AGRONOMY 511 : LESSON 8

Breeding Self-Pollinated Crops

Introduction

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Completion Time: 1 week

Readings

Chapter 9, p. 137-154, Sleper and Poehlman

Introduction

The general objective of plant breeders is to develop improved cultivars or varieties of crop species. What is a cultivar? A cultivar is a distinct agricultural population within a species. Populations within a species are distinguished on the basis of their phenotypic differences for particular characters. Breeders take advantage of these differences or variability to develop improved cultivars. The methods used depend on the reproductive mode of the species. In this lesson, you will learn about methods used to breed self-pollinated crops, including small grains (e.g., wheat, barley, rice, oat) and many of the pulse and oil crops (e.g., common bean, soybean, peanut).

Objectives

1. Review the genetics of self-pollinated species.
2. Understand the breeding methods commonly used for self-pollinated crops.
3. Examine the factors to consider in selecting parents for hybridization.
4. Be able to identify the advantages and disadvantages of the breeding methods.

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Genetics of Self-Pollinated Species

Recall that self-pollinated species rarely hybridize naturally. Although cross-pollinating may occasionally occur, ovules of a self-pollinated plant are normally fertilized by pollen produced on that same plant. The result of repeated generations of selfing is that **homozygosity** is increased or maintained.

- Homozygous loci will remain homozygous.
- Heterozygous loci will segregate such that the **frequency of homozygotes will increase** at the expense of the frequency of heterozygotes with each generation of selfing.

How does a locus become heterozygous? A contrasting allele can be acquired when a plant out-crosses or when a mutation occurs. Each successive self-pollination thereafter will reduce heterozygosity by half. Breeders rely on the natural tendency of self-pollinated crops to become homozygous to obtain lines that exhibit uniformity in characters that affect appearance and performance.

Study Question 8.1

In a self-pollinated species, Variety A and Variety B differ in their alleles at one locus. Variety A is crossed with Variety B. Each subsequent generation self-pollinates.

a. What would be the proportion of heterozygous plants in the F_6 generation?

   ______ % Check Answer

b. What would be the proportion of plants genetically like variety A in the F_6 generation?

   ______ % Check Answer

c. If self-pollinated variety A differs from variety B in alleles at 3 loci, what would be the proportion of heterozygous plants in the F_3 generation following crossing?

   ______ % Check Answer

Notice how rapidly populations lose heterozygosity with selfing. For self-pollinated crops, one of the breeder's objectives is usually to develop pure lines. Since pure lines are homozygous, their rapid loss of heterozygosity speeds cultivar development. Some background heterozygosity may remain in a pure line, but the line is sufficiently homozygous to provide the uniformity in characters required for reliable and predictable appearance and performance.

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Breeding Methods

Improved self-pollinated cultivars can be obtained through three basic approaches.

- Introductions—Assemble lines currently grown in other regions and identify those lines that exhibit desirable characteristics and are adapted to the new target area. Many of these genetic materials have been collected and are maintained by **gene banks** as genetic reserves;
- Selection—Isolate the best genotypes from a mix of genotypes; or
- Hybridization—Combine materials with desirable characteristics. This is the most common approach for developing new cultivars today.

Today most breeding of self-pollinated crops is conducted utilizing hybridization methods.

FYI : Genebanks

A network of international research centers is responsible for the collection, maintenance, and evaluation of most landrace accessions. Network activities are coordinated by the International Board for Plant Genetic Resources (IBPGR), with headquarters in the Food and Agriculture Organization (FAO) of the United Nations. Each center has the primary responsibility for a particular set of the world's crop species.

Research Center	Location	Principal Crops
International Maize and Wheat Improvement Center (CIMMYT)	Mexico	Maize, wheat, and triticale
International Potato Center (CIP)	Peru	Potato and sweet potato
Asian Vegetable Research and Development Center (AVRDC)	Taiwan	Soybean, tomato, mungbean, Chinese cabbage, and pepper
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	India	Sorghum, pearl millet, chickpea, pigeonpea, and groundnut (peanut)
International Center of Tropical Agriculture (CIAT)	Colombia	Dry bean, cassava, tropical forages
International Institute of Tropical Agriculture (IITA)	Nigeria	Cowpea, cassava, yam, sweet potato
International Center for Agricultural Research in Dry Areas (ICARDA)	Syria	Wheat, barley, lentil, broad bean

These centers are part of the Consultative Group on International Agricultural Research (CGIAR). Visit the following CGIAR web page (http://www.sgrp.cgiar.org/?q=node/164) to access the websites of the research centers. A wealth of agricultural information is also available through the FAO homepage. Some countries, including the U.S., have national genebank programs. Generally, these can provide some information about each accession in their collection, as well as seed samples. Information about the materials in the United States National Plant Germplasm System (NPGS) is available through their computer network called GRIN (the Germplasm Resources Information Network).

For more information about germplasm resources and conservation, refer to Chapter 13, p. 207-217 in your text.

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Selection Methods

In early stages of a breeding program there is often genetic diversity in the materials available, so selection can be practiced to improve the crop. This occurs when a new crop is introduced into an area, such as when European settlers brought wheat to North America and when soybean was introduced into the U.S. from Asia. Selection is the process by which individuals or groups of individuals are sorted out from a mixed population to increase the proportion of desired genotypes or groups of genotypes in succeeding generations.

In self-pollinated crops, there are two general types of selection:

- Mass selection—A mixture of genotypes is selected and advanced as a group.
- Pure-line selection—Single homozygous plants are chosen and advanced.

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Selection Methods

Mass Selection

Mass selection can be used to generate new cultivars. Mass selection produces a population that is phenotypically more uniform or that performs better than the initial population. Mass selection involves two main steps.

1. Seed from individuals exhibiting similar desired trait(s) are selected and mixed.
2. This mixture is grown out to produce the next generation without testing the progeny.

The resulting population will be heterogeneous, but the individuals within the population will be homozygous for the selected trait(s).

Phenotypic variation in mass selections can be caused by genetic variation or environmental effects, and because selections are based on phenotype rather than genotype, it is difficult to identify the source of variability. Thus, mass selection is more useful for improving qualitative traits that exhibit little variation in response to environment.

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Selection Methods

Pure-line Selection

Pure-line selection, like mass selection, begins with a heterogeneous population of homozygous plants. The selected line is homogenous; thus, a pure line is more uniform than lines developed by mass selection. Pure-line selection involves identifying and propagating the best genotypes.

1. Individual plants in a mixed population that exhibit the desired trait(s) are chosen.
2. The seed from each selected plant is grown out separately and evaluated in **progeny tests**. Progeny testing is an important difference between mass and pure-line selection.

Any variation that occurs in a pure line can be attributed to environmental effects because a pure line will remain homogenous as long as natural out-crossing, mutations, or mixing of seed from other sources does not occur.

Study Question 8.2
For each statement, match the selection method that best applies by dragging the label next to the statement.

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Hybridization Methods

Hybridization and gene recombination generate new genotypes. Hybridization in self-pollinated crops may occur naturally, albeit usually at a low frequency, or through controlled cross-pollinations. The types of genotypes that can be generated are a function of the genotypes of the parents. Thus, selection of the parents is a critical step in the development of improved cultivars.

What factors should the breeder take into consideration when selecting parents for hybridization? The most rapid breeding progress occurs when both parents are adapted and perform well. Often, however, the desired trait is not available in adapted or advanced lines, and so the trait will have to be introduced from unadapted materials. There are several general sources of potential parents.

- Advanced breeding lines—Lines already adapted and productive can often be obtained from public breeding programs (e.g., university, state, or national programs). Some seed companies develop and sell breeding stocks that are in the advanced stages of improvement but not yet ready for release as commercial cultivars; these stocks often possess particular traits (e.g., herbicide, disease, or insect resistance) or special quality traits (e.g., high oil or improved protein quality). Plants from advanced lines may be mated to obtain a new genetic combination from which the best genotypes can be selected.
- Folk varieties—Also known as landraces, these traditional varieties have been developed and used by generations of local farmers. These varieties are typically well-adapted for local conditions, but often not readily transferable to other production situations. If a landrace is adapted, it may be used directly; if not, landraces possessing the desired traits are mated with adapted materials to improve the adapted lines.
- Many folk varieties have been collected and are maintained by genebanks as genetic reserves. Although genebank accession of these landraces is critical for the long-term maintenance of crop genetic diversity, genebanking disrupts the evolutionary trajectory of folk varieties unless the varieties continue to also be used in the local area from which they were collected. Such germplasm is used infrequently in commercial breeding programs because most landraces are heterogeneous and unadapted. In addition, their potential genetic contributions often have not been adequately evaluated; most breeding programs cannot justify expending resources to evaluate materials of unknown and uncertain usefulness.

In addition to combining favorable qualitative characters, hybridization and recombination provides opportunity to obtain superior quantitative traits, such as yield and vigor. **Transgressive segregates** exhibit phenotypes outside the range exhibited by either parent. These recombinants that perform better than the parents are particularly desired.

Study Question 8.3

In a self-pollinated species, two adapted cultivars are mated. The breeder's objective is to improve on the general performance of both parents. After hybridization, each subsequent generation self-pollinates. How many generations of selfing will be necessary before segregation ceases and the breeder can begin selecting from among homozygotes?

- F_3
- F_4
- F_6
- F_8

Check Answer

Following hybridization, procedures are applied to identify and select favorable genotypes and to develop them into lines. A line or strain is a population developed from a single genotype or single mixture of genotypes. Two common breeding methods that have been used for self-pollinated crops are the pedigree and bulk population methods. Let's take a closer look at these procedures.

- Pedigree method—The genealogy of each plant is known. Selection begins in the F_2 generation.
- Bulk population method—Harvested seed is mixed and advanced. Selection begins in later generations, about F_5 or F_6.

The single seed descent method can overcome some of the disadvantages of both the pedigree and bulk breeding methods. In the single-seed descent method, a single seed is advanced from each plant in each generation; however, unlike the pedigree method, genealogical records are not kept and selection does not begin until the F_5 or F_6 generation.

Assignment 8.1

Write a half to one page paper listing and discussing the possible advantages and disadvantages of the pedigree and single seed descent methods. Indicate which you would choose and why.

Discussion Topic 8.1

Discuss how the bulk breeding method might be modified to evaluate and select both qualitative and quantitative traits more effectively in the procedure.

An additional method used to breed self-pollinated species is the doubled-haploid procedure. No segregating generations need be grown to obtain homozygous lines because doubled-haploid F_2 plants are ordinarily homozygous at all loci. Selection begins in the F_3 generation.

Study Question 8.6

For each of the following methods, choose the generation in which selection usually begins.

Pedigree	Bulk population	Single-seed descent	Doubled-haploid
choose..	choose..	choose..	choose..

Check Answer

Study Question 8.7

For each of the following statements, identify the breeding method it best describes.

IN DETAIL : Pedigree Method

The pedigree method is the most widely used method and is useful for improving both qualitative and quantitative characters. Pedigree method has several advantages over other breeding methods.

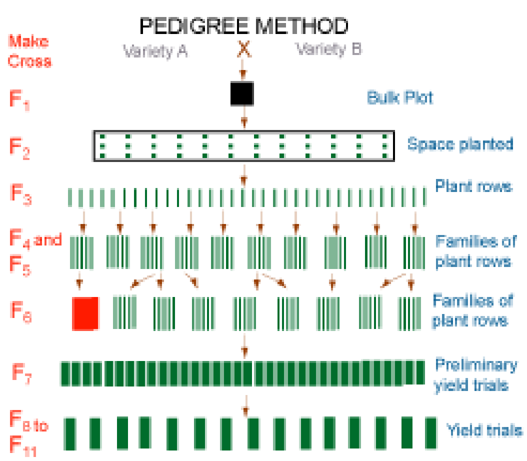
- Only progeny lines that possess the desired trait(s) are advanced, limiting the number of lines that must be grown out and evaluated.
- The performance of selections is evaluated over more years.
- Genetic information contributes to basic genetic understanding of the particular character and to refinement of breeding procedures.

The pedigree method, however, is expensive and time-consuming because of the detailed record-keeping involved. Information on kinship and traits may be recorded.

1. Genetic relationships.
   - An example will be shown after an explanation of the process.
2. Distinguishing characteristics, such as
   - Maturity
   - Plant height
   - Disease reaction
   - Color (e.g. In soybean, flower, pubescence, and/or hilum color may be noted)
   - Based on the characters observed, a simple checkmark in a column is often used to indicate whether to save or eliminate the line.

Pedigree method is not a retraceable route—it only establishes a record of kinship. If the same cross were made again, the same ultimate selections would not be expected because we would not expect the same genotypes of gametes to be produced and combine in the same way during the segregating generations.

To apply the pedigree method for the development of a superior wheat cultivar, review pages 141-142 of the text, and click on the thumbnail below.



Example of genetic relationships shown by the pedigree:

> In each generation complete pedigrees of selected plants will be added until the final selection is finished. Thus, it is easy to compare individuals within a cross

and determine how closely they are related, e.g., if they both came from the same F_3 family, or the same F_5 family, or if they had nothing in common except the two original parents that were crossed.

Table 8.1 Example of three pedigrees derived from a single cross.

Cross	F_2 plant	F_3 plant	F_4 plant	F_5 plant
C48	22	3	1	2
C48	22	1	1	3
C48	57	2	2	2

In the three pedigrees given above, we can see that the first two are more closely related with each other than either one is to the third. These first two originated from a single self-pollinated F_2 plant whose seed was planted the next year to become an F_3 family. From this F_3 family different individual self-pollinated F_3 plants were selected of which these are two. The third individual is not as closely related because it had a different F_2 plant as its progenitor.

Study Question 8.4

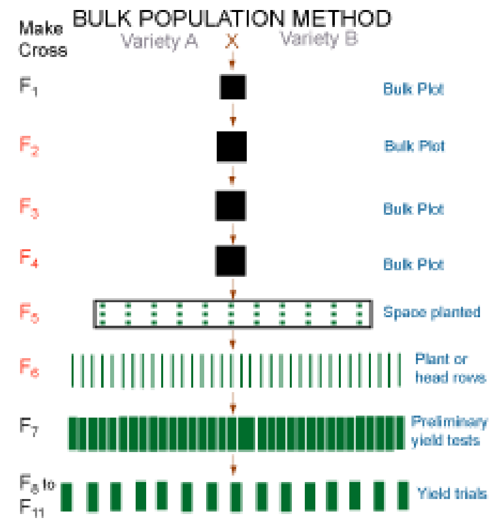
The pedigree method can be modified to further reduce the number of families that are carried forward. How might the pedigree method described above be modified so that yield and other quantitatively inherited characteristics can be evaluated sooner in the process?

Check Answer

IN DETAIL : Bulk Population Method

The bulk method is a form of mass selection. It produces a population that is phenotypically more uniform than the initial population.

The bulk method has some similarities with the pedigree method, but differs importantly at several steps, including the generation of selection. Review pages 142-144 of the text, and click on the thumbnail below to examine those differences.



Although selection is usually not done until the F_6 generation, when plants are nearly homozygous, one can do selection in any generation, e.g., select against disease susceptibility when it occurs or artificially inoculate in one or more of the growing seasons. Throughout, undesirable phenotypes should be eliminated.

With the bulk method, natural selection (selection imposed by the environment) may be a disadvantage or an advantage. One potential problem with the bulk method is that natural selection will tend to delete poorer competitors although they may not be the poorest yielders when grown in pure stands. Thus, the proportion of each genotype in a bulk or blend may not remain constant from generation to generation, or year to year. Why? The survival of a species and a given genotype that reproduces by seed depends on

- Number of seeds produced by a plant
- Proportion of plants maturing and producing offspring

Both of these factors are dependent on many other factors, such as plant size, root proliferation, disease resistance, temperature, insects, drought, salt, etc.

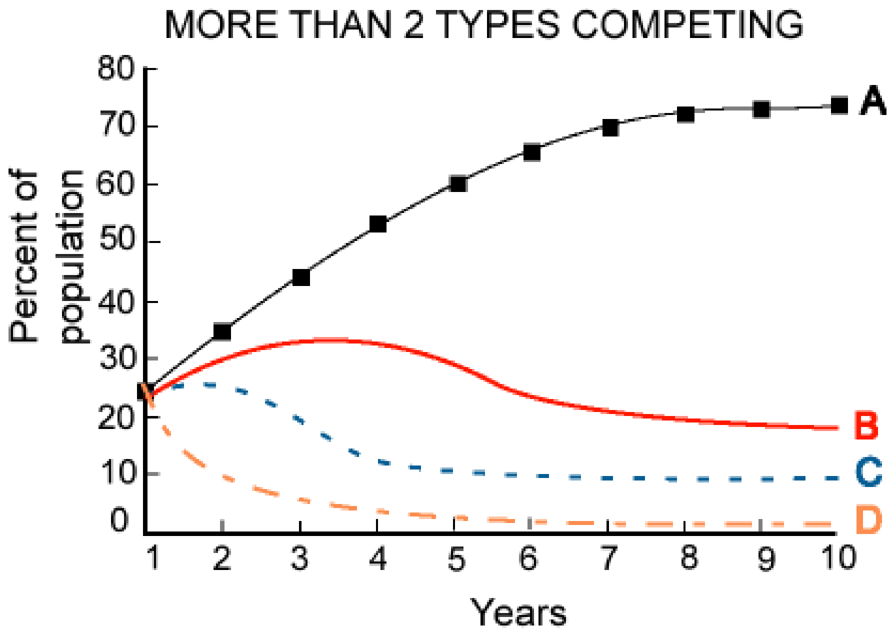


Fig. 8.1 Change with time in proportions of genotypes A, B, C, and D in a bulk or blend.

When one (or a few) genotype present in a blend is disproportionately represented, the predominate genotype may skew the performance of the bulk.

Study Question 8.5

Compare the data in the following two tables. Notice that the experimental lines are present in similar proportions in year 1, but over time become unequally represented in the population.

Blend A				
	% Plants of Each Line			Yield in Pure Stand
Line	Year 1	Year 4	Year 8	Mean Years 1-8
1	25.4	42.8	63.2	73.3
2	24.7	22.7	17.3	69.9
3	24.7	12.5	8.3	70.2
4	25.2	19.9	11.3	79.0

Blend B				
	% Plants of Each Line			Yield in Pure Stand
Line	Year 1	Year 4	Year 8	Mean Years 1-8
5	25.4	42.8	63.2	55.2
6	24.7	22.7	17.3	65.4
7	24.7	12.5	8.3	79.8
8	25.2	19.9	11.3	62.3

Would yield tend to increase, decrease, or remain stable between years 1 and 8?

Blend A

choose..

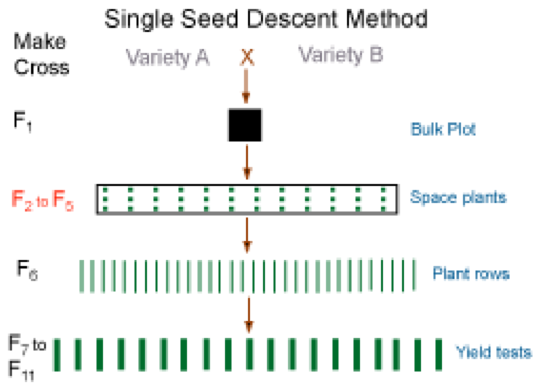
Check Answer

Blend B

choose..

IN DETAIL : Single Seed Descent

The single seed descent method maintains greater genetic diversity longer in the breeding process than the pedigree or bulk methods. Let's take a closer look. Review pages 144-146 of the text, and click on the thumbnail below.



Single seed descent offers both advantages and disadvantages compared to the pedigree and bulk breeding methods.

- Advantages:
  - Can use greenhouse and off—season nurseries up to F_6-saves time
  - Test nearly homozygous lines
  - No natural selection to eliminate superior genotypes that don't compete well in mixtures of genotypes
  - Greater amount of genetic diversity to select within F_7 than for bulk or pedigree—each F_7 line is from a different F_2 plant
  - In early generations more work than bulk, but much less than pedigree
- Disadvantages:
  - No natural nor artificial selection to eliminate poorer types in early generations
  - Lots of lines to test in F_7
  - No information on materials until F_6 or F_7

Neither the pedigree method nor the bulk method is suited to greenhouse use and off-season nurseries except for crossing and possibly growing F_1 plants. The single seed descent method lends itself quite well to use of greenhouse and off-season nurseries.

IN DETAIL : Doubled-Haploid Procedure

The doubled-haploid method generates cultivars often following *in vitro* androgenesis (**anther culturing**) and for many crop plants procedures and media have been developed to utilize this approach to haploid development. Chromosomes of the generated haploid plants must be doubled to produce the homozygous doubled-haploid plants. Review the doubled-haploid method on pages 146-147 of the text.

Another method that has come into more frequent use in maize in the past several years uses an inducer genotype (parent that will induce haploids from the other parent) crossed to heterozygous F_1 plants. There are two types of inducers; maternal, where the inducer pollen parent is crossed to the F_1 plants to produce haploids from the maternal parent, and paternal, where the inducer seed parent is crossed to the F_1 plants to produce haploids from the paternal parent.

Advantages of the different methods:

Anther culturing

- No need of inducer

Paternal inducer

- Simple inheritance
- Good for cytoplasmic male sterility conversion
- No need of tissue culture

Maternal inducer

- Limited genotype dependency
- Higher induction rate (10%)
- No need of tissue culture

Disadvantages of the different methods:

Anther culturing

- Low induction rate
- Genotype dependency
- Need of tissue culture
- Tissue culture-induced variation often present

Paternal inducer

- Low induction rate

Maternal inducer

- Background effects (maternal parent influences production of haploids)
- Complex inheritance in induction characteristic makes it difficult to develop and improve inducer parents

Several seed companies have laboratories to develop doubled haploids in maize. Iowa State University now offers as a service maize doubled haploid production using maternal haploid inducers. Please see http://www.plantbreeding.iastate.edu/DHF/DHF.htm (Verified 15 November 2010) for more information.

Although doubled-haploids offer the advantages that all loci are theoretically homozygous and that preliminary yield testing can be done earlier, doubled-haploid cultivars are often more expensive to produce. Single-seed descent, pedigree, and bulk population methods may actually be less labor intensive, and are certainly less lab intensive.

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Backcross Method

The backcross method is used to incorporate a desirable characteristic into an adapted cultivar deficient in that characteristic. The desired trait is acquired from a donor line, and the adapted variety is the recurrent parent. Several factors must be taken into consideration to effectively use the backcross method.

- Usually the character is controlled by one or a few genes.
- The donor parent must carry the desired alleles.
- The recurrent (recipient) parent should have an otherwise favorable genotype.

Examine the backcross technique for transferring disease resistance from one cultivar into an adapted cultivar on pages 148-150 of the text.

Study Question 8.8
Variety A is used as the recurrent parent in a backcross breeding program involving varieties A and B. What percent of the germplasm of variety A is in the BC_6 progeny?

[ ] % Check Answer

How many backcrosses are needed? The number of backcrosses will vary, depending on the donor parent used.

- If the donor parent is itself an elite, adapted line or cultivar, only three or four backcrosses are needed.
- If the donor parent is an exotic or unadapted material, use five or six backcrosses to limit the effect of unadapted genes on the backcross cultivar.

Backcross cultivars are never exactly like originals. Often genes closely linked to the allele being transferred are transferred with the desired allele. Thus, yield testing is still necessary, but extensive yield testing is not usually required.

As with any breeding method, the backcross method also has some advantages and disadvantages.

- Advantages:
  - Predictable
  - Repeatable
  - Fast—Environment is not so important. The breeder need only be able to recognize the one character that is being transferred. Often three generations can be produced in a single year: two in the greenhouse and one in the field.
  - Molecular markers can be used very effectively in a backcrossing program to

reduce the amount of progeny testing, and to allow more rapid recovery of recurrent parent germplasm.
    - Small numbers of plants needed
    - Extensive yield test evaluation is not necessary
- Disadvantages:
    - No breakthroughs—no unusual combinations of genes from the two parents will occur
    - Cultivar may no longer be the best available by the time the backcross procedure has been completed.

Despite the disadvantages, backcross has been extremely important in plant breeding in developing improved cultivars and inbred lines. It continues to be important in the incorporation of transgenes into elite germplasm.

Study Question 8.9

A semi-domesticated, self-pollinated species is being developed as an alternative crop. You have been assigned the task of designing a breeding program to improve this species for use as a crop. The crop provides a source of high quality oil, exhibits a wide range of maturities, and seems to have few disease or insect pests. However, the species tends to shatter upon seed maturity. This characteristic requires the most immediate attention. A few non-shattering lines have been identified, but the genetics of the species are not understood. Which breeding method would you use first to improve this species?

- Pedigree
- Bulk population
- Single-seed Descent
- Doubled-haploid
- Backcross

Why?

Check Answer

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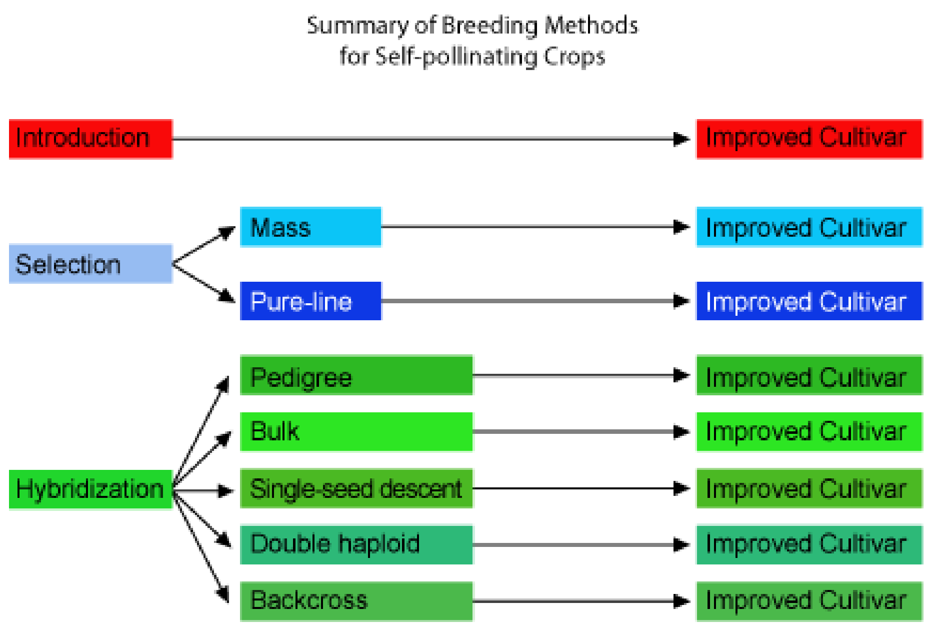
Summary

There are three general breeding methods for improvement of self-pollinated species: introduction, selection, and hybridization followed by selection to develop pure lines. Selection can be mass or pure-line selection. There are four specific methods of hybridization which are simply hybridization with different schemes of selection in the segregating generations. There is also the backcross method which is a special hybridization method because after the initial cross it utilizes selection and then crossing back to a recurrent parent for several generations. Pure-line selection and all methods of hybridization lead to the development of pure-line cultivars (all plants homozygous and of the same genotype, or a homogenous population of homozygous plants). Mass selection leads to the development of cultivars that are heterogeneous populations of homozygous plants. Introductions are often heterogeneous but in some cases are pure lines. Here's an outline of the breeding methods for self-pollinated species.



Lesson 8 Reflection

Why reflect? | ***Grading***

Submit your answers to the following questions in the **Student Notebook System.**

1. In your own words, write a short summary (<300 words) for this lesson.
2. What is the most valuable concept that you learned from the lesson? Why is this concept valuable to you?
3. What concepts in the lesson are still unclear/the least clear to you?