**Breeding self-pollinated species**

**Types of cultivars**

At the beginning of each project, the breeder should decide on the type of cultivar to breed for release to producers. The breeding method used depends on the type of cultivar to be produced. There are six basic types of cultivars that plant breeders develop. These cultivars derive from four basic populations used in plant breeding – **inbred pure lines**, **open-pollinated populations**, **hybrids**, and **clones**. Plant breeders use a variety of methods and techniques to develop these cultivars *Pure-line cultivars*

**Pure-line cultivars** are developed for species that are highly self-pollinated. These cultivars are homogeneous and homozygous in genetic structure, a condition attained through a series of self-pollinations. These cultivars are often used as parents in the production of other kinds of cultivars. Pure-line cultivars have a narrow genetic base. They are desired in regions where uniformity of a product has a high premium.

**Open-pollinated cultivars**

Contrary to pure lines, **open-pollinated cultivars** are developed for species that are naturally cross-pollinated. The cultivars are genetically heterogeneous and heterozygous. Two basic types of open-pollinated cultivars are developed. One type is developed by improving the general population by **recurrent** (or repeated) **selection** or bulking and increasing material from selected superior inbred lines. The other type, called a **synthetic cultivar**, is derived from planned matings involving selected genotypes. Open-pollinated cultivars have a broad genetic base.

**Hybrid cultivars**

Hybrid cultivars are produced by crossing inbred lines that have been evaluated for their ability to produce hybrids with superior vigor over and above those of the parents used in the cross. Hybrid production exploits the phenomenon of hybrid vigor (or heterosis) to produce superior yields. Heterosis is usually less important in crosses involving self-pollinated species than in those involving cross-pollinated species. Hybrid cultivars are homogeneous but highly heterozygous. Pollination is highly controlled and restricted in hybrid breeding to only the designated pollen source.

**Clonal cultivars**

Seeds are used to produce most commercial crop plants. However, a significant number of species are propagated by using plant parts other than seed (vegetative parts such as stems and roots). By using vegetative parts, the cultivar produced consists of plants with identical genotypes and is homogeneous. However, the cultivar is genetically highly heterozygous. Some plant species sexually reproduce but are propagated clonally (vegetatively) by choice. Such species are improved through hybridization, so that when hybrid vigor exists it can be fixed, and then the improved cultivar propagated asexually.

**Multilines**

Multilines are developed for self-pollinating species. These cultivars consist of a mixture of specially developed genotypes called **isolines** (or **near isogenic lines**) because they differ only in a single gene (or a defined set of genes). Isolines are developed primarily for disease control, even though these cultivars could, potentially, be developed to address other environmental stresses. Isolines are developed by using the techniques of backcrossing in which the F1 is repeatedly crossed to one of the parents (recurrent parent) that lacked the gene of interest (e.g., disease resistance).

**Genetic structure of cultivars and its implications**

The products of plant breeding that are released to farmers for use in production vary in genetic structure and consequently the phenotypic uniformity of the product. Furthermore, the nature of the product has implications in how it is maintained by the producers, regarding the next season’s planting.

**Homozygous and homogeneous cultivars**

A cultivar may be genetically homozygous and hence produce a homogeneous phenotype or product. Self-pollinated species are naturally inbred and tend to be homozygous. Breeding strategies in these species are geared toward producing cultivars that are homozygous. The products of economic importance are uniform. Furthermore, the farmer may save seed from the current season’s crop (where legal and applicable) for planting the next season’s crop, without loss of cultivar performance, regarding yield and product quality. This attribute is especially desirable to producers in many developing countries where the general tradition is to save seed from the current season for planting the next season. However, in developed economies with well-established commercial seed production systems, intellectual property rights prohibit the reuse of commercial seed for planting the next season’s crop, thus requiring seasonal purchase of seed by the farmer from seed companies.

**Heterozygous and heterogeneous cultivars**

Other approaches of breeding produce heterozygous and homogeneous (relatively) cultivars, for example, synthetic and composite breeding. These approaches will allow the farmer to save seed for planting. Composite cultivars are suited to production in developing countries, while synthetic cultivars are common in forage production all over the world.

**Clonal cultivar**

Clones, by definition, produce offspring that are not only identical to each other but also to the parent. Clones may be very heterozygous but whatever advantage heterozygosity confers is locked in for as long as propagation is clonally conducted. The offspring of a clonal population are homogeneous. Once the genotype has been manipulated and altered in a desirable way, for example through sexual means (since some species are flowering, but are vegetatively propagated and not through seed), the changes are fixed for as long as clones are used for propagation. Flowering species such as cassava and sugarcane may be genetically improved through sex-based methods, and thereafter commercially clonally propagated.

**Types of self-pollinated cultivars**

In terms of genetic structure, there are two types of self-pollinated cultivars:

1. Those derived from a single plant.
2. Those derived from a mixture of plants.

Single-plant selection may or may not be preceded by a planned cross but often it is the case. Cultivars derived from single plants are homozygous and homogeneous. However, cultivars derived from plant mixtures may appear homogeneous but, because the individual plants have different genotypes, and because some outcrossing (albeit small) occurs in most selfing species, heterozygosity would arise later in the population. The methods of breeding self-pollinated species may be divided into two broad groups – those preceded by hybridization and those not preceded by hybridization.

**Symbols for basic crosses**

1. **F**: The symbol F (for **filial**) denotes the progeny of a cross between two parents. The subscript (*x*) represents the specific generation (F*x*). If the parents are homozygous, the F1 generation will be homogeneous. Crossing of two F1 plants (or selfing an F1) yields an F2 plant (F1 × F1 = F2). Planting seed from the F2 plants will yield an F2 population, the most diverse generation following a cross, in which plant breeders often begin selection. Selfing F2 plants produces F3 plants, and so on. It should be noted that the seed is one generation ahead of the plant, that is, an F2 plant bears F3 seed.
2. O: The symbol O is the notation for selfing.
3. **S**: The S notation is also used with numeric subscripts. In one usage S0 = F1; another system indicates S0 = F2.

**Symbols for inbred lines**

Inbred lines are described by two systems. System I describes an inbred line based on the generation of plants that are being currently grown. System II describes both the generation of the plant from which the line originated as well as the generation of plants being currently grown. Cases will be used to distinguish between the two systems.

**Case 1**: The base population is F2. The breeder selects an F2 plant from the population and plants the F3 seeds in the next season.

* System I: the planted seed produces an F3 line.
* System II: the planted seed produces an F2 derived line in F3 or an F2:3 line.

If seed from the F3 plants is harvested and bulked, and the breeder samples the F4 seed in the next season, the symbolism will be as follows:

* System I: the planted seed produces an F4 line.
* System II: the planted seed produces an F2 derived line in F4 or an F2:4 line.

**Case 2**. The breeder harvests a single F4 and plants F5 seed in a row.

* System I: the planted row produces an F5 line.
* System II: the planted row constitutes an F4 derived line in F5 or an F4:5 line.

Similarly the S notation may be treated likewise.

Taking case 1 for example:

* System I: S1 line.
* System II: S0 derived line in S1 or an S0:1 line.

**Notation for pedigrees**

Knowing the **pedigree** or ancestry of a cultivar enables the plant breeder to retrace the steps in a breeding program to reconstitute a cultivar. Plant breeders follow a short-hand system of notations to write plant pedigrees. Some pedigrees are simple, others are complex. Some of the common notations are as follows:

1. A slash, /, indicates a cross.
2. A figure between slashes, /2/, indicates the sequence or order of crossing. A /2/ is equivalent to // and indicates the second cross. Similarly, / is the first cross, and /// the third cross.
3. A backcross is indicated by \*; \*3 indicates the genotype was backcrossed three times to another genotype.

The following examples will be used to illustrate the concept.

**Pedigree 1**: MSU48-10/3/Pontiac/Laker/2/MS-64.

Interpretation:

(a) The first cross was Pontiac (as female) × Laker (as male).

(b) The second cross was [Pontiac/Laker (as female)] × MS-64 (as male).

(c) The third cross was MSU48-10 (as female) × [Pontiac/Laker//MS-64 (as male)].

**Pedigree 2**: MK2-57\*3/SV-2.

Equivalent formula: MK2-57/3/MK2-57/2/MK2-57/SV-2.

Interpretation: the genotype MK2-57 was backcrossed three times to genotype SV-2.

**Mass selection**

Mass selection is an example of selection from a biologically variable population in which differences are genetic in origin. The Danish biologist, W. Johansen, is credited with developing the basis for mass selection in 1903. Mass selection is often described as the oldest method of breeding self-pollinated plant species. However, this by no means makes the procedure outdated. As an ancient art, farmers saved seed from desirable plants for planting the next season’s crop, a practice that is still common in the agriculture of many developing countries. This method of selection is applicable to both self- and crosspollinated species.

**Key features**

The purpose of mass selection is population improvement through increasing the gene frequencies of desirable genes. Selection is based on plant phenotype and one generation per cycle is needed. Mass selection is imposed once or multiple times (recurrent mass selection). The improvement is limited to the genetic variability that existed in the original populations (i.e., new variability is not generated during the breeding process). The goal in cultivar development by mass selection is to improve the average performance of the base population.

**Applications**

As a modern method of plant breeding, mass selection has several applications:

1. It may be used to maintain the purity of an existing cultivar that has become contaminated, or is segregating. Existing cultivars become contaminated over the years by natural processes (e.g., outcrossing, mutation) or by human error (e.g., inadvertent seed mixture during harvesting or processing stages of crop production).
2. It can also be used to develop a cultivar from a base population created by hybridization, using the procedure described next.
3. It may be used to preserve the identity of an established cultivar or soon-to-be-released new cultivar.
4. Some breeders use mass selection as part of their breeding program to rogue out undesirable plants, thereby reducing the materials advanced and saving time and reducing costs of breeding.

**Procedure**

***Steps***

The breeder plants the heterogeneous population in the field, and looks for off-types to remove and discard (Figure 16.1).

**Year 1:** If the objective is to purify an established cultivar, seed of selected plants may be progeny-rowed to confirm the purity of the selected plants prior to bulking. This would make a cycle of mass selection have a 2-year duration instead of 1 year. The original cultivar needs to be planted alongside for comparison.

**Year 2:** Evaluate composite seed in a replicated trial, using the original cultivar as a check. This test may be conducted at different locations and over several years. The seed is bulk harvested.

****

**Advantages and disadvantages**

***Advantages***

1. It is rapid, simple, and straightforward.
2. It is inexpensive to conduct.
3. The cultivar is phenotypically fairly uniform even though it is a mixture of pure lines, hence making it genetically broad-based, adaptable, and stable.

***Disadvantages***

1. To be most effective, the traits of interest should have high heritability.
2. Because selection is based on phenotypic values, optimal selection is achieved if it is conducted in a uniform environment.
3. Phenotypic uniformity is less than in cultivars produced by pure-line selection.
4. With dominance, heterozygotes are indistinguishable from homozygous dominant genotypes. Without progeny testing, the selected heterozygotes will segregate in the next generation

**Pure-line selection**

The theory of the pure line was developed in 1903 by the Danish botanist Johannsen. Studying seed weight of beans, he demonstrated that a mixed population of selfpollinated species could be sorted out into genetically pure lines. However, these lines were subsequently nonresponsive to selection within each of them (Figure 16.2). Selection is a passive process since it eliminates variation but does not create it.

**Key features**

A **pure line** suggests that a cultivar has identical alleles at all loci. Even though plant breeders may make this assumption, it is one that is not practical to achieve in a breeding program. What plant breeders call pure-line cultivars are most aptly called “near” pure-line cultivars, because as researchers such as K. J. Frey observed, high mutation rates occur in such genotypes. Line cultivars have a very narrow genetic base and tend to be uniform in traits of interest (e.g., height, maturity). In cases of proprietary dispute, lines are easy to unequivocally identify.

**Applications**

Pure-line breeding is desirable for developing cultivars for certain uses:

1. Cultivars for mechanized production that must meet a certain specification for uniform operation by farm machines (e.g., uniform maturity, uniform height for location of economic part).
2. Cultivars developed for a discriminating market that puts a premium on visual appeal (e.g., uniform shape, size).
3. Cultivars for the processing market (e.g., demand for certain canning qualities, texture).
4. Advancing “sports” that appear in a population (e.g., a mutant flower for ornamental use).
5. Improving newly domesticated crops that have some variability.

**Procedure**

***Steps***

**Year 1:** The first step is to obtain a variable base population (e.g., introductions, segregating

populations from crosses, landrace) and space plant it in the first year, select, and harvest desirable individuals (Figure 16.3).

**Year 2:** Grow progeny rows of selected plants. Rogue out any variants. Harvest selected

progenies individually. These are experimental strains.

**Years 3–6:** Conduct preliminary yield trials of the experimental strains including appropriate

check cultivars.

**Years 7–10:** Conduct advanced yield trials at multiple locations. Release highest yielding line as new cultivar.

****

**Advantages and disadvantages**

***Advantages***

1. It is a rapid breeding method.
2. The method is inexpensive to conduct.
3. The cultivar developed by this method has great “eye appeal” because of the high uniformity.
4. It is applicable to improving traits of low heritability, because selection is based on progeny performance.
5. Only the best pure line is selected for maximum genetic advance.

***Disadvantages***

1. The purity of the cultivar may be altered through admixture, natural crossing with other cultivars, and mutations.
2. The cultivar has a narrow genetic base and hence is susceptible to devastation from adverse environmental factors, because of uniform response.
3. A new genotype is not created. Rather, improvement is limited to the isolation of the most desirable or best genotype from a mixed population.
4. The method promotes genetic erosion because most superior pure lines are identified and multiplied to the exclusion of other genetic variants.
5. Progeny rows take up more resources (time, space).

**Pedigree selection**

Pedigree selection is a widely used method of breeding self-pollinated species (and even cross-pollinated species such as corn and other crops produced as hybrids). A key difference between pedigree selection and mass selection or pure-line selection is that hybridization is used to generate variability (for the base population), unlike the other methods in which production of genetic variation is not a feature. The method was first described by H. H. Lowe in 1927.

**Key features**

Pedigree selection is a breeding method in which the breeder keeps records of the ancestry of the cultivar. The base population, of necessity, is established by crossing selected parents, followed by handling an actively segregating population. Documentation of the pedigree enables breeders to trace parent–progeny back to an individual F2 plant from any subsequent generation. To be successful, the breeder should be able to distinguish between desirable and undesirable plants on the basis of a single plant phenotype in a segregating population. It is a method of continuous individual selection after hybridization. Once selected, plants are reselected in each subsequent generation. This process is continued until a desirable level of homozygosity is attained. The breeder should develop an effective, easy to maintain system of record keeping. The most basic form is based on numbering of plants as they are selected, and developing an extension to indicate subsequent selections. The key is to keep it simple, manageable, and informative.

**Applications**

Pedigree selection is applicable to breeding species that allow individual plants to be observed, described, and harvested separately. It has been used to breed species including peanut, tobacco, tomato, and some cereals, especially where readily identifiable qualitative traits are targeted for improvement.

**Procedure**

***Steps***

**Year 1:** Identify desirable homozygous parents and make about 20–200 crosses (Figure 16.4).

**Year 2:** Grow 50–100 F1 plants including parents for comparison to authenticate its hybridity.

**Year 3:** Grow about 2,000–5,000 F2 plants. Space plant to allow individual plants to be examined and documented. Include check cultivars for comparison. Desirable plants are selected and harvested separately keeping records of their identities. In some cases, it may be advantageous not to space plant F2s to encourage competition among plants.

**Year 4:** Seed from superior plants are progeny-rowed in the F3–F5 generations, making sure to space plant the rows for easy record keeping. Selection at this stage is both within and between rows by first identifying superior rows and selecting 3–5 plants from each progeny to plant the next generation.

**Year 5:** By the end of the F4 generation, there should be between 25–50 rows with records of the plant and row. Grow progeny of each selected F3.

**Year 6:** Family rows are planted in the F6 to produce experimental lines for preliminary yield trials in the F7. The benchmark or check variety is a locally adapted cultivar. Several checks may be included in the trial.

**Year 7:** Advanced yield trials over locations, regions, and years are conducted in the F8–F10 generations, advancing only superior experimental material to the next generation. Ultimately, the goal is to identify one or two lines that are superior to the check cultivars for release as a new cultivar. Consequently, evaluations at the advanced stages of the trial should include superior expression of traits that are deemed to be of agronomic importance for successful production of the particular crop (e.g., lodging resistance, shattering resistance, disease resistance). If a superior line is identified for release, it is put through the customary cultivar release process (i.e., seed increase and certification).

**Advantages and disadvantages**

The pedigree method of breeding has advantages and disadvantages, the major ones include the following.

***Advantages***

1. Record keeping provides a catalog of genetic information of the cultivar.
2. Selection is based not only on phenotype but also on genotype (progeny row).
3. Using the records, the breeder is able to advance only the progeny lines in which plants that carry the genes for the target traits occur.
4. A high degree of genetic purity is produced in the cultivar.

***Disadvantages***

1. Record keeping is slow, tedious, time-consuming, and expensive.
2. The method is not suitable for species in which individual plants are difficult to isolate and characterize.
3. Pedigree selection is a long procedure, requiring about 10–12 years or more to complete, if only one growing season is possible.
4. It is not effective for accumulating the number of minor genes needed to provide horizontal resistance.

******

**Bulk population breeding**

Bulk population breeding is a strategy of crop improvement in which the natural selection effect is solicited more directly in the early generations of the procedure by delaying stringent artificial selection until later generations. The Swede, H. Nilsson-Ehle, developed the procedure. H. V. Harlan and colleagues provided an additional theoretical foundation for this method through their work in barley breeding in the 1940s. As proposed by Harlan and colleagues, the bulk method entails yield testing of the F2 bulk progenies from crosses and discarding whole crosses based on yield performance. In other words, the primary objective is

to stratify crosses for selection of parents based on yield values. The current application of the bulk method has a different objective.

**Key features**

The rationale for delaying artificial selection is to allow natural selection pressure (e.g., abiotic factors such as drought, cold) to eliminate or reduce the productivity of less fit genotypes in the population. Just like the pedigree method, the bulk method also applies pure-line theory to segregating populations to develop pure-line cultivars. Genetic recombination in the heterozygous state cannot be used in self-pollinated species because self-pollination progressively increases homozygosity. By F6 the homozygosity is about 98.9%. The strategy in plant breeding is to delay selection until there is a high level of homozygosity.

**Applications**

It is a procedure used primarily for breeding selfpollinated species, but can be adapted to produce inbred populations for cross-pollinated species. It is most suitable for breeding species that are normally closely spaced in production (e.g., small grains – wheat, barley). It is used for field bean and soybean. However, it is not suitable for improving fruit crops and many vegetables in which competitive ability is not desirable.

**Procedure**

**Year 1:** Identify desirable parents (cultivars, single crosses, etc.) and make a sufficient number of crosses between them (Figure 16.5).

**Year 2:** Following a cross between appropriate parents, about 50–100 F1 plants are planted and harvested as a bulk, after rouging out selfs.

**Year 3:** The seeds from the second year are used to plant a bulk plot of about 2,000–3,000 F2 plants. The F2 is bulk harvested.

**Years 4–6:** A sample of the F2 seed is planted in bulk plots, repeating the steps for year 2 and year 3 until the F4 is reached or when a desired level of homozygosity has been attained in the population. Space plant about 3,000–5,000 F5 plants and select about 10% (300–500) superior plants for planting F6 progeny rows.

**Year 7:** Select and harvest about 10% (30–50) progeny rows that exhibit genes for the desired traits for planting preliminary yield trails in the F7.

**Year 8 and later:** Conduct advanced yield trials from F8 through F10 at multiple locations and regions, including adapted cultivars as checks. After identifying a superior line, it is put through the customary cultivar release process.

******

**Advantages and disadvantages**

***Advantages***

1. It is simple and convenient to conduct.
2. It is less labor intensive and less expensive in early generations.
3. Natural selection may increase frequency of desirable genotypes by the end of the bulking period.
4. Bulk breeding allows large amounts of segregating materials to be handled. Consequently, the breeder can make and evaluate more crosses.
5. The cultivar developed would be adapted to the environment, having been derived from material that had gone through years of natural selection.

***Disadvantages***

1. Superior genotypes may be lost to natural selection, while undesirable ones are promoted during the early generations.
2. It is not suited to species that are widely spaced in normal production.
3. Genetic characteristics of the populations are difficult to ascertain from one generation to the next.
4. Genotypes are not equally represented in each generation because all the plants in one generation are not advanced to the next generation. Improper sampling may lead to genetic drift.
5. The procedure is lengthy, but cannot take advantage of off-season planting.

**Single-seed descent**

The method of single-seed descent was born out of a need to speed up the breeding program by rapidly inbreeding a population prior to beginning individual plant selection and evaluation, while reducing a loss of genotypes during the segregating generations. The concept was first proposed by C. H. Goulden in 1941 when he attained the F6 generation in 2 years by reducing the number of generations grown from a plant to one or two, while conducting multiple plantings per year, using the greenhouse and off-season planting. H. W. Johnson and R. L. Bernard described the procedure of harvesting a single seed per plant for soybean in 1962. However, it was C. A. Brim who in 1966 provided a formal description of the procedure of single-seed descent, calling it a **modified pedigree method**.

**Key features**

The method allows the breeder to advance the maximum number of F2 plants through the F5 generation. This is achieved by advancing one randomly selected seed per plant through the early segregating stages. The focus on the early stages of the procedure is on attaining homozygosity as rapidly as possible, without selection. Discriminating among plants starts after attainment of homozygosity.

**Applications**

Growing plants in the greenhouse under artificial conditions tends to reduce flower size and increase cleistogamy. Consequently, single-seed descent is best for self-pollinated species. It is effective for breeding small grains as well as legumes, especially those that can tolerate close planting and still produce at least one seed per plant. Species that can be forced to mature rapidly are suitable for breeding by this method. It is widely used in soybean breeding to advance the early generation. One other major application of single-seed descent is in conjunction with other methods.

**Procedure**

**Year 1:** Crossing is used to create the base population. Cross selected parents to generate an adequate number of F1 for the production of a large F2 population.

**Year 2:** About 50–100 F1 plants are grown in a greenhouse in the ground, on a bench, or in pots. They may also be grown in the field. Harvest identical F1 crosses and bulk.

**Year 3:** About 2,000–3,000 F2 plants are grown. At maturity, a single seed per plant is harvested and bulked for planting F3. Subsequently, the F2 plants are spaced enough to allow each plant to produce only a few seeds.

**Years 4–6:** Single pods per plant are harvested to plant the F4. The F5 is space planted in the field, harvesting seed from only superior plants to grow progeny rows in the F6 generation.

**Year 7:** Superior rows are harvested to grow preliminary yield trials in the F7.

**Year 8 and later:** Yield trials are conducted in the F8–F10 generations. The most superior line is increased in the F11 and F12 as a new cultivar.

**Advantages and disadvantages**

Single-seed descent has certain advantages and disadvantages, the major ones including the following.

***Advantages***

1. It is an easy and rapid way to attain homozygosity (2–3 generations per year).
2. Small spaces are required in early generations (e.g., can be conducted in a greenhouse) to grow the selections.
3. Natural selection has no effect (hence it can not impose an adverse impact).
4. The duration of the breeding program can be reduced by several years by using single-seed descent.
5. Every plant originates from a different F2 plant, resulting in greater genetic diversity in each generation.

***Disadvantages***

1. Natural selection has no effect (hence no benefit from its possible positive impact).
2. Plants are selected based on individual phenotype not progeny performance.
3. An inability of seed to germinate or a plant to set seed may prohibit every F2 plant from being represented in the subsequent population.
4. The number of plants in the F2 is equal to the number of plants in the F4. Selecting a single seed per plant runs the risks of losing desirable genes. The assumption is that the single seed represents the genetic base of each F2. This may not be true.

**Backcross breeding**

The application of this method in plants was first proposed by H. V. Harlan and M. N. Pope in 1922. In principle, **backcross breeding** does not improve the genotype of the product, except for the substituted gene(s).

**Key features**

The rationale of backcross breeding is to replace a specific undesirable gene with a desirable alternative, while preserving all other qualities (adaptation, productivity, etc.) of an adapted cultivar (or breeding line). Instead of inbreeding the F1 as is normally done, it is repeatedly crossed with the desirable parent to retrieve (by “modified inbreeding”) the desirable genotype. The adapted and highly desirable parent is called the **recurrent parent** in the crossing program, while the source of the desirable gene missing in the adapted parent is called the **donor parent**. Even though the chief role of the donor parent is to supply the missing gene, it should not be significantly deficient in other desirable traits. An inferior recurrent parent will still be inferior after the gene transfer.

**Applications**

The backcross method of breeding is best suited to improving established cultivars that are later found to be deficient in one or two specific traits. It is most effective and easy to conduct when the missing trait is qualitatively (simply) inherited, dominant, and produces a phenotype that is readily observed in a hybrid plant. Quantitative traits are more difficult to breed by this

method. The procedure for transferring a recessive trait is similar to that for dominant traits, but entails an additional step.

Backcrossing is used to transfer entire sets of chromosomes in the foreign cytoplasm to create a cytoplasmic male-sterile (CMS) genotype that is used to facilitate hybrid production in species including corn, onion, and wheat. This is accomplished by crossing the donor (of the chromosomes) as male until all donor chromosomes are recovered in the cytoplasm of the recurrent parent. Backcrossing is also used for the introgression of genes via wide crosses. However, such programs are often lengthy because wild plant species possess significant amounts of undesirable traits. Backcross breeding can also be used to develop **isogenic lines** (genotypes that differ only in alleles at a specific locus) for traits (e.g., disease resistance, plant height) in which phenotypes contrast. The method is effective for breeding when the expression of a trait depends mainly on one pair of genes, the heterozygote is readily identified, and the species is self-fertilizing. Backcrossing is applicable in the development of multilines (discussed next).

**Procedure**

**Steps: dominant gene transfer**

**Year 1:** Select the donor (*RR*) and recurrent parent (*rr*) and make 10–20 crosses. Harvest the F1 seed (Figure 16.6).

**Year 2:** Grow F1 plants and cross (backcross) with the recurrent parent to obtain the first backcross (BC1).

**Years 3–7:** Grow the appropriate backcross (BC1–BC5) and backcross to the recurrent parent as female. Each time, select about 30–50 heterozygous parents (backcrosses) that most resemble the recurrent parent to be used in the next backcross. The recessive genotypes are discarded after each backcross. The breeder should use any appropriate screening techniques to identify the heterozygotes (and discard the homozygous recessives). For disease-resistance breeding, artificial epiphytotic conditions are created. After six backcrosses, the BC5 should very closely resemble the recurrent parent and express the donor trait. As generations advance, most plants would be increasingly more like the adapted cultivar.

**Year 8:** Grow BC5F1 plants to be selfed. Select several hundreds (300–400) desirable plants and harvest them individually.

**Year 9:** Grow BC5F2 progeny rows. Identify and select about 100 desirable non-segregating progenies and bulk.

**Year 10:** Conduct yield tests of the backcross with the recurrent cultivar to determine equivalence before releasing.

**Steps: recessive gene transfer**

**Years 1**–**2:** These are the same as for dominant gene transfer. The donor parent has the recessive desirable gene (Figure 16.7).

**Year 3:** Grow BC1F1 plants and self, harvest, and bulk the BC1F2 seed. In disease-resistance breeding, all BC1s will be susceptible.

**Year 4:** Grow BC1F2 plants and screen for desirable plants. Backcross 10–20 plants to the recurrent parent to obtain BC2F2 seed.

**Year 5:** Grow BC2 plants. Select 10–20 plants that resemble the recurrent parent and cross with the recurrent parent.

**Year 6:** Grow BC3 plants, harvest and bulk the BC3F2 seed.

**Year 7:** Grow BC3F2 plants, screen, and select the desirable plants. Backcross 10–20 plants with the recurrent parent.

**Year 8:** Grow BC4 plants, harvest, and bulk the BC4F2 seed.

**Year 9:** Grow BC4F2 plants, screen, and select the desirable plants. Backcross 10–20 plants with the recurrent parent.

**Year 10:** Grow BC5 plants, harvest, and bulk the BC5F2 seed.

**Year 11:** Grow BC5F2 plants, screen, and backcross.

**Year 12:** Grow BC6 plants, harvest, and bulk the BC6F2 seed.

**Year 13:** Grow BC6F2 plants and screen; select 400–500 plants and harvest separately for growing progeny rows.

**Year 14:** Grow progenies of selected plants, screen, and select about 100–200 uniform progenies; harvest and bulk the seed.

**Years 15–16:** Follow the procedure as in breeding for a dominant gene.

The key difference between the transfer of dominant and recessive alleles is that in the latter case, phenotypic identification is not possible after a cross. Each cross needs to be followed by selfing so that the progeny with the homozygous recessive genotype can be identified and backcrossed to the recurrent parent.

**The genetic advance in backcross breeding depends on several factors:**

1. **Heritability of the trait:** As previously indicated, traits that are conditioned by major genes and have high heritability are easier to transfer by backcrossing.
2. **Sustainable intensity of trait expression:** Progress with selection will be steadier where the expression of the trait of interest remains at a high intensity throughout the program (i.e., no modifier gene action).
3. **Availability of selection aids:** The ability to identify and select desirable genotypes after the backcross is critical to the success of the procedure. Depending on the trait, special selection techniques may be needed. For disease-resistance breeding, artificial disease epiphytotics may be necessary. Molecular markers may be helpful in selection to reduce the number of backcrosses needed for the program.

**Advantages and disadvantages**

***Advantages***

1. The method reduces the number of field testings needed since the new cultivar will be adapted to the same area as the original cultivar (especially true when both parents are adapted).
2. Backcross breeding is repeatable. If the same parents are used, the same backcrossed cultivar can be recovered.
3. It is a conservative method that does not permit new recombination to occur.
4. It is useful for introgressing specific genes from wide crosses.
5. It is applicable to breeding both self-pollinated and cross-pollinated species.

***Disadvantages***

1. Backcrossing is not effective for transferring quantitative traits. The trait should be highly heritable and readily identifiable in each generation.
2. The presence of undesirable linkages may prevent the cultivar being improved from attaining the performance of the original recurrent parent.
3. Recessive traits are more time-consuming to transfer.