5

Principles and Practices of Seed Selection

learning objectives

- Define breeding systems.
- Categorize seed-propagated cultivars and species.
- Define procedures to control genetic variability.
- Describe systems of seed selection and production.
- Define legal controls on genetic purity.

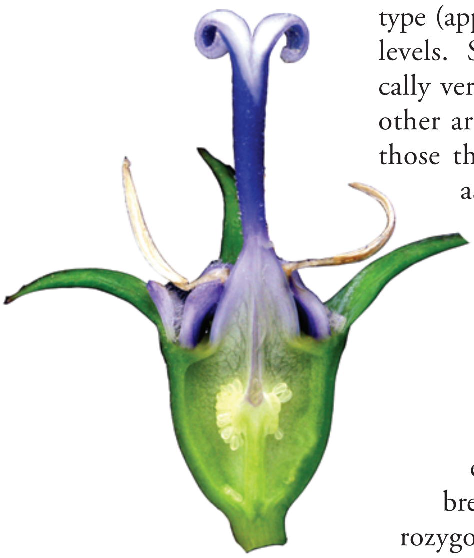
INTRODUCTION

Many annual and biennial crop, forage, vegetable, and ornamental selections are produced by plant breeding to be propagated by seed (7, 8, 29, 34). Breeding involves selection of parents, specific breeding procedures, and genotype stabilization (1, 3, 47). The last process is sometimes referred to as **"fixing the genotype."** Seed is used to reproduce most woody perennial plants in forestry as well as in the landscape. Propagation of many ornamental, fruit, and nut trees utilizes seedlings for rootstocks that are then grafted (49, 58). However, characteristics important in agriculture, horticulture, and forestry may not be consistently perpetuated into the next seedling generation unless appropriate principles and procedures are followed. This chapter deals with seed selection and the management of genetic variability in seedling populations in both herbaceous and perennial plant species for the purposes of propagation.

"fixing" The process of stabilizing the genotype of a seedling population to make it homozygous so that it will "breed true."

BREEDING SYSTEMS

The main objective of a breeding program is to use the observed variability available within a particular genus or species to create new, stable populations with improved plant characteristics. Variability in seed-propagated plants can be described both at the phenotype (appearance) and genotype (genetic) levels. Seedlings that are phenotypically very similar in appearance to each other are termed **homogeneous**, while those that are dissimilar are described as **heterogeneous.** When more specific information is known about the seedling population's genetic makeup, they can be described as **homozygous** or **heterozygous.** Homozygous populations share many common paired alleles (genes) at each chromosome loci and breed true-to-type offspring. Heterozygous populations have dissimilar



homogenous A population of seedlings that are phenotypically similar.

heterogeneous A population of seedlings that are phenotypically dissimilar.

homozygous A population of seedlings whose genotypes are very similar.

heterozygous A population of seedlings whose genotypes are dissimilar.

paired alleles at many chromosome loci and generally lead to diverse genetic offspring. These characteristics are determined by the breeding system, characteristics of the crop species, and management conditions under which seed populations are grown (1, 3, 22). Three important considerations for determining a plant breeding system are whether the plants reproduce primarily from **self-pollination, cross-pollination,** and **apomixis** (22).

self-pollination A breeding system in which the plant flower is pollinated by itself because of flower structure or isolation.

cross-pollination A breeding system in which the plant is pollinated by pollen from a separate genotype either because of flower structure or artificial control during pollination.

apomixis A breeding system in which the embryo is apomictic (i.e., produced from a vegetative cell and not as a result of reduction division and fertilization).

Self-Pollination

Self-pollination occurs when pollen germinates on the stigma and the pollen tube grows down the style to fertilize the same flower or a flower of the same plant or clone. Self-pollination is a natural condition in some species because of flower structure. The extreme case is when pollination occurs before the flower opens (Fig. 5–1). This type of behavior is called cleistogamy and occurs in some crop plants like peanuts (*Arachis*). A wonderful example of this reproductive strategy is found in several types of violets (*Viola*). Violets can produce two types of flowers. Chasmogamous (open) flowers are produced in the spring or summer when pollinators are plentiful and active. Chasmogamous flowers open to permit cross-pollination between flowers and produce offspring (seeds) with generous genetic diversity. These same plants also produce underground cleistogamous flowers in the autumn that never open and self-pollinate. Although this restricts genetic diversity, it does not require the same level of plant resources for seed production and provides insurance against poor seed production from earlier out-crossing flowers.

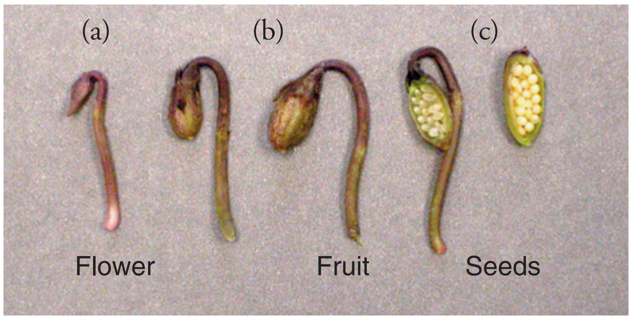


Figure 5–1
A cleistogomous flower in violet. The flower remains underground and never opens, forcing self-pollination. (a) Unopened cleistogomous flower. (b) Fruit with developing seeds. (c) Fruit with ovary wall removed to show the seeds.

The degree to which self-pollination occurs can vary among species. Some are highly self-pollinated (i.e., less than 4 percent cross-pollinated) such as cereal grains [barley (*Hordeum*), oats (*Avena*), wheat (*Triticum*), rice (*Oryza*)], legumes [field pea (*Pisum*), and garden bean (*Phaseolus*)], flax (*Linum*), and some grasses. There are also those that are self-fertile but can cross-pollinate at more than 4 percent, including cotton (*Gossypium*), pepper (*Capsicum*), and tomato (*Solanum*). Self-pollination is not typically found in most woody plant species, but some exceptions occur, such as peach (*Prunus*) (58).

Homozygosity in a self-pollinated herbaceous cultivar is **"fixed"** by consecutive generations of self-fertilizations (Table 5–1) (1, 22, 47). To produce a "true-breeding" homogeneous and homozygous cultivar, plant breeders will start with a single plant and then eliminate the off-type plants each generation for a period of six to ten generations. If one assumes a more or less homogeneous population with individuals possessing homozygous traits, self-pollination will result in a population of individuals that will remain homogeneous and homozygous. If a mutation occurs in one of the alleles and is recessive, the genotype for that trait becomes heterozygous. Then the next generation will produce homozygous plants that are similar in appearance but genetically heterozygous for the mutant allele. The proportion of homozygous individuals with the two traits will increase in consecutive generations, while the proportion with heterozygous genotypes will decrease by a factor of one-half each generation. The group of descendants of the original parent will segregate into a heterogeneous mixture of more or less true-breeding lines.

Cross-Pollination

In nature, many, if not most, species are naturally cross-pollinated, a trait that seems to be desirable both for the individual and its population. Not only does the increased heterozygosity provide the opportunity for evolutionary adaptation within the population confronted with environmental change, but plant vigor

Table 5–1
Effect of Self-Pollination and Roguing Following Crossing of a Tall (DD) Pea and Dwarf (dd) Pea (see Fig. 2-14). "Fixing" of the two parental phenotypes can be observed in succeeding generations in the proportion of tall and dwarf plants. Continuous roguing for the recessive trait never quite eliminates its segregation from residual heterozygous individuals.

	A. Continuing self-pollination proportions				B. Roguing of all dwarfed plants		
	DD	Dd	Dd	Percent homozygous	Tall	Dwarf	%dd
P_1	1		1	100			
F_1		1		0	all		
F_2	1	2	1	50	3	1	25
F_3	3	2	3	75	14	1	7.1
F_4	7	2	7	87.5	35	1	2.8
F_5	15	2	15	93.75	143	1	0.7
F_6	31	2	31	96.88	535	1	0.2
F_7	126	2	126	98.44	2143	1	0.05

also tends to be enhanced. Enforced self-pollination of naturally cross-pollinated plants through consecutive generations may result in homozygous plants and a homogeneous population **(inbred line),** but vigor, size, and productivity may be reduced, a condition described as **inbreeding depression.** If, however, two inbred lines are crossed, the vigor of the plants of the resulting population may not only be restored but may show more size and vigor than either parent, a phenomenon known as **heterosis** or **hybrid vigor.** In this case, the individual plants will be heterozygous, but the population is likely to be homogeneous and have uniform characteristics.

inbred line A population of seedlings that produced a consecutive series of self-pollinations.

hybrid vigor Vigor expressed by a seedling population that exceeds that of either of the parents.

Many species have also developed morphological or genetic mechanisms to prevent self-pollination and promote cross-pollination.

Here are four illustrations of morphological adaptations to facilitate cross-pollination (6):

- **Dioecy. Dioecious** plants have pistillate (female) and staminate (male) flowers present in separate plants, such as asparagus (*Asparagus*), pistachio (*Pistacia*) and holly (*Ilex*) (Fig. 5–2). Plants with only female flowers are called gynoecious, and those with only male flowers are androecious. This type of flower arrangement usually forces cross-pollination.

dioecious Plant trait in which male and female flowers are produced on different plants.

- **Monoecy. Monoecious** plants have pistillate (female) and staminate (male) flowers in separate flowers on the same plant. This system occurs in cucurbits (*Cucurbita*), corn (*Zea*), walnut (*Juglans*) (Fig. 5–3), oak (*Fagus*), and many conifers. Although this facilitates cross-pollination,

monoecious Plant trait in which the male and female parts are in different flowers but on the same plant.

(a) (b)

Figure 5–2
Holly (*Ilex*) plants are dioecious, producing female (a) and male (b) flowers on separate plants, forcing cross-pollination. Many flowers in dioecious plants produce remnant female and male parts that are usually non-functional. Note the non-functional male stamens present in the female flowers.

(a) (b)

Figure 5–3
Some nut-producing tree species have pollination systems that ensure cross-pollination. Walnuts (Juglans) are monoecious with female (a) and male (b) flowers produced separately on the same plant.

self-pollination is usually possible in monoecious plants unless another barrier to self-pollination is present.

- **Dichogamy. Dichogamy** is the separation of female and male flower function in time (50). There are two types of dichogamy depending on whether the female becomes receptive before the male sheds pollen (protogyny) or the male sheds pollen before the female is receptive (protandry). There are numerous examples of this type of flowering including carnation (*Dianthus*) (Fig. 5–4). Dichogamy does not ensure cross-pollination but reduces the ratio of self- to cross-pollinated flowers (40).

dichogamy Genetic trait in which male and female flowers on the same plant bloom at different times.

- **Polymorphism.** Floral polymorphisms refer to different arrangements of flower parts in flowers from the same or different plants within the same species. Many of these adaptations are designed to alter the ratio of self- to cross-pollination. A range of flower structures is illustrated in asparagus (*Asparagus*) (Fig. 5–5, page 144). These types of polymorphisms were of particular interest to Darwin (14) as he described the different flower forms in primrose (*Primula*) referred to as heterostyly. Plants exhibiting heterostyly have two or three different flower morphologies where the style of the female and the filaments of the male are produced at differernt lengths (Fig. 5–6, page 144). In addition to the different heterostylous morphologies, each style and filament length combination may be linked to a sexual incompatibility system to limit which flowers can cross with each other (23).

Figure 5–4
Sweet William carnation (Dianthus) flowers show dichogamy. Note how the flower on the left has anthers (an) shedding pollen before the style (s) has fully developed and the flower on the right that has fully receptive female parts after the anthers have withered.

Sexual incompatibility (10, 15) is a general term that describes the inability of plants that are not genetically related to cross and produce offspring. **Self-incompatibility** is a form of sexual incompatibility that has evolved to prevent self-pollination within closely related species and has been found in over 250 plant genera from at least 70 families. Some horticulturally important plants showing self-incompatibility include lily (*Lilium*), cabbage (*Brassica*), *Petunia,* almond (*Prunus dulcis*), apple (*Malus*), cherry, and plum (*Prunus*).

sexual incompatibility Genetic trait in which the pollen either fails to grow down the style or does not germinate on the stigma of a plant with the same incompatibility alleles.

Self-incompatible crosses are characterized by a lack of pollen germination or arrested pollen-tube growth (53). Self-incompatibility is a genetic mechanism controlled by a single gene locus (in diploids) with several different S alleles. It is controlled by protein-to-protein recognition determined by the type of S allele in the male and female partners. The two most common forms of self-incompatibility are gametophytic and sporophytic (Fig. 5–7, page 145). **Gametophytic self-incompatibility** is the most common form of self-incompatibility, and the interaction between the male and female partners is determined by a single S-allele derived from the haploid genetics within the pollen grain. Recognition only occurs after pollen germination and tube growth. When the male and female share a common S-allele genotype, there is a protein-to-protein interaction that stops pollen-tube

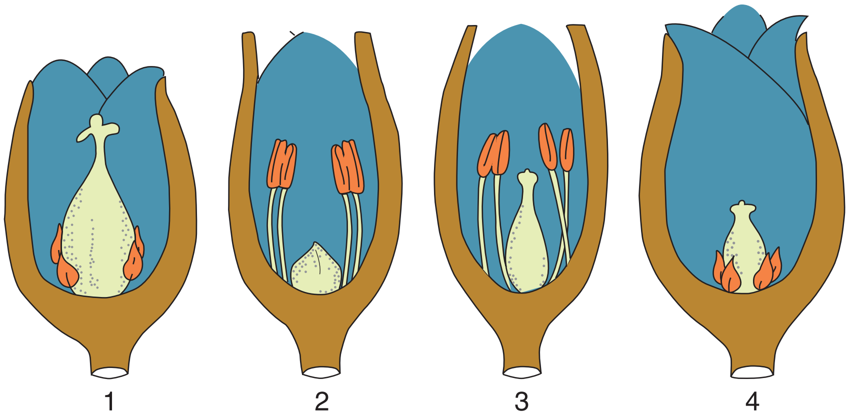
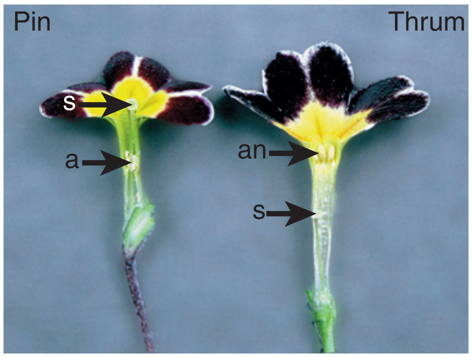


Figure 5–5
Range of flower structure types expressed in different asparagus flowers of individual plants. *Type 1.* Completely female. Dioecious. Flowers contain only the pistil; stamens (male) are reduced and nonfunctioning. *Type 2.* Completely male. Dioecious. Flowers only contain stamens. The pistil is reduced and nonfunctioning. *Type 3.* Both male and female structures are functioning. Perfect. *Type 4.* Both male and female structures are nonfunctioning. Sterile. Commercial seed production of asparagus results from growing Type 1 and Type 2 plants together to enforce cross-pollination and produce the desirable hybrid plants.
Courtesy Bryan Benson.

(a)

(b)



(c)

Figure 5–6
Examples of heterosyly in primrose (Primula). On the left are "pin" flowers where the stigma (s) is elevated above the corolla and the anthers (an) held on a short filament. On the right are "thrum" flowers with elongated filaments exposing the anthers above the corolla, and a shortened style, keeping the stigma within the corolla tube.

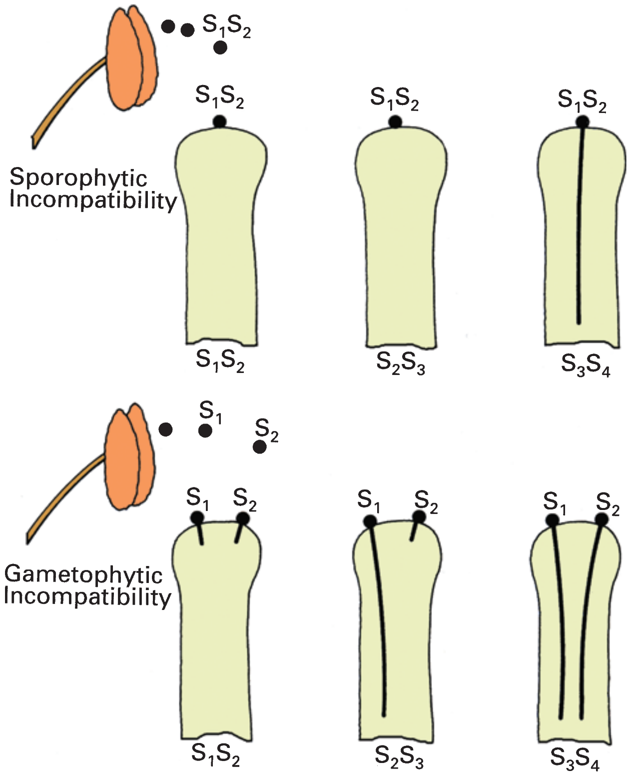


Figure 5–7
Incompatibility mechanisms prevent self-pollination in some species. Top (*cabbage*): Sporophytic incompatibility. Each pollen contains genes of both S_1 and S_2 alleles, and the pollen tube will only grow down a style with a different genotype. Bottom (*clover*): Gametophytic incompatibility. Each pollen grain has a single S allele. A pollen tube will not grow down a style where that allele is represented. Redrawn with permission from Stoskopf, et al. *Plant Breeding Theory and Practice*. Westview Press: Boulder, CO.

growth. In some families (i.e., Papaveraceae), the pollen tube stops growing soon after initial germination, while in others (i.e., Solanaceae, Rosaceae) the pollen tube will growth a considerable distance down the style before its growth is arrested (21). A unique breeding technique to bypass incompatibility in lily (*Lilium*) is to remove the upper two-thirds of the style (including the stigma) before applying pollen. This allows time for the pollen tube to reach the embryo sac before being arrested by the incompatibility reaction.

Sporophytic self-incompatibility differs from gametophytic self-incompatibility because it is the diploid S-allele pair from the male and female parents that determines compatibility (32). Protein types determined by different S alleles are deposited on the surface of the pollen grain where they interact with proteins on the stigmatic surface to determine whether the pollen grain will germinate and initiate tube growth. Examples of plants with this type of incompatibility are found in the Brassicaceae, Asteraceae, and Convolvulaceae families. Because multiple S alleles are involved in this recognition system, pollen/stigma interactions can be complex (Fig. 5–7).

Cross-pollination is mostly carried out by the movement of pollen by wind or insects. Also, pollination is sometimes by bats, birds, and water (48). Insect pollination is the rule for plants with white or brightly colored, fragrant, and otherwise conspicuous flowers that attract insects. The honeybee is one of the most important pollinating insects, although wild bees, butterflies, moths, and flies also obtain pollen and nectar from the flower (Fig. 5–8). Generally, pollen is heavy, sticky, and adheres to the body of the insect. Some important seed crops that require cross-pollination are alfalfa (*Trifolium*), birdsfoot trefoil (*Lotus*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*), onion (*Allium*), watermelon *(Citrullis)* and sunflower (*Helianthus*) (Fig. 5–8c). In addition, many flower and vegetable crops are insect pollinated as are many fruit plants, ornamental plants, and deciduous and broad-leaved evergreens used in the landscape.

(a) (b) (c)

Figure 5–8
Important insect pollinators include (a) bees and (b) butterflies. (c) Bee hives are included in production fields to help pollination.

Wind pollination is the rule for many plants that have inconspicuous flowers, or those with monoecious, dioecious, or dichogamous flowers. Examples are grasses, corn, olive, and catkin-bearing trees such as the walnut (*Juglans*), oak (*Quercus*), alder (*Alnus*), cottonwood (*Populus*), and conifers (Fig. 5–9). The pollen produced from such plants is generally light and dry and, in some cases, carried long distances in wind currents.

Most trees and shrub species are both heterozygous and cross-pollinated such that considerable potential for genetic variability exists among the seedling progeny. Selection of seed source plants must take into account not only the characteristics of the plant itself but also the potential for cross-pollination with other species in the surrounding population. For example, the presence of off-type individuals in seedlings propagated from imported seed of *Eucalyptus* from Australia and pear (*Pyrus*) species from China and Japan (30) could be traced to hybridization with other species nearby.

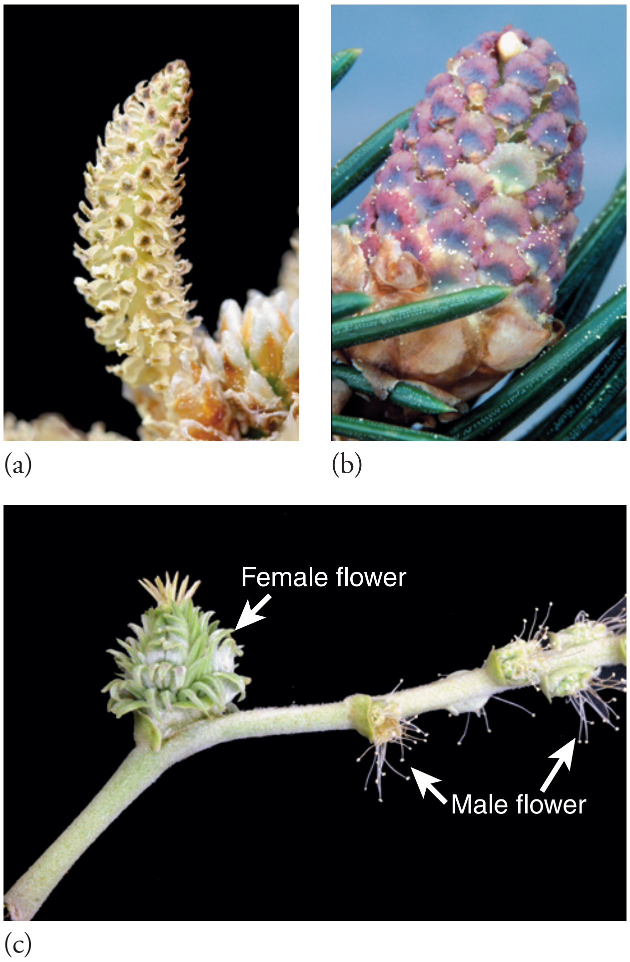


Figure 5–9
Conifers are usually wind pollinated. Male strobili (a) release pollen that is deposited on the female cone (b). True flowering plants (Angiosperms) developed along with insect pollinators. Wind pollination is a derived character that is usually associated with reduced flower parts (i.e., no petals) and unisexual flowers (c) as illustrated for chestnut (Castanea).

Apomixis

Apomixis occurs when an embryo is asexually produced from a single cell of the sporophyte and does not develop from fertilization of two gametes (28). This new "vegetative" embryo may arise by mechanisms that were described in Chapter 4. In each case, the effect is that seed production becomes asexual and seed reproduction results in a clone. In some species, both apomictic and sexual seeds are produced, sometimes within the same ovule **(facultative);** bluegrass (*Poa pratensis*) falls into this category. Other species are essentially 100 percent apomictic **(obligate);** for example, Bahia grass (*Paspalum notatum*) and buffelgrass (*Pennisetum ciliare*).

facultative apomictic
A plant in which both sexual and asexual embryos are produced by the same plant.

obligate apomictic
A plant in which all the embryos are apomictic.

Breeding of apomictic cultivars requires that a genetic source for apomictic reproduction be found within that species. This trait is not identifiable by visual inspection of the parent plant but by its genetic performance (i.e., unexpected uniformity of its progeny from among normally variable populations). Apomixis has been most important in the breeding of grasses, forage crops, and sorghum. Introduced cultivars have included 'King Ranch' bluestem, 'Argentine' Bahia grass (*Paspalum*), and 'Tucson' side oats grama, 'Bonnyblue' and 'Adelphi' Kentucky bluegrass (*Poa*) (24), and buffelgrass (*Pennisetum*) (28). Relatively few genes apparently control apomixes, and breeding systems have been described to incorporate this trait into cultivars and particular species.

Apomictic reproduction in woody plant species and cultivars is found in many *Citrus* (9), mango (*Mangifera*), and some apple (*Malus*) species (52). Although apomixis produces genetically uniform seedlings, it is not necessarily useful for growing specific fruit cultivars because of undesirable juvenile tendencies, such as **thorniness, excess vigor,** and **delayed fruiting.** On the other hand, these characteristics make apomictic seedlings useful as rootstocks, characteristics exploited extensively in *Citrus.*

In apomixes, the seedling population is immediately stabilized as a "true-breeding" line without seedling variation. Such plants exhibit the apomictic cycle and express typical juvenile traits of the seedling population. Apomixis is particularly appropriate for plants whose value lies in their vegetative characteristics—as occurs in forages and grasses—rather than in plants whose value depends on fruiting characteristics.

CATEGORIES OF SEED-PROPAGATED CULTIVARS AND SPECIES

Herbaceous Annual, Biennial, and Perennial Plants

Landraces Historically, farmers throughout the world have maintained seed-propagated plants by saving selected portions of the crop to be used to produce the next cycle. These populations, called **landraces,** evolved along with human societies and are still found in some parts of the world (56). These populations are variable but identifiable and have local names. This practice results in genetic populations adapted to a localized environment. Their inherent variability provides a buffer against environmental catastrophe and preserves a great deal of genetic diversity (Fig. 5–10).

landrace Primitive varieties developed and maintained before the modern era of genetics.

Changes in cropping patterns have occurred during the 20th Century, particularly since about 1960. Many of the older populations around the world are being replaced by modern cultivars, which tend to be uniform and high yielding, particularly when grown in conjunction with high irrigation and fertility inputs. Sometimes, new cultivars lack adaptation to local environments. Although the trend has been to increase the world supply of essential food crops, concerns have been raised that a parallel loss of genetic diversity and germplasm has occurred. Exploration and conservation efforts have expanded to maintain these important raw materials for future use (19).

Cultivars A **cultivar** is a uniform and stable plant population that possesses recognizably distinct characteristics. Stated another way, a cultivar is a plant population that shows a minimum of variation, that can be propagated true-to-type for at least one characteristic, and is unique compared to the wild species or other cultivars. The term **variety** is often used interchangeably with cultivar especially when describing flower and vegetable populations. Care should be taken not to confuse variety with the concept of a true **botanical variety** (*varietas* or *var.*) that describes a type of naturally occurring population.

botanical variety A population of plants originating in nature that are within one species but are phenotypically distinct.

Categories of seed-propagated cultivars include open-pollinated, lines, hybrids, synthetic, F_2, and clonal cultivars.

Open-pollinated cultivars can be maintained in cross-pollinated species that produce a relatively homogeneous population for specific traits important for production of that crop. Open-pollinated seed is often cheaper to produce compared to hybrid seed because

Figure 5–10
A landrace of soybeans (Glycine) in Africa showing the diversity inherent in seeds saved over many generations.

they do not require hand pollination to maintain the cultivar. However, because open-pollinated cultivars are a genetically heterogenic population, they can be more variable than hybrids (41).

Historically, many open-pollinated vegetable and flower varieties were maintained by families in their "kitchen gardens." Many of these varieties have since been maintained by generations of gardeners and local farmers and are being offered as **heirloom varieties.** The preservation and distribution of information concerning these varieties has been an objective of certain groups including Seed Savers Exchange, Inc., in Decorah, Iowa (4, 54, 59). There are also numerous commercial flower and vegetable crops produced as open-pollinated cultivars including *Begonia*, marigold (*Tagetes*), cucumber (*Cucumis*), and squash (*Cucurbita*).

line A population of seedling plants whose genotype is maintained to a specific standard in consecutive generations.

Lines result in seedling populations whose genotype is maintained relatively intact during consecutive generations. These may be maintained as self- or cross-pollinated lines. An important type of seed population in this category is the **inbred** line, which are mainly used as parents for later production of F_1 hybrids (55).

Hybrid Cultivars include groups of individuals reconstituted each generation from specific parents. **F_1 hybrids** are the first generation of a planned cross. For seed production, they result from the cross between seedling populations of two or more inbred lines. When crossed with another inbred line, the result is a population of uniform, but heterozygous, plants. Often these populations exhibit greater vigor than the parents due to hybrid vigor (heterosis), depending on the combining ability of the parents. Hybridization is a means of "fixing" the genotype of the population similar to that described for self-pollinated lines. **Hybrid lines** were first produced in corn (*Zea mays*) (55) but have since been applied to many agronomic, vegetable, and flower crops (1, 26).

hybrid line A seedling population that is produced by cross-pollinating two or more parental lines.

Hybrids may be produced between two inbred lines **(single-cross),** two single-crosses **(double-cross),** an inbred line and an open pollinated cultivar **(top-cross),** or between a single-cross and an inbred line **(three-way cross)** (55). Seeds saved from the hybrid population normally are not used for propagation because in the next generation, variability in size, vigor, and other characteristics may appear.

Synthetic cultivars are derived from the first generation of the open cross-fertilization of several lines or clones. For example, 'Ranger' alfalfa seed is made from intercropping five seed-propagated lines that results in genetically distinct but phenotypically similar seedlings in the seeded crop. Other crops in this category include pearl millet (*Pennisetum glaucus*), bromegrass (*Bromus*) and orchard grass (*Dactylis*).

synthetic line Acultivar seedling population that is produced by combining a number of separately developing lines to produce a heterozygous but homozygous Cultivar.

F_2 cultivars are derived for open-pollination of an F_1 hybrid. Some flower crops, (*Petunia,* pansy (*Viola*), and *Cyclamen*) and vegetables (tomato and melon) can be maintained as F_2 populations.

Clonal seed cultivars are maintained through apomictic seed production (25, 51). Apomixis occurs when an embryo is asexually produced and does not develop from fertilization of two gametes (28). The result is a clonal copy of the parent plant. Apomixis is discussed in detail in Chapter 4. The degree of clonal seed production depends on whether the species has a **facultative** or **obligate** form of apomixis. In species with facultative apomixis, both apomictic and sexual seeds are produced, sometimes within the same seed. Bluegrass (*Poa pratensis*) falls into this category. Other species show essentially 100 percent obligate apomictic seed production. Examples include Bahia grass (*Paspalum notatum*) and buffelgrass (*Pennisetum ciliare*).

Woody Perennial Plants

Wild Populations In nature, most species can be recognized as a more or less phenotypically (and genotypically) uniform seedling population that has evolved over time through consecutive generations to be adapted to the environment at a particular site. If the species covers a wide area, local variation in environment can result in different populations becoming adapted to different areas even though the plants may appear phenotypically similar. Plants within the species that show morphological differences compared to the species, but that are reproduced by seed, may be designated as **botanical varieties** or ***varietas*** or ***var.*** The term **form** indicates a particular

ecotype A genetically distinct group of plants within a species that is adapted to a specific ecological location.

cline Continuous genetic variation from one area to another in ecological adaptation.

phenotypic difference, as a blue or white color. Subgroups of a particular species that are morphologically similar but specifically adapted to a particular environmental niche are known as **ecotypes.** Variations that occur continuously between locations are known as **clines** (35, 43).

Provenance The climatic and geographical locality where seed is produced is referred to as its **seed origin** or **provenance** (2, 3, 38, 54). Variation can occur among plants associated with latitude, longitude, and elevation. Differences may be shown by morphology, physiology, adaptation to climate and to soil, and in resistance to diseases and insects. Natural plant populations growing within a given geographical area over a long period of time evolve so that they become adapted to the environmental conditions at that site.

provenance A forestry term used to indicate the climatic and geographical locality where the seed originated.

Consequently, seeds of a given species collected in one locality may produce plants that are completely inappropriate to another locality. For example, seeds collected from trees in warm climates or at low altitudes are likely to produce seedlings that will not stop growing sufficiently early in the fall to escape freezing when grown in colder regions. The reverse situation—collecting seed from colder areas for growth in warmer regions—might be more satisfactory, but it also could result in a net reduction in growth resulting from the inability of the trees to fully utilize the growing season because of differences in the response to photoperiod (61).

Distinct ecotypes have been identified by means of **seedling progeny tests** in various native forest tree species, including Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus murrayana*), eastern white pine (*Pinus strobus*), slash pine (*Pinus caribaea*), loblolly pine (*Pinus* sp.), shortleaf pine (*Pinus echinata*), and white spruce (*Picea alba*) (66). Other examples include the Baltic race of Scotch pine (*Pinus sylvestris*), the Hartz Mountain source of Norway spruce (*Picea abies*), the Sudeten (Germany) strain of European larch (*Larix*), the Burmese race of teak, Douglas-fir (*Pseudotxuga menziesii*) from the Palmer area in Oregon, ponderosa pine (*Pinus ponderosa*) from the Lolo Mountains in Montana, and white spruce (*Picea alba*) from the Pembroke, Ontario (Canada) area (16, 20, 31). Douglas-fir (*Pseudotsuga menziesii*) has at least three recognized races—*viridis, caesia,* and *glauca*—with various geographical strains within them that show different adaptations. For instance, progeny tests showed that a *viridis* strain from the United States West Coast was not winter-hardy in New York but was well suited to Western Europe. Those from Montana and Wyoming were very slow growing. Trees of the *glauca* (blue) strain from the Rocky Mountain region were winter-hardy but varied in growth rate and appearance. Strains collected farther inland were winter-hardy and vigorous; similar differences occurred in Scotch pine (*Pinus sylvestris*), mugho pine (*P. mugho*), Norway spruce (*Picea abies*), and others.

Improved Seed Sources Nursery propagation by woody plant seed can be upgraded significantly by the selection and development of improved seed sources. This practice applies to the production of rootstocks for fruit and nut trees (49, 58), shade trees (20, 43), and trees in the landscape. Likewise, foresters have been engaged in recent years in "domesticating" and upgrading forest tree production over that of "local" seed (38, 40, 60).

Elite Trees. Foresters refer to single seed-source trees with a superior genotype, as demonstrated by a progeny test, as **elite trees.** Nursery progeny tests can identify and characterize specific seed sources (e.g., for landscape or Christmas tree uses).

elite tree An individual tree with outstanding phenotypic characteristics to be used as a seed source.

Clonal Seed Sources. Superior (elite) seed-source trees can be maintained as clones in seed orchards to preserve the genotype of the parent. Seeds from this clonal source are then used to produce seedling trees in the nursery. This procedure is used to produce rootstock seed for fruit and nut cultivars. For instance, 'Nemaguard' is a peach hybrid whose nematode-resistant seedling progeny are used for almond, peach, plum, and apricot trees in central California (49). Named cultivars of ornamental trees have been

clonal seed source Cultivar maintained as a clone selected for producing outstanding seedlings.

identified as producing uniform, superior seedling progeny (16).

selected families Consecutive groups of progeny trees related by origin and showing superior characteristics.

Selected Families. Genetic improvement of forest-tree species has brought about **family selection** by growing progeny trees either from controlled crossing or selection from single open-pollinated superior (elite) trees. Seed orchards then may be established either from seedlings of these trees or established by grafting the parent trees. A minimum number of individual genotypes are selected—usually around twenty-five—to avoid the dangers of inbreeding and limits to the genetic range. Progeny trees are planted in test sites and evaluated for various forestry characteristics. Over time, superior sources are identified and preserved as parents to produce the next generation of new families of improved seed genotypes. Inferior seed sources are identified and eliminated.

Hybrid Seed Sources. F_1 hybrids of two species usually produce uniform populations of plants in the same manner as hybrid seeds of corn and other inbred lines (see p. 157). For example, hybridization has been valuable in producing vigorous almond × peach hybrids for almond and peach rootstocks (33, 34), Paradox hybrids (*Juglans hindsii* × *J. regia*) for walnuts and fast-growing poplars from crosses with North American and European poplars (like *Populus trichocarpa.* × *P. deltoides*). Forest tree hybrids, such as *Pinus rigida* × *P. taeda* in Korea and *Larix decidua* × *L. leptolepsis* in Europe are not necessarily uniform, however, but have been a focus of improved forests. Because of expense and uncertainty of production, seeds of F_1 hybrids of the forest trees have been used to produce F_2 seedling populations. The more vigorous hybrid plants dominate and the weaker trees are crowded out.

CONTROL OF GENETIC VARIABILITY DURING SEED PRODUCTION

Herbaceous Annual, Biennial, and Perennial Plants

Isolation Isolation is used to prevent mechanical mixing of the seed during harvest and to prevent contamination by unwanted cross-pollination with a different but related cultivar. Isolation is achieved primarily through distance, but it can also be attained by enclosing plants or groups of plants in cages, enclosing individual flowers, or removing male flower parts (i.e., de-tasseling corn) and then manually applying pollen of a known source by hand or various other devices (Fig. 5–11). On a large scale, this goal can be achieved by using male-sterile parents (36). In a number of crop species [e.g., tobacco *(Nicotiana)* and onion *(Allium)*], specific genes have been identified that prevent normal formation of the male (pollen) reproductive structures (Fig. 5–12). This means that no viable pollen is produced. The most common form of **pollen sterility** is cytoplasmic male sterility, which is a complex interaction between nuclear and mitochondrial plant genes (12). Such traits can be bred into parental lines of specific cultivars for the production of **hybrid seed.** Using molecular biology to induce male sterility has also become a potential strategy to limit gene flow from transgenic plants into the environment (11).

pollen sterility Genetic phenomenon in which the pollen is nonviable.

hybrid seed Seed produced by the crossing of two dissimilar parents, usually produced when made between species.

(a)

(b)

Figure 5–11
Isolation is used to prevent unwanted cross-pollination during seed production. (a) An onion hybrid cross being isolated with an individual sac. (b) A small cage where flies will be introduced to pollinate onions for hybrid production. Female plants in the cage are made sterile to prevent self-pollination.

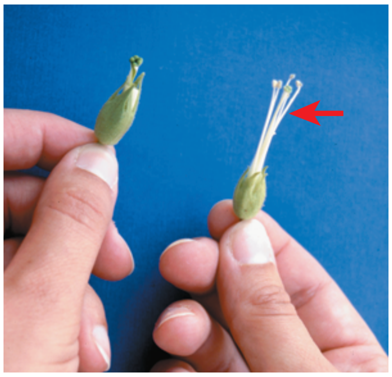


Figure 5–12
Male sterility in tobacco (Nicotiana). Note how the flower on the left lacks developed anthers compared to the perfect flower on the right with elongated and fertile anthers (arrow).

Self-pollinated cultivars of herbaceous plant species need only to be separated to prevent mechanical mixing of seed of different cultivars during harvest. The minimum distance usually specified between plots is 3 m (10 ft), but may be up to 50 to 65 m (150 to 200 ft) depending on the degree of cross-pollination capacity in the crop. For example, bell pepper is a self-pollinating crop but, given the opportunity, will cross-pollinate to a high degree from bee pollinators. Careful cleaning of the harvesting equipment is required when a change is made from one cultivar to another. Sacks and other containers used to hold the seed must be cleaned carefully to remove any seed that has remained from previous lots.

More isolation is needed to separate cultivars cross-pollinated by wind or insects. The minimum distance depends on a number of factors:

- the degree of natural cross-pollination
- the relative number of pollen-shedding plants
- the number of insects present
- the direction of prevailing winds

The minimum distance recommended for insect-pollinated herbaceous plant species is 0.4 km (¼ mi) to 1.6 km (1 mi). The distance for wind-pollinated plants is 0.2 km (⅛ mi) to 3.2 km (2 mi), depending on species.

Effective cross-pollination usually can take place between cultivars of the same species; it may also occur between cultivars of a different species but in the same genus; rarely will it occur between cultivars belonging to another genus. Since the horticultural classification may not indicate taxonomic relationships, seed producers should be familiar with the botanical relationships among the cultivars they grow. It is also important to isolate GMO (genetically modified organisms) crops from non-GMO seed crops of the same cultivar or species.

In seed production areas, such as regions of Oregon, Washington, and California, seed companies cooperate to locate seed production fields at appropriate isolation distances from each other. The fields are located on "pinning" maps (each colored pin indicating a field and crop type), and the maps are located in County Extension offices within the production areas. Recently, these have also become available as virtual maps on the Internet, as is the case in California.

Roguing The removal of off-type plants, plants of other cultivars, and weeds in the seed production field is known as **roguing** (37). During the development of a seed-propagated cultivar, positive selection is practiced to retain a small portion of desirable plants and to maximize the frequency of desirable alleles in the population. During seed production, roguing following visual inspection exerts selection by eliminating the relatively small population that is not "true to type," thus keeping the cultivar "genetically pure."

roguing The act of removing off-type plants, weeds, and plants of other cultivars in seed production fields.

Off-type characteristics (i.e., those that do not conform to the cultivar description) may arise because recessive genes may be present in a heterozygous condition even in homozygous cultivars. Recessive genes arising by mutation would not be immediately observed in the plant in which they occur. Instead, the plant becomes heterozygous for that gene, and, in a later generation, the gene segregates and the character appears in the offspring. Some cultivars have mutable genes that continuously produce specific off-type individuals (45). Off-type individual plants should be rogued out of the seed production fields before pollination occurs. Systematic inspection of the seed-producing fields by trained personnel is required.

Other sources of off-type plants include contamination by unwanted pollen due to inadequate isolation or volunteer plants arising from accidentally planted seed or from seed produced by earlier crops. Seed production fields of a particular cultivar should not have grown a potentially contaminating cultivar for a number of preceding years.

Weeds are plant species that have been associated with agriculture as a consequence of their ability to exploit disturbed land areas when cultivation occurs (29). Some weed species have evolved seed types that closely resemble crop seeds and are difficult to screen out during seed production.

Seedling Progeny Tests Planting representative seeds in a test plot or garden may be desirable to test for trueness-to-type. This procedure is used in the development of a cultivar to test its adaptability to various environments. The same method may be necessary to test whether changes have occurred in the frequency of particular genes or new gene combinations may have developed during seed increase generations. These changes can result from selection pressure exerted by management practices or environmental interaction. For example, intensive roguing may result in a **genetic drift** due to changes in the frequency of particular genes or gene combinations (24). Shifts may also occur due to environmental exposure in a growing area which is different from the initial selection area. Seedlings of particular genotypes may survive better than others and contribute more to the next generation. If sufficiently extensive, genetic drift could produce populations of progeny plants that differ somewhat from those of the same cultivar grown by other producers. Or the cultivar may have changed from the original breeder's seed.

genetic drift Change in the frequency of specific genes as a result of environmental or other types of selection.

Problems can result if seed crops of particular perennial cultivars are grown in one environment (such as a mild winter area) to produce seed to be used in a different and more severe environment (such as an area requiring cold-hardiness). This situation has occurred, for example, with alfalfa (24) where rules for production of forage crop seed in a mild winter area can specify only one seedling generation of increase.

Woody Perennial Plants

Use of Local Seed "Local seed" means seed from a natural area subjected to a restricted range of climatic and soil influences. As applied to forest tree seed, this usually means that the collection site should be within 160 km (100 mi) of the planting site and within 305 m (1,000 ft) of its elevation. In the absence of these requirements, seed could be used from a region having as nearly as possible the same climatic characteristics. The reason for the historical emphasis on local seed is the phenomenon previously defined as seed origin or provenance (27). The use of local seed for herbaceous and woody plants is particularly important in the effort to restore any native ecosystem where the use of exotic species would be inappropriate (43).

Pure Stands. **Pure stand** refers to a group of phenotypically similar seedling plants of the same kind. This concept could apply both to plants growing in a natural environment or in a planting such as a wood lot. These populations are useful in seed collection because cross-pollination would likely occur from among this group of plants and one can judge both the female and the male parents. Although the individuals are likely to be heterozygous, they should produce good seeds and vigorous seedlings. The population should be homogeneous and reproduce the parental characteristics.

pure stand An interbreeding group of phenotypically similar plants of the same kind growing in a given site.

Phenotypic Tree Selection Versus Genotypic Tree Selection. **Phenotypic selection** refers to evaluation of a seed source through visual inspection of the source plant(s). The basis of this procedure is that many important traits in forestry—such as stem form, branching habit, growth rate, resistance to diseases and insects, presence of surface defects, and other qualities—are inherited quantitatively. Geneticists refer to this relationship as high phenotypic correlation between parents and offspring. In practical terms, this means that the parental performance can be a good indicator of the performance of the offspring (57).

phenotypic selection Selection of a seed source based on the phenotypic appearance of the source tree.

When individual trees in native stands show a superior phenotype, foresters call them "plus" or elite trees and sometimes leave them for natural reseeding or as seed sources. Such dominant seed trees may contribute the bulk of natural reseeding in a given area.

Genotypic selection refers to evaluation of a seed source based on the performance of their seedling progeny test (39). Seeds may be produced by open pollination (OP) where only one parent is known. Or the test may be made from a controlled cross, where both parents are known and the contributions of each can be evaluated. A progeny test establishes the breeding value of a particular seed source (5) because genetic potential is based on actual performance of the progeny.

genotypic selection Selection of a seed source based on the phenotypic appearance of the seedling progeny.

A representative sample of seeds is collected, planted under test conditions, and the progeny observed over a period of years. A high correlation between the average phenotypic traits of the parent(s)

high additive heritability High correlation between phenotypic traits of offspring with the phenotypic traits of the parents.

low additive heritability Low correlation between phenotypic traits of offspring with the phenotypic traits of the parents.

and the average phenotypic response of the offspring is referred to as **high additive heritability** and justifies using the "best" trees for seed sources of the next generation (38). A low statistical correlation between parent and progeny characteristics is referred to as **low additive heritability** in that the desired traits of the progeny cannot be predicted from inspection of the parents.

Progeny testing is useful to verify the suitability of individual seed sources for future seed collecting. The procedure is an important component to the improvement of woody plants whether in forestry or horticulture.

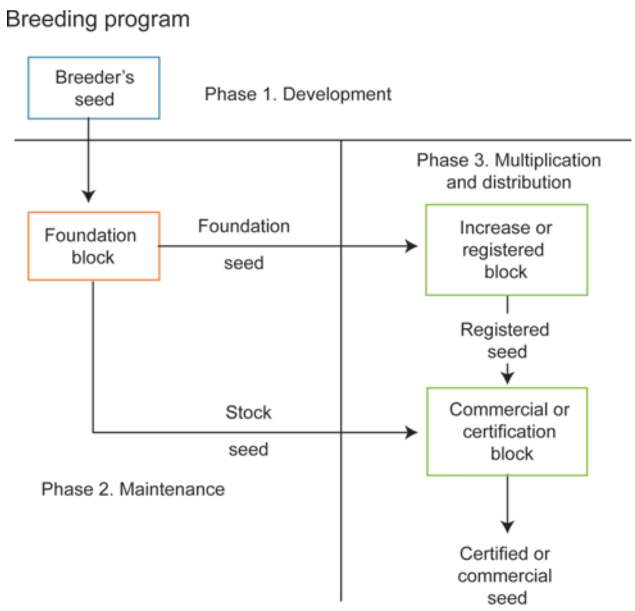


Figure 5–13
Pedigree system for seed production. See text for discussion.

SEED PRODUCTION SYSTEMS

Herbaceous Annual, Biennial, and Perennial Plants

Commercial Plantings Traditional seed selection of herbaceous plants utilized a portion of the seed from one year's crop to plant a crop for the next year. This system would be satisfactory for self-pollinated cultivars that are easy to maintain genetically. For cross-pollinated cultivars, knowledge of the production requirements of individual crops is needed and specific conditions are practiced depending upon the plant (3). Note, however, that inadequacies of this method led to its replacement by the pedigree system.

Pedigreed Stock System (4, 42) Commercial seed production of most self-pollinated and cross-pollinated lines is carried out in three steps (Fig. 5–13). The purpose of a **pedigreed stock system** is to maintain genetic purity through consecutive seed generations following appropriate standards of isolation, inspection, and roguing (with high costs) at the initial release with decreased standards (and lower costs) in the distribution of commercial seed. The overall program includes three phases. Phase 1 includes the *development* phase, which ends with the production of a small quantity of seeds **(breeder's seed)** that is maintained by the originating institution as the primary reference for the cultivar. Phase 2 is a *maintenance* phase in which a quantity of seed called **foundation seed** (for certified seed classes; see Box 5.1, page 154) or **stock seed** (in commercial enterprises) is maintained under high standards of isolation, inspection, and roguing. Phase 3 is the *distribution* phase, which may include two steps: a *second-generation increase* block and a *third-generation* block to produce commercial seed for distribution to the public. A foundation planting originates only from breeder's seed or another foundation planting. An increase block originates only from a foundation seed or another increase planting. A seed production planting originates from foundation seed or increase block seed. This entire production process is carried out either by large commercial firms or groups of independent growers joined within a Crop Improvement Association to produce certified seed.

pedigreed stock system A controlled seed-production system of consecutive generations with standards to maintain genetic purity leading to commercial distribution.

Seed Certification (4, 13, 17, 42) **Seed certification** is a legalized program that applies the previously mentioned principles to the production of specific seed-propagated plant cultivars to ensure the maintenance of seed purity. The system was established in the United States and Canada during the early 1920s to regulate the

seed certification A system of seed production utilizing pedigreed stock principles, which provides for legally enforceable standards of quality and genetic purity.

BOX 5.1 **GETTING MORE IN DEPTH ON THE SUBJECT**

CLASSES OF CERTIFIED SEEDS

Breeder's seed: that which originates with the sponsoring plant breeder or institution and provides the initial source of all the certified classes. **Foundation seed:** progeny of breeder's seed that is handled to maintain the highest standard of genetic identity and purity. It is the source of all other certified seed classes but can also be used to produce additional foundation plants. (**Select seed** is a comparable seed class used in Canada.) Foundation seed is labeled with a *white* tag or a certified seed tag with the word "foundation." **Registered seed:** progeny of foundation seed (or sometimes of breeder's seed or other registered seed) produced under specified standards approved and certified by the certifying agency and designed to maintain satisfactory genetic identity and purity. Bags of registered seed are labeled with a *purple* tag or with a blue tag marked with the word "registered." **Certified seed:** progeny of registered seed (or sometimes of breeder's, foundation, or other certified seed) that is produced in the largest volume and sold to crop producers. It is produced under specified standards designed to maintain a satisfactory level of genetic identity and purity and is approved and certified by the certifying agency. Bags of certified seed have a *blue* tag distributed by the seed-certifying agency.

commercial production of new cultivars of agricultural crops then being introduced in large numbers by state and federal plant breeders. The principles (as described for the pedigreed stock system) and accompanying regulations of seed maintenance were established through the cooperative efforts of public research, extension, regulatory agencies, and seed-certifying agencies known as Crop Improvement Associations, whose membership included commercial producers. These organizations were designated by law through the Federal Seed Act (1939) to conduct research, establish production standards, and certify seeds that are produced under these standards. Individual state organizations are coordinated through the Association of Official Seed Certifying Agencies (AOSCA) (4) in the United States and Canada. Similar programs exist at the international level where certification is regulated through the Organization for Economic Cooperation and Development (OECD).

The principal objective of seed certification is to provide standards to preserve the genetic qualities of a cultivar. Other requirements of seed quality also may be enforced as well as the eligibility of individual cultivars. The seed-certifying agency may determine production standards for isolation, maximum percentage of off-type plants, and quality of harvested seed; make regular inspections of the production fields to see that the standards are being maintained; and monitor seed processing.

The international OECD scheme includes similar classes but uses different terms. These include **basic** (equivalent to either foundation or registered seed), **certified first-generation** (blue tag) seed, and **second-generation** (red tag) seed.

Hybrid Seed Production (1) Hybrid cultivars (Fig. 5–14) are the F_1 progeny of two or more parental lines. Parent plants are maintained either as inbred lines (corn, onion) or as vegetatively propagated clones (asparagus). The same standards of isolation as for nonhybrid seed production may be required. To mass-produce hybrids, some system must be used to prevent self-pollination and to enforce cross-pollination. Hand pollination is sometimes practiced to produce seed in crops or situations in which the production of seed per flower is very high and/or the high value of the seed justifies the expense (Fig. 5–15, page 156). Hand pollination is used to produce some hybrid flower seeds and in breeding new cultivars (Fig. 5–16, page 157).

Perennial Sources

Commercial Sources Seeds for fruit and nut crops historically have been collected more or less successfully from commercial orchards particularly where the specific cultivar or origin is known. Fruit tree seeds such as apple (*Malus*), pear (*Pyrus*), and peach (*Prunus*) have been collected from canneries and dry yards where specific commercial cultivars, such as 'Lovell' peach, are used. Pure stands of local seedling landscape trees might be used. In several forest-tree species, seed has been collected from phenotypically above-average trees in commercial plantations. In New Zealand, seed from such trees is designated "CS" ("climbing selects") and rated higher in value than the seed from the surrounding trees, but below that of seed orchards or from well-tested families.

Seed-Collection Zones A **seed-collection zone** for forest trees is an area with defined boundaries and altitudinal limits in which soil and climate

seed-collection zone Naturally occurring zone (forest plants) designated by elevation, latitude, and longitude that identifies a specific seed source.

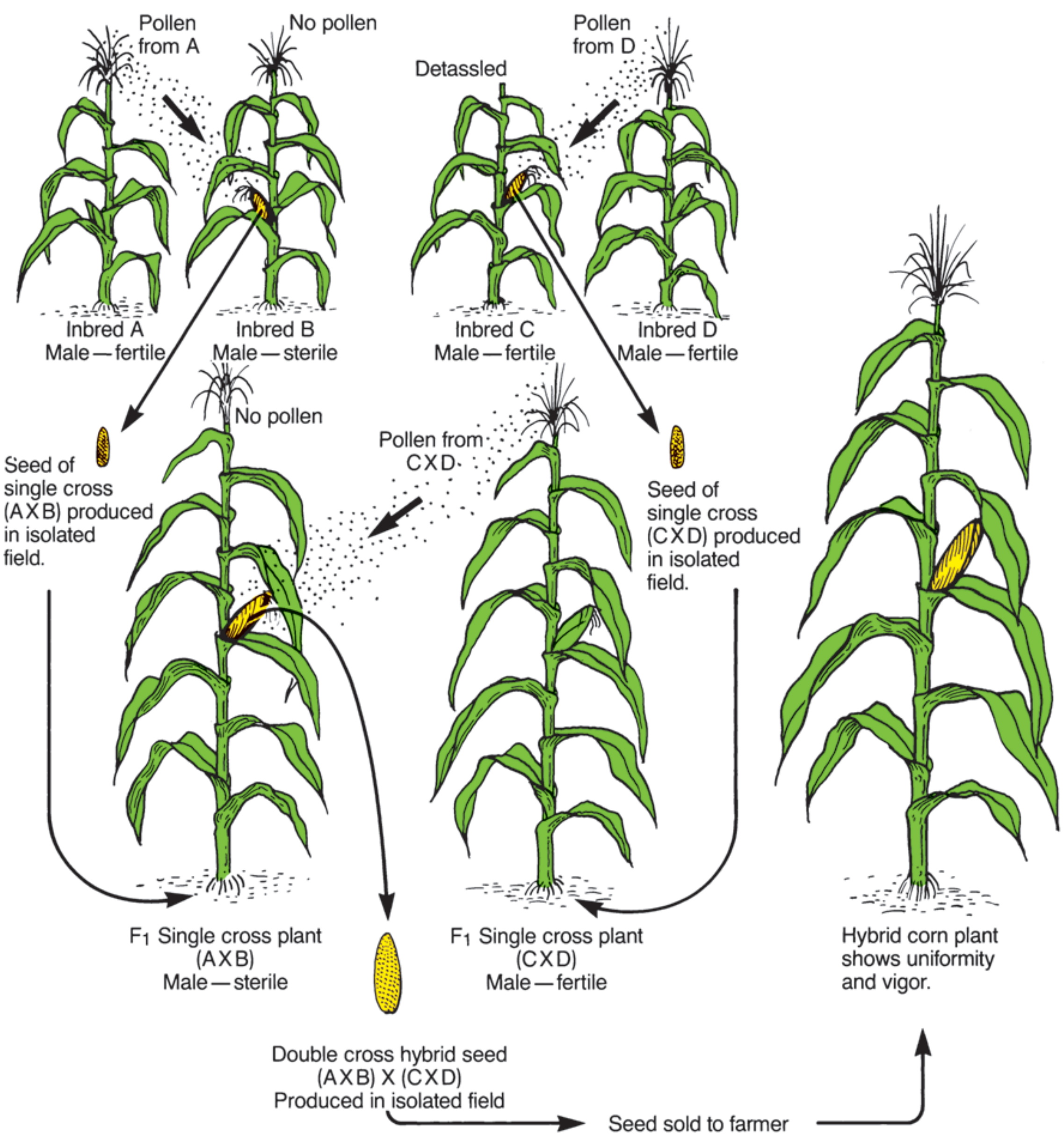


Figure 5–14
Hybrid seed corn production. Four inbred lines are produced to be used as parents for cross-pollination utilizing either detasseling (removal of male flower) or a pollen-sterile parent. The resulting F_1 plants are used as parents of the next (F_2) generation which are then sold for commercial crop production. The individual progeny plants are highly heterozygous, but the population is highly homogeneous, showing high vigor and production. Redrawn from USDA Yearbook of Agriculture 1937, Washington, D.C.: U.S. Government Printing Office.

are sufficiently uniform to indicate a high probability of reproducing a single ecotype. Seed-collection zones, designating particular climatic and geographical areas, have been established in most of the forest-tree–growing areas in the world (61). California, for example, is divided into six physiographic and climatic regions, 32 subregions, and 85 seed-collection zones (Fig. 5–17, page 158). Similar zones are established in Washington and Oregon and in the central region of the United States.

Seed-Production Areas (43)
A **seed-production area** contains a group of plants that can be identified and set aside specifically as a seed

seed-production area An area of source plants specifically utilized for seed collection.

Figure 5–15
(a and b) Hybrid pollination in petunia. Hand pollination involves removal of the male anthers (emasculation) before the flower opens; (c and d) followed by transfer of the pollen to the receptive stigma. Pollen is collected and stored dry in small vials at cold temperature. Pollen is transferred to the stigma using a small transfer stick or brush. (e) A successful pollination/fertilization is evident by continued development (red arrow). (f) Seed yield per capsule is high and the seed is very valuable justifying the use of hand labor.

source. Seed plants within the area are selected for their desirable characteristics. The value of the area might be improved by removing off-type plants, those that do not meet desired standards, and other trees or shrub species that would interfere with the operations. Competing trees can be eliminated to provide adequate space for tree development and seed production. In forestry, an isolation zone at least 120 m (400 ft) wide

(a) (b) (c)

Figure 5–16
F_1 hybrid cultivars of many vegetable and flowering annuals are created following large-scale hand pollination in a controlled environment. (a) Removing male parts in snapdragon prior to hand pollination. (b) Hand pollination. (c) Pepper fruit prior to harvest for seed extraction.

from which off-type plants are removed should be established around the area.

Seed orchards **Seed orchards** are established to produce tree seeds of a particular origin or source. For example, fruit tree nurseries maintain seed orchards to produce seeds of specific rootstock cultivars under conditions that will prevent cross-pollination and the spread of pollen-borne viruses. A clonal cultivar such as 'Nemaguard' peach is budded to a rootstock, planted in isolation to avoid chance cross-pollination by virus-infected commercial cultivars, and grown specifically for rootstock seed production as part of the nursery operations.

seed orchard
A planting used in forestry or in fruit tree nurseries to maintain seed sources as seedling populations of selected seed families or of a clone (fruit and nut trees) or collections of clones (forestry).

BOX 5.2 GETTING MORE IN DEPTH ON THE SUBJECT
TREE CERTIFICATION CLASSES

Certification of forest-tree seeds is available in some states and European countries similar to that for crop seed (17, 18, 61). Recommended minimum standards are given by the Association of Official Seed Certifying Agencies (4). Forest-tree seed have different standards than agricultural seeds.

Tree certification classes are defined as **source-identified:** tree seed collected from natural stands where the geographic origin (source and elevation) is known and specified or from seed orchards or plantations of known provenance, specified by seed-certifying agencies. These seeds carry a *yellow* tag. **Selected:** tree seed collected from trees that have been selected for promising phenotypic characteristics but have not yet been adequately progeny-tested. The source and elevation must be stated (44). These seeds are given a *green* label. **Certified:** two types of seed are recognized. Seeds are from trees growing in a seed orchard whose genetic potential is based on phenotypic superiority. These are identified by a *pink* tag. When seedlings or seeds have been proven to be genetically superior in a progeny test, they are classified as **tested** and identified by a *blue* tag.

Fruit-tree rootstock clones that are self-pollinated are planted in solid blocks. An isolation zone 120 m (400 ft) wide should be established around the orchard to reduce pollen contamination from other cultivar sources. The size of this zone can be reduced if a buffer area of the same kind of tree is present around the orchard. Hybrid seed production involves planting both the parental clones in adjoining rows under the same condition.

Three general types of seed orchards are used for forest trees (42, 61): (a) seedling trees produced from selected parents through natural or controlled pollination; (b) clonal seed orchards in which selected clones are propagated by grafting, budding, or rooting cuttings; and (c) seedling-clonal seed orchards in which certain clones are grafted onto branches of some of the trees. The choice depends on the particular strategy used in the seed improvement program.

A site should be selected for good seed production. Forest trees and most other native species should include a range of genotypes in a suitable arrangement to ensure cross-pollination and to decrease the effects of inbreeding. Seven to thirty unrelated genotypes have been recommended to avoid this problem in a purely clonal orchard.

Nursery Row Selection Sometimes phenotypically unique individuals appear in nursery seed populations planted in the nursery row and can be identified visually. This is referred to as **nursery row selection.** Identification requires that the character be distinctive in vigor, appearance, or both (Fig. 5–11). For example, Paradox hybrid walnut seedlings (*Juglans regia* × (*J. hindsii*) used as a rootstock in California are produced by planting seeds of specific seed tree sources of black walnut (*Juglans hindsii*). Once germination takes place, leaf characteristics, bark color, and greater

nursery row selection
A system of selection where specific progeny trees can be identified in the nursery row due to phenotype.

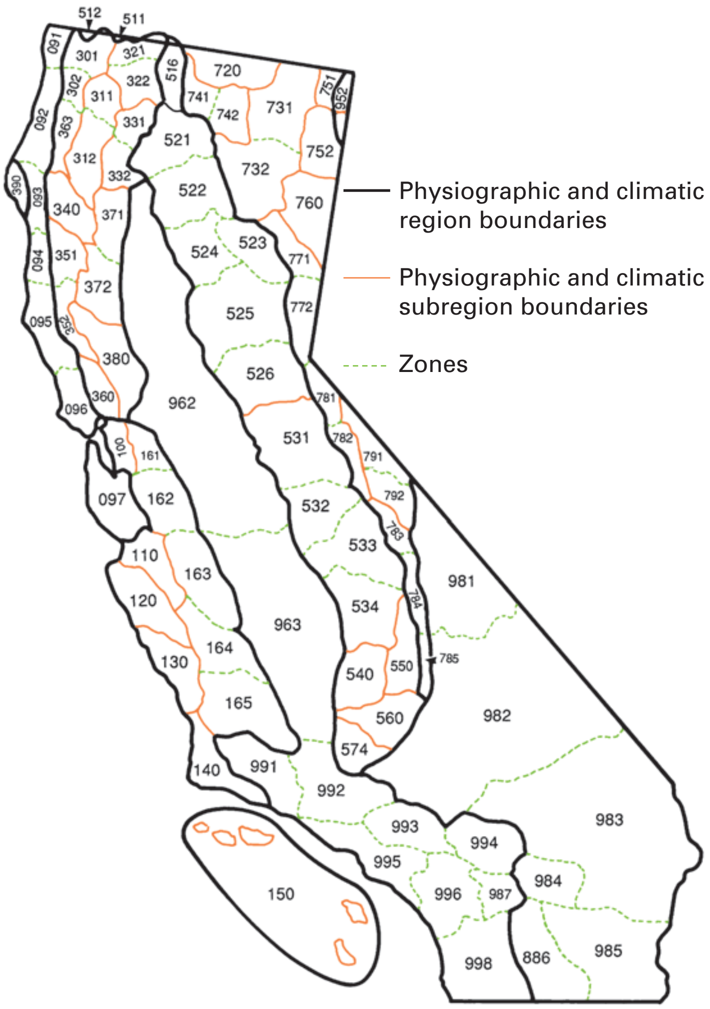


Figure 5–17
Seed collection zones in California. The 85 zones are identified by a three-digit number. The first gives 1 of the 6 major physiographic and climatic regions, the second gives 1 of the subregions, of which there are 32, and the third gives the individual zone. 0 = Coast; 1 = South coast; 3 = North coast; 5 = Mountains of Sierra Nevada and Cascade ranges; 7 = Northeast interior; 9 = Valley and desert areas, further divided into the central valley (6), southern California (9), and the desert areas (7). Redrawn from G. H. Schubert and R. S. Adams. 1971. Reforestation Practices for Conifers in California. Sacramento: Division of Forestry.

BOX 5.3 **GETTING MORE IN DEPTH ON THE SUBJECT**

PLANT VARIETY PROTECTION ACT

Breeders of a new seed-reproduced plant variety (cultivar) in the United States may retain exclusive propagation rights through the Plant Variety Protection Act, established in 1970 (7), and revised in 1994 (46). The breeder applies to the U.S. Department of Agriculture for a Plant Variety Protection Certificate. For one to be granted, the cultivar must be "novel": it must differ from all known cultivars by one or more morphological, physiological, or other characteristics. It must be uniform; any variation must be describable, predictable, and acceptable. It must be stable (i.e., essential characteristics must remain unchanged during seed propagation). A certificate is good for 20 years. The applicant may designate that the cultivar be certified and that reproduction continue only for a given number of seed generations from the breeder or foundation stock. If designated that the cultivar be certified, it becomes unlawful under the Federal Seed Act to market seed by cultivar name unless it is certified. The passage of this law has greatly stimulated commercial cultivar development.

vigor of the hybrid seedlings allow identification of the desired hybrid seedlings, whereas the black walnut seedlings are rogued out of the nursery row or separated at a later date. Genotypic progeny tests based on previous commercial experience indicate which walnut tree sources produce the highest percentages of hybrids, presumably from natural crossing with surrounding Persian walnut (*J. regia*) orchards.

Sometimes the phenotype of the propagated plant is sufficiently striking as to allow for selection in the nursery. For example, blue seedlings of the Colorado spruce (*Picea pungens*) tend to appear among seedling populations having the usual green form. Differences in fall coloring among seedlings of *Liquidambar* and *Pistacia chinensis* necessitate fall selection of individual trees for landscaping.

DISCUSSION ITEMS

Propagators of many plant species and cultivars may not be involved directly in the selection and handling of the seeds used but depend on the skill and knowledge of the specialized seed industry. Nothing is more important, however, than using seeds that are true-to-type and true-to-name. Consequently, knowledge of the basic principles and practices that are required to produce genetically pure seeds is important to propagators whether or not they are directly involved in seed selection.

1. From the propagator's standpoint, why do you think crop plants such as wheat, rye, and barley played such an important role in human history?
2. What are some major reasons why seed producers like to produce hybrid seed lines?
3. What are the differences and similarities among apomictic, inbred, and hybrid seed lines?
4. What is the function of seedling progeny tests in seed production?
5. Why is the seed origin (provenance) important to users of tree crops?
6. Would it be better to collect seeds from a single woody plant or from multiple plants?

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