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|  | **C:\Users\SHEZI\Desktop\CONFERENCE ROUGH\New Picture.bmp** **INTRODUCTORY**  **PLANT**  **BREEDING**  **C:\Users\SHEZI\Desktop\CONFERENCE ROUGH\University-of-Sargodha-logo.jpg**  **Muhammad Shehzad Adil**  [Muhammad.shehzad@uos.edu.pk](mailto:Muhammad.shehzad@uos.edu.pk)  +92-312-746-0-746 |  |

**Plant Breeding**

Art and science of improving the heredity of plants.

Plant breeding aim is to improve the characteristics of plants in a way that they become more desirable agronomically and economically.

**Breeding Objective**

The aim or goal for which we want to improve the crop plant is called its breeding objective. All breeding efforts are concentrated to improve plants for desirable characteristics or traits. Some of important breeding objectives are

* High Yield: It is the primary breeding objective for any crop.
  + Grain yield (Wheat, Rice, Maize etc.)
  + Vegetative yield (Sugar Cane stem, onion bulbs, potato tubers, Fodder crops etc.)
* Yield Contributing Traits (Agronomic traits that contribute towards high yield)

i.e. No of tillers,plant height, spike length Photosynthetic rate

* Improved Quality (Nutrients, Doughing ability, Fineness of cotton fiber)
* Resistance against Biotic Stress (Insect Pest and diseases)
* Resistance against A-Biotic Stress (Drought and Salt stress)
* Early maturity
* Synchronized Maturity

**VARIATION, THE BASIS OF PLANT BREEDING**

Plants differ in many ways. It may be safely generalized that no two plants are exactly alike, even though we may limit our observations to a single species like corn. Upon casual examination we may be impressed with the similarity of the plants within a field of hybrid corn. However, if we should compare adjacent plants of hybrid corn in minute detail and make precise measurements of the separate plant parts, we would find that individual plants differ in many respects.

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|  | Variations among plants of a particular crop species are of two kinds: |  |
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|  | * variations due to *environment*, and | | |  |
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|  | * variations due to *heredity*. |  |
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**ENVIRONMENTAL VARIATIONS** are variations in the size, shape, color, composition, or development among plants responding to different intensities of an environmental stress. Environmental variations may be observed by comparing plants in a genetically uniform population. This type of variation is not heritable and it has no significance in terms of selection for next generation. i.e plants showing stunted growth when they are under the shade of some tree or plants on the border of field showing high vigor as compared to more competitive plants in the field.

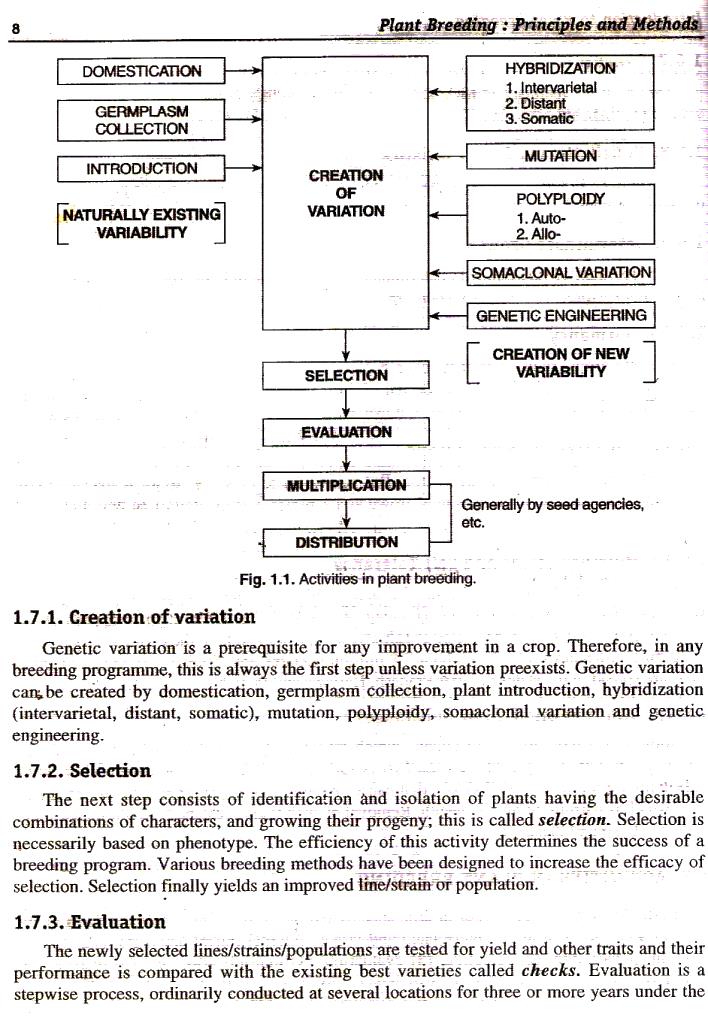
**HEREDITARY VARIATIONS** are variations that result from heritable causes and are transmitted to the next generation (progeny). Plant breeder needs heritable variation to start breeding process.

If heritable variation is present plant breeder starts selecting the desirable plants from the available variation on the basis of breeding objective, but if the variation is not present or if it is not sufficient to select the plants on the basis of breeding objective then there is a **need to create variation**.

**CREATION OF VARIATION**

**Collecting Variation by Artificial Creation**

**Natural Resources of Variation**



***Collecting Variation from Natural Resources***

Natural Variation can be collected from many resources and then included in the breeding program in many ways as mentioned below

**Domestication** is the process of bringing wild species under human management.

Any wild plant in the natural environment can be source of variation. The wild plants living in natural environment without the influence of human might have some valuable traits that are not present in the cultivated plants. i.e. wild cotton or wheat plants may have the resistance against biotic and abiotic stresses which is not present in cultivated plants.

**Germplasm Collection:** Germplasm is any kind of propagation material that is used to grow next generation of crop pant e.g. seed or vegetative parts like cuttings or buds.

Breeder collect germplasm from various sources like gene banks, world banks, gene pools so that variation can be attained by collecting different variant germplasm.

**Introduction:** means taking a genotype or group of genotypes into a new area where they were not grown before. Introduction of new varieties also contributes towards the variation as new introduced genotypes have different traits. Introduction can be of two types

*Primary Introduction*: if new introduced variety is well adapted to local environment it is directly released for general cultivation without any selection.

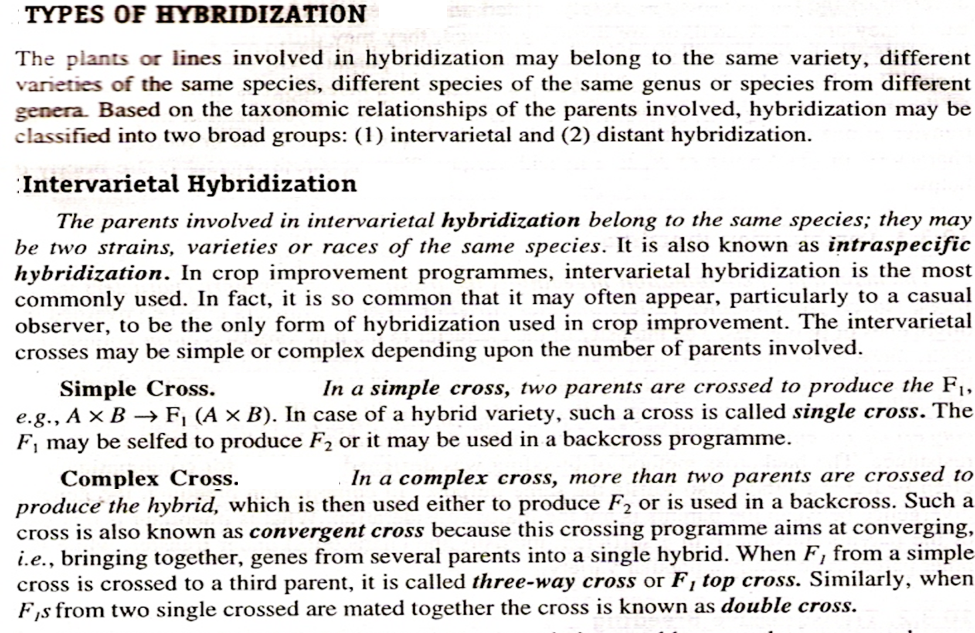
*Secondary Introduction*: if new introduced variety is not well adapted to local environment it has to be subjected to selection for desirable adapted types before it is released for general cultivation.

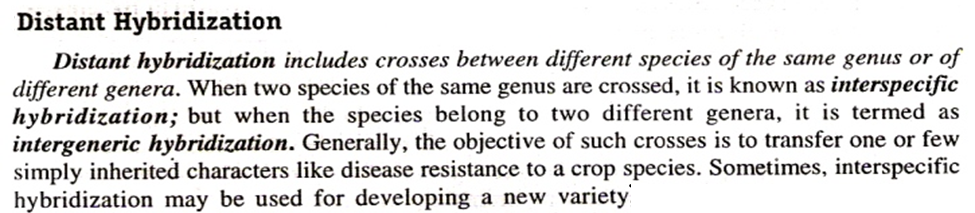
***Artificial Creation of Variation***

There are five potential means of creation of variation

1. Hybridization
2. Mutation
3. Polyploidy
4. Somaclonal Variation
5. Genetic Engineering

**HYBRIDIZATION**

**C**rossing of individuals of unlike genetic constitution; a method of breeding new cultivars that utilizes crossing to obtain genetic recombination.

**Somatic Hybridization:** This hybridization refers to the hybridization at cellular level. As two cells of different genotypes are fused together so that a new variant cell of different genotype is attained.

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|  |  | **MUTATION**  *A mutation* is a sudden heritable change in the hereditary material of a cell or organism. Mutation may be **genic**, involving deletions, or **molecular changes** within the physical limits of the gene; or **chromosomal**, involving the rearrangement, loss, or duplication of chromosome segments. Most mutations are deleterious and harmful and many are lethal. |  |  |
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|  | For a mutation to be detected some phenotypic change in the plant must occur.   * A visible change in a morphological characteristic plant stature, pericarp color, leaf marking, chlorophyll deficiency, vestigial organ, endosperm texture, spike density, etc.is most easily identified. * Mutations causing minute changes in quantitative plant characteristics, such as size, physiological activity, chemical content, or productivity, are more difficult to identify. Their effects may require measurements on a population of plants rather than a single plant.  |  |  | | --- | --- | | ***TYPES OF MUTATIONS*** |  | |  | | |  | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | **DOMINANT OR RECESSIVE MUTATION**  ***Recessive Mutation* (*A* » a)**  Gene mutation which result in conversion of a dominant allele (A) into a recessive Allele (a)  ***Dominant Mutation* *(a* » A).**  Gene mutation which result in conversion of a recessive allele (a) into a dominant Allele (A)   * The recessive gene mutation is by far the more common. Recessive mutations are not visible until the plant is in homozygous form (aa). * If the recessive gene mutation occurs in the somatic tissue of a homozygous plant, its effects are not expressed until the next generation when the seed is produced on the portion of the plant in which the mutant allele is carried. * This is because only one gene in the homozygote mutates (*AA* to *Aa*), and the dominant gene remaining in the heterozygote will mask the effect of the mutant recessive allele. After self-fertilization, segregation occurs giving rise to mutant plants (*aa*) in the next generation. i.e. AA:2Aa: aa   **CLASSIFICATION ON THE BASIS OF ORIGIN** |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | Mutations may be identified according to their origin, whether *spontaneous* or *induced*. ***Spontaneous Mutation*** is one that occurs in nature purely by chance. Spontaneous mutation is the mechanism by which new genetic traits arise in nature. Frequency of spontaneous mutation is one out of one million 1/1000,000  ***Induced Mutation*** is a type of mutation which is artificially induced as a results from the action of a *mutagenic agent*.  **CLASSIFICATION ON THE BASIS OF SIZE**  ***Major Mutation***  If a mutation size is large enough so that its effects can be observed in a single plant.  ***Minor Mutation***  If the effect of mutation is so small that its effects cannot be observed in a single plant but we a need a group of plants to observe the mutation. Mutations with invisible phenotypic changes. Generally observed in quantitative characters.  **CLASSIFICATION ON THE BASIS OF SURVIVAL**  ***Lethal****:* A mutation which kills all the individuals that carries it. ***Sub-lethal****:* When mortality is more than 50% of individuals that carry mutation. ***Sub-vital****:* When mortality is less than 50% of individuals that carry mutation. ***Vital****:* When all mutant individuals survive.  ***LD-50*** is the mutagen dose which results in 50% mortality of the individuals. This dose is considered standard as sub-lethal mutations are considered to cause enough variation in order to make selection effective  **CLASSIFICATION ON THE BASIS OF DIRECTION**  ***Forward Mutation:*** Any change from wild type allele to mutant form. ***Reverse Mutation:*** A change from mutant allele to wild allele.  **CLASSIFICATION ON THE BASIS OF TISSUE**  ***Somatic Mutation***: A mutation in somatic tissue. ***Germinal Mutation***: A mutation in germ line cell.  **CLASSIFICATION ON THE BASIS OF SITE OF OCCURANCE**  ***Nuclear Mutation***: A mutation in nuclear gene. ***Cytoplasmic Mutation:*** A mutation in cytoplasmic gene.  **CLASSIFICATION ON THE BASIS OF CHARACTER**  ***Morphological:*** A mutation that alters morphological character of an individual. ***Biochemical:*** A mutation that alters biochemical function of an individual.   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | **INDUCTION OF MUTATION** |  |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***Mutagenic Agents*** |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *Any agent that causes mutation is called mutagenic agent*  *Ionizing radiations and chemical mutagens have been the principal agents employed to increase mutation frequency in plants.*  ***Ionizing Radiations***  The radiations include X rays, neutrons, gamma rays, ultraviolet, and laser beams.  X rays were used most extensively in early experiments because X ray equipment was widely available and easily operated, and seeds, plants, or pollen could be treated with fairly accurate doses.  Neutron radiation became possible with the development of nuclear reactors. Neutron radiation produces more severe damage to the chromosomes than X rays and is used principally with seeds |  | |  | Gamma rays, emitted from radioactive cobalt or radioactive isotopes, cause less injury to the plant cells and are frequently used for radiation of whole plants or plant parts including pollen. The use of laser beams is a more recent event.  *All kinds of radiation must be used with extreme caution and with experienced operators handling the equipment*.  *The radiation dose is determined by the intensity of the radiations and length of the exposure. It is expressed in Roentgen (r) units, which are a measure of the number of ionizations that occur*.  If an ionization occurs in or near a chromosome, its force can split chemical bonds, causing various structural changes within the DNA, such as a change in a single nucleotide base of a gene (called a *point mutation*),  ***Chemical Mutagens***  Chemicals can cause mutation and these chemicals are often preferred over radiation because   * they are simpler to apply * Produce less damaging effects.   The most widely used chemical mutagen is *ethyl methane sulfonate* (EMS), an alkylating agent. *Ethyl methane sulfonate is a powerful carcinogen and must be used with extreme caution*. Seeds, buds, roots, and dormant cuttings can be treated by soaking in a solution of the chemical mutagen,  Mutation by treatment with EMS is relatively simple as compared to expensive X ray mutation as no equipment is needed.  The precise concentration and treatment duration will vary with the plant part being treated. | | |  | |  | |  |

**POLYPLOIDY**

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|  | **Heteroploidy**  Any change in chromosome number |  |
| **PolyPloidy (Euploidy)**  Change in chromosome number is exact multiple of basic chromosome number |  | **Aneuploidy**  Change in chromosome number is not exact multiple of basic chromosome number |
| **Autopolyploidy**  If change in chromosome number has arised by exact multiplication of a single genome |  | **Hypoploidy**  **Monosomy(2n-1)**  If a single chromosome is missing from any single pair of the genome  **Nullisomy(2n-2)**  IF a complete pair of chromosome is missing from the genome |
| **AlloPolyploidy**  IF the change in chromosome number has arised by combining two or more different genomes |  | **HyperPloidy**  **Trisomy(2n+1)**  If an extra chromosome is present in addition to normal somatic chromosomes  **Tetrasomy (2n+2)**  If an extra pair of chromosome is present in addition to normal somatic chromosomes |

***Basic Chromosome Number (Genome)***

*The haploid chromosome number of the specie from which the existing species has evolved.Change in chromosome number is always measured in reference to basic chromosome number or haploid chromosome number*

*The* genome is the basic *monoploid* set of chromosomes for the species (or group of related species) and contains only one of each kind of chromosome.

The monoploid or basic chromosome number for a species is designated by the symbol **X,**

The *haploid* or gametic chromosome number for a species is designated by the symbol ***n*,**

The diploid or *somatic* chromosome number for a species is designated by the symbol **2*n*.**

For example, in corn, the basic and haploid number is 10, and the diploid and somatic number is 20. The haploid number is written *n* = *x* = 10, and the diploid or somatic number is written 2*n* = 2*x* = 20. In cultivated wheat, the basic chromosome number is 7, the haploid number is 21,(*n=3x=21*) and the somatic number is 42; the latter is written as 2*n* = 6*x* = 42.

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| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *Triticum monococcum* |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 7 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 7 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 2*n* = 2*x* = 14 |  | |  | | | |  | | | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *Triticum turgidum* |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 14 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 7 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 2*n* = 4*x* = 28 |  | |  | | | |  | | | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *Triticum aestivum* |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 21 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 7 |  | |  | | | |  | | | | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | 2*n* = 6*x* = 42 |  | |  | | | |  | | | |

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|  |  | **POLYPLOIDY** |  |  |
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|  | *Polyploids are* euploids in which the somatic cells possess multiples of complete basic chromosome sets (*x*) in excess of the diploid number. Polyploids and the number of basic chromosome sets, or genomes, in each are |  |
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|  | Euploid plants may arise by duplication of genomes of a single species, *autoploidy* or *autopolyploidy* (auto = same), or by combining genomes from two or more unrelated species, *alloploidy* or *allopolyploidy* (allo = different). An alloploid derived from combining chromosome sets from two different diploid species is called an *allotetraploid* or *amphidiploid*. An autoploid created by duplicating the chromosomes of a diploid species is called an *autotetraploid*. |  |

**GENETIC ENGINEERING**

AS the whole codon is composed of 4 alphabets A, T, G and C, hence we can use the genetic information from any organism and then transfer to any other organism by means of genetic engineering in this way desirable variation can be created. E.g. B.T cotton has a BT gene transferred from bacteria named *Bacillus* [*thuringiensis*](https://www.google.com/search?q=bacillus+thuringiensis&spell=1&sa=X&ved=0ahUKEwiTwuD95MXgAhVJwAIHHTPRA5gQkeECCCgoAA), this gene perforates the gut of any chewing insect that bites on the cotton plant. In this way desirable characters can be transferred from any species across the species barrier. Any gene from any species can be transferred to any other species for creating useful variation. Any organism having foreign DNA is called ***Transgenic Organism.***

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|  | **BREEDING**  **SELF-POLLINATED CROPS** |  |
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|  | **WHAT IS A CULTIVAR?** |  |
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|  | *The cultivar (agricultural variety) is a group of genetically similar plants, which by structural features and performance may be identified from other groups of genetically similar plants within a species*.  In binomial nomenclature The plant kingdom is divided into Phylum, which is subdivided into class, which is further subdivided into order, Orders are divided in families, *families* of plants are divided into *genera*, which are subdivided into *species*. Within the species, the agronomist and horticulturalist recognize numerous *agricultural varieties*, more commonly referred to as *varieties* or *cultivars*. |  |
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|  | This relationship can be clarified by examining the taxonomic classification of a common crop plant, the Wheat, a species in the family, Poaceae: |  |
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|  | Family: Poaceae (subfamily Pooideae)  Genus: *Triticum*  Species: *aestivum* |  |
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|  | The scientific name of the cultivated Wheat is *Triticum aestivum*; the first word designates the genus, the second word the species. The species, *T. aestivum*, contains many forms that are genetically different and distinguished from each other by heritable traits such as maturity, seed color, presence or absence of awns, plant type, disease resistance, gluten content of seed etc. |  |
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|  | A population of Wheat may be composed of a single genotype or a mixture of genotypes and may be variously referred to as an ***Experimental Strain*, A *Strain*, or A *Line***. Thousands of |  |
| Experimental strains are generated in the plant breeder's nursery each year.  Once a superior strain is identified, it may be named, the seed increased, and distributed as an 'agricultural variety' or 'cultivar'. Earlier, the term 'variety' was commonly used by farmers and seed producers; later the term 'cultivar' was coined to serve as the international equivalent of a cultivated variety. Variety and cultivar may be used interchangeably, but cultivar is now preferred in scientific literature and is used in this text. ***The distinction of being Named and Distributed Commercially serves to set apart the cultivar from the experimental strain or breeding line*.** In the Pakistan, the name, description, and developer of new field crop cultivars are registered by a board e.g. Punjab Seed Council, KPK Seed Council etc. | | | |  |
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|  | Two essential characteristics of a cultivar are **(1) *Identity* And (2) *Reproducibility***. Identity is necessary so that the cultivar may be recognized and distinguished from other cultivars within the species. Typically, the distinguishing features may be morphological structures, color markings, physiological response, disease reaction, or performance. Reproducibility is needed so that the characteristics by which the cultivar is identified will be reproduced in the progeny. In self-fertilized crops, a cultivar increased from a single, homozygous genotype will be uniform in appearance, whereas a cultivar increased from a mixture of genotypes will exhibit a range of genetic variability according to that present in the mixture. |  |
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|  | **GENETIC SIGNIFICANCE OF POLLINATION METHOD** |  |
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|  | Self-pollinated crops differ in genetic make-up from plants in crop species that are normally cross-pollinated. In a crop that is self-pollinated, it is the rule that plants will be homozygous. This assumption may be made because: |  |
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|  | * Loci with identical genes (*AA* or *aa*) will remain homozygous following self-pollination, |  |
|  | * Loci with contrasting genes (*Aa*) will segregate, producing homozygous and heterozygous progeny in equal proportions. |  |
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|  | Heterozygosity is reduced by 50% with each successive self-fertilization (Fig.1). After several successive generations of self-pollination, the proportion of heterozygous loci remaining in a population is very small. Although complete homozygosity is theoretically unattainable, plants selected from a mixed population after five to eight generations of selfing will normally have reached a practical state of homozygosity such that their progeny will be uniform in appearance and performance. |  |
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|  | Breeding procedures in self-pollinated species are based on the genetic structure of self-pollinated populations. A mixed population of a self-pollinated crop is composed of plants with different homozygous genotypes. If single plants differing in genotype are harvested and the seed increased, each will produce a pure population, although the populations will differ from each other. Heterozygous plants may arise in a population of a self-pollinated crop through  **(1) *Cross-pollination* among plants with different genotypes, or**  **(2) *Mutation*.**  The progenies of the heterozygous plants will quickly segregate in succeeding generations giving rise to homozygous subpopulations. |  |
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| Fig.1.Proportions of homozygous and heterozygous genotypes in a population after successive generations of self-pollination, assuming equal fitness for survivalamong genotypes. S0, original selfed plant; S1, first selfed generation; S2, second selfed generation; and so on. |

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|  | **BREEDING METHODS IN SELF-POLLINATED CROPS** |  |
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|  | Homozygosity is the rule for breeding self-pollinated crops. A new cultivar of a self-pollinated crop normally originates from an increase of: |  |
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|  | * A mixture of plants, or a single plant, selected from introduced germplasm, | | | | |  |
|  | * A mixture of plants, or a single plant, selected from a local population, or | | |  |  |
|  | * A single plant selected from a hybrid population. |  |  |
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|  | In the breeding of self-pollinated crops, thousands of strains are normally grown in adjacent plots in the breeding nursery without pollination control. Some natural cross-pollination generally occurs, but the amount is usually so small that it is ignored except when extreme purity is essential, as in genetic studies, or when a strain is being increased for final distribution as a new cultivar. If the amount of natural cross-pollination is sufficient to visibly affect uniformity, reselection is practiced to re-purify the strain. |  |
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|  | **ASSEMBLY OF GERMPLASM** |  |
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|  | The initial step in a breeding program is to *assemble a wide assortment of germplasm* (genetic strains of diverse origin) of the desired species, this collection of germplasm will help to collect all potentially useful genes from all possible sources like   * ***Commercial cultivars:*** are a desirable source of useful germplasm, except where their use is restricted by legal protection. * ***Advanced breeding lines:*** with proven adaptation and productivity are another useful source of germplasm. These lines may be assembled from state, national, or international breeding programs or from gene banks |  |
|  | * ***Landraces:*** are verities which were previously cultivated in the native area but now are replaced by modern cultivars. Landraces still serve as a source of useful genes.   Germplasm accessions should be grown initially in the local environment to identify sources of genes for maturity, yield potential, disease resistance, and other desired traits, and to observe inherent weaknesses. | | |  |
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|  | **SELECTION** |  |
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|  | ***Selection, as a breeding procedure, involves identification and propagation of individual genotypes or groups of genotypes from mixed populations, or from segregating populations following hybridization.***  Selection may not be effective in isolating the desired genotypes unless genetic variation can be identified and distinguished from environmentally caused variability within the mixed population, Selection procedures practiced in mixed populations of self-pollinated crops are *mass selection and pure-line selection*. The populations created are referred to as *mass selections* or *pure lines*, respectively. |  |
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|  | **MASS SELECTION**. ***In the mass-selection procedure, plants are chosen and harvested on the basis of phenotype and the seeds composited without progeny testing.*** Cultivars developed by mass selection are normally uniform for qualitative characters but quantitative traits may still have variation. It is because in quantitative traits are controlled by many genes so phenotypic differences are too small to be recognized, or cannot be accurately distinguished from environmentally caused variations. |  |
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|  | The objectives in mass selection are to: |  |
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|  | * Purify a mixed cultivar or plant population by selecting and propagating visibly similar plants, or | | |  |
|  | * Develop a new cultivar by improving the average performance of the population. |  |  |
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|  | **PURE-LINE SELECTION**.  ***A pure line*** *is a progeny descendent solely by self-pollination from a single homozygous plant.*  ***Pure Line*** *is progeny of single selfed homozygous plant*  ***Pure-line selection*** *refers to the procedure of isolating pure lines from a mixed population*.  Pure Lines are developed by identifying superior plants in a mixed population and then they are continuously selfed for many generations until the plants attain homozygosity nearly at all loci. A cultivar developed by pure-line selection is more uniform than a cultivar developed by mass selection, because all of the plants in the cultivar will have the same genotype. This is based on assumption that the plant originally selected is homozygous at all loci. | | |  |
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|  | **How long does the new cultivar remain pure?**  That depends upon amount of: |  |
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|  | * Seed mixtures from other sources, | | |  |
|  | * Natural crossing with other cultivars or breeding lines, and | | | | |  |  |
|  | * Mutations. |  |  |
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|  | **THE PURE-LINE THEORY**. The theory of the pure-line was established by the Danish botanist, Johannsen, in 1903. Johannsen conducted selection experiments for seed weight in a mixed seed lot of the 'Princess' bean Because beans are self-fertilized, the seeds in the original lot were homozygous for genes affecting seed weight. Initially Selection within the original mixed lot of beans was effective in isolating lines that were genetically different as the beans were divided beans in two groups one with high seed weight (0.64 g/seed) and other with low seed weight(0.35 g/seed). But when he continued the selection process to next generation. He found that there is no use of further selection in low seed weight group or high seed weight group. So he proposed pure line theory which states  ***Once the pure line was isolated, further selection within the pure line was ineffective.***  In Johannsen's original mixed lot of beans, the variations in seed weight were both hereditary and environmental; but whatever variation was observed within the pure lines, the variations were only due to differences in the effects of the environment. |  |
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|  | **HYBRIDIZATION** |  |
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|  | *Hybridization* is a breeding method that utilizes cross-pollination between genetically different parents to obtain gene recombination. Following the cross-pollination, segregating |  |
|  | Generations F1, F2 ……..F11 are grown. F1 is uniform but plants startto segregate in F2. There is a possibility that when plants segregate their genes recombine for the better or worse. Plants may recombine to an extent that fall outside the range of the parents. | | |  |
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|  | These plants falling outside the range of the parents are known as ***transgressive segregants***. Transgressive segregates with a combination of genes superior to either parent in a quantitative feature, such as yield, seed weight, winter hardiness, or straw stiffness, in which inheritance is determined by multiple genes, may be selected and utilized in the breeding program. |  |
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|  | In every succeeding generation homozygosity increases and Heterozygosity decreases by 50 % and segregation has virtually ceased in 5th or 6th generation, so plants with a superior combination of the desired parent characteristics need to be identified and increased as a pure population. Performance of the new lines are evaluated in field trials in comparison with the parent lines. |  |
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|  | **SELECTION PROCEDURES FOLLOWING HYBRIDIZATION** |  |
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|  | Selection procedures that may be used to identify desirable genotypes from segregating progenies, following hybridization in self-pollinated crops, include (1) *pedigree-selection*, (2) *bulk-population*, (3) *single-seed-descent*, and (4) *doubled-haploid*. |  |
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|  | **PEDIGREE-SELECTION** |  |
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|  | In the pedigree-selection procedure, selection for plants with the desired combination of characters is started in the F2 generation, and continued in succeeding generations until genetic purity is reached (Fig). An example of the pedigree-selection method follows: |  |
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|  | ***Crossing generation***. Cross cultivar A × cultivar B. |  |
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|  | ***F1* *generation***. Grow 50 to 100 F1 plants. Before harvest, eliminate plants that may have arisen from self-pollination. |  |
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|  | ***F2* *generation*.** Grow 2000 to 3000 F2 plants. Space plants sufficiently that individual plants may be examined. Select and harvest superior plants in which desired characteristics of the parent cultivars are combined, harvesting the seed separately from each plant. |  |
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|  | ***F3*to *F5* *generations***. Grow progeny rows with seed harvested from superior plants harvested in the previous generation. Space plants in the row so that individual plants may be studied. Identify superior rows, then select and harvest 3 to 5 of the best plants within these rows. Continue selection between and within rows through the F5 generation. Normally, 25 to50 families may be retained at the end of the F5 generations. Identity of plant and row is maintained and superior traits of the plants are recorded.   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  |  |  |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***F6* *generation***. Grow families of plant rows. Uniform related families may be harvested together and the seed bulked. The separate seed lots are designated experimental lines. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***F7* *generation*.** Grow the experimental lines in a preliminary yield trial in comparison with adapted cultivars. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***F8* *to F10* *generations*.** Yield trials of superior experimental lines are continued at two or more locations in comparison with adapted commercial cultivars. Only the highest yielding lines are retained for testing in the next yield trial. During the testing period, observations are made on height, tendency to lodge, maturity, disease and insect resistance, quality, and other characteristics as appropriate in the crop being studied. Growing the lines in regional yield |  | |  | trials in environmentally diverse locations will assist in identifying lines with adaptation to a wide range of environments. If, after 3 to 5 years of yield testing, lines superior to the check cultivars have been identified, one line may be chosen for increase and distributed as a new cultivar. | | |  | |  | | | | | |  | | | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***F11* *and F12* *generations*.** Increase seed and distribute the new cultivar. |  | |  |
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| Pedigree method of selection. From selected F2 plants, progenies of 25 to 30 plants are grown in plant rows in F3.  Superior plants from the best rows are selected and planted in families of plant rows in F4 to F6, with selection being made of best plants, in best rows, of best families. By F6 families should be relatively uniform. Preliminary yield  trials  areplanted in F7, and yield trials are continued through F10. Various modifications of this procedure may be  made. For example, after plants are selected in F3 and F4, remaining plants in row may be bulked and preliminary  yield tests started. |

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|  | **Modifications of The Pedigree-Selection** procedure may be employed, such as introducing yield trials as early as the F3 or F4 generation. Only the high-yielding lines are then grown in advanced generations. Or, selection may be terminated earlier than indicated if the lines appear to be uniform. |  |
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|  | **PROs:** It has the advantage that only progeny lines in which plants with genes for the desirable characters have been identified are carried forward to the next generation. This method also permits the collection of genetic information which is not possible with other procedures. The pedigree-selection method of breeding is best suited to crops where individual plants may be examined and harvested separately, as in cereals, garden bean, peanut, soybean, tobacco, or tomato. Pedigree-selection procedure requires 12 years to develop a cultivar if only one generation is grown each year. The number of years may be reduced by growing more than one generation per year, either in the greenhouse or by growing winter or off-season nurseries in an area with a favorable climate.  **CONs:** The pedigree-selection method is labor intensive and requires detailed record-keeping during the early segregating generations. |  |
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|  | **BULK-POPULATION** |  |
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|  | In the bulk-population procedure, seeds harvested in the F2 and succeeding generations are bulked and grown, with selection delayed until an advanced generation, commonly the F5 or the F6, at which time the segregation will have virtually ceased (Fig). An example of the bulk-population procedure follows: |  |
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|  | ***Crossing generation*.** Cross cultivar A × cultivar B. |  |
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|  | ***F1* *generation*.** Grow 50 to 100 F1 plants. Before harvest, eliminate plants that may have arisen from self-pollination. Harvest en masse and bulk seed. |  |
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|  | ***F2* *generation*.** Grow 2000 to 3000 F2 plants. Harvest en masse and bulk seed from all plants. |  |
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|  | ***F3* *to F4* *generations*.** Grow 1/50- to 1/100-hectare plots with bulked seed harvested from the preceding generation. |  |
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|  | ***F5* *generation*.** Space plant 3000 to 5000 seeds. Select and harvest 300 to 500 superior plants keeping seed separate from each plant. |  |
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|  | ***F6* *generation*.** Grow progeny rows of selected plants; harvest 30 to 50 progenies in which plants exhibit the desired characteristics of the parents. |  |
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|  | ***F7* *generation***. Grow superior progenies harvested in the F6 in a preliminary yield trial. |  |
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|  | ***F8* *to F10* *generations*.** Yield trials are continued in multiple locations as in the pedigree-selection procedure. |  |
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|  | ***F11* *and F12* *generations*.** Increase seed of a superior line and distribute as a new cultivar.  **PROs:** The bulk-population method of breeding is **simple, convenient, requires less labor, and is less expensive to conduct** during the early segregating generations than the pedigree-selection procedure. It is necessary to grow large populations of spaced plants in the selection generation to have a reasonable chance of finding desirable segregates.The bulk-population method is suited to crops normally planted in thick spacing, like small grains, in which it is difficult to separate and identify individual plants.  **CONS:** In contrast to the pedigree-selection method, no information is obtained during the early generations on inheritance of specific traits or performance of specific lines. During the segregating generations some desirable genotypes may be lost from the population, for example, tall and late plants may suppress short and early plants.  The **bulk-population selection procedure may be modified** by selecting in the F3 or the F4 and starting yield trials even though the lines are still segregating. Superior yielding lines may be reselected while yield testing continues |  |
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|  | **SINGLE-SEED-DESCENT** |  |
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|  | In single-seed-descent the progenies of the F2 plants are advanced rapidly through succeeding generations from single seeds (Fig). An example of the single-seed-descent procedure follows: |  |
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|  | ***Crossing generation*.** Cross cultivar A × cultivar B. |  |
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|  | ***F1* *generation*.** Grow 50 to 100 F1 plants. |  |
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|  | ***F2* *generation*.** Grow 2000 to 3000 F2 plants. Harvest a single seed from each plant. Identity of the F2 plant is not maintained. |  |
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|  | ***F3* *and F4* *generations*.** Grow seeds harvested in previous generation. Harvest a single seed from each plant. |  |
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|  | ***F5* *generation*.** Space plants in field from seeds harvested in previous generation. Select plants superior for desired characteristics and harvest seeds from the selected plants. |  |
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|  | ***F6* *generation*.** Grow progeny rows from plants harvested in the previous generation. Harvest rows superior for desired characteristics. Each row will have originated from a different F2 plant. |  |
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|  | ***F7* *generation*.** Grow preliminary yield trial from rows harvested in the previous generation. |  |
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|  | ***F8* *to F10* *generations*.** Continue yield trials in multiple locations as in pedigree-selection and bulk-population procedures. |  |
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|  | ***F11* *and F12* *generations***. Increase superior line and distribute as a new cultivar. |  |
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|  | An alternative procedure would be to space plant the F4 generation and plant the F5 in rows, thereby getting lines into yield trials one generation earlier. |  |
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|  | ***The single-seed-descent procedure was proposed as a means of maintaining descendants from the maximum number of F2 plants, thereby reducing the loss of genotypes during the segregating generations.*** As currently practiced, single-seed descent is utilized to reduce the time required to grow the segregating generations. Because only one seed is harvested from each plant, optimum plant development in the F2 to F4 generations is unnecessary. By thickly planting seeds in a greenhouse bench, growing plants with low soil fertility, and using temperature and lighting regimes that force early flowering, two to three generations are commonly harvested in a 1-year period, and the preliminary yield trial can be reached 1 to 2 years earlier. Species that can be forced to mature rapidly, such as soybean or summer-grown cereals (wheat, oat, barley), are suited for the single-seed-descent procedure.  With single-seed-descent, weak plants are not eliminated as in a field-grown nursery, and there is no provision for selection of superior segregates within families descendent from F2 plants. Modifications to the procedure may be introduced, such as screening for disease resistance or other appropriate characteristics in any generation. No record-keeping is required during the early segregating generations. Final evaluation of progenies and yield trials are conducted in the field. |  |
| |  |  | | --- | --- | | 0169-001.gif |  | |  | | |  | |  |  | | --- | | Fig. 9.4. Single-seed-descent method of selection. Seeds harvested from F1 plants are  space planted in F2. A single seed harvested from each F2 plant is used  to plant the F3. Succeeding generations through the F5 are likewise planted  from single seeds harvested from each plant grown in the preceding generation.  In the F5 generation plants are harvested and a progeny row grown in the F6.  A preliminary yield trial is grown in the F7 and yield trials continued through the F10.  Some breeders combine single-seed descent with the pedigree selection procedure,  by growing only the F3 and F4 by single-seed descent to accelerate the time required  to reach a yield trial. | | | | | |

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|  |  | **A modification of the procedure** has developed in soybean in which several pods are harvested from each plant instead of a single seed. A two- to three-seed sample from each plant is bulked to grow the next generation. This modified single-seed-descent procedure has become the principal method of advancing early generations in soybean breeding programs. With tropical winter nurseries, two or three generations can be advanced in a year with the modified procedure. |  |  |
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|  | **DOUBLED-HAPLOID** | | |  |
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|  | In the doubled-haploid procedure, haploid plants are generated from anthers of F1 plants, or by other means, and the chromosomes of the haploid plants are doubled with colchicine to produce diploid plants (Fig. 9.5). An example of the doubled-haploid procedure using anther culture follows: |  |
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|  | ***Crossing generation*.** Cross cultivar A × cultivar B. |  |
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|  | ***F1* *generation*.** Culture anthers to produce 2000 to 3000 haploid plants. |  |
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|  | ***F2* *generation*.** Double chromosomes of haploid plants and harvest seeds from the doubled-haploid plants produced. |  |
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|  | ***F3* *generation*.** Grow progeny rows from doubled-haploid plants and harvest seed from superior rows. |  |
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|  | ***F4* *generation*.** Grow progeny rows in the field and select superior lines. |  |
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|  | ***F5* *generation*.** Grow preliminary yield trial. |  |
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|  | ***F6* to *F8* *generations*.** Continue yield trials. |  |
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|  | ***F9* *and F10* *generations*.** Increase and distribute superior line as a new cultivar. |  |
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|  | Doubled-haploid plants are normally **homozygous at all loci** and it is **unnecessary to grow segregating generations**. Lines generated by the doubled-haploid procedure may reach preliminary yield trials two to three generations earlier than with the pedigree-selection or bulk-population procedures. Like the single-seed-descent procedure, early generations are not exposed to environmental stresses in the field, and attrition of lines is greater in initial field evaluation trials than with pedigree-selection or bulk-population procedures, in which the early generations are field grown. For successful use of the doubled-haploid procedure in plant breeding, efficient and reliable techniques for generating haploid and doubled-haploid plants are essential. The doubled-haploids should be vigorous, stable, free from tissue-culture-induced variations, and represent a random selection of the F1 pollen gametes. Current procedures for production of haploids and doubled-haploids have only been partially successful in attaining these characteristics. |  |
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|  | ***Choice of Procedure*** |  |
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|  | The superiority of a new cultivar is determined by the combination of genes that it contains, not by the procedure by which the cultivar was produced. Choice of procedure should be determined by the efficiency with which a superior combination can be assured and will vary with the crop species, the breeding objectives, and the resources available to the breeder. The current trend is to adopt breeding procedures that will reduce the number of years to develop and release a cultivar, and that will enable the breeder to grow and examine the largest number of lines with the resources available. Reduction in years may be accomplished by |  |

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| Fig. 9.5. Doubled-haploid procedure. Crosses are made and F1 progeny grown as in  previous procedures. Anthers from F1 plants are cultured and chromosome number  of haploid plants generated is doubled with colchicine to produce doubled haploids.  Progenies of doubled-haploid plants are evaluated in the field in F3 and F4 and superior  lines tested in yield trials in F5 to F5 generations.   |  |  |  | | --- | --- | --- | |  | growing two or more generations per year through winter nurseries, by single-seed-descent, or by reducing the number of segregating generations as with the doubled-haploid procedure. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | The pedigree-selection procedure is certainly the most precise system when the objective is to combine particular parent traits that are simply inherited and easily observed in progeny plants, but it is less precise if the characters to be combined are quantitatively inherited, particularly if the heritability is low. It is labor-intensive in the early generations, due to the extensive seed packaging, planting, note-taking, and record-keeping required. The bulk-population system has gained favor due to the economy of labor and ease of growing large populations in the early generations. Single-seed-descent is suitable for crops that can be grown in a greenhouse environment or in winter nurseries in a semitropical climate. It is economical to pursue, and reduces the time required to grow the early segregating generations. The doubled-haploid procedure is labor intensive in the production of haploids and does not have the proven reliability of the other procedures. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | Success in the hybridization method of breeding self-pollinated crops is dependent upon: |  | |  | | | |  | | |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  |  | | | | | | |  | |  | | | | | | | |  | * Choosing the correct parents, and | | | | |  | |  | * Identifying the superior plants from the segregating populations. |  |  | |  | |  | The choice of parents will be facilitated by clear and specific breeding objectives and superiority of the parents in characteristics contributing to those objectives. The contributions from the parents should complement each other, so that selected progeny plants will not be lacking in some important agronomic characteristic. Identification of the superior genotypes in the segregating progenies requires exhaustive testing and exposure to many adversities (e.g., disease, drought, or cold), extensive observation in various stages of growth, and accurate recording of the observations. Testing in different seasons at several locations with diverse climatic conditions will aid in identifying genotypes adapted over wide geographic areas. Only those lines that are distinctly superior and fulfill the objectives of the cross should be propagated, with rigorous rejection of mediocre selections or crosses. *The latter requires judgment decisions that can best be made by a skilled and experienced breeder*. | | |  | |  | |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | If only one quantitative character is being emphasized in a cross, it should be possible to select transgressive segregates superior to either parent. If two or more quantitative characters are being improved, some compromise may be necessary, because one would seldom find superior transgressive segregation occurring simultaneously for two or more characters. At this point the breeder must choose which line best exemplifies the objectives of the cross and will be increased for further evaluation. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | **BACKCROSS BREEDING** |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | The *backcross* is a form of recurrent hybridization by which a desirable allele for a character is substituted for the alternative allele in an otherwise desirable cultivar. The plan of the backcross is to cross an adapted and productive cultivar, yet one that lacks a desirable allele (or alleles) controlling a superior character, to a breeding line or cultivar in which the desirable allele is present. Beginning in the F1 and continuing for several generations, hybrid plants containing the dominant allele are selected and successively crossed back to the adapted parent cultivar. The adapted parent, to which the allele is being added, enters into each backcross and is called the ***recurrent parent***. The parent with the superior character enters into the initial cross |  | |

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|  | but does not enter into the backcrosses, and is called the ***donor* or *nonrecurrent parent***. | | | |  |
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|  | The purpose of the backcross is to recover the genotype of the recurrent parent, except for the substitution of the allele (or alleles) for superior expression of the character being contributed from the donor or nonrecurrent parent. The backcross is a form of inbreeding, and the features of the recurrent parent are automatically recovered after successive backcrosses. The only selection practiced is for the one superior trait contributed by the nonrecurrent parent. The number of backcrosses may vary from two to five, or more, depending upon how completely the breeder wishes to recover the genes from the recurrent parent. **The *backcross procedure is most easily carried out if the character being added is simply inherited, dominant, and easily recognized in the hybrid plants*.**  **SIGNIFICANCE OF BACK CROSS MATHOD**   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | One feature of the backcross procedure is that a backcross derived cultivar will be adapted in the same general environment as the recurrent parent, reducing the testing normally necessary to confirm adaptation of the backcross derived cultivar. An additional feature is that it is repeatable. A breeder can recover the same line if the same recurrent and donor parents are used. If two or more characters are to be added to the same recurrent cultivar, separate backcross procedures may be pursued for each character and the backcross-derived lines from each finally merged into a single line. |  |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | The backcross procedure is further utilized to transfer entire sets of chromosomes into a foreign cytoplasm to obtain cytoplasmic male sterility for the production of hybrid seed as in corn, millet, onion, sorghum, wheat, and other crops. The species or cultivar with the foreign cytoplasm is the female and recurrent parent as cytoplasm is transferred only through the egg. The donor of the chromosomes is crossed as the pollen parent until all donor chromosomes are recovered in the cytoplasm of the recurrent parent. Normally, the original cross and four or five backcrosses are required. |  | |  |
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|  | **BACK CROSS FOR DOMINANT GENE TRANSFER**  The backcross procedure is illustrated in Fig. 9.6 in which the dominant alleles for a gene controlling disease resistance (*RR*) are to be substituted for the recessive alleles in an adapted cultivar. In this cross cultivar A is the recurrent parent, and contains the genes for adaptation and yield that the breeder wishes to recover in the new cultivar. Cultivar B is the donor parent with a dominant allele for disease resistance that the breeder wishes to add to cultivar A. With each successive backcross, the progeny becomes more like the recurrent parent as additional genes for adaptation are recovered. With completion of the fourth backcross, theoretically, 93.75 % of the genes of the adapted parent will have been recovered in the backcross progeny. After each backcross, disease resistant progeny plants (*Rr*) are identified, by artificially inoculating all progeny plants and noting their disease reaction. As many backcrosses may be made as are necessary to obtain plants that are indistinguishable from the recurrent parent except for the substituted allele for disease resistance. The disease-resistant plants in the final backcross progeny will be heterozygous for resistance (*Rr*), and must be selfed for one generation to obtain true breeding resistant plants (*RR*). |  |
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| Fig. 9.6.Procedure for a backcross in which a dominant allele for disease resistance (R) is transferred from a disease resistant cultivar to an adapted cultivar A. The resistant donor cultivar is crossed to the adapted recurrent cultivar A, and the F1 backcrossed to cultivar A. The BC1 generation from this cross will be segregating for disease resistance  (Rr:rr). The Rr plants may be identified from the rr plants by inoculating the seedling plants with the disease pathogen and observing whether plants exhibit the resistant or the susceptible disease reactions. Only Rr (resistant) plants are backcrossed to A in the second and succeeding backcross generations. After the final backcross, the heterozygous  (Rr) plants are selfed one generation to obtain homozygous (RR) and heterozygous (Rr) resistant plants. Progeny tests of the resistant (RR and Rr) plants are grown to identify the homozygous (RR) from the heterozygous (Rr) plants,  so that lines pure for resistance may be established. | | |
|  | **BACK CROSS FOR RECESSIVE GENE TRANSFER**  If the alleles for disease resistance being transferred should be recessive (*rr*), the progeny of the first backcross would segregate into genotypes (*RR*) and (*Rr*). Because the heterozygous plants that contain the resistance allele (*r*) cannot be identified, it is necessary to self the progeny one generation to find resistant (*rr*) plants before making the next backcross to the recurrent parent. Another procedure would be to backcross both the homozygous (*RR*) and heterozygous (*Rr*) plants to the recurrent parent and simultaneously self each backcross derived plant and test the selfed progenies for resistance. The backcross progenies from the plants that prove to be heterozygous are then kept, and the backcross progenies from the homozygous plants are discarded. If genes for undesirable characters are closely linked with the gene for resistance, they may be added along with the resistance gene. The new cultivar would then differ from the recurrent parent by the genes that were added. If characteristics being added by the backcross procedure are determined by multiple genes, it will be necessary for the backcross progenies to be grown through the F2 or later generations to obtain plants that exhibit the desired characteristics before proceeding with the next backcross.  F:\CHAPTERS\18\313.jpg |  |
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|  | **MULTILINE BREEDING** |  |
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|  | The traditional breeding procedures for self-pollinated crops were developed around the pure-line concept. Pure-line selection was utilized to isolate the superior plant from genetically mixed populations, such as landraces, or from segregating populations following hybridization. Extreme uniformity among the plants within the selected line was stressed. The uniformity often led to cultivars with a single gene for resistance to a particular pathogen being propagated over large geographic areas. If a new race of the pathogen that was virulent on cultivars with the resistance gene arose, widespread disease damage would be caused. The rapidity with which new races of disease pathogens arose sometimes limited the usefulness of cultivars with a particular resistance gene to no more than 5 to 10 years. This condition led to the proposition that greater diversification in resistance genes would provide stronger genetic barriers and spread the risk from disease damage. One solution proposed was the use of multiline cultivars. |  |
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|  | As proposed to combat disease resistance, a ***Multiline Cultivar* is a composite of genetically similar lines**, **except that each line possesses a different gene for resistance to the disease pathogen** (Fig. 9.7)  Lines that are genetically identical, except for a single gene, are called ***Isolines*.**  The procedure for producing a multiline cultivar is to   * Develop isolines of a desirable cultivar, each with a different gene for resistance to a particular disease pathogen. Each gene should contribute resistance to a different physiologic race, or group of races, of the disease pathogen. * The backcross-derived isolines are then composited to form the multiline cultivar. * As changes occur in the prevalent races of the disease pathogen, isolines with new genes for resistance may be developed. * Because the multilines are reconstituted each year, the new genes for resistance may be introduced by changing the mix of the isolines. |  |
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| Fig. 9.7.Procedure for production of a disease resistant, multiline cultivar. Genes for.rust resistance, R1 to R5, are backcrossed from donor cultivars to a common disease susceptible, recurrent cultivar A. Isolines are generated that differ only in a gene for disease resistance and composited to synthesize the multiline cultivar. The isolines are maintained so that the multiline can be resynthesized as needed. Five crosses (original and four backcrosses) were made to the recurrent cultivar. | |
| The theory of the multiline is to produce a population uniform for height, maturity, and other features, yet mixed in genes for resistance to pathologic races of a virulent disease.  ***Merits***  multiline cultivar are based on the assumption that it will provide partial protection to a broad spectrum of races of a disease-producing pathogen and provide a buffering effect against rapid disease development should a new race of the disease pathogen arise. These assumptions have not yet been fully tested. |  |
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|  | ***Disadvantages***: |  |
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|  | * A multiline has limited utility except in high risk areas where severe disease damage occurs regularly from a highly specialized disease pathogen, |  |
|  | * There is no genetic improvement in yield or other characteristics, except that provided by the disease resistance, as long as the same cultivar is used as the recurrent parent for isolines development, (unless the recurrent parent is improved the multiline may soon become obsolete), |  |
|  | * The labor required to produce and maintain the isolines reduces the resources for improvement in cultivar characteristics other than disease resistance, and |  |
|  | * The release of a multiline cultivar is delayed until all of the isolines are produced and increased. |  |
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|  | The term ''multiline" is sometimes loosely applied to mixtures of genetically diverse lines combined in various ways to buffer against environmental stresses. More accurately, these mixed populations should be called *composites*. |  |
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|  | **VARIETY BLEND** |  |
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|  | *A variety blend* is a composite cultivar produced by mixing seed of two or more cultivars, the suggestion being that a blend of genotypes will yield consistently higher than the average of the pure component genotypes, **due to the buffering effect against genotype × environment interactions**, and will be **more stable over locations and years than a pure-line cultivar**. The advantage of the latter tends to diminish as the number of cultivars in the blend is increased. A variety blend will be **less uniform in appearance than a pure-line cultivar**. In making a variety blend, cultivars should not be mixed that will adversely affect uniformity in maturity, or features that will reduce the quality of the product. Variety blends need to be reconstituted at regular intervals to maintain stable performance. |  |
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|  | **NON-TRADITIONAL BREEDING PROCEDURES** |  |
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|  | Traditionally, breeding procedures for improving self-pollinated crops involved crosses between two parents, followed by several segregating generations; yield-testing began only after a high degree of purity was reached. When the cycle was completed, superior segregates were crossed to start a new breeding cycle. Opportunities for gene recombination were limited by the narrow, two-parent gene pool, and opportunities to break-up linkage blocks were restricted by a 10 to 15 year breeding cycle. To overcome these deficiencies, breeders sought ways to increase the contributions into the gene pool. This has led to such non-traditional breeding practices as making large numbers of crosses, early generation yield testing and rapid elimination of low-yielding lines, and systems to increase potential gene recombination. |  |
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|  | ***LARGE NUMBERS OF CROSSES***  In a hybridization breeding program to improve simply inherited characteristics like seed color or disease resistance, parents with the desired genes may be readily identified. Choosing parents for crosses to improve characters with complex inheritance like yield, is less precise because the complementary genes contributing to yield from a set of parents cannot be identified by examining the parents. Only after the cross has been made and the range of segregation examined can the success of the cross be determined. This has led breeders to make large numbers of crosses to improve the odds that hybrid populations with superior transgressive segregates will have been made. It is also necessary to grow large segregating populations to improve the odds that the plant with the superior genotype will be included. Because resources are never unlimited, the breeder usually must choose between growing moderate populations of a large number of crosses or large populations of a moderate number of crosses. The former is generally favored because it involves use of larger numbers of parent cultivars and increases the odds that cross combinations with greater potential will have been made. |  |
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|  | ***EARLY TESTING*** |  |
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|  | After a cross is made, the progenies from each cross must be evaluated to find the superior segregates, a task that greatly exceeds the labor of making the crosses. One procedure to reduce growth in the testing program is *early testing*, i.e., the evaluation of crosses, or selections from crosses, in yield trials at an early generation. With early testing, inferior segregates, or entire crosses, may be quickly eliminated and only the superior segregates carried to the advanced generations where homozygosity and uniformity are attained. Selection and yield testing, concurrently, in the early generations reduces the population size rapidly so that relatively few strains will be remaining by the F5 or F6 generation when a practical state of homozygosity is reached. Superior yielding lines identified in an early generation may immediately be used as parents in new crosses, even though homozygosity has not been fully attained, thus reducing the generations required to complete the crossing cycle and enabling the breeder to make more rapid progress. |  |
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|  | **POPULATION IMPROVEMENT** |  |
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|  | **RECUR RENT SELECTION**. ***Recurrent selection is a population improvement procedure designed to increase the frequency of desirable alleles for a particular quantitative character by frequent intermatings among superior genotypes within the population*.** Ideally, superior genotypes are isolated after each cycle of mating and intercrossed to produce the next generation. Considerable success has been achieved with population improvement procedures in cross-pollinated species, where random mating among plants occurs by natural means. Application of population improvement procedures to self-pollinated crops has shown similar success, but is difficult to employ due to the labor involved in making the larger number of hand pollinations required to intermate the selected genotypes. |  |
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|  | **MULTIPLE CROSS**. The *multiple cross*, also called *convergent cross*, is produced by crossing pairs of parents, and then crossing pairs of F1s until all parents enter into a common progeny according to the following scheme: |  |

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|  | With this system, many potential genetic combinations exist, because every seed produced after the initial cross is potentially a new hybrid. A disadvantage is that many undesirable combinations are also brought together. Exceedingly large numbers of hybrid seeds must be obtained in the second and later crosses if the maximum number of genotypes is to be represented in the progenies. |  |
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|  | **MALE-STERILE-FACILITATED HYBRIDIZATION**. Male-sterile genes have been used in barley and other self-pollinated crops to facilitate crossing by eliminating the need for emasculation. A common procedure is to incorporate a male-sterile gene into a few standard cultivars by backcrossing. The male-sterile isolines produced are each pollinated from a group of cultivars and the crossed seeds bulked to plant a composite cross. With uncontrolled pollination, male-sterile flowers will be pollinated from male-fertile plants, thus facilitating gene recombination within the population. To obtain maximum gene recombination, seeds are harvested only from male-sterile plants. During the segregating generations, male-sterile plants may be hand-pollinated from selected male-fertile plants, and the seeds from these crosses used to plant the next generation. |  |
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|  | **PLANT BREEDING: A NUMBERS GAME?** |  |
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|  | To generate the full range of potential genotypes from a cross it is necessary to grow large segregating populations. This concept, combined with the concept that large numbers of crosses among heterozygous genotypes are needed to break linkages, has often led to the popular notion that plant breeding is a numbers game; that chances for success in developing superior cultivars are enhanced by a proliferation in the number of crosses made, by increasing the size of the segregating generations, and by growing a myriad of selections from each cross. The rarity with which really superior genotypes occur provides considerable validity to these concepts. |  |
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|  | The danger with the numbers approach is that the breeder may extend crossing and testing activities beyond the resources available needed to evaluate the materials adequately. There appears to be little value in generating the rare genotype unless it can be identified efficiently in the breeding materials being grown. The physical size of the breeding nursery, particularly for yield testing, may be extended by mechanization and standardization of procedures, and by computerization of data collection and processing. But the visual evaluation of the breeding lines, and the final evaluation of the data generated, requires personal judgements, which cannot be wholly mechanized or computerized and are limited in number by the breeder's time. Thus, the breeder needs to compromise between the number of recombinations desired and the number that can be evaluated efficiently and accurately within the resources of the program. While the breeder should select rigorously for the desired genotype and ruthlessly discard those |  |
|  | that are inferior, it is important that there be accurate and dependable information on which to base these judgments. | | |  |
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|  |  | **BREEDING CROSS-POLLINATED AND**  **CLONALLY PROPAGATED CROPS**  Breeding procedures in crop plants are designed to exploit the reproductive structure of the particular species. Thus, the breeding procedures used with cross-pollinated crops will differ from those used with self-pollinated crops. Furthermore, procedures may differ with different species of cross-pollinated crop plants because the species differ in the structure of the reproductive system. Most species of commonly cultivated cross-pollinated crops are seed propagated. Other species, potato and sugarcane for example, that reproduce sexually in their native habitat with normal cross-pollination are propagated asexually as clones when cultivated. |  |  |
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|  | ***BREEDING CROSS-POLLINATED VERSUS SELF-POLLINATED CROPS*** |  |
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|  | *In the breeding of self-pollinated crops, the homozygous nature of the individual plant is exploited*. *With selection focused on plants in self-pollinated crops, characters with Qualitative Inheritance tend to receive major attention*. |  |
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|  | ***In the breeding of cross-pollinated species, The Heterozygous Nature of the individual plant is exploited***. In a population of a cross-pollinated species, open-pollinated corn, red clover, or perennial ryegrass are typical examples,. As a consequence of natural cross-pollination, the genes are reshuffled each generation and regrouped into new genetic combinations. So almost never would two plants be found with identical genotypes. Under natural environmental influences, cross-pollinated populations are relatively fluid, in which genes favoring adaptation and increased seed production tend to increase at the expense of genes unfavorable for adaptation or fitness to reproduce. In a breeding population, the shift toward more adapted genotypes may be accelerated by selection, and by environmental stresses to which the breeding population is subjected. |  |
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|  | ***In cross-pollinated crops the focus of the breeder is on population improvement instead of individual plants, and more emphasis is given to Quantitative Inheritance in breeding systems than in self-pollinated crops*.** Due to the extensive heterozygosity in cross-pollinated crops, there is an abundance of phenotypic variation; hence, cultivars of cross-pollinated crops are less uniform than cultivars in self-pollinated crops. Genetic variability for qualitatively inherited characters may be drastically reduced by rigid selection, but genetic variability in quantitatively expressed characters continues to be present, due to inability of the breeder to select accurately for individual gene effects and to the influence of the genotype × environment interactions. |  |
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|  | ***PROGENY TEST VS COMBINING ABILITY TEST*** |  |
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|  | In a self-pollinated crop, in which individual plants tend to be homozygous, the genotype is reproduced in the progeny rather precisely and may be evaluated by progeny tests. In a cross-pollinated crop, individual plants are heterozygous and field grown plants will largely be pollinated by pollen from other heterozygous plants growing in the vicinity. Under these conditions, or even if self-fertilized, the genotype of a heterozygous plant is not faithfully reproduced in its progeny. Thus growing a progeny test of an open-pollinated plant does not provide information comparable to that obtained from growing a progeny test of a self-pollinated plant. A more suitable test would be provided if the plant had been pollinated with a heterogeneous collection of pollen (gametes) of known origin. Performance could then be compared among progenies of plants pollinated with the same source of pollen |  |
| .A more precise comparison could be made by pollinating the plants with pollen from an inbred (homozygous) line. A test comparing progeny performance of plants or strains pollinated with a known tester line is called a ***Testcross*** and evaluates the ***Combining Ability*** of the mother plants or strains with the common tester line.  The average or overall performance of a plant or genetic strain in a series of crosses with different tester lines is a measure of its ***General Combining Ability***,  whereas the performance of a plant or genetic strain in a specific combination in comparison with the performance of other cross combinations is a measure of its ***Specific Combining Ability***. | | | |  |
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|  | **INBREEDING** |  |
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|  | Self-pollination, or inbreeding, in cross-pollinated crops leads to a decline in vigor and productiveness, a phenomenon observed by many early plant hybridizers who failed to grasp |  |
|  | its significance. **Dr. G.H. Shull** reported the deteriorating effect of inbreeding open-pollinated corn (maize) in a report to the American Breeders Association in 1908, and suggested that the breeder should strive to maintain superior hybrid combinations. This concept led to the development of procedures for breeding hybrid cultivars in corn and other crops. In forage crops, inbreeding may lead to a reduction in fertility and seed production. | | |  |
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|  | *Breeding procedures in cross-pollinated crops are based largely on population improvement principles, i.e., increasing the frequency of genes in the population for the desired breeding objectives.* |  |
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|  | **MASS SELECTION** |  |
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|  | *Mass selection* in cross-pollinated crops is a selection procedure in which: |  |
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|  | * Individual plants are chosen visually for their desirable traits, and |  |
|  | * The seeds harvested from the selected plants are bulked to grow the following generation without any form of progeny evaluation (Fig. 10.3). | | |  |  |
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|  | Repeating mass selection utilizes the recurrent selection principle. An example of the procedure follows: |  |
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|  | ***First season*:** Select 50 to 100 plants with desired features from the source population and harvest open-pollinated seed from each. |  |
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|  | ***Second season*:** Plant a mixture of the seed harvested in the previous year. From this population, again harvest open-pollinated seed from 50 to 180 plants selected for desired features. |  |
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| Fig. 10.3.Mass selection. Individual plants are selected for desirabletraits and seed is composited to grow the next generation. The composite may serve as the ''source population" for thenext selection cycle. |

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|  | A procedure known as ***Gridding*** may be used to reduce errors in selection caused by uneven environments. The land area on which the source population is grown is divided into small plots or *grids*. Plants are evaluated within each grid and only one superior plant from each grid is harvested. This procedure gives equal representation in the mass selection from all areas of the field regardless of field gradients in soil fertility or moisture supply. The grid system may be utilized when making selections from the source populations in the half-sib, full-sib, and S1 procedures that follow. |  |
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|  | Fig. 10.4.Progressive improvement in sugar beet for curly-top-virus resistance through a combined mass/recurrent-selection breeding procedure. Improvement was possible because  (1) genotypes with genes for resistance were present in the European source population,  (2) the severity of the curly-top-virus disease eliminated the susceptible genotypes from the population, and  (3) interpollination among the resistant.genotypes resulted in sugar beet plants with transgressive segregation for resistance.  About 25% of the plants in US 1 were resistant to the curly-top-virus, 40 to 50% of the plants in US 33 were resistant, 75% of the plants in US 12 were resistant, and 85 to 90% of  the plants in US 22 were resistant. | | |  |
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|  | |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***THE RECURRENT-SELECTION PRINCIPLE*** |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *Recurrent selection is any breeding system designed to increase the frequency of desired alleles for particular quantitatively inherited characters by repeated cycles of selection.*  *A* recurrent-selection cycle involves: |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | * Identification in a source population of genotypes superior for the specific quantitative character being improved, and |  | |  | * The subsequent intermating of the superior genotypes to produce new gene combinations with improved expression of the character. | | |  | |  | | | | | |  | | | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | Selection cycles may be repeated as long as superior genotypes are being generated. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | PHENOTYPIC RECURRENTSELECTION is selection to improve a plant quantitative character based on visual observation or physical measurement of the character. Examples are oil content in corn (Fig. 10.1), fiber strength in cotton, sugar content in sugarbeets, or seed size in wheatgrass. Phenotypic recurrent selection is an appropriate breeding procedure in naturally cross-pollinated species or species where artificial cross-pollinations are made easily. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | *GENOTYPIC RECURRENT SELECTION* is selection to improve a plant quantitative character based on progeny performance as measured by test crosses, or by other means, and is utilized to improve complex characters such as combining ability in corn inbred lines. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | A model for simple phenotypic recurrent selection is illustrated in Fig. 10.2 in which plants are visually selected from the source population and the progenies of the selected plants are grown and intercrossed to obtain new gene combinations. The crossed seed is used to grow a new source population, which starts the next selection cycle. Selection based on phenotype will be effective insofar as the phenotype accurately identifies the superior genotype for the character under consideration. Phenotypic recurrent selection is most effective for characters with low genotype x environment interaction, such as height of ears (in corn), seed size, or disease resistance. For quantitative characters that cannot be selected accurately from the phenotype, breeding procedures have been devised based on progeny or testcross performance that utilize the recurrent selection principle. |  | |  | | | |  | | |  |  |  |  | | --- | --- | --- | |  |  |  | |  | |  |  | 0186-001.gif |  |  | |  | | | |  | | |  |  | | --- | | Fig. 10.2.Model for phenotypic recurrent selection. Note that the mean of the populations has increased  following each selection cycle. |  |  |  |  | | --- | --- | --- | |  |  |  | |  |   **HALF-SIB SELECTION WITH PROGENY TEST** |  |
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|  | ***Half-sib*** refers to a plant or family of plants with a common parent or pollen source. A half-sib selection procedure based on a progeny test differs from mass selection because the new population is constituted by compositing half-sib lines selected from progeny performance rather than from phenotypic appearance. Progenies of 25 to 50 plants are grown in replicated plots, so that the variance and mean performance may be evaluated. An example of the half-sib selection procedure as used with corn follows (Fig. 10.5): |  |
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|  | ***First season***. Select 50 to 100 plants with desired features from an open-pollinated source population, keeping the seed harvested from each plant separate. The seed from each plant will constitute a different breeding line. |  |
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|  | ***Second season*.** Using seeds harvested from open-pollinated plants in the previous season, grow a progeny test of each line in an isolated area. Retain some of the seed of each line as remnant seed. |  |
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|  | ***Third season*.** The population is reconstituted by compositing equal quantities of either (a) seed harvested from the 5 to 10 superior progenies, or (b) remnant seed from the 5 to 10 lines with superior progeny performance. Grow the composite in isolation with open-pollination to obtain new gene combinations. Seed harvested in the third season may be:   |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | |  |  | * increased as a new open-pollinated cultivar, | | | | |  |  | |  | * planted as a source population to start a new selection cycle, or |  |  | |  | * planted as a source population for isolation of new inbreds in a hybrid breeding program. | | |  |   The half-sib procedure is applicable to cross-pollinated crops, like corn or sugarbeets, where sufficient seed can be harvested from a single plant to grow a yield trial, or to cross-pollinated crops where self-pollination cannot be consummated due to self-incompatibility systems. |  |
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| **HALF-SIB SELECTION WITH TESTCROSS** | | | | |  |
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|  | In this procedure the selection of the half-sib lines to composite is based on testcross performance rather than progeny performance. An example of the procedure as used with corn follows (Fig. 10.6): |  |
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|  | ***First season***. Prior to flowering, select 50 to 100 plants with desired plant characters from a source population:   1. pollinate a tester parent plant with pollen from each of the selected plants and harvest crossed seed from the tester parent and open-pollinated seed from the selected plants, keeping identity of each seed lot; or 2. With pollen from each selected plant, pollinate a tester plant and self-pollinate the selected plant. Harvest crossed seed from tester parent plants and selfed seed from selected plants, keeping identity of each seed lot. |  |
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|  | ***Second season***. Grow testcross progenies. |  |
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|  | ***Third season***. Reconstitute the population (a) by mixing equal quantities of open-pollinated seed from 5 to 10 selected plants with superior testcross progeny performance; or (b) by mixing equal quantities of selfed seed from 5 to 10 selected plants with superior testcross progenies. Grow the seed composite in an isolated seed plot with open-pollination to obtain new gene combinations. |  |
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|  | The half-sib testcross procedure permits control over the testcross parents so that a more precise evaluation of the genotype of the selected plant is obtained than from growing a progeny obtained by open-pollination as in the previous procedure. If the tester is an inbred line, plants in each of the lines in the testcross progeny nursery will have one parental gamete in common. Procedure (b) would be superior to procedure (a) because only genes from the plants with superior testcross progenies enter into the gene pool of the composite, whereas in procedure (a) one-half of the genes originate from a random selection of pollen from the source population. |  |
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|  | The procedures outlined are applicable to corn and other cross-pollinated crops in which sufficient seed can be produced by crossing to grow a replicated testcross progeny trial. For procedure (b), self-pollination is necessary in addition, a requirement that could not be accommodated in self-incompatible species. |  |
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|  | **FULL-SIB SELECTION**  With full-sib selection, crosses are made between selected pairs of plants in the source population, with the crossed seed used for progeny tests and for reconstituting the new population. An example of the procedure follows (Fig. 10.7): |  |
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| ***First season*.** Cross 150 to 200 pairs of plants selected from the source population. Reciprocal crosses may be made to provide a larger quantity of crossed seed.  ***Second season***. Grow a replicated progeny test with seed from each pair of crosseskeeping the remnant crossed seed. |  |
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|  | ***Third season***. Reconstitute the source population by mixing equal quantities of remnant crossed seed from 15 to 20 paired crosses with superior progeny performance, and grow in isolation with open-pollination to obtain new gene combinations. |  |
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|  | Full-sib selection measures the combining ability from mating specific pairs of plants and only those pairs with superior progeny performance enter into the composite. The procedure is applicable to many cross-pollinated species, including self-incompatible species |  |
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| Fig. 10.7.Full-sib selection based on progeny test performance of paired crosses. |

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|  | **SELECTION FROM S1 PROGENY TEST** |  |
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|  | S1 progeny tests may be utilized to evaluate selected plants from an open-pollinated source nursery. S1 refers to the progeny following self-pollination of plants in an open-pollinated population, or in the F2 following a cross. The procedure follows (Fig. 10.8): |  |
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|  | ***First season***. Select 50 to 100 plants from a source nursery prior to flowering. Self-pollinate and harvest selfed seed from selected So plants. |  |
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|  | ***Second season*.** Grow replicated S1 progeny trial, keeping remnant selfed (S0) seed. |  |
| ***Third season*.** Composite equal quantities of remnant seed from the So plants with superior progenies, and grow the seed composite in isolation to obtain new gene combinations 0192-001.gif | | | | |  |
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| Fig. 10.8.Selection based on S1 progeny performance. |

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|  | Selection is based on performance of S1 plant progenies. Each S1 progeny evaluated receives only the genes present in the parent So plant; no genes are introduced into the line from open-pollination or tester parents. The procedure is applicable to corn and other cross-pollinated species in which a quantity of seed sufficient for a replicated progeny trial and remnant seed for making the composite can be obtained by self-pollination. It would not be applicable to self-incompatible species |  |
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|  | **SYNTHETIC CULTIVAR** |  |
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|  | *A synthetic cultivar is an advanced generation of a seed mixture of strains, clones, inbreds, or hybrids among them, propagated for a limited number of generations by open-pollination*. The word "synthetic" implies a population of plants artificially produced by the breeder. The component strains, clones, or inbreds are maintained, and the synthetic is reconstituted at regular intervals. It is incorrect to apply the term synthetic to populations originating from seed mixtures advanced by open-pollination without periodic reconstitution. |  |
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|  | The synthetic procedure is widely used in breeding forage crops. In forage species, the half-sib, full-sib, or S1 selection procedures are rarely applicable because: |  |
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|  | * The quantity of seed produced from a single plant is usually inadequate to grow a progeny test, | | | | |  |
|  | * Self-incompatibility inhibits production of selfed seed in many forage species, and | | |  |  |
|  | * Controlled cross-pollinations are difficult to make in most forage species. |  |  |
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|  | In addition to forage crops, synthetic cultivars may be developed in corn, sugarbeets, sunflower, and other cross-pollinated species. |  |
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|  | The design of the synthetic cultivar utilizes the partial exploitation of heterosis during a limited number of generations of seed increase. This feature has made the synthetic cultivar popular in breeding forage species where conventional crossing procedures to obtain heterosis are not feasible. The procedure for developing a synthetic cultivar has these essential characteristics: |  |
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|  | * The synthetic cultivar is constituted from reproducible units of a cross-pollinated crop (clones in forage species, inbreds in corn or sugarbeets). |  |
|  | * The plant materials entering into the synthetic cultivar are selected from performance in combining ability or progeny tests. |  |
|  | * The synthetic cultivar is constituted by random interpollination of the component units. |  |
|  | * The component units are maintained so that the synthetic may be reconstituted at regular intervals. |  |
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|  | A model for the development of a synthetic cultivar in a forage species that embodies these characteristics is illustrated in Fig. 10.9. The procedure involves several distinct populations   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | ***Source population*.** Plant selections are assembled from many sources to ensure a broad range of genetic variability. The original plant selections may come from old established pastures or meadows, improved cultivars, introductions, bulked populations after several cycles of recurrent selection for a particular characteristic, or other sources. The clones should be |  |  | |  | vigorous and productive so that they can be easily maintained and will produce vigorous and productive progenies. | | |  | |  | | | | | |  | | | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***Clonal line nursery***. From the source nursery several hundred superior plants, are chosen and multiplied as clones for establishing a clonal line nursery (Fig. 10.10). Each clonal line in the nursery will be comprised of 20 to 25 plants propagated vegetatively from the original plant. The clonal lines are evaluated for vigor, persistence, and other superior characteristics, depending upon the species and the objectives of the breeding program. Exposure of the clones to adversities, such as severe clipping, disease epidemics, cold, or drought, will aid in identifying clones with superior qualities. Finally, 25 to 50 of the superior clones will be selected for progeny testing in a polycross nursery. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***Making the polycross***. Seed for growing a progeny performance test is obtained by making a polycross. *The polycross is an isolated group of clonal lines replicated in such a manner that each clone will be pollinated by a random sample of pollen from all of the other clones*. The seed from each clone is harvested separately with the identity of the clone maintained. |  | |  |
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| Fig.10.9.Procedure for development of a synthetic cultivar of a forage crop, based on polycross progeny performanc |

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|  | ***Polycross progeny test****. The* open-pollinated seeds harvested from the clone in the polycross are planted in a progeny test for evaluation of yield and other characters. From the polycross progeny test performance, 5 to 10 of the clones are chosen as components for the synthetic. |  |
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|  | ***Syn 0 generation*.** The 5 to 10 clones chosen to be utilized in the synthetic are vegetatively propagated and randomly transplanted into an isolated seed field, or, in the case of a legume, the clones may be transplanted into an insect-proof cage and pollinated with bees to obtain seed. This constitutes the Syn 0 generation. Random cross-pollination among the Syn 0 clones fosters gene recombination. |  |
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| Fig. 10.10.Strains of weeping lovegrass. In the development of a synthetic cultivar in forage crops, the characteristics of the individual breeding lines are evaluated by growing the lines in a field nursery. The combining ability of the lines are evaluated by growing the lines in a polycross yield nursery. | |
| ***Syn 1 generation***. Open-pollinated seed harvested from the Syn 0 generation is planted in isolation for seed increase. This constitutes the Syn 1 generation and may be distributed as a synthetic cultivar if seed can be produced in sufficient quantity. Superior plant selections from the Syn 1 generation may be vegetatively propagated to start a new source nursery. |  |
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|  | ***Syn 2 generation*.** Open-pollinated seed harvested from the Syn 1 generation is increased in isolation. This constitutes the Syn 2 generation. |  |
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|  | The purpose of growing the Syn 2 generation is to increase the quantity of seed that will be available to the farmer. If sufficient seed to meet market demand can be produced in the Syn 1 generation, it will be unnecessary to grow the Syn 2 generation. In most instances it is necesary to go to the Syn 3 or later generations to have adequate seed for sale to farmers. The Syn 1 and  Syn 2 generations are comparable to the F1 and F2 generations, respectively, in conventional hybridization. Each generation the synthetic cultivar is advanced beyond the Syn 1 there will be successive reductions in vigor. The original clones are maintained so that the synthetic cultivar can be reconstituted when the seed fields need to be renewed. The Syn 1 generation may be utilized as a source nursery from which to select clones that could be used in breeding future synthetics, thus introducing the recurrent-selection principle. In addition to polycross performance, as illustrated here, to evaluate clones, the clones may be evaluated by S1 performance trials. |  |
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|  | A synthetic cultivar in corn is produced in a similar manner to that illustrated with a forage crop except that the breeder will be working with inbreds instead of clones. The corn inbreds to be used as component lines in the synthetic cultivar are chosen on the basis of combining ability tests, and crossed in all combinations to produce the seed for growing the Syn 1 generation. The inbreds are maintained so that the synthetic can be reconstituted. Similar procedures may be utilized to produce synthetic cultivars in other cross-pollinated crops. In annual species of plants such as corn, the synthetic will need to be reconstituted each season, otherwise, the population behaves as an open-pollinated cultivar. |  |
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|  | CHOICE OF SOURCE GERMPLASM AND TEST ENVIRONMENT |  |
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|  | With recurrent-selection procedures, the performance level of the source population and the test environment are important. A superior combination of alleles for the character being improved will not be forthcoming if the genes are not in the source population. In choosing component lines for the source population, only those with the highest expression of the desired characters should be included. If the lines have a diverse origin, there may be a greater possibility that they will contain different alleles for the character. When evaluating the populations, they will need to be grown in an environment that fosters expression of the character to be improved, if the superior genotype is to be identified. |  |
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|  | **BREEDING CLONALLY PROPAGATED CROPS** |  |
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|  | *A clone* is a vegetatively propagated population of genetically identical plants. In asexually propagated species, the separate genotypes are propagated as clones. Clonal propagation may be practiced with species that produce seeds poorly or that produce seeds only under special conditions. Some crops normally propagated as clones are sugarcane (see Fig. 2.10), potato, sweet potato, cassava, sisal, taro, and some species of perennial grasses, such as bermuda-grass. Asexually propagated species have not normally been subjected to self-pollination and |  |
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|  | inbreeding, and individual plants are highly heterozygous, the heterozygosity being maintained through clonal propagation. With potatoes as an exception, most clonally propagated species are perennials. Aneuploid or polyploid chromosome genomes are maintained with clonal propagation, resulting in clones with chromosome numbers that differ from those recorded for the species. Breeding procedures for clonally propagated species may be grouped into: |  |
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|  | * Germplasm assembly and maintenance, |  |
|  | * Clonal selection of natural or induced variants, and | | |  |  |
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|  | hybridization followed by selection and propagation of superior clones in the segregating population. |  |
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|  | ***GERMPLASM ASSEMBLY AND MAINTENANCE*** |  |
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|  | As with crops that reproduce sexually, the initial step in breeding asexually propagated species is to assemble a germplasm collection that is maintained as clones. The germplasm assembly may include clones selected from local populations if the species is native to the locality, introduced clones from genebanks or other breeders, commercially grown cultivars, or wild relatives introduced from their native habitat. The germplasm collection of clones constitutes the breeder's source nursery. Clones from the source nursery may be propagated and grown directly as cultivars, or the clones may be used as parents in a hybridization program. The germplasm collection is maintained as a collection of living plants in the field; this differs from maintaining a seed collection as in a sexually propagated species. Because vegetative propagation maintains the genotypes without change, except for mutation, large numbers of clones may be grown in the breeding nursery without isolation. In most countries it is mandatory that clones introduced from a foreign source first be grown in isolation to prevent the possible introduction of new species of insects or disease pathogens along with the clone. The hazard may be reduced by introduction of seeds instead of clones, if the species produces viable seeds. |  |
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|  | ***CLONAL SELECTION*** |  |
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|  | In a genetically mixed population of an asexually propagated species such as exists in nature, a superior clone may be isolated and propagated as a cultivar. In a mixed population, progress through clonal selection is limited to the isolation of the best genotype present. Genetic variability may arise in a clone by mutation producing bud sports, chimeras, or genetic mosaics. In species of ornamental plants, variants originating from natural or induced mutations are often utilized as the source of new clones. A high mutation rate has been observed in genotypes of sugarcane maintained through tissue culture techniques, with the mutant plants then propagated as clones. |  |
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|  | ***HYBRIDIZATION*** |  |
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|  | *Gene recombination occurs with sexual reproduction. In a crop species that is normally propagated asexually, sexual reproduction is necessary to create genetic variability through gene recombination*. By crossing clones with superior characters, source populations will be created that may be utilized for the selection of new clones as in self-pollinated crops. A typical procedure for developing a cultivar from an asexually propagated species, such as sugarcane, follows (Fig. 10. 11):   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | ***Crossing generation***: Cross Clone A × Clone B. |  |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***1st season*:** Grow 10,000 F1 seedling plants. Select 1000 vigorous plants and propagate vegetatively. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***2nd and 3rd seasons*:** Grow 1000 clonal rows in 2nd season; select 100 superior clones. Grow 100 clones in 3rd season, preferably at two locations; select 10 superior clones. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***4th to 7th seasons*:** Grow selected clones in replicated field trials at several locations in comparison with standard cultivars or advanced breeding lines. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | ***8th to 10th seasons*:** Increase propagules of superior new clone and release as a new cultivar. |  | |  | | | |  | | |  |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | | |  | |  | | | |  | Number of seedling plants and clones to grow are suggestive only and will vary with the species and resources of the breeding project |  | |  | Due to the open-pollination, the parent clones will be heterozygous, segregation occurs in the F1 generation; each F1 plant is thus a potential source for a new clone and a new cultivar. Clones propagated from F1 plants are heterozygous and the heterozygosity of the clone is maintained through asexual propagation. If the breeder does not find a superior genotype in the F1 generation, the crosses are remade, or different crosses may be made. Self-pollination to produce an F2 is seldom practiced because self-pollination leads to a reduction in vigor and fertility. If a superior F1 plant is identified in the hybrid progeny, it is propagated vegetatively to establish a new clone which is evaluated in observation and replicated plot tests. | | |  | |  |
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| Fig. 10.11.Hybridization procedure for a clonally propagated species. The seedlings grown in the first season are comparable to an F2 generation in a conventional hybridization procedure. The genotype of each seedling plant is maintained by vegetative propagation in the first and succeeding seasons. |

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