant breeding and genetics

Apply it to maximize yields with quality seeds

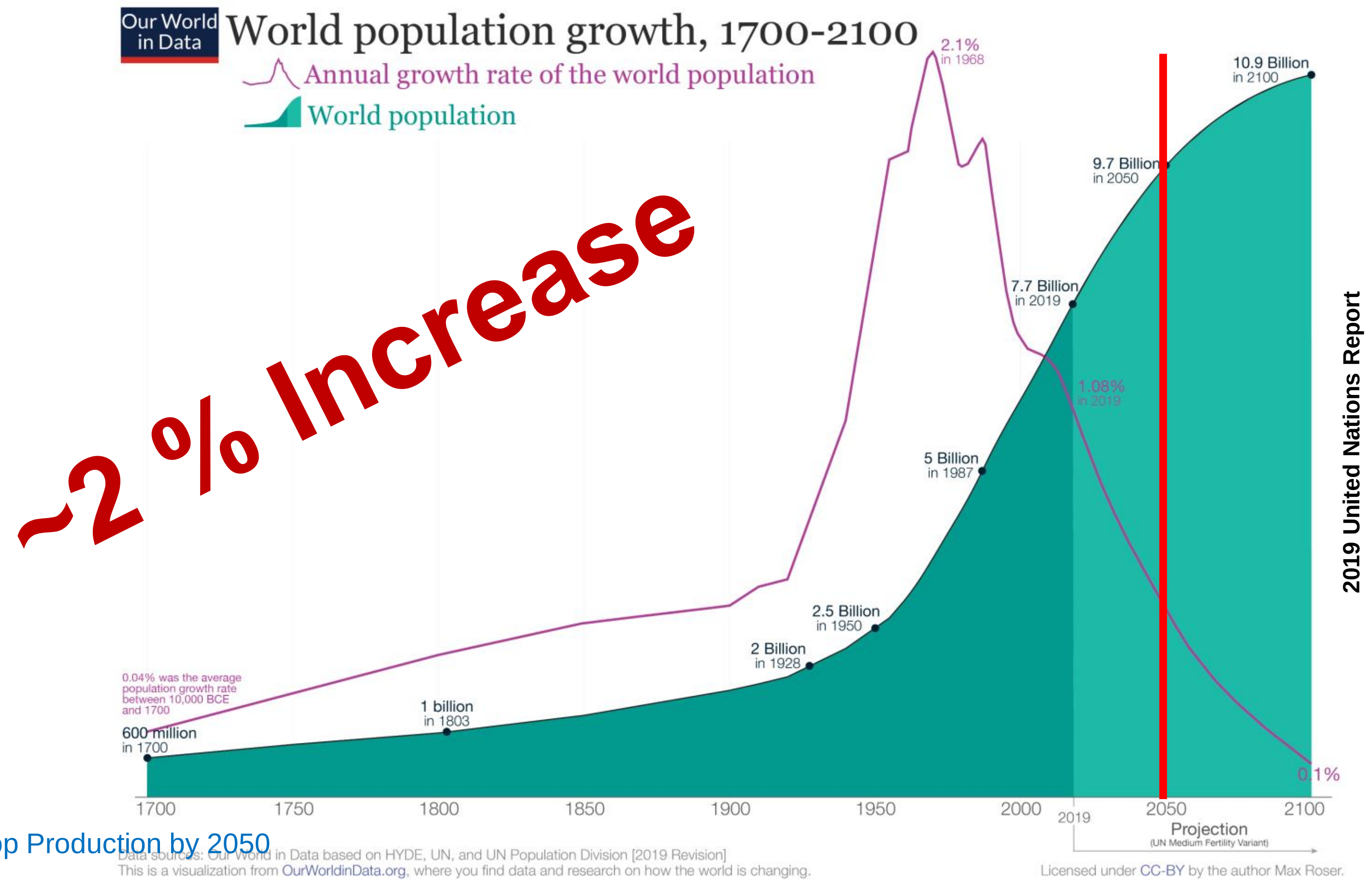
Outline

- ❑Grand challenge – World population
- ❑Plant breeding -definition
- ❑Importance of plant breeding to economies
- ❑Contribution to Food security solution
- ❑Cultivar – definition, types, propagation, reproduction type, mechanisms
- ❑Phenotype - determining factors
- ❑Review basic Genetics
- ❑Trait and inheritance
- ❑Breeding process/steps, pure-line/hybrid, breeding methods
- ❑Doubled haploids use
- ❑Tools enhancing breeding process

Grand challenge World Population:

- **Current**
  - 8.1 billion (February 2024)
- **Projected**
  - 8.6 billion in 2030
  - 9.7 billion in 2050,
- **Challenges**
  - Crop land shrinking; limited water
  - Climate change threats
  - Crop yields must increase 2-fold by 2050

Deepak et al. 2013. Yield Trends Are Insufficient to Double Global Crop Production by 2050



Food Security

https://www.worldometers.info/world-population

Plant Breeding can play significant role in addressing challenge

Plant breeding - definition

- “Plant breeding is the genetic improvement of plants for human benefit.” Rex Bernardo, Essentials of Plant Breeding
- A “modern” plant breeder is a professional that knowingly manipulates the nature of plants to improve their appearance and performance in predetermined ways
- The ‘science’ of maximizing positive genetic traits in plants to produce desirable effects
- Plant breeding is the collection, creation/manipulation, and evaluation of genetic variation to make permanent/heritable changes in plants that are advantageous to *hu*mankind

Plants are improved for the benefit of *hu*mankind

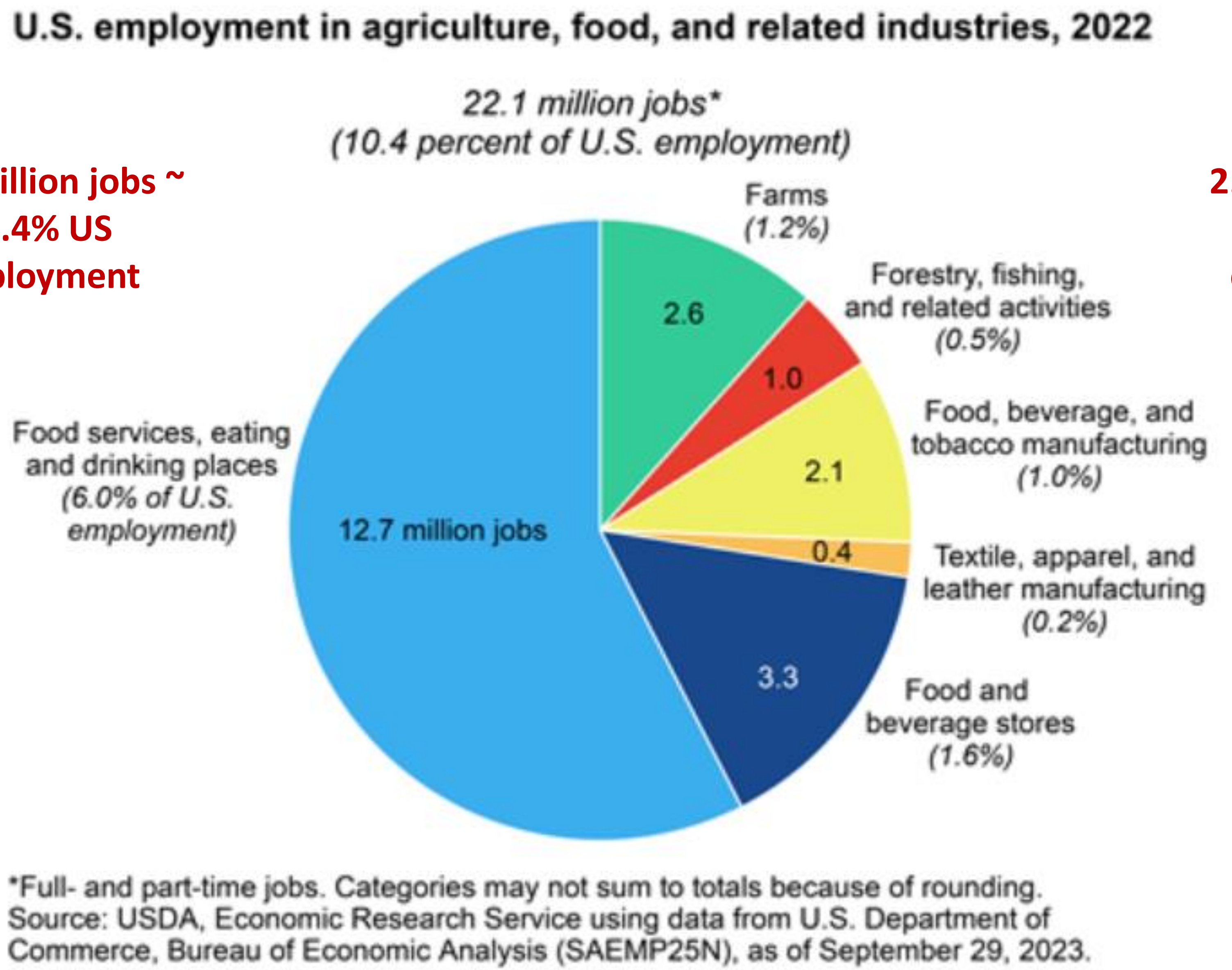
Importance of plant breeding

To US economy

- Agriculture, food, and related industries contributed **$1.264** trillion to U.S. gross domestic product (GDP) in 2021, **a 5.4 percent share**
- The output of America's **farms** contributed **$164.7** billion of this sum - **about 0.7 percent** of **GDP**

Employment in Ag, food, related industries

22.1 million jobs ~ 10.4% US employment

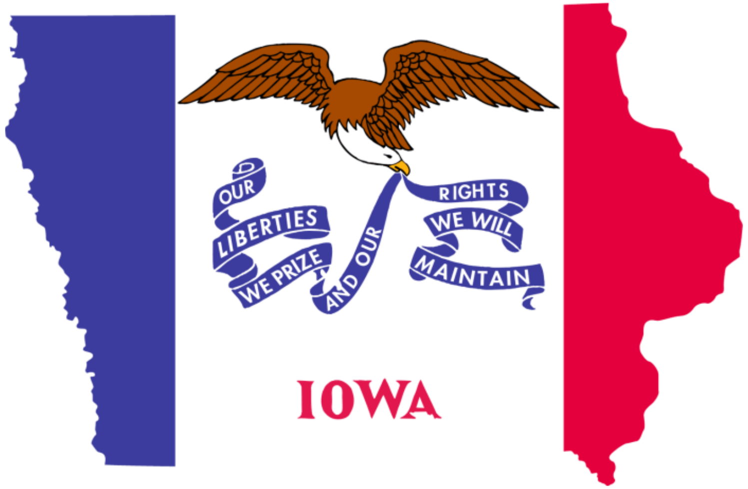


2.6 million jobs are on-farm employment

Importance of plant breeding

To Iowa economy

- In **2022**, total production agriculture responsible for **$88.3 billion in** direct economic output; added to the processing sector represents - **11.1%** of state GDP
- **1** in every **6** Iowans (~17% of workforce is employed by ag or ag-related industries (responsible for ~ 325,800 jobs & $17.6 billion in wages) Ag is vital to Iowa's economy (iowafarmbureau.com)




https://www.iowafarmbureau.com/Article/An-engine-for-Iowas-economy

Agriculture sector important – improved seed and seed-related activities – your work?

Contribution to food security solutions

How done?

- Accomplished by:
  - **Directly** increasing **yield/**quality
  - Increasing the **efficiency/productivity** of crops and production system
  - Increasing the **bioavailability** of key nutrients and reducing anti-nutritive compound
  - **Indirectly** making forages **more digestible** and creating **super efficient bio-renewable fuels**
  - Advantageous to humankind

Improve plants produced for humans

Tolerance to growth conditions

- **Directly** by increasing **yield/**quality of plants produced for humans
- By increasing the **efficiency/productivity** of crops and production system – e.g. adaptation to:

Flooding

Drought

High density planting

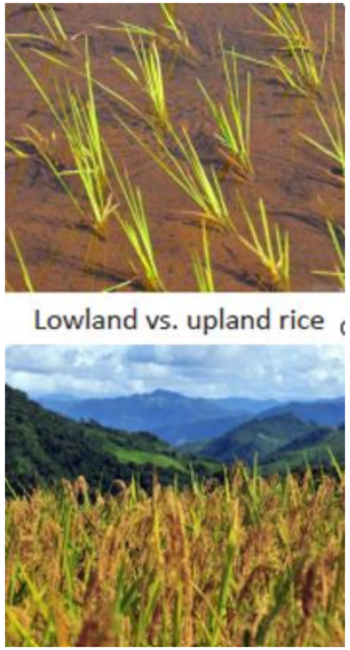
Modify crops for specific production systems to make them more efficient and profitable e.g.

Mechanical Harvest

Cold Tolerance

Organic Production

Lowland vs. Highland Rice



Modified/Vertical Production

Increased nutrients – reduced toxin

- By increasing the bioavailability of key nutrients and reducing anti-nutritive compounds

Golden Rice ↑ beta-carotene

↑ Quality Protein maize (QPM)
Lysine & tryptophan

	Normal	QPM
Lysine	160-180	256-300
Tryptophan	30-40	60-100
Leucin	827	507
Isoleucin	206	193
Protein digestibility	82	92
Biological value	45	80

Cassava with ↓ cyanide

Purple tomato - ↑ anthocyanin/antioxidants

Increased digestibility

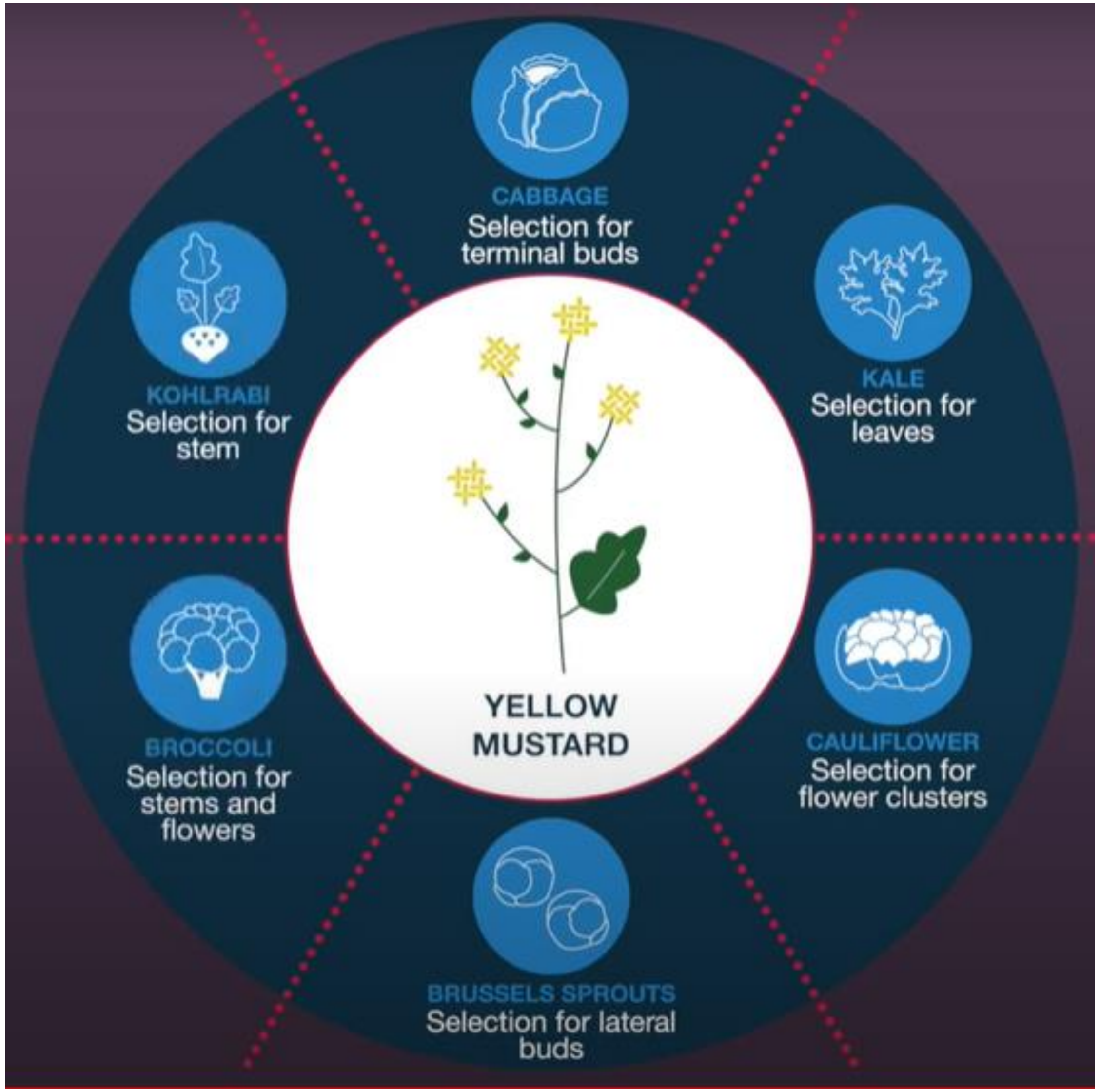
- **Indirectly** by making forages more digestible and creating super efficient bio-renewable fuels

Highly digestible forage

Corn for ethanol

Switchgrass for ethanol

Diversity: Yellow Mustard Example



Ensuring improved plants via

- Use of cultivars
  - Value in testing – purity assurance


Definition of cultivar

- A cultivar is a group of one or more genotypes that possess a combination of characters (phenotype) that is distinct, uniform, and stable (DUS)
    1. **Distinct:** distinctness is based on phenotypic characters that are not greatly influenced by the environment, as well as physiological and chemical qualities
    2. **Uniform:** uniformity of a cultivar must be commercially acceptable and predictable, and capable of being described
    3. **Stable:** a cultivar must remain stable and true to its description when reproduced or propagated

What is the value of understanding this for your work?

Types of cultivar

1. **P**ureline
2. **H**ybrid
3. **O**pen-pollinated variety (OPV)
4. **S**ynthetic
5. **C**lone

Types of cultivar

1. Purelines

What is the value of understanding this for your work?

- Self pollinated crops
- 100% **homozygous** (AABBCCDD, aabbccdd, AAbbCCdd, aaBBccDD, AABBccDD, OR aabbCCDD
- 100% **homogeneous** in the field (each plant is genetically identical)
- Maintained by selfing (occurs naturally in self pollinated species)

Soybean

Wheat

Types of cultivar

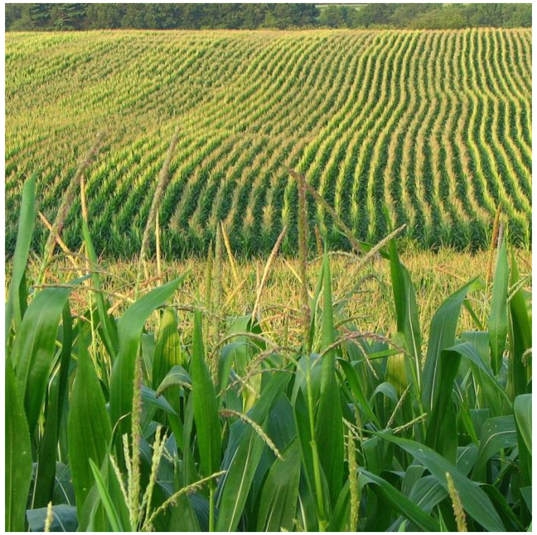
2. Hybrids

What is the value of understanding this for your work?

- Cross pollinated crops
- 100% **heterozygous** (AaBbCcDdEe)
- 100% **homogeneous** in the field (each plant is genetically identical
- Created by crossing 2 inbred lines (AAbbCCddEE x aaBBccDDee

Examples:

Corn



Sunflower

Cabbage/broccoli

Types of cultivar

3. Open pollinated varieties (OPVs)

- ➢Cross pollinated crops
- ➢ Individuals range in heter /homozygosity, heterogeneous population

4. Synthetics

https://www.iiste.org/Journals/index.php/ALST/article/viewFile/22241/22587

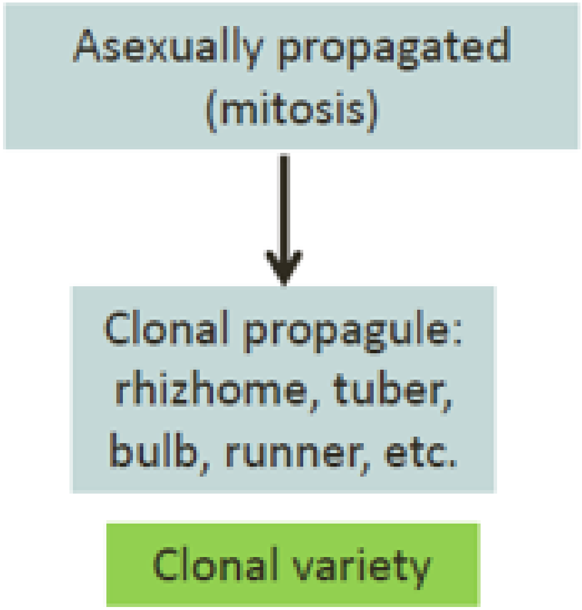
- ➢ Cross pollinated crops
- ➢ Individuals range in heter/homozygosity (more heterozygous than OPVs), heterogeneous population

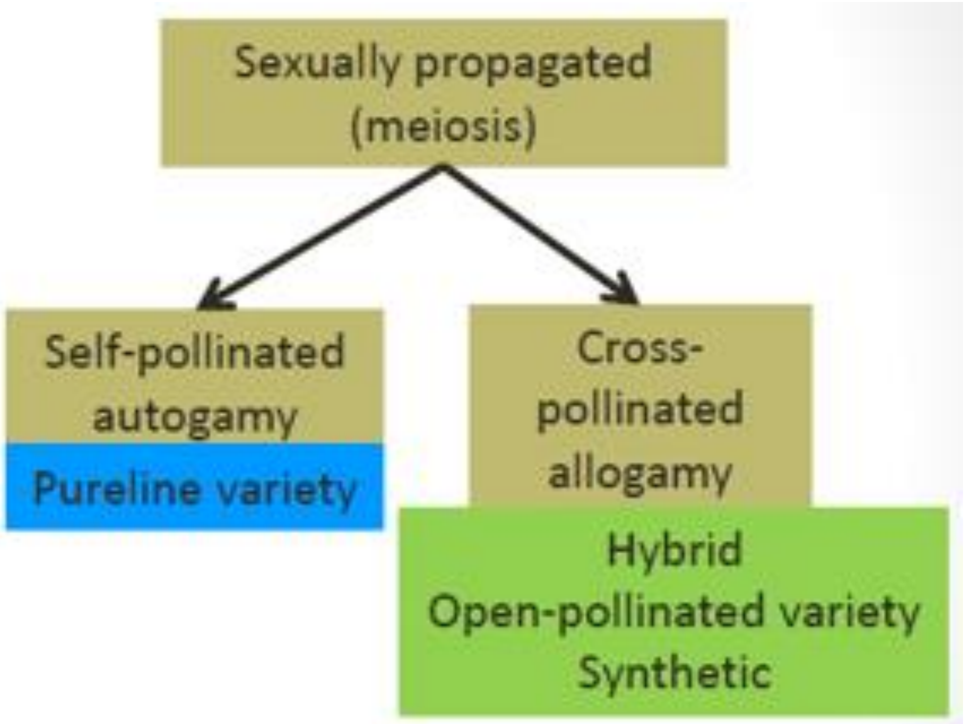
5. Clones

- ➢ Cross pollinated crops
- ➢Heterozygous and homogeneous (each individual is genetically identical = clone)
- ➢Maintained via clonal propagation

What is the value of understanding this for your work?

Propagation, reproduction, Cultivar types

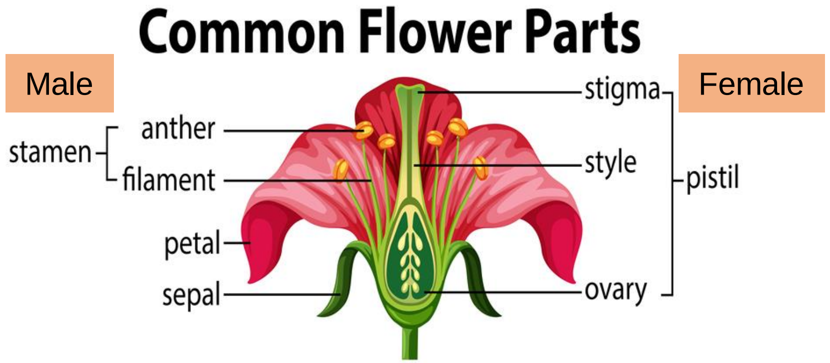




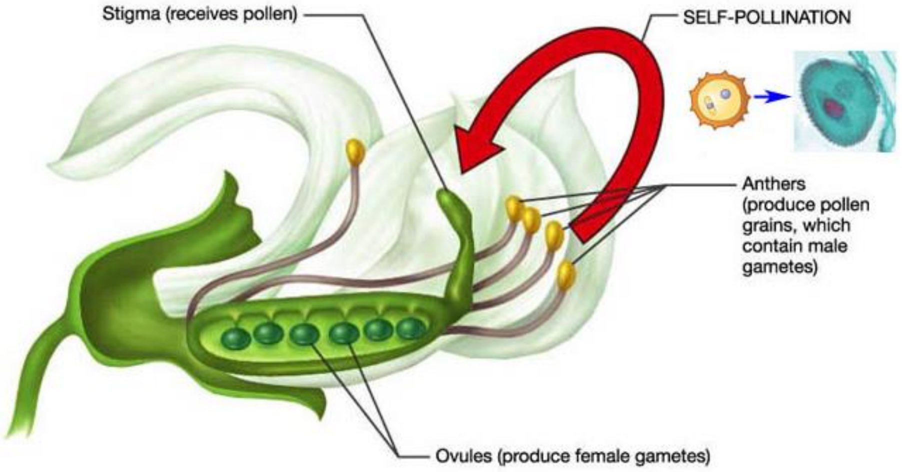
The type of cultivar and the breeding methods used to develop a cultivar are determined by the mode of propagation (asexual vs. sexual) used to produce a crop and how that crop reproduces (i.e., self-pollinated vs. cross-pollinated)

What is the value of understanding this for your work?

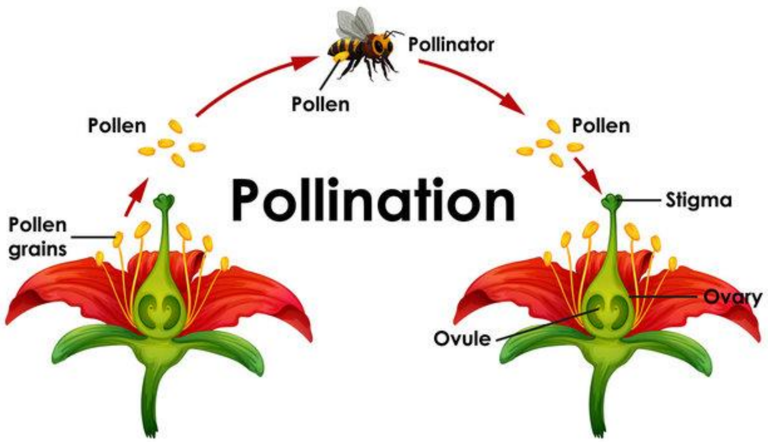
Types of Sexual Reproduction



Self-pollination



Cross-pollination



Sexual reproduction

Haploid gametes (pollen, egg cell) fuse to form a diploid embryo

- **Self-pollination**: pollen is transferred from an anther to the stigma in the same flower, to the stigma in a different flower on the same plant, or to a stigma on a separate plant that is genetically identical = clone
  - Barley, bean, chickpea, cowpea, flax, lentil, millet, oat, peanut, pea, soybean, wheat, tomato*, rice *

    *sold commercially as purelines and hybrids

Pureline variety

- **Cross-pollination**: pollen is transferred from an anther on one plant to the stigma of another plant (not a clone)
  - Cabbage, corn, cucumber, onions, peppers, rye, sunflower, sugar beet, alfalfa, Bermuda grass, hops

Hybrid, OPV, Synthetics, Clones

What is the value of understanding this for your work?

Mechanisms promoting **self-pollination**

- **Small**, inconspicuous flowers (**without petals**), do not attract insects
  - Wheat, rice
- **Perfect flowers** – anthers and stigmas in close proximity
  - Wheat, pepper
  - Rice spike w/ individual
- **Cleistogamous flowers** – do not open or open after self-pollination
  - Wheat, peanut, soybean
- **Colorful showy flowers** – attract insects; hibiscus, cotton, broccoli

What is the value of understanding this for your work?

Mechanisms promoting **cross-pollination**

- ❑ **Colorful showy flowers** – attract insects
  - ➢E.g., blueberries, apple
- ❑ **Imperfect flowers**
  - ➢ staminate/male - have stamens (male part) but no pistil (female part)
  - ➢ pistillate/female – have pistil but no stamens
- ❑ **Monoecious plants**– pistillate and staminate flowers on **same plant** – stigma and pollen physically separated
  - ➢Corn, squash, watermelon, cucumber, banana
- ❑ **Self-incompatibility**
- ❑ **Male sterility**

OR

Phenotype

=

Genotype

RR Rr rr

+

Environment

Value of understanding these in purity your work?

Phenotype

- expression of genotype (genetic) influenced by environment
- variation due to genotype (genetic) plus variation due to environment (non-genetic)

Genotype

- genes/alleles in plant

Genetic variation

- is heritable (carried over generation to generation)

Environmental variation

- is not heritable (plant response varies according to different environmental facts - environment to environment or generation to generation
  - Abiotic environment – temperature, precipitation, wind, light, nutrients
  - Biotic environment – disease, insects, weeds, seed size

Environmental variation affecting phenotype

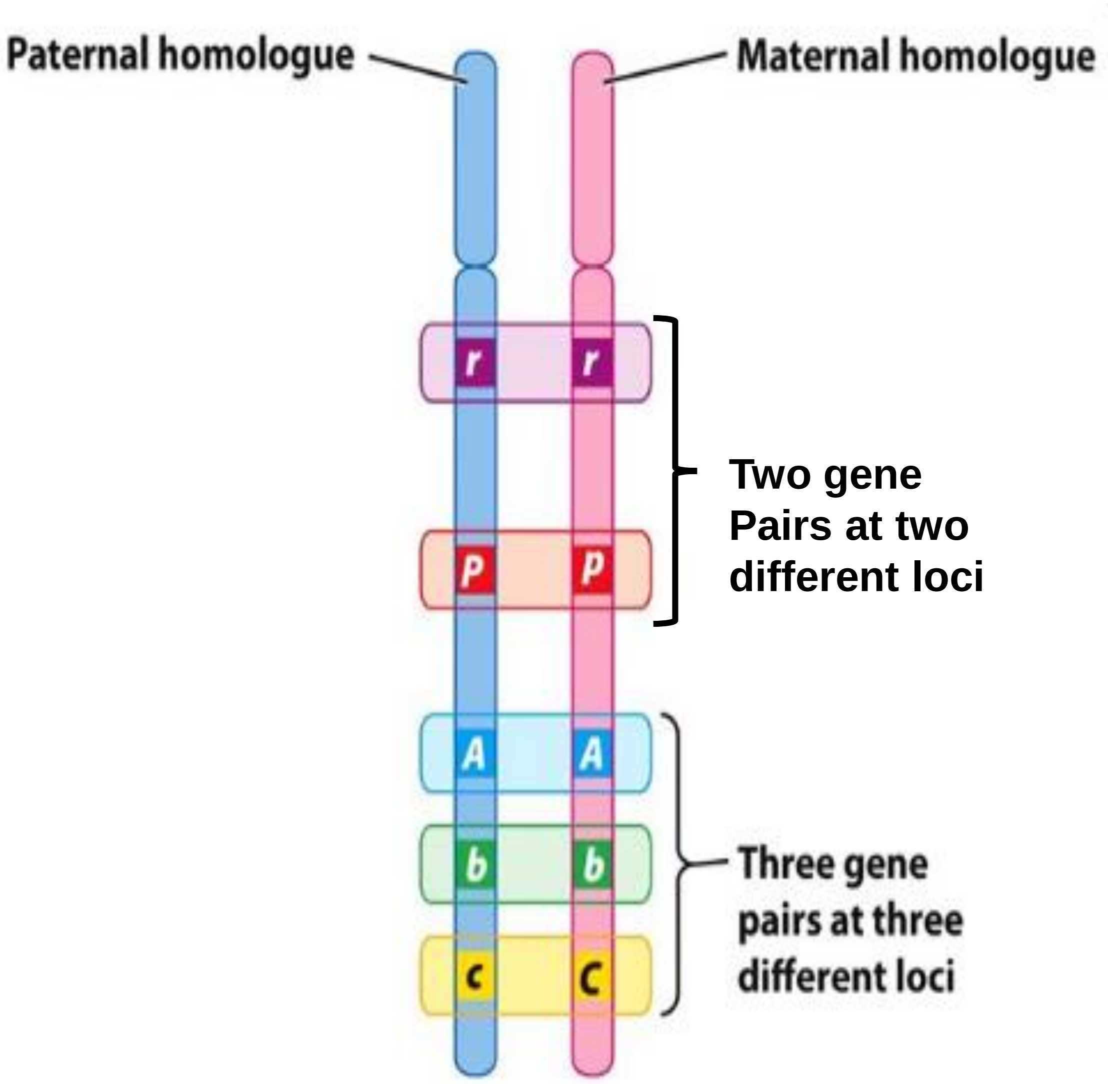
- Abiotic environment – nutrients, temperature, precipitation, wind, light
- Biotic environment – insects, weeds, seed size, disease

Corn grown under different N treatments results in environmental variation (not passed on to the next generation)

Review - Basic Genetics

Trait, gene, genome, locus

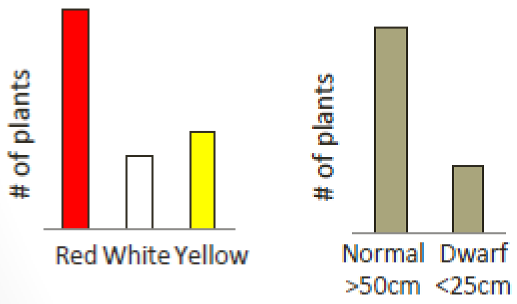
- ❑ **Trait** = a measurable character under genetic control
- ❑ **Gene/allele** = unit of inheritance for a trait, e.g. R/r, P/p/, AA, b/b, cC, etc.
- ❑ **Genome** = all of the genetic material of an organism
- ❑ **Locus** (plural loci) = position/location of a gene on chromosome



Traits and Inheritance

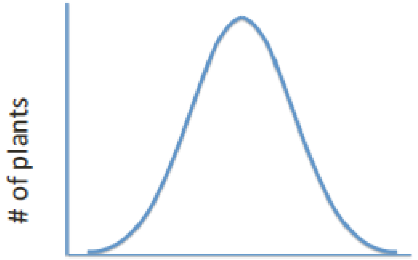
- **Qualitative traits**
  - Discrete phenotype
  - Less affected by environment
  - Simply inheritance – one or few genes
  - **Examples:**
    - Flower color
    - Plant height
    - Leaf color; etc.
- **Quantitative traits**
  - Continuous distribution of phenotypes
  - More affected by environment
  - Complex inheritance – many genes, with small effects
  - **Examples:**
    - Flowering time
    - Yield, Plant height
    - Maturity
    - Lodging resistance, etc.

Qualitative trait



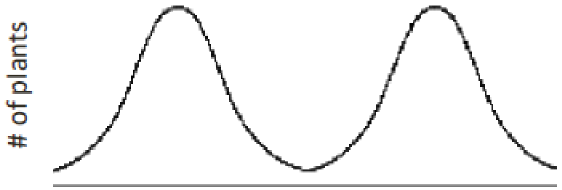
Discrete classes
One/few genes
e.g., flower color

Quantitative trait



Continuous distribution
Many genes
e.g., yield

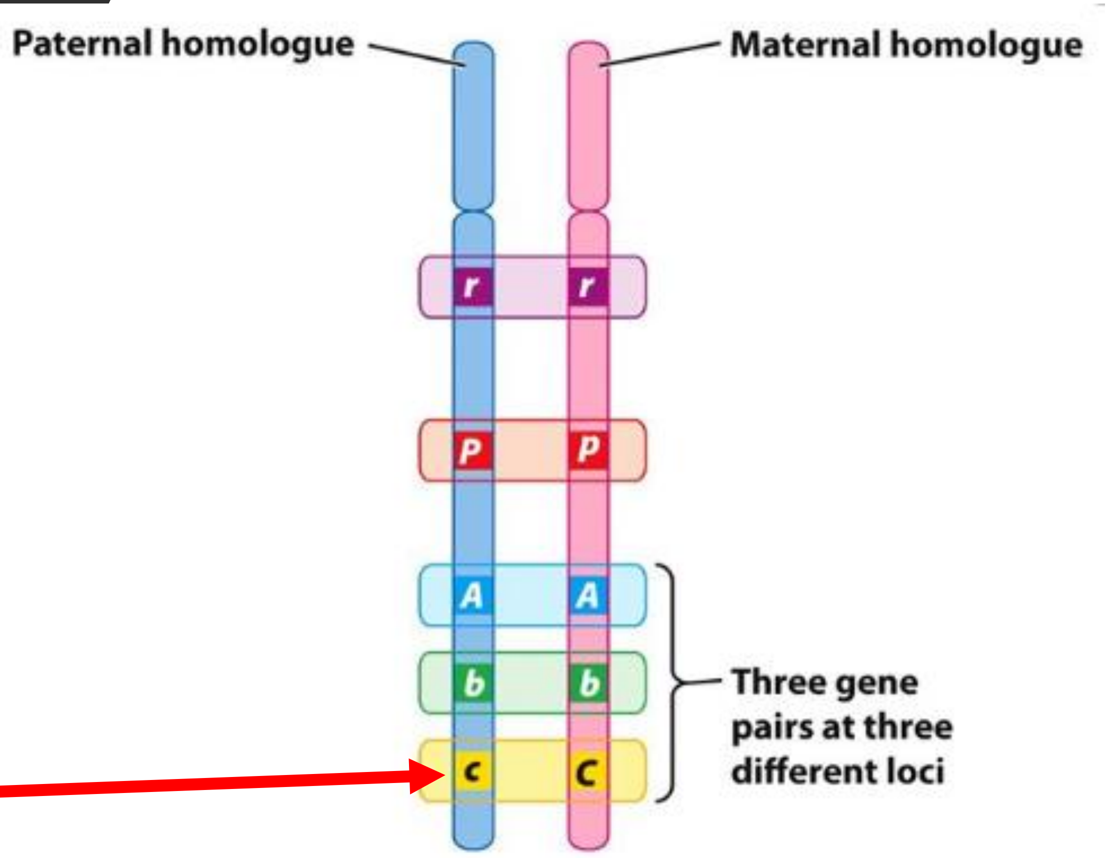
Trait controlled by qualitative and quantitative genes



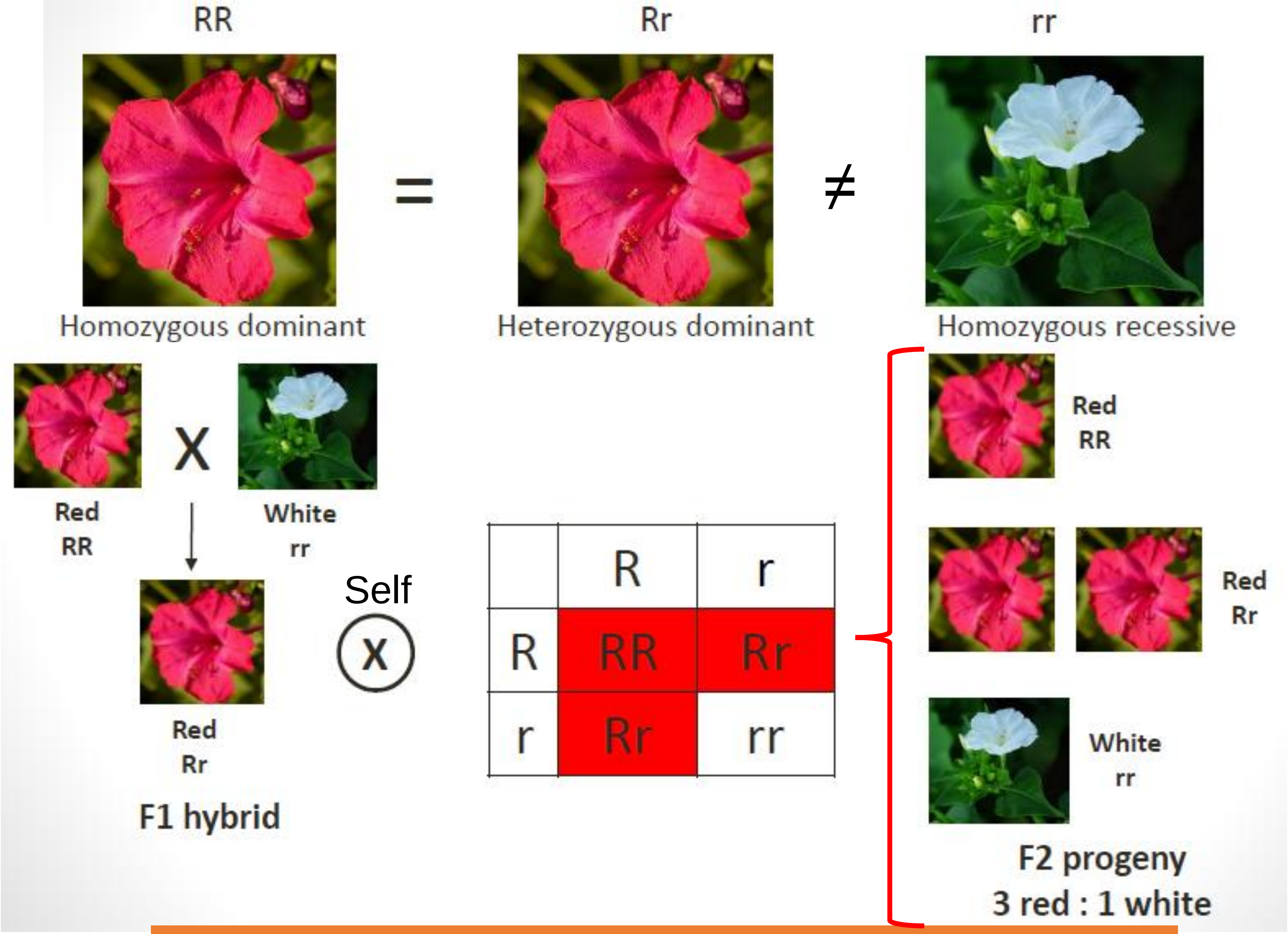
Continuous bimodal distribution
One major gene (2 peaks) + multiple modifier genes
e.g., disease resistance

Allele and genotype

- **Allele** = one of contrasting forms of a gene, R vs. r; A vs. a; B vs. b
  - in diploid maximum of 2 alleles
  - But > 2 alleles in population (R, r, R’, R+, etc. (e.g., disease resistance or self-incompatibility genes)
- **Homozygous** = alleles are same at a locus, e.g. rr, PP, AA, bb
- **Heterozygous** = alleles are different at a locus, e.g., Cc



Genetic control: allele dominant(R) or recessive(r)



Other forms of dominance: incomplete/partial; codominance

Recall plant breeding is

- The:
  - collection
  - creation/manipulation
  - evaluation of genetic variation
  - make permanent/heritable changes in plants
  - advantageous to *hu*mankind

Breeding steps of plant breeding

1. Identify breeding objectives/goals
2. Assemble germplasm & maintain a breeding nursery
3. Develop segregating populations via hybridization
4. Evaluate the progeny
5. Select plants that possess superior qualities that are under genetic control (i.e., heritable and be passed on to the next generation) and self them
6. Develop pureline varieties or inbred lines to make hybrids
7. Conduct prelim and advanced yield trials
8. Certify, release, and distribute the new cultivar

Cultivar development takes 6-12 years, so breeders must predict which traits and qualities will be important in the future

Breeding steps of plant breeding

1. Identify breeding objectives/goals
   - ❑ Yield, disease and pest resistance, abiotic stress resistance (high/low temp, excessive water/flooding, drought, high salinity, alkaline soils), plant architecture, quality traits (protein/oil content, fruit size, shape/symmetry, color
   - ❑ flesh/skin, soluble solids, acidity, taste, aroma, pH, sugar content, shelf life/fruit firmness, vitamin C/E content, lycopene content…..
     - ➢ Must be specific
     - ➢ Must be measurable, quantifiable
2. Assemble germplasm & maintain a breeding nursery




Breeding steps ctnd.

3. Develop segregating populations via hybridization
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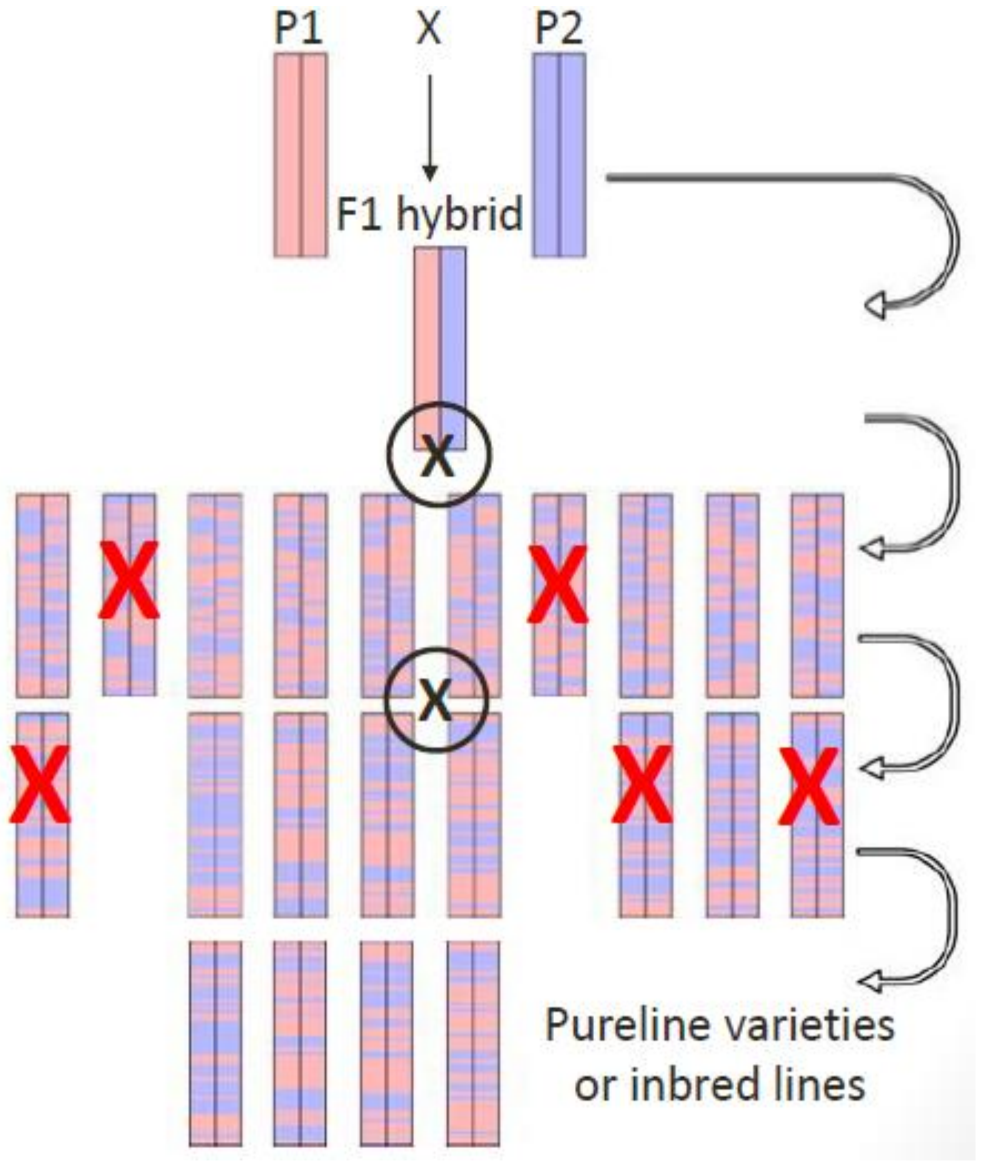


Genetics of self-pollination

Homozygosity increases and heterozygosity decreases by ½ after each generation of selfing

AA X aa

F_1

⊗

$F_2 = S_1$ → 50% AA + aa, 50% Aa

⊗

$F_3 = S_2$ → 75% AA + aa, 25% Aa

⊗

$F_4 = S_3$ → 87.5% AA + aa, 12.5% Aa

⊗

$F_5 = S_4$ → 93.75% AA + aa, 6.25% Aa

% heterozygotes = $(1/2)^n$

% homozygous = $1 - (1/2)^n$

n = # of generations of selfing

Goal: Increase level of homozygosity

Practical level of homozygosity reached at about 5-8 generations of self-pollination

What is the value of understanding this for your work?

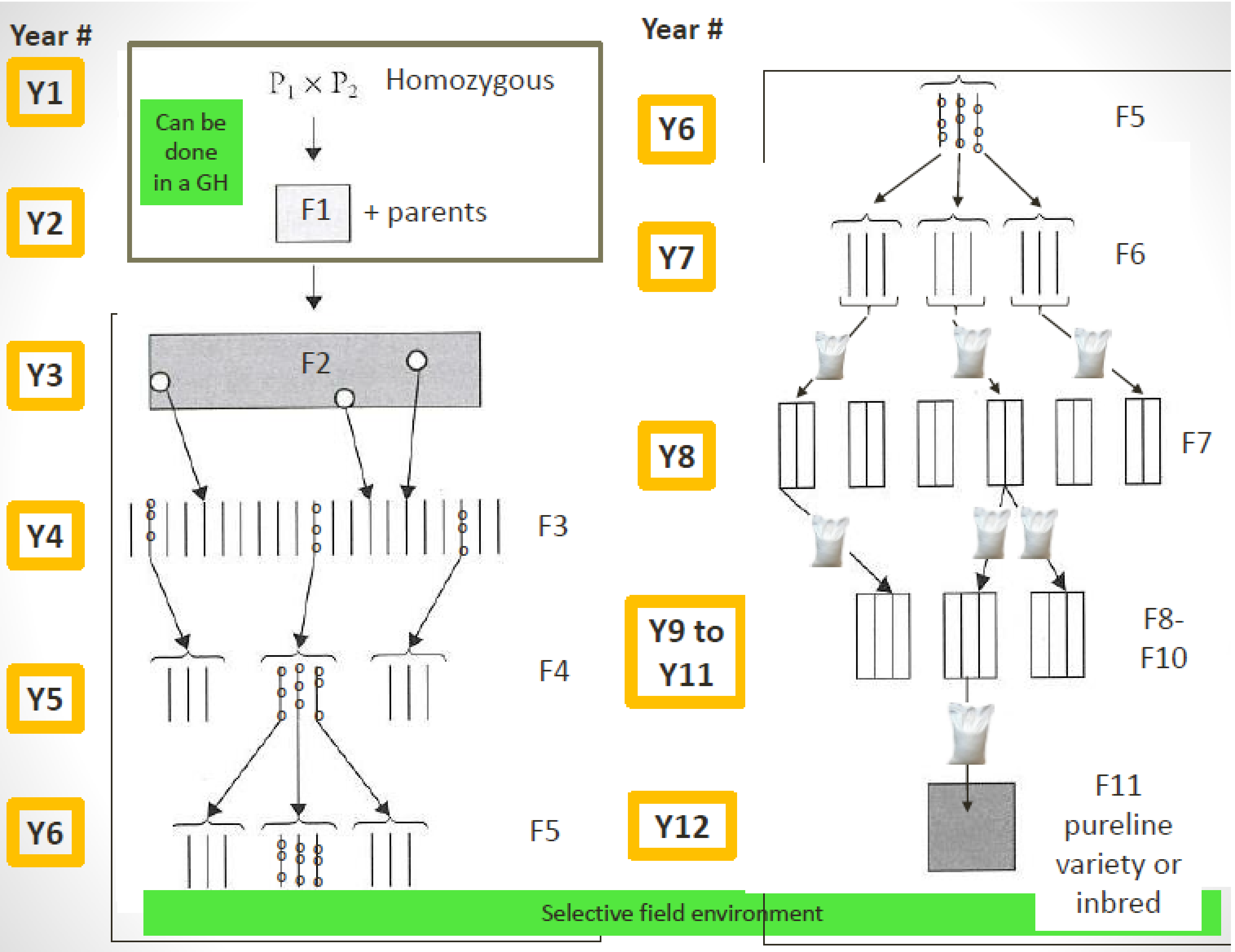
Breeding process

Create genetic variation → Select desirable plants, self them to create homozygous lines
Select – Self – Advance - Repeat → Cultivar or an inbred line

Starting Material	**Method**	**Goal or end-product**
Cross between two parents	Pedigree selection	Pureline variety or an **inbred line** (100% homozygous, 100% homogeneous)
	Bulk population	
	Single seed descent (SSD)	

Also need to evaluate for combining ability of different inbred lines and how well their **hybrids perform (testcross hybrids)**

Pedigree selection



Hybrid Development

Why make hybrids?

- To capitalize on hybrid vigor by crossing unrelated parents
- The greater the genetic diversity b/t inbred parents the greater the hybrid vigor observed in the hybrid (more heterozygosity)

A X B

AABBCCDDEE → aabbccddee

AB

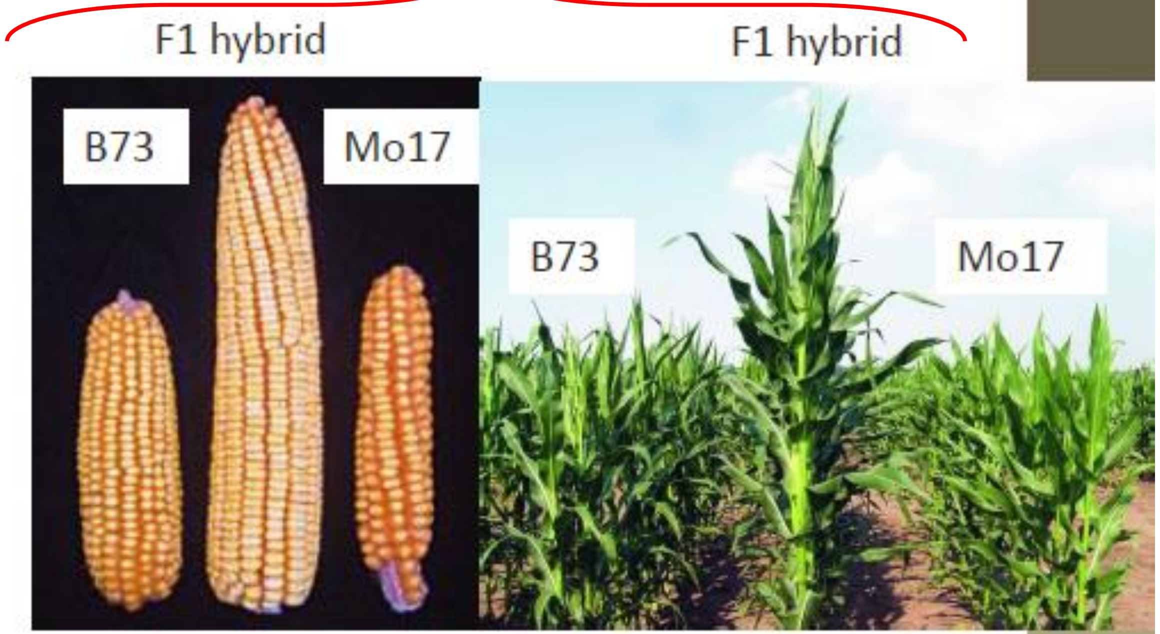
50% A, 50% B

AaBbCcDdEe

100% heterozygous

100% homogeneous in the field

(each plant is genetically identical)



Goal – to produce a hybrid cultivar (100% heterozygous – lots of hybrid vigor, completely homogeneous/genetically identical)

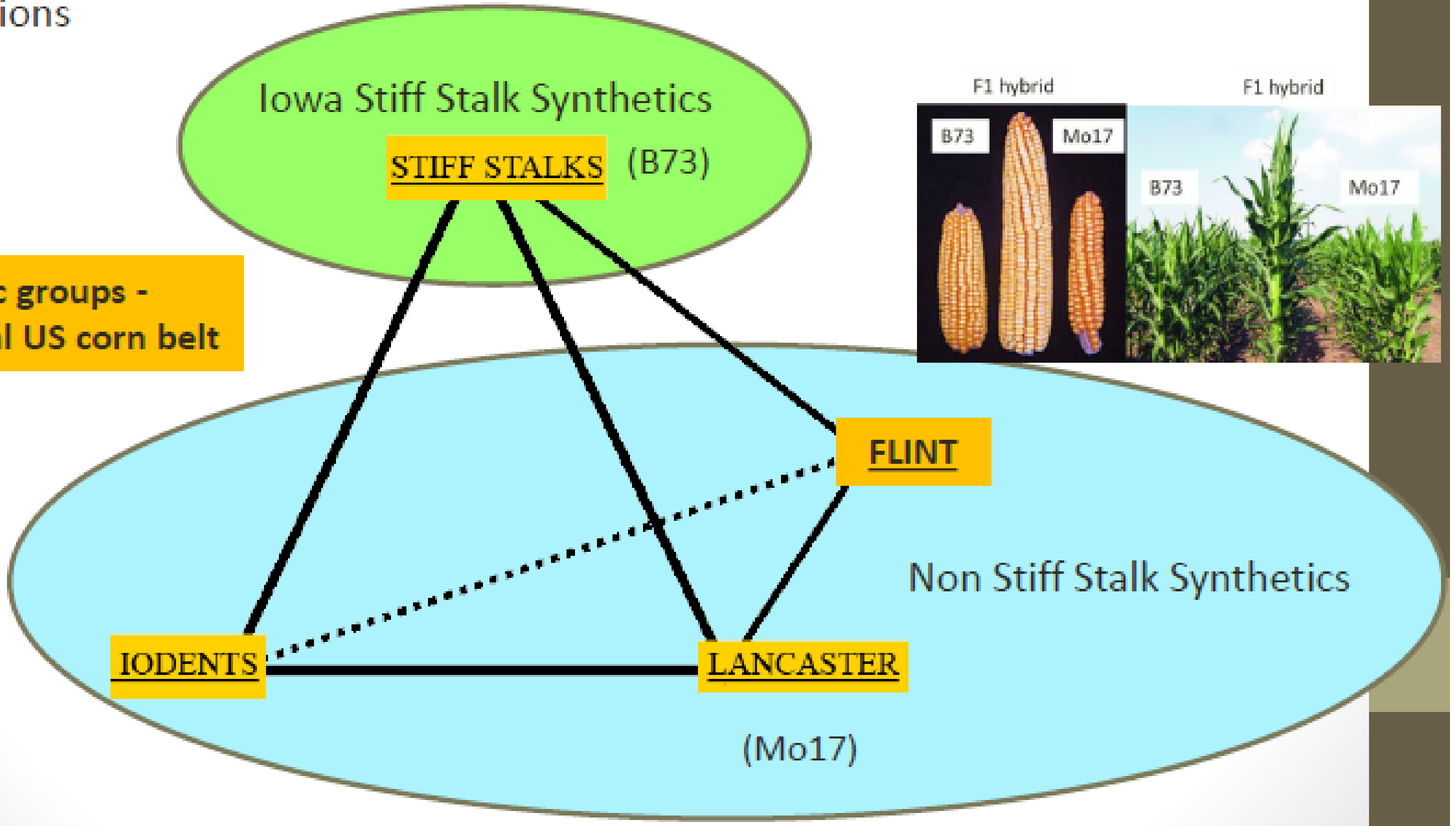
What is the value of understanding this for your work?

Heterotic groups

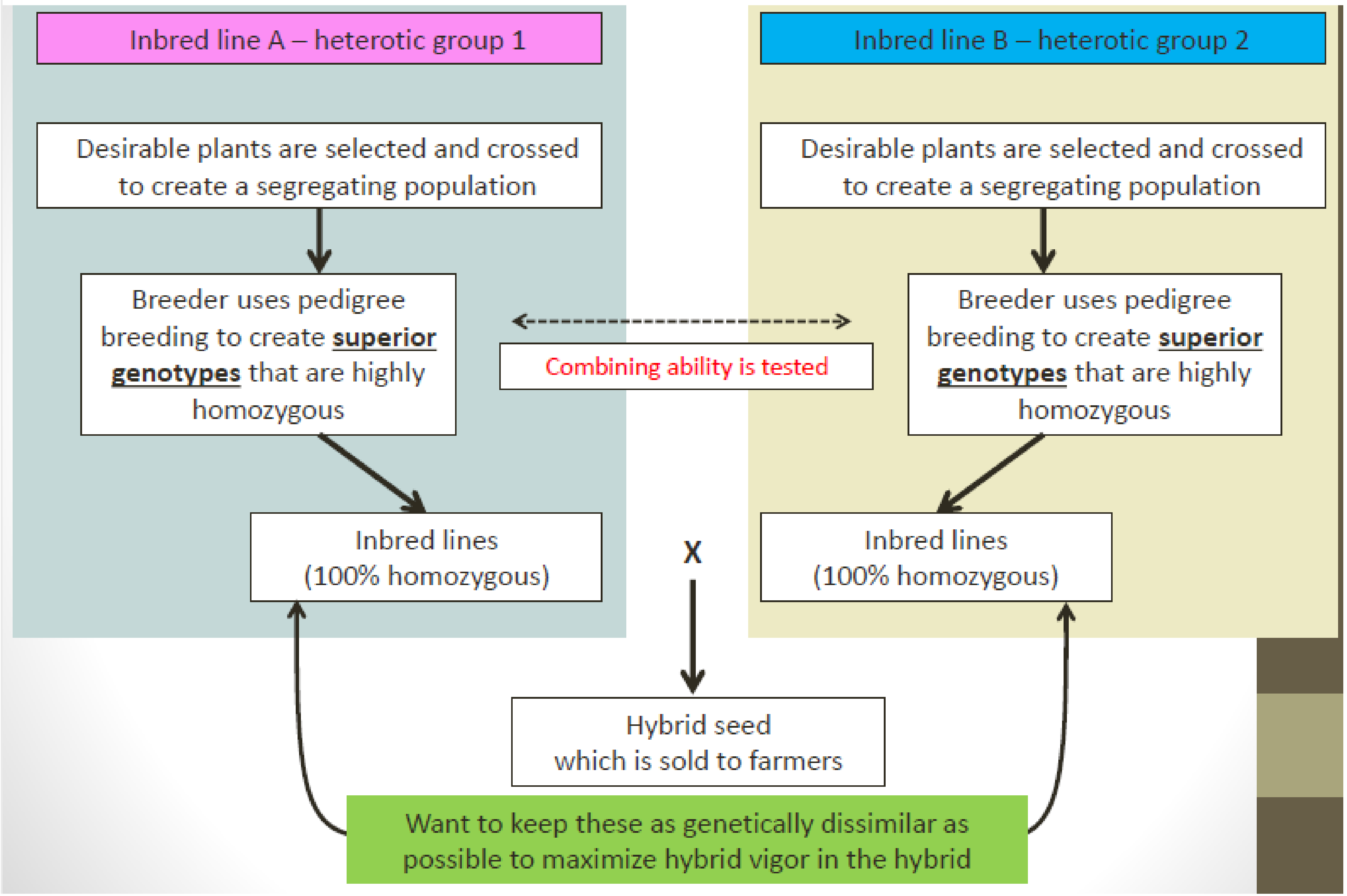
Hybrid Development

- Inbred lines used to create hybrids come from different heterotic groups
- A heterotic group consists of genotypes that **display similar combining ability when crossed to another group of genotypes**
- Classified based on pedigree, molecular markers, performance of hybrid combinations

Heterotic groups - North/Central US corn belt

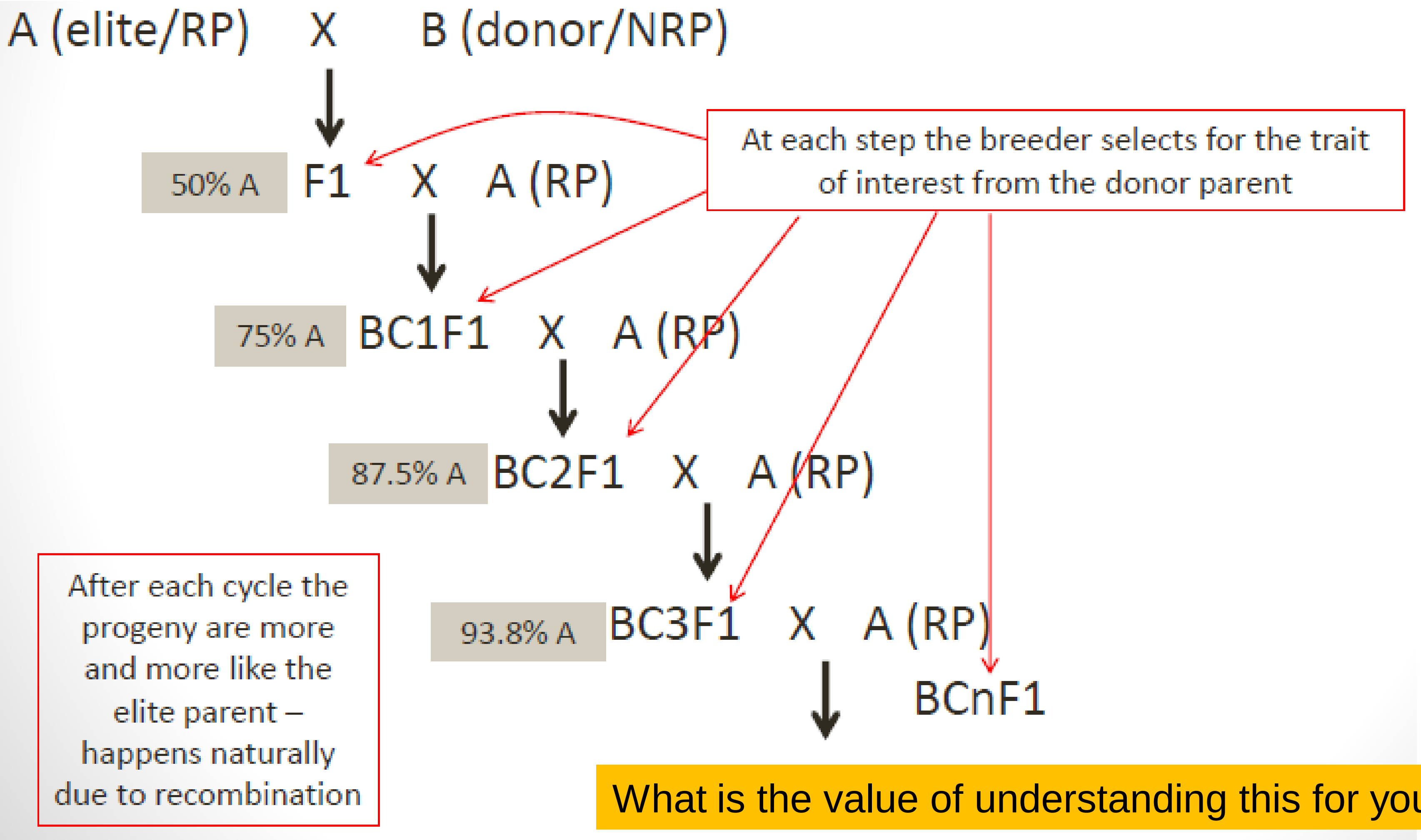


Breeding methods: cross-pollinated crops



Backcross method

Goal: incorporate a specific trait from a donor = B into an elite cultivar = A (recurrent parent) without losing the desirable traits of A

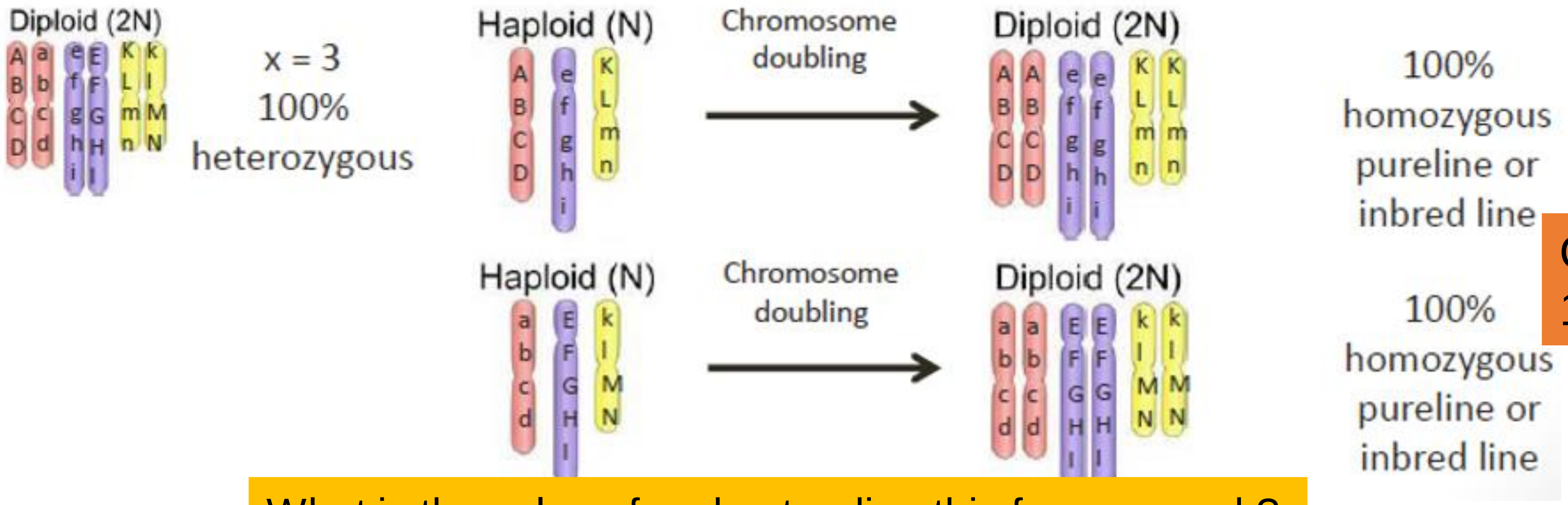


- ❑ Advantages
  - Repeatable
  - Fewer plants
  - Do in greenhouse for elite lines
  - Stack traits
  - Etc.
- ❑ Disadvantages
  - Difficult with recessive traits
  - Not efficient for quantitative traits
  - Undesirable linkages can limit performance
  - Stack traits
  - Etc.

What is the value of understanding this for your work?

Doubled haploids (DHs)

Starting Material	Method	Goal/end product
Heterozygous individual F	Doubled haploids	Large collection of 100% homozygous lines (each one different) representing the genetic variation in the starting individual



One generation for 100% homozygous

What is the value of understanding this for your work?

Methods of creating doubled haploids

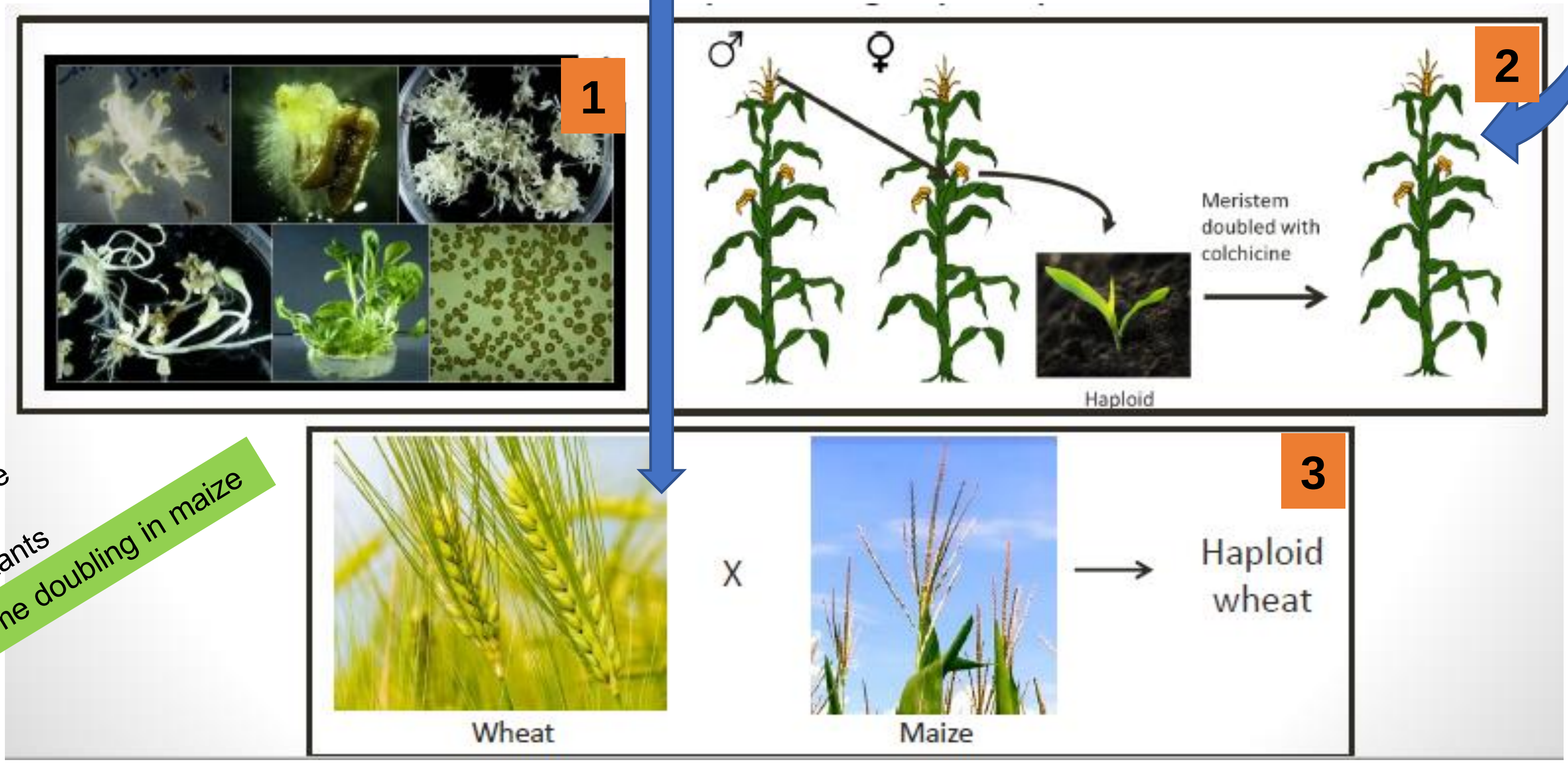
Start with heterozygous plant AaBbCcDcEe

1. Anther/pollen culture
2. Inducer lines that stimulate the production of haploid plants (only in corn)
3. Wide hybrid crosses where the chromosomes of the male parent are eliminated after fertilization thus producing haploid plants

Advantages
- 100% AA, 1 year
- Saves money

Disadvantages
- Works for some species
- Expensive anther culture
- Low% haploids
- Lethal recessive mutants

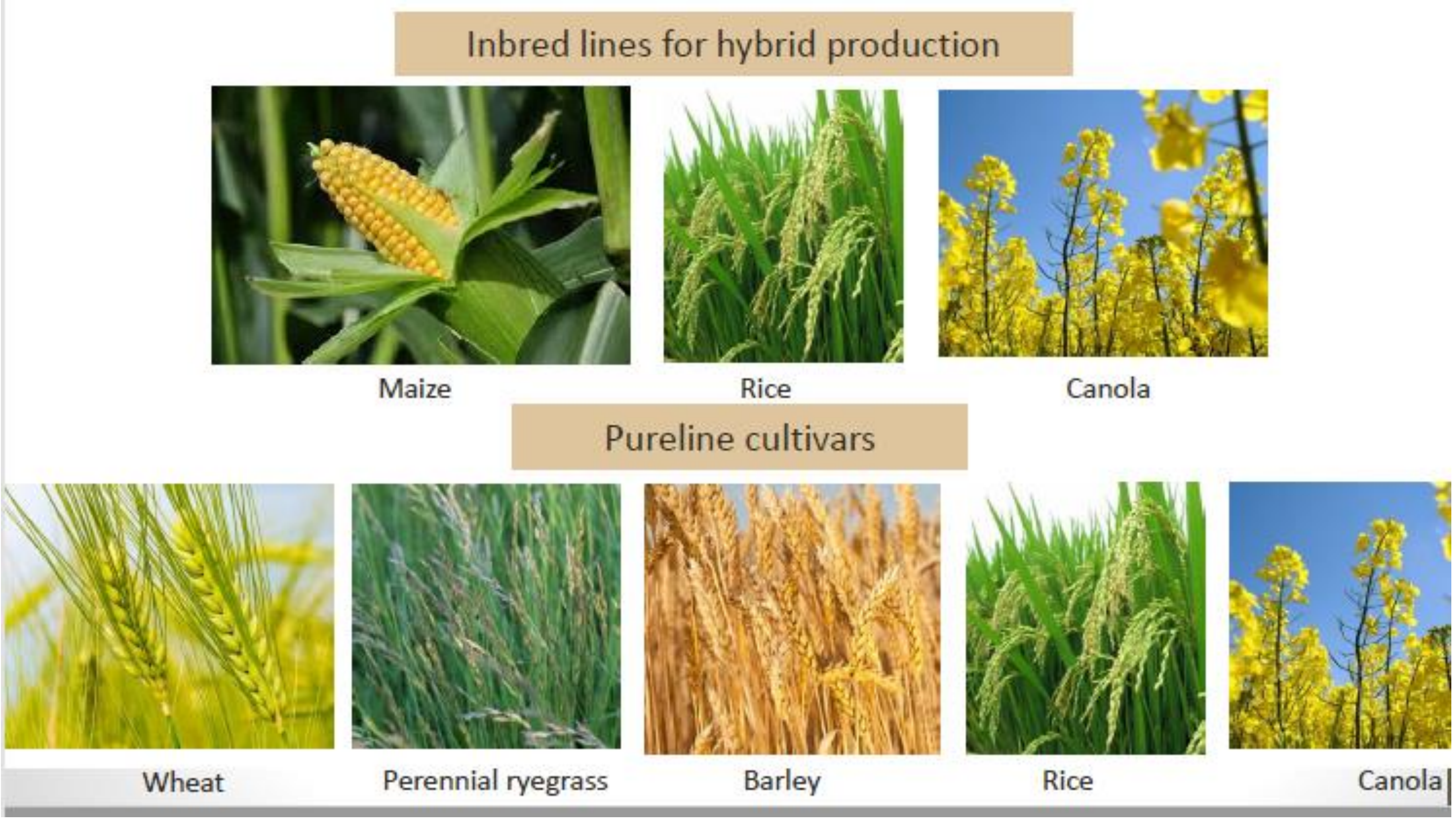
Spontaneous genome doubling in maize



For some details: https://www.researchgate.net/figure/Doubled-haploid-DH-technology-A-Comparison-between-conventional-breeding-and-DH_fig1_320591213

Adoption of Doubled Haploid methods

- For maize: >90% adoption (Dow AgroSciences, Monsanto, DuPont, & Syngenta), 100% for AgReliant
- For wheat, canola, rice >50% of purelines are created using DH methods

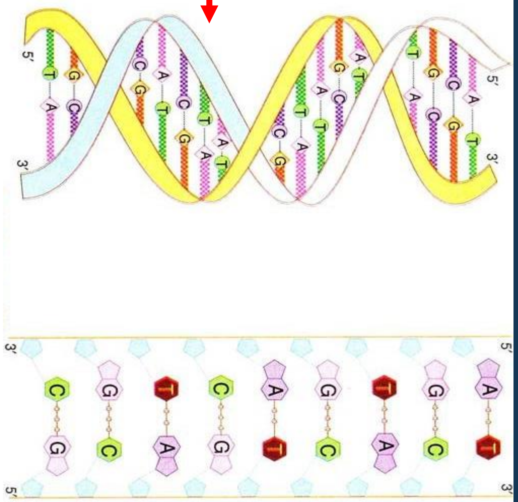


Plant Breeding – used to be on trial-and-error basis

- Enhancements needed for greater or faster progress
- Molecular markers – focus on DNA-based

Tools for enhancing breeding process

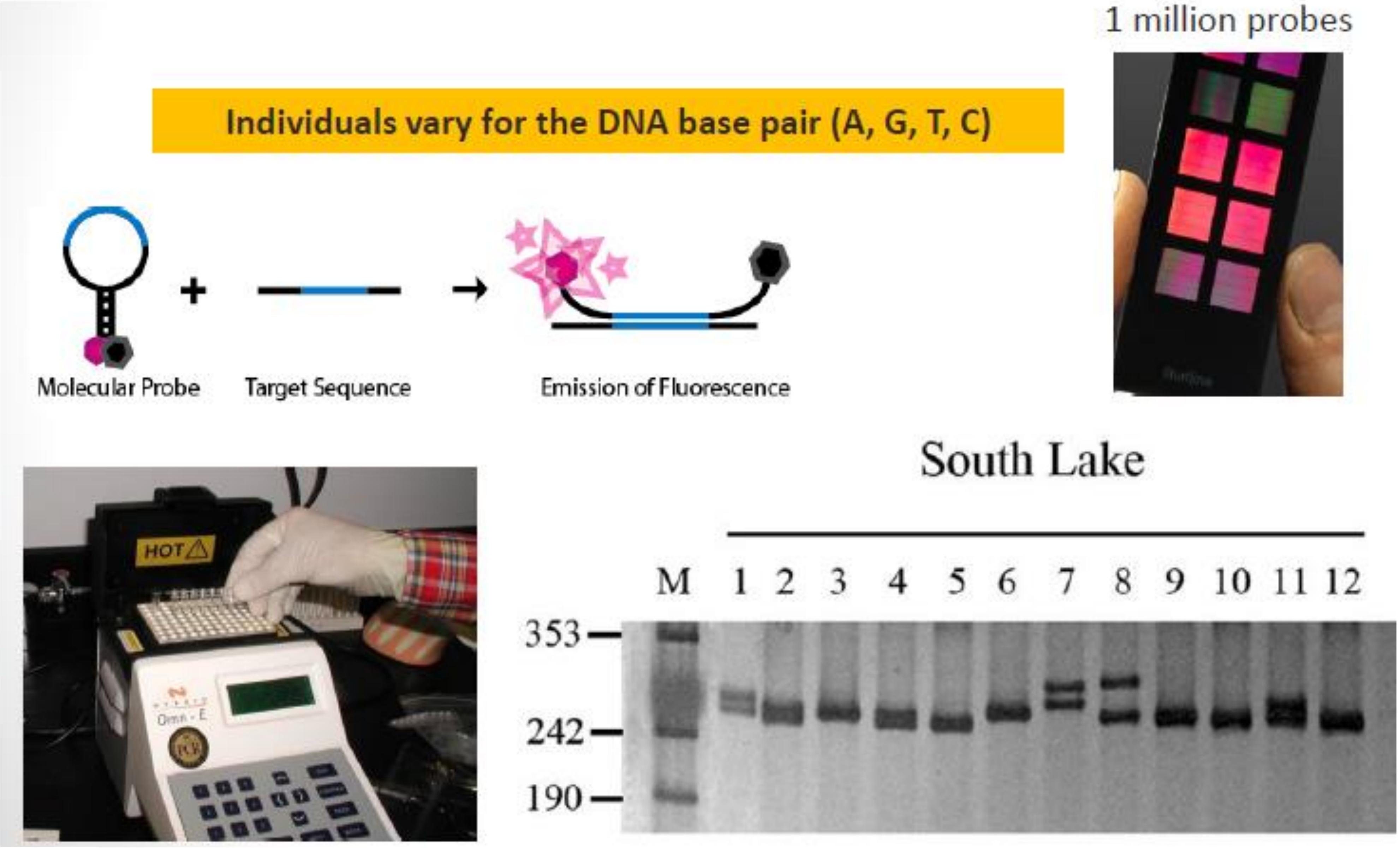
- Molecular Markers - Genomic Selection - Predictive Breeding
- Gene/Genome Editing
- Anther Culture



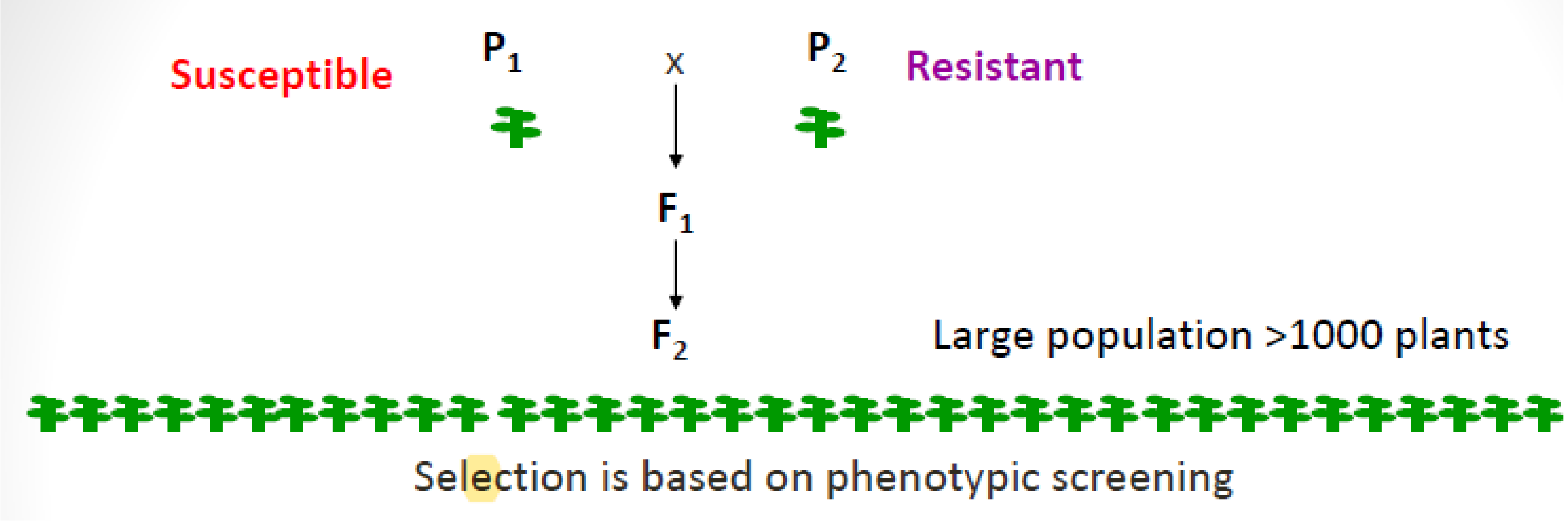
How molecular markers can be used

- ❑ Cultivar identification (DNA fingerprinting for protecting proprietary rights)
- ❑ Seed purity - AA vs Aa vs BB vs CC; GMOs
- ❑ Identify hybrid progeny when making crosses vs. accidental selfs or outcrosses
- ❑ Characterize germplasm (assignment of heterotic pools)
- ❑ Selection of genetically divergent parents for crosses (AA vs Aa vs BB vs CC)
- ❑ Population improvement
- ❑ Marker assisted selection increase the accuracy of phenotyping (disease resistance), selection for disease resistance without the presence of the pathogen
- ❑ Marker assisted backcrossing
- ❑ Gene pyramiding (multiple disease resistance genes in one genotype)
- ❑ Basic research: identifying quantitative trait loci (QTL), gene isolation, etc.
- ❑ Predictive breeding genomic selection

Marker Assisted Breeding (MAB)

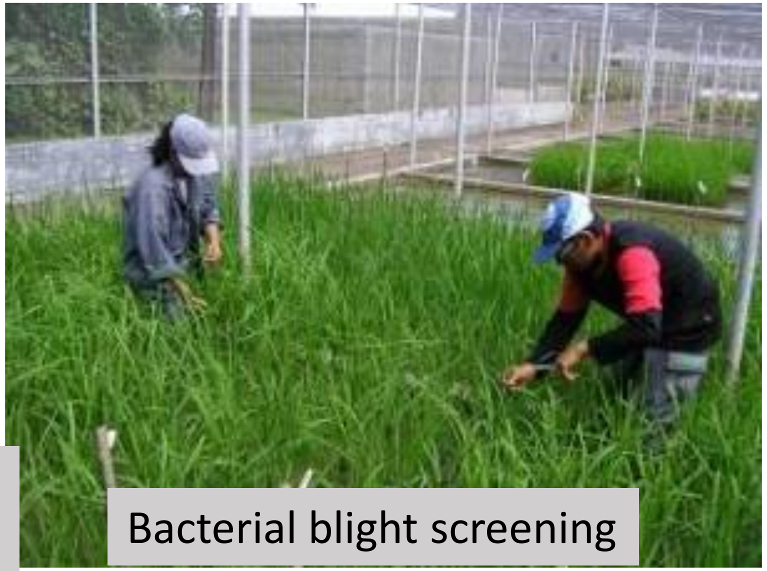


Traditional selection without markers



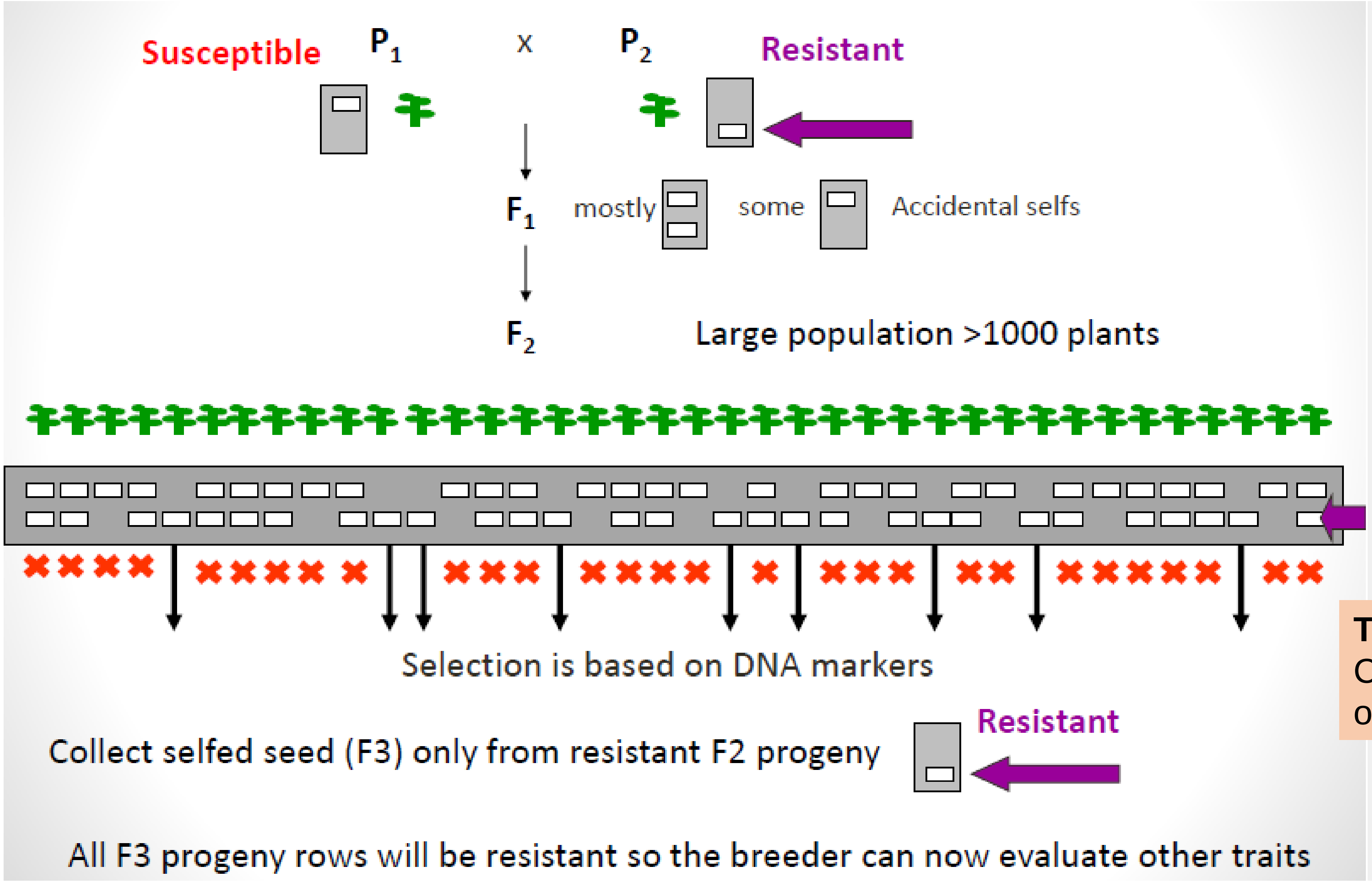
Take home
Lots of plants evaluated, one trait at a time


Salinity screening in Phytotron


Bacterial blight screening

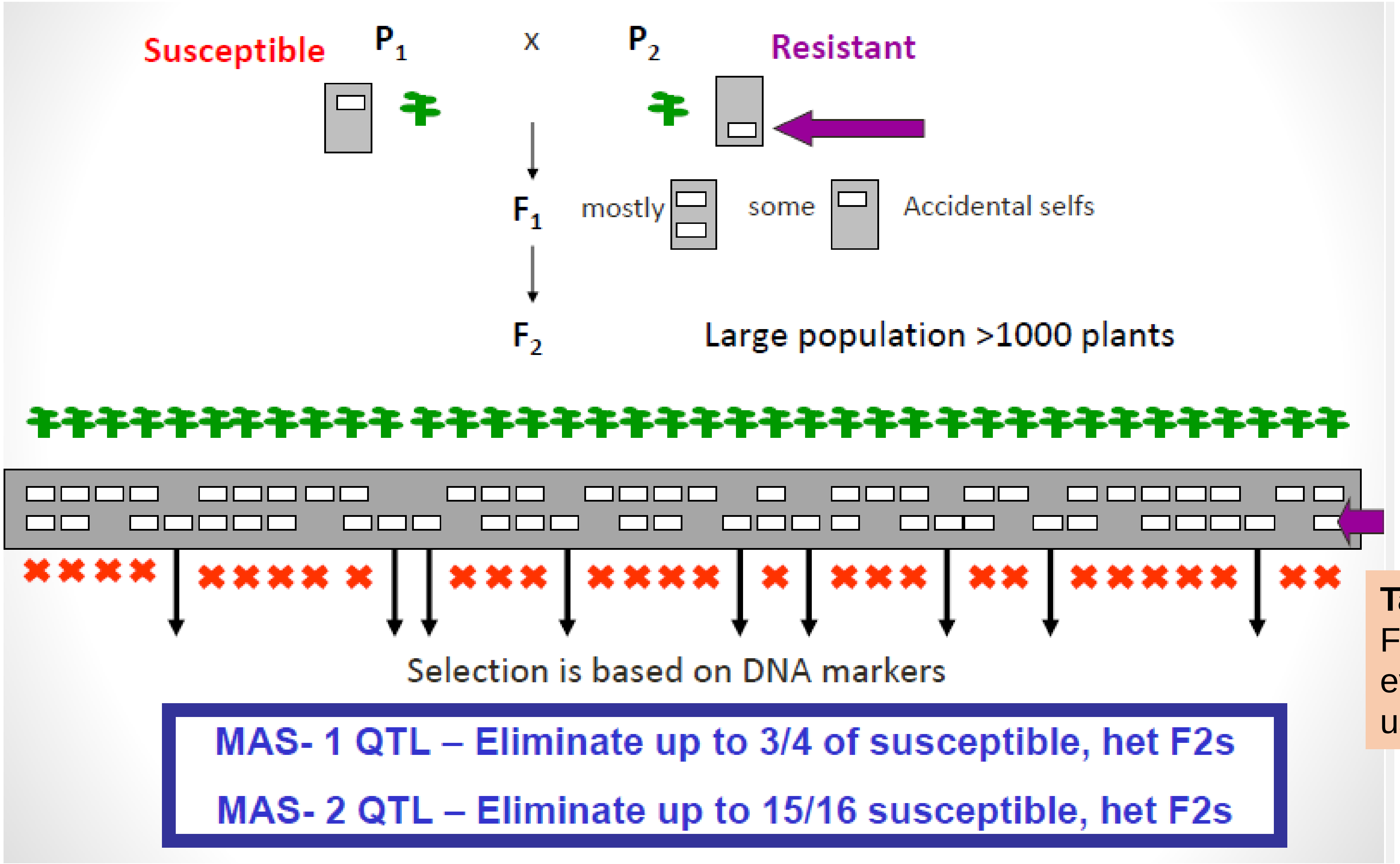

Phosphorus deficiency screening

Marker assisted selection (MAS)



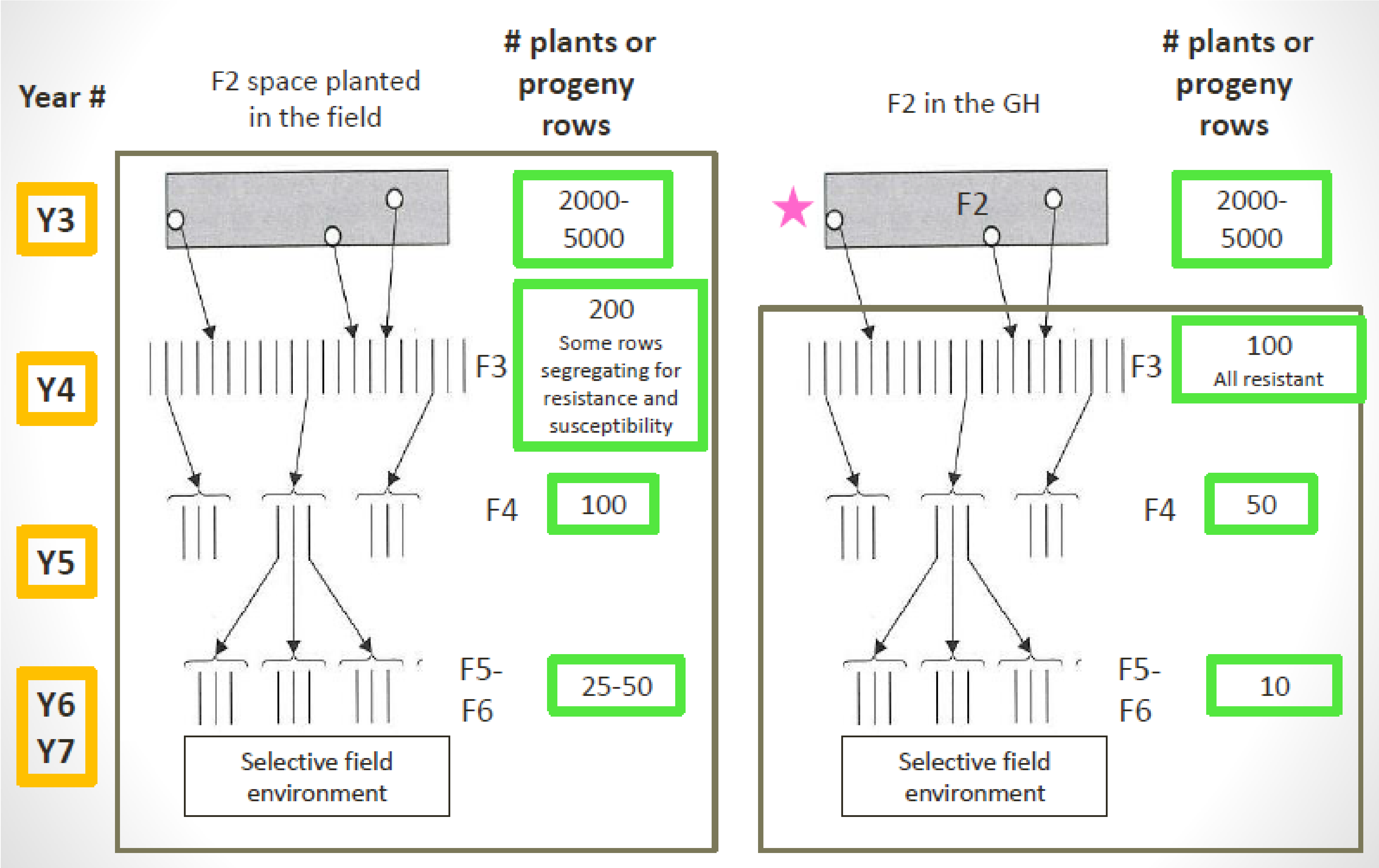
Take home
Can evaluate other traits

Marker assisted selection (MAS)



Take home
Fewer plants evaluated with use of markers

Pedigree method versus Pedigree with MAS★



Take home
Fewer plants evaluated with use of markers

Predictive breeding

Genomic selection - MAS in which markers covering the entire genome are used so that all genes/QTL are linked to at least one marker

- ❑ Training population - lines/individuals that have both phenotypic and genotypic data
- ❑ Model parameters - estimated by using training population
- ❑ Calculate (predict) GEBVs - for lines/individuals that have only genotypic data using the trained model
- ❑ Use GEBVs - to select the individuals for advancement in the breeding cycle
- ❑ Maximize GEBV accuracy - the training population must be representative of selection candidates in the breeding program to which GS will be applied
- ❑ Useful for traits with lots of small effect genes, e.g., yield
- ❑ Useful for predicting hybrid performance = combining ability

Take home
Select plants not evaluated in the field

What is the value of understanding this for your work?

Thank you/Feedback

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