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Conventional Methods of Plant Breeding: Principles and Techniques

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Abstract

Plant breeding has been a critical endeavour for centuries, playing a pivotal role in improving crop productivity, enhancing nutritional content, and developing plants with desirable traits to meet the ever-increasing demands of a growing global population. This chapter explores the conventional methods of plant breeding that have been employed by plant breeders over the years to achieve these goals. Conventional plant breeding is the method of improving plant trait using conservative tools to achieve the desire trait within the species' natural genetic boundaries.

Subsequently, the conventional breeding techniques employed by plant breeders. It discusses the process of cross-pollination and the benefits of hybridization in generating improved plant varieties. The common methods for breeding of self-pollinated species include mass selection, pure line selection, single seed descent, bulk population, pedigree, backcrossing, multiline and composite. The chapter also explores the significance of germplasm preservation and the establishment of plant genetic resources for future breeding endeavours. It emphasizes the importance of maintaining diverse germplasm collections to ensure a broad genetic base for breeding programs. It also focused on hybrid cultivar breeding exploits the phenomenon of heterosis, and is applicable to both self and cross-pollinated species. Hence this chapter provides a comprehensive overview of the conventional methods of plant breeding. By exploring the principles, techniques, and

advancements in the field, it serves as a valuable resource for plant breeders, researchers, interested in understanding the foundation and application of conventional breeding methods in agriculture.

The chapter begins with an overview of the fundamental principles and objectives of plant breeding, highlighting the importance of genetic variation and selection. It delves into the concept of heritability, genetic recombination, and the role of natural and artificial selection in shaping plant populations. Additionally, it emphasizes the need for careful planning and well-designed breeding strategies to maximize genetic gain.

Keywords: *Plant Breeding, Conventional Breeding, Breeding Methods, Self Pollination, Cross Pollination.*

I. INTRODUCTION

Plant breeding is a science that focuses on the development of new plant varieties in a systematic and ongoing method. The fundamental discoveries of Darwin and Mendel established the scientific basis for plant breeding and genetics at the turn of the 20th century. Humans have been consciously breeding plants for thousands of years, from *in-situ* care to *ex-situ* planting. Plant breeding is a multifaceted endeavour, which intersects with many other disciplines and professions. The breeding process involves collecting, inducing, and rearranging genetic diversity followed by selection. Plant breeding involves both traditional and modern techniques. Conventional breeding methods involve selecting and crossing plants with desirable traits, while modern techniques include genetic engineering and marker- assisted selection. Genetic diversity is a key factor in plant breeding, as it allows for the selection of desirable traits for the development of new varieties.

Non-Mendelian heredity, including epigenetic inheritance, cytoplasmic inheritance, hybrid vigour, and LOH (Loss of heterozygosity), also plays a role in plant breeding. A contemporary breeding curriculum should include hands-on experience with the inheritance and selection of complex traits in actual plant populations, basic biology of plants, principles of quantitative genetics and selection theory, principles and practice of plant breeding, and related sciences such as genomics, applied statistics, experimental design, and pest sciences.

In conclusion, plant breeding is a vital science that has been practiced for thousands of years. It involves both traditional and modern techniques, and its goal is to develop new plant varieties that are more productive, disease-resistant, and better adapted to changing environmental conditions. Genetic diversity and non-Mendelian heredity play important roles in the breeding process, and a comprehensive breeding curriculum should include a range of scientific disciplines. The goal of plant breeding is to develop new plant varieties that are more productive, disease-resistant, and better adapted to changing environmental conditions

II. THE HISTORICAL DIMENSION OF PLANT BREEDING

Conventional plant breeding is a discipline that has shaped agricultural practices for centuries, contributing to the development of improved crop varieties through selective breeding techniques. Dating back thousands of years, the history of conventional plant breeding can be traced through major milestones that have revolutionized agriculture. This brief history will explore key events and breakthroughs in conventional plant breeding.

The origins of plant breeding can be found in early human civilizations. Around 8000 BCE, humans began practising agriculture, transitioning from a hunter-gatherer lifestyle to settled farming communities. During this time, early farmers recognized the value of saving seeds from plants with desirable traits, such as higher yields and resistance to pests and diseases. By selectively planting these seeds, they unintentionally initiated the process of domestication. Fast forward to the mid-19th century, when Gregor Mendel, an Austrian monk, conducted ground breaking experiments with pea plants. Between 1856 and 1863, uncovering the principles of dominant and recessive traits. His work laid the foundation for modern genetics and paved the way for more targeted plant breeding efforts.

The early 20th century witnessed significant advancements in conventional plant breeding. In 1900, Danish plant breeder Wilhelm Johannsen introduced the term "gene" to describe the fundamental units of heredity. This concept deepened our understanding of how traits are passed from one generation to the next.

Another crucial milestone occurred in the 1920s when Soviet scientist Nikolai Vavilov conducted extensive plant collection expeditions, creating one of the largest seed banks in the world. Vavilov's work laid the groundwork for the establishment of gene banks, preserving plant genetic diversity for future breeding efforts.

In the 1930s and 1940s, hybridization emerged as a key technique in plant breeding. Scientists discovered that crossing two genetically diverse parent could produce offspring with superior traits, such as higher yields and/or disease resistance. This approach led to the development of hybrid maize varieties that revolutionized corn production in the United States.

The mid-20th century brought the green revolution, a period of remarkable plant breeding and agricultural practices advancements. In the 1960s and 1970s, scientists like Norman Borlaug introduced high-yielding wheat and rice varieties, helping to avert famine and increase food production worldwide. These varieties were bred to respond well to fertilizers and withstand environmental stresses.

Advances in biotechnology began to impact conventional plant breeding in the late 20th century. In 1983, the first genetically modified (GM) crop, a tomato, (Flavr Savr) with delayed ripening, was developed *(Kumar et al., 2020).* This marked the beginning of a new era in which scientists could directly manipulate the genetic makeup of plants to introduce desirable traits. Throughout the 21st century, conventional plant breeding has continued to evolve. Researchers have harnessed advanced genomic tools, such as marker-assisted selection and genomic selection, to accelerate the breeding process and improve the accuracy of trait prediction *(Kumar et al., 2016).* Hence, a growing focus has been on developing crop varieties with enhanced nutritional value, improved tolerance to abiotic stresses like drought and salinity, and increased resistance to pests and diseases.

The history of conventional plant breeding spans thousands of years and is marked by significant milestones. From the early recognition of seed selection by ancient farmers to the modern genomic tools and techniques used today, conventional plant breeding has continually shaped agricultural practices, contributing to the development of improved crop varieties that meet the evolving needs of humanity.

III. DEFINITION OF CONVENTIONAL BREEDING

The practice of plant breeding has advanced from the cynical view of "crossing the best with the best and hoping for the best," to the now carefully planned and thoughtout strategies for developing high performing cultivars with high predictability (Acquaah *2012).* Modern plant breeding is both a science and an art. The methods and tools employed, which keep changing with advances in science and technology, provide the basis for categorizing plant breeding approaches into two basic types – conventional as well as molecular breeding (molecular). (Acquaah *2012;* Chahal and Gosal *2002).* Traditional breeding is the development of new varieties of plants by using older tools and natural processes, more sophisticated and sometimes radical tools of molecular plant breeding (Jain and Kharkwal *2004).* In conventional breeding, breeders assemble desirable traits from different but usually closely related plants into the new cultivar using the techniques of (hybridization) (Acquaah *2012;* Kiran *et al.,* 2019). Thus, the product of conventional breeding only emphasizes target traits which pre-exist in the genetic potential of the species, without introducing new genes (Jakowitsch *et al.* 1999).

3.1 Macro-Evolution and Micro-Evolution

Darwin did not distinguish between macro- and micro-evolution when he used the phrase "evolution by natural selection" to explain the creation of species (see Microevolution and Variations in Population Genetics). Macro- evolution (Greek: macro = huge) creates new species and takes millions of years of geological time. For instance, although humans and chimpanzees are separate species, they have a seven million year old common ancestor. Micro-evolution (Greek: micro = little) creates new ecotypes within historical periods measured in years. These ecotypes, variations within a species, are the outcome of several ecosystem-level selection pressures.

The main distinction between the two types of evolution is that while micro-evolution requires rearranging the existing genetic code, macro-evolution entails the creation of a new genetic code. Industrial melanism is arguably the best illustration of ecotype change and microevolution. Many trees in England developed black bark during the Industrial Revolution as a result of the soot in the smoggy air. The moths created brand-new black ecotypes in all seventy species. Micro-evolutionary breeding studies revealed that changing black moths into light-coloured camouflaged moths and back again was rather simple. Micro-evolution occurs during traditional plant breeding. Because it is the consequence of artificial selection rather than natural selection, it varies from natural micro-evolution. Wild ecotypes are the result of natural microevolution.

IV. DOMESTICATION OF PLANTS

The domestication of plants is a crucial aspect of plant breeding that refers to the process by which wild plants are transformed into cultivated crops with desirable traits. It involves the intentional selection and propagation of plants with favourable characteristics by humans over generations. The domestication of plants is a fundamental step in the development of agriculture and the establishment of food production systems.

Domestication typically involves a series of changes that occur over time, leading to plants that are more adapted to human cultivation and consumption. The process begins with the identification of wild plant species that possess certain traits that are beneficial to humans, such as larger seeds, reduced toxicity, or improved taste. Early farmers selectively collect seeds or other propagules from wild plants exhibiting these desired traits. By saving and replanting these selected seeds, they unintentionally initiate the domestication process. Over generations, as plants with favourable traits are consistently chosen for propagation, the genetic composition of the population gradually shifts, resulting in a domesticated plant population that differs significantly from its wild ancestors.

The domestication process often involves changes in various plant characteristics. For example, through selection, plants may develop larger fruits or seeds, reduced shattering (the tendency to release seeds easily), and changes in plant architecture, such as increased branching or reduced height for easier cultivation. These changes are driven by natural variations in the plant's genetic makeup and the selective pressures applied by humans. As domestication progresses, plants become more dependent on human intervention for their survival and reproduction. They may lose some of their ability to compete with other plants in the wild, as they rely on humans for protection, watering, and nutrient supply. This dependence is accompanied by a reduction in genetic diversity, as a limited number of individuals are favoured and propagated, leading to a narrower genetic base compared to their wild counterparts.

The domestication of plants has played a vital role in the development of agriculture and has provided humans with a stable and abundant food supply. Crops that have undergone domestication, such as wheat, rice, maize, and soybeans, are the backbone of modern agriculture and form the basis of global food systems (Kumar *et al.,* 2019). Plant breeding builds upon the domestication process by further refining cultivated plants through selective breeding techniques. Breeders aim to enhance desirable traits such as yield, disease resistance, nutritional quality, and adaptation to specific environmental conditions. By crossing different domesticated varieties or introducing genetic variations through mutagenesis or genetic engineering, plant breeders continue to improve crop plants to meet the evolving needs of agriculture and society.

Domestication of plants is a critical component of plant breeding. It involves the intentional selection and propagation of wild plants with desirable traits, leading to cultivated crops better adapted to human needs and cultivation practices. The domestication process is the foundation upon which plant breeding has been built, enabling the development of diverse and improved crop varieties throughout history.

The purpose of domestication of plants in plant breeding is to transform wild plants into cultivated crops with desirable traits that meet human needs. The process involves a combination of selective breeding, cultivation, and human intervention over generations. The ultimate goal is to develop more productive, nutritious, and resilient crops, improving food security and agricultural productivity.

The domestication process begins with the identification of wild plant species that possess certain characteristics beneficial to humans. These traits can vary depending on the intended use of the crop, such as more fruits, increased yield, improved taste, reduced toxicity, or resistance to pests and diseases. Wild plants exhibiting these desired traits are selectively collected, and their seeds or other propagules are saved and replanted.

Over time, as the selected plants are continuously propagated, certain genetic variations associated with the desired traits become more prevalent within the population. This is achieved through both selective and non-selective selection. Intentional selection involves actively choosing plants with desirable traits for reproduction, while unintentional selection occurs through natural variations in the plant's genetic makeup and the survival of individuals that exhibit beneficial characteristics.

4.1 The Process of Domestication Often Involves Several Key Steps

1. **Collection and Initial Cultivation:** Wild plants with desirable traits are collected and brought into cultivation. They are initially grown in controlled environments to ensure their survival and adaptation to cultivation practices.

2. **Selective Breeding:** As plants are cultivated, they are subjected to further rounds of selective breeding. This involves choosing plants with the desired traits and crossing them to create offspring that inherit and combine these favourable characteristics.

3. **Artificial Selection:** Humans actively intervene in the selection process by choosing plants with the most desirable traits for reproduction, thereby directing the course of genetic change within the population.

4. **Environmental Adaptation:** Domesticated plants are adapted to human-managed environments, such as fields or gardens, and may lose certain traits no longer beneficial under cultivation conditions. This includes traits related to seed dispersal mechanisms, defence mechanisms against herbivores, or adaptation to diverse ecological niches.

5. **Loss of Genetic Diversity:** Through the repeated selection of specific individuals or genetic lines, the genetic diversity of domesticated plants may decrease compared to their wild counterparts. This reduced genetic diversity can lead to increased vulnerability to pests, diseases, and environmental stresses.

The purpose of domestication in plant breeding is to transform wild plants into cultivated crops with desired traits. The process involves selective breeding, cultivation, and human intervention over generations. It aims to improve agricultural productivity, enhance food security, and develop crops that are better adapted to human needs and environmental conditions.

4.2 Center of Origin

The center of origin in plant breeding refers to the geographic region where a particular plant species or crop originated and underwent natural evolution and domestication. It is the geographical area where the wild ancestors of cultivated crops are found. The centre of origin is of significant importance in plant breeding as it is often associated with the highest genetic diversity and a rich reservoir of valuable traits that can be utilized for crop improvement.

The concept of the center of origin was first proposed by Russian botanist Nikolai Vavilov in the early 20th century. Vavilov conducted extensive plant collection expeditions and identified several regions around the world that served as centers of origin for various crop species. He observed that these regions were characterized by the presence of a wide range of wild relatives of cultivated crops and exhibited high levels of genetic diversity.

The centre of origin is determined by multiple factors, including the natural distribution of wild relatives, the availability of diverse ecological niches, and the historical interactions between humans and plants. It is in these regions that the process of natural selection and evolution shaped the genetic diversity and traits found in the wild plant populations.

The Center of Origin Holds Immense Importance for Plant Breeders Due to the Following Reasons

1. **Genetic Diversity:** The center of origin often harbours the highest genetic diversity of a crop species. This diversity provides a valuable resource for breeders to access and utilize a wide range of genes and traits for crop improvement, including resistance to diseases, pests, and environmental stresses.

2. **Adaptation:** Plants in the center of origin have evolved and adapted to the local environmental conditions over time. They possess unique traits that enable them to survive and thrive in specific climates, soils, or ecological

niches. Breeders can tap into this adaptation potential to develop crop varieties that are well-suited to similar environmental conditions.

3. **Novel Traits:** The center of origin is known to host wild relatives of cultivated crops that possess traits not found in domesticated varieties. These traits may include resistance to specific pests or diseases, tolerance to abiotic stresses, or nutritional qualities. Breeders can introduce these novel traits into cultivated varieties through breeding and genetic improvement programs.

4. **Conservation:** Identifying the center of origin helps in prioritizing the conservation of wild relatives and their associated genetic diversity. Conservation efforts in these regions are crucial for preserving the genetic resources that may be vital for future crop breeding programs and ensuring the long-term sustainability of agriculture.

Centers of original domestication of some important crop plants as proposed by Vavilov (1926)

	Center	Species Evolve
1	Chinese	Soybean, Apricot, Peach, Orange
2	Indian	Rice, chickpea, cucumber
2a	Indo-Malayan	Banana, coconut
3	Central Asiatic (Afghanistan, Tibet, Iran)	Bread wheat, cereal rye, peas, apple, walnut
4	Near Eastern (Transcaucasia, Turkey, Syria, Southern Russia)	Diploid wheat, barley, lucerne
5	Mediterranean	Durum wheat, oats, broad bean, lettuce, cabbage, olive
6	Abyssinian	Durum wheat, barley, peas, flax
7	South and Central American	Maize, common bean, pepper, cotton (upland), squash, pumpkin
8	South American (Peru, Ecuador, Bolivia)	Sweet potato, potato, Lima bean, tobacco, tomato
8a	Chile	Potato
8b	Brazilian-Paraguayan	Potato

5. **Crop Evolutionary History:** Understanding the center of origin provides insights into the historical processes of crop domestication and the genetic changes that occurred during the transition from wild plants to cultivated

crops. This knowledge enhances our understanding of the genetic basis of important traits and informs breeding strategies.

V. GERMPLASM CONSERVATION

The collection of germplasm refers to the systematic gathering and preservation of plant genetic resources for use in crop improvement programs. Germplasm encompasses the diverse genetic material found within a plant species, including seeds, plant tissues, and reproductive materials. The collection and maintenance of germplasm play a vital role in plant breeding as they provide a valuable resource for breeders to access and utilize genetic diversity for developing improved crop varieties. Here are key aspects of the collection of germplasm: (Singh, B.D. 1990)

1. **Plant Exploration:** Plant breeders and scientists conduct plant exploration expeditions to diverse regions of the world to collect plant materials from their centers of origin, as well as from other areas of interest. These expeditions involve identifying and collecting seeds, plant cuttings, or other reproductive materials of wild relatives, landraces, and locally adapted crop varieties.

2. **Genetic Resource Centers:** Germplasm collections are often maintained in specialized institutions called genetic resource centers or gene banks. These centers serve as repositories for storing and preserving the collected plant materials. They employ specific techniques, such as seed drying, freezing, or cryopreservation, to maintain the viability and longevity of the germplasm.

3. **Documentation and Characterization:** Each collected sample is meticulously documented, including information about its origin, taxonomy, and any available associated data. Additionally, the collected germplasm is characterised and evaluated to identify their key traits, such as disease resistance, yield potential, and nutritional quality. This information aids breeders in selecting suitable genetic resources for specific breeding objectives.

4. **Conservation and Maintenance:** Genetic resource centers implement conservation strategies to ensure the long-term preservation of the germplasm. This involves regular monitoring, periodic viability testing, and regeneration of samples to prevent loss of genetic diversity due to seed aging or accidental damage. Duplicate samples are often maintained in multiple locations to safeguard against natural disasters or other risks.

5. **Access and Exchange:** Germplasm collections are made available to plant breeders, researchers, and other stakeholders through germplasm banks or international seed exchange programs. Access to germplasm resources promotes collaboration, facilitates the exchange of genetic diversity, and allows breeders to incorporate valuable traits into their breeding programs.

6. **Pre-breeding and Breeding Programs:** Plant breeders utilize the collected germplasm as a source of genetic diversity for pre-breeding and breeding efforts. Pre- breeding involves crossing and selection to transfer desired traits from wild relatives or landraces into elite breeding lines. The diverse germplasm resources serve as a genetic toolbox for breeders to introduce novel traits, enhance genetic variability, and develop improved crop varieties.

5.1 Methods of Germplasm Conservation

Germplasm conservation refers to the preservation and maintenance of plant genetic resources for future use. Germplasm encompasses the genetic material found within a plant species, including seeds, tissues, and reproductive materials. These genetic resources are essential for plant breeding, research, and the sustainable development of agriculture. Germplasm conservation aims to safeguard the diversity and variability of plant species to ensure their long-term availability and utilization. It involves collecting, storing, and managing plant genetic resources to prevent genetic erosion and potential loss of valuable traits.

There are two important methods of germplasm preservation.

- In-situ conservation and
- Ex situ conservation.

1. **In-Situ Conservation:** In-situ conservation describes the preservation of germplasm in its natural environment. This is accomplished by preventing human interference in the region; such a place is frequently referred to as a natural park, biosphere reserve, and /or gene sanctuary. Citrus gene sanctuaries were developed in Meghalaya and the northeastern regions for musa, citrus, oryza, and saccharum by NBPGR, New Delhi.

2. **Ex-Situ Conservation:** It refers to the preservation of germplasm in gene banks. This is the most practical method of germplasm conservation and can be achieved in various ways:
   - **Seed Banks:** Seed banks are the most widely used method of germplasm conservation. Seeds are collected, dried, and stored under controlled

temperature and humidity conditions. This method is effective for many plant species as seeds can remain dormant and viable for long periods. Seed banks are often established at different locations to reduce the risk of losing the entire collection due to natural disasters or accidents.

- ***Invitro* Conservation:** In vitro conservation involves maintaining and growing plant tissues, cells, or organs under sterile conditions in a laboratory (Kumar *et al.,* 2023). Techniques such as tissue culture, cryopreservation, and slow growth storage methods (e.g., meristem culture) are used to preserve the genetic material. In vitro conservation is particularly useful for conserving species that do not produce orthodox seeds or are difficult to store as seeds.

- **Field Gene Banks:** Field gene banks are established by planting and maintaining living collections of plant species in their natural or representative environments. This method involves growing plants in designated areas, where they can be monitored and conserved in situ. Field gene banks are often used for maintaining crops with recalcitrant seeds, perennial crops, or plants that require specific environmental conditions.

- **Cryopreservation:** Cryopreservation involves the preservation of plant genetic resources at extremely low temperatures, typically using liquid nitrogen (-196°C). Plant tissues or cells are treated with cryoprotectants to protect them from freezing damage and then stored in liquid nitrogen or in ultra-low temperature freezers. Cryopreservation allows for long-term storage and conservation of plant germplasm with minimal genetic changes.

- **DNA Banks:** DNA banks store the genetic material of plants in the form of purified DNA samples. These samples can be extracted from various plant parts, including leaves, seeds, or stored tissues. DNA banks provide an alternative means of conserving genetic diversity, especially for species that are difficult to maintain as living collections or for those with low seed viability.

- **Community Seed Banks:** Community seed banks involve the active participation of local communities in the conservation and management of plant genetic resources. These banks are established at the community level and focus on conserving locally adapted landraces and traditional crop varieties. Community seed banks promote local ownership, traditional knowledge, and the conservation of crop diversity within specific agroecological contexts.

VI. PLANT INTRODUCTION

Plant introduction, in the context of plant breeding, refers to bringing new plant materials, including varieties, lines, or wild relatives, from their original place of origin or another location to a new area or region for evaluation, utilization, and incorporation into breeding programs. Plant introduction is an important step in accessing and expanding the genetic diversity available for plant breeding purposes. It allows breeders to explore and incorporate novel traits, genetic variability, and adaptive characteristics from different sources into their breeding programs.

Types:
- Primary or Direct plant introduction
- Secondary or Indirect plant Introduction

Primary or Direct Plant Introduction: when a new variety is successfully introduced into an environment and is directly made available for commercial cultivation without any modifications to the original genotype. In civilizations having well-organized crop development systems, it is less frequent.

E.g., Semi dwarf Wheat – Sonora-64, Lerma Rojo, etc, Semi dwarf Rice – TN-1, IR-8, IR-28, etc, Tomato-Sioux, Clark-63, Tobacco- Virginia Gold.

Secondary or Indirect Plant Introduction: When the introduced variety may be subjected to selection to detach a superior variety. Alternatively, it may be hybridized with local varieties to transfer one or a few characters. The introduced material is not used directly as a variety. Hence it is much more common than primary plant introduction.

E.g. Egyptian cotton variety Sujata was published following selection from the Egyptian variety Karnak. Kalyan Sona and Sonalika wheat varieties were chosen from the material imported from CIMMYT, Mexico.

6.1 Purpose of Plant Introduction

Plant introduction provides breeders with access to new sources of genetic diversity, expands the genetic base of breeding populations, and facilitates the development of improved crop varieties. Here are the key purposes of plant introduction in plant breeding:

- **Accessing Genetic Diversity:** Plant introduction allows breeders to access a wider range of genetic diversity present in different regions or centers of origin. By collecting and introducing plant materials from diverse sources, including landraces, wild relatives, or improved varieties, breeders can tap into new genes, alleles, and traits that may be beneficial for crop improvement. This helps to increase the available genetic pool for breeding programs and promotes the development of improved varieties with enhanced agronomic traits and adaptation to changing environments.

- **Incorporating Desirable Traits:** Plant introduction provides breeders with the opportunity to incorporate specific desirable traits into their breeding populations. By introducing plant materials with known or observed traits of interest, such as disease resistance, abiotic stress tolerance, yield potential, or quality attributes, breeders can transfer those traits into their breeding lines or cultivars. This process helps to enhance the performance and productivity of crop varieties and address specific challenges or needs in agriculture.

- **Broadening the Genetic Base:** Plant introduction helps to broaden the genetic base of breeding populations by introducing novel genetic variations. This is particularly important to counteract genetic erosion, which occurs when a limited number of elite varieties dominate agricultural systems. By introducing diverse plant materials, breeders can introduce new allelic combinations, break undesirable linkages, and increase genetic variability, which can lead to the development of more robust and adaptable crop varieties.

- **Developing Adaptable Cultivars:** Plant introduction allows breeders to evaluate and select plant materials for their adaptability to different agroecological conditions. By introducing materials from regions with diverse climates, soil types, or other environmental factors, breeders can identify genotypes that perform well in specific environments or possess traits suitable for particular production systems. This helps develop cultivars well-adapted to different regions, climates, or farming practices, enhancing their productivity and resilience.

- **Enhancing Breeding Options:** Plant introduction expands the breeding options available to plant breeders. It provides them with a wider range of parental lines, populations, or hybrid combinations to work with. By introducing new genetic materials, breeders can create novel crosses, explore new gene combinations, and expand the potential for genetic improvement. This increases the chances of discovering superior genotypes and facilitates the development of improved crop varieties with desirable traits.

6.2 Different Procedure Involves in Plant Introduction

The procedure of plant introduction in plant breeding involves several key steps to ensure the successful acquisition, evaluation, and utilization of new plant materials. While the specific procedures may vary depending on the goals and resources of the breeding program, here are the general steps involved in plant introduction:

- **Exploration and Collection:** Plant breeders and scientists conduct field expeditions to various regions or centers of origin to collect plant materials with desired traits or genetic diversity. This involves identifying target species or populations, obtaining necessary permits, and collecting seeds, cuttings, or other reproductive materials. Proper documentation, including geographical and ecological data, is recorded for each collected sample.

- **Quarantine and Phytosanitary Measures:** After collection, the introduced plant materials are subjected to quarantine procedures and phytosanitary measures. This is done to ensure that potentially harmful pests, diseases, or weeds are not introduced to the receiving country or region. The materials may undergo treatments, inspections, or testing to meet the regulations and minimize the risk of introducing harmful organisms.

- **Seed Processing and Storage:** Collected seeds or other reproductive materials are processed to remove impurities and dried to an appropriate moisture content. Proper seed storage conditions, including temperature, humidity, and light, are maintained to ensure seed viability and longevity. Seeds are often stored in seed banks or germplasm repositories, following established protocols for seed conservation.

- **Evaluation and Screening:** The introduced plant materials undergo evaluation and screening to assess their characteristics, performance, and adaptability. This includes field trials, laboratory analyses, or controlled environment studies to evaluate traits such as yield potential, disease resistance, abiotic stress tolerance, quality attributes, or other specific breeding objectives. Screening helps identify promising materials for further breeding or utilization.

- **Breeding and Genetic Improvement:** Selected plant materials from the introduced collection are integrated into breeding programs. This can involve crossbreeding the introduced materials with local varieties or advanced breeding lines to create new populations or hybrids. Breeding techniques such as selection, hybridization, or backcrossing are employed to combine desirable traits and improve the genetic potential of the breeding lines.

- **Maintenance and Utilization:** The introduced plant materials are maintained through proper seed regeneration, vegetative propagation, or other multiplication methods to ensure their availability for future breeding or utilization. This may involve periodic seed increase, tissue culture, or clonal propagation to maintain the genetic integrity and viability of the materials. The materials may be utilized directly in breeding programs, shared with other breeders, or used for research purposes.

VII. DEVELOPMENT OF SELF-POLLINATED CROPS

7.1 Development through Mass Selection

It involves the selecting of a group of individuals from a population on the basis of their similar phenotype in an attempt to improve the performance of the population for that traits A knowledge of the genetic basis and the extent of the population variability for the character indicates to the crop breeder the potential offered for improvement through selection. In the mass selection procedure, there is no progeny test (in contrast to pure line selection, and progeny selection and line breeding) but the selected population is usually evaluated against the original unselected population to gauge the effectiveness of selection.

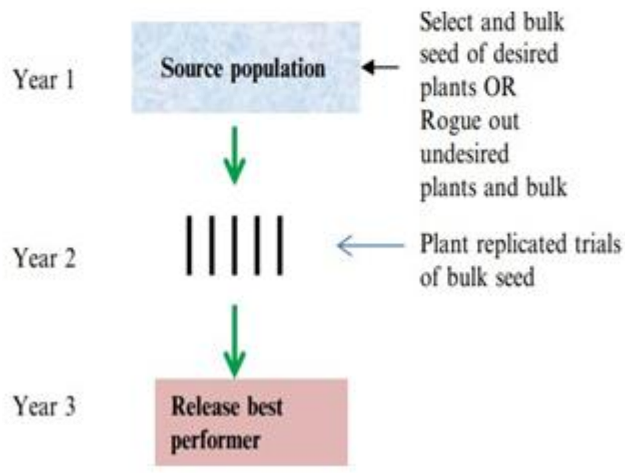


Figure 1: A general procedure of Mass selection can be summarized in the following steps. (Singh, B.D.*1990)*

Merits of Mass Selections

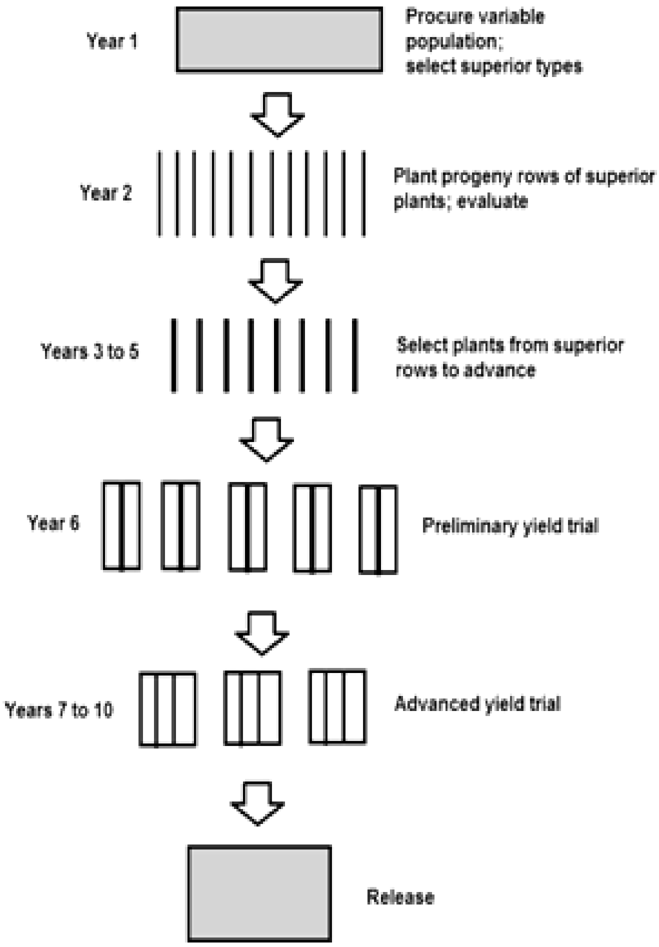
- Variety developed through mass selection having a wider adaptability
- Extensive and prolonged yield trials are not required
- Mass selection retain considerable genetic variability

Demerits of Mass Selection

- Varieties developed via mass selection is not highly uniform
- Without a progeny test, we are unable to determine if the chosen plant is homozygous or heterozygous.
- Mass selection often produces less improvement than pure line selection

7.2 Pureline Selection

The pureline selection method depends on the knowledge that continued selfing of a heterozygous individual or population of a self-pollinated plant species will result in an increasing proportion of the subsequent population becoming homozygous. Eventually all individuals will be homozygous. In crop breeding the parents of a cross usually differ by a large number of gene pairs and this number will influence the number of generations of self- fertilisation necessary for the hybrid population to reach homozygosity. At this point the population would be heterogeneous and composed of a large number of different homozygous individuals. The degree of homozygosity of the hybrid population depends on the number of distinct gene pairs by which the parents fluctuate and the number of generations of selfing since hybridisation.



Year 1: The first step is to obtain a variable base population (e.g., introductions, segregating populations from crosses, land race) and space plant it in the first year, select, and harvest desirable individuals.

Year 2: Grow progeny rows of selected plants. Rogue out any variants. Harvest selected progenies individually. These are experimental strains.

Year 3–6: Conduct preliminary yield trials of the experimental strains including appropriate check cultivars.

Year 7–10: Conduct advanced yield trials at multilocation. Release highest yielding line as new cultivar.

Figure 2: The General Procedure of Pedigree Selection can be summarized in the Following Steps (Singh, *B.D. 1990)*

Advantages of Pureline Selection

- This technique offers the greatest enhancement to the original variety.
- Because pureline selection produces exceedingly uniform varieties, farmers and consumers prefer them.
- Due to extreme consistency, seed certification scheme participants may quickly identify the variety.

Disadvantages of Pureline Selection

- Pureline selection does not provide variety with broader acceptance or stability.
- It require more time, labour, space and other resources than mass selection
- The upper limit of improvement is depended upon the genetic variation present in original population.

7.3 Pedigree Selection

Pedigree selection in plant breeding is a method of selection that involves the systematic mating of individuals with known or superior genetic backgrounds to improve the genetic characteristics of a plant population or variety. It relies on the principle that genetic traits are inherited from parents to offspring and aims to select and propagate individuals with desired traits through controlled breeding.

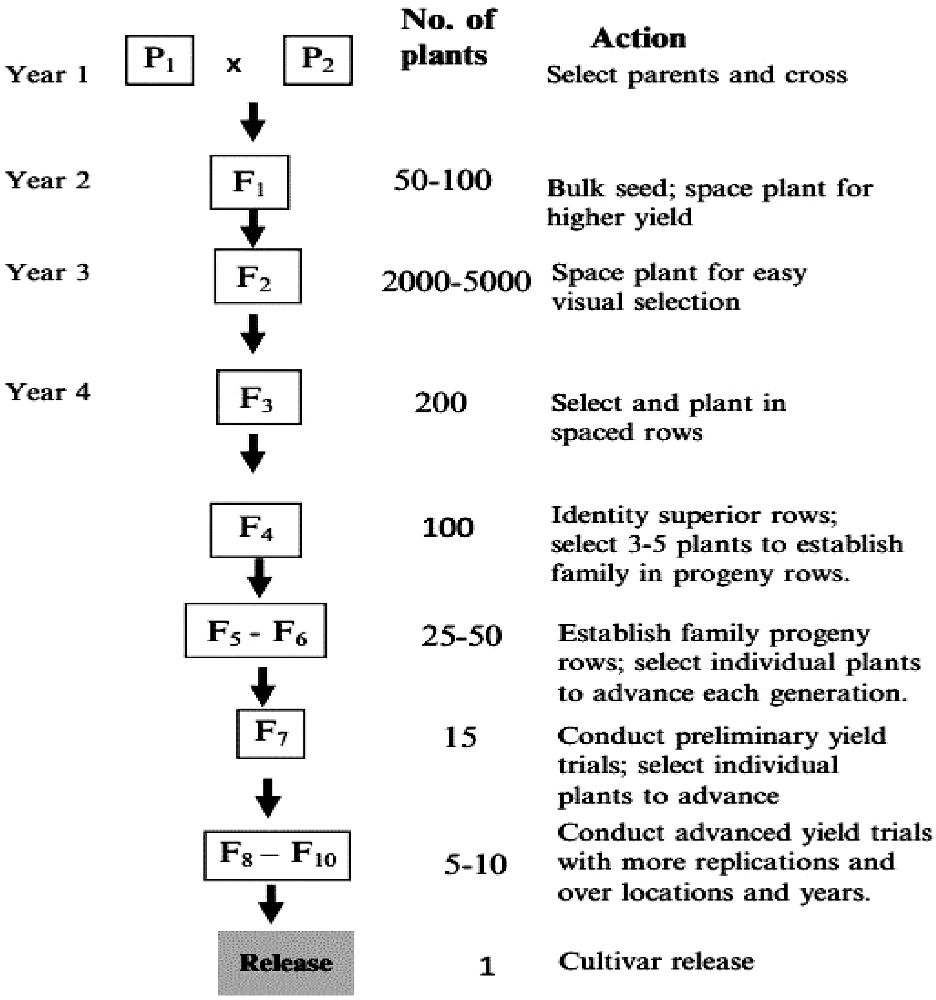


Figure 3: Generalized Steps in Breeding by Pedigree Selection. (Singh, B.D. 1990)

In pedigree selection, the breeding program begins with the identification and selection of superior parent plants based on their known or observed performance for specific traits of interest. These parents, also known as founders or elite lines, possess desirable traits such as high yield, disease resistance, quality attributes, or any other traits targeted for improvement.

The progenies are subsequently evaluated for the traits of interest through phenotypic observations, measurements, or other suitable methods. The performance of the progeny helps in identifying individuals with superior genetic potential for the desired traits. This evaluation can be conducted in controlled environments, field trials, or specific testing locations to assess the performance under different conditions. And based on the evaluation results, individuals with the most desirable trait combinations are selected as parents for the next generation.

Merits of Pedigree Method

1. Selection is based on both genotype (progeny row) and phenotype (phenotype), making it an efficient strategy for choosing superior lines from segregating populations.
2. Provide maximum opportunity to breeder to utilize his skill
3. Method is useful for enhancing traits that are immediately recognisable and easily inherited.

Demerit of Pedigree Method

1. Record keeping is slow, tedious, time consuming, and expensive.
2. Selection has to be carried out between as well as within a large number of progenies in every generation.
3. If a single growing season is possible, pedigree selection takes a long time to complete— up to 10 to 12 years.

7.4 Bulk Population Method of Breeding

The Bulk Population Method, also known as the Bulk Breeding Method or Mass Breeding Method, is a breeding approach used to improve the genetic characteristics of a population or variety. It involves selecting and intermating a large number of individuals within a population without considering their specific genetic makeup. The method is particularly suitable for self-pollinated crops, such as wheat, rice, or barley, where controlled mating is not necessary.

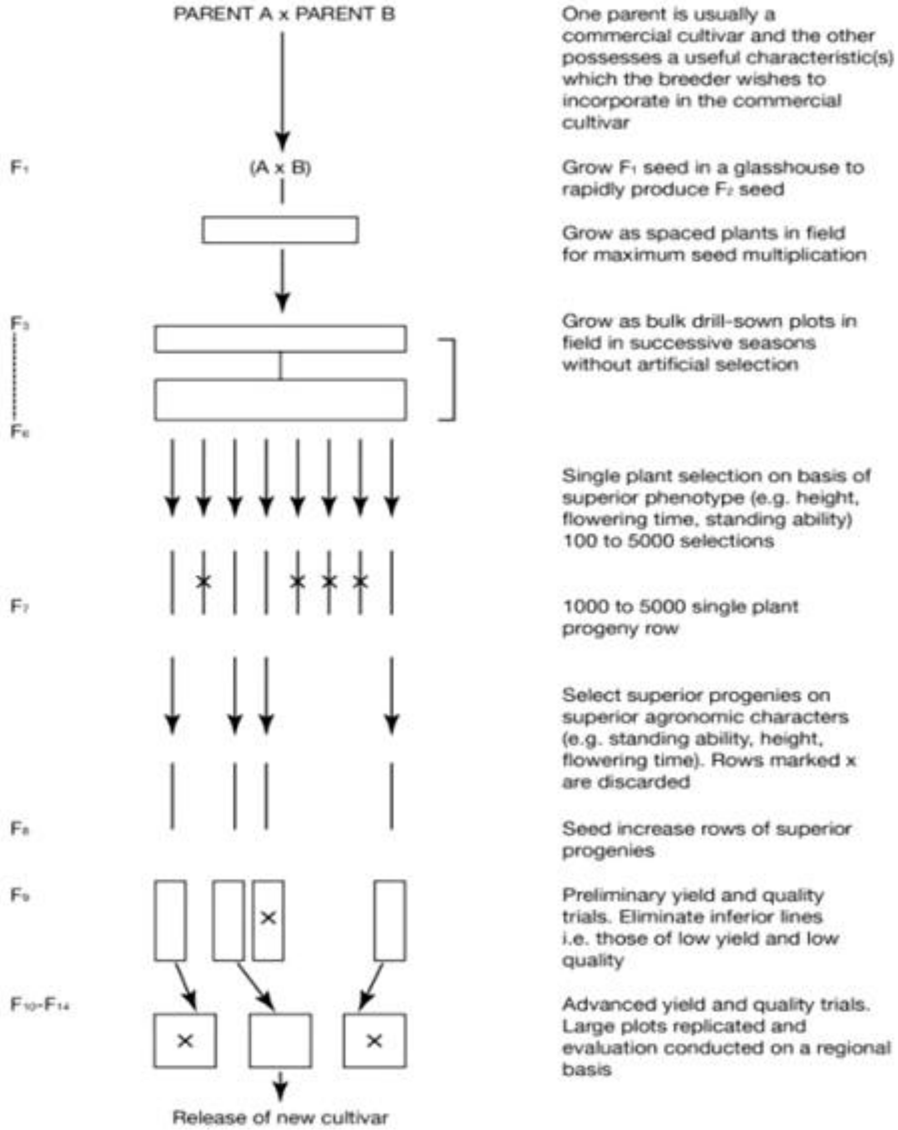


Figure 4: Generalized steps in breeding by bulk population method of Breeding. (Created in Microsoft PowerPoint Presentation) (Singh, B.D. *1990)*

Merits of Bulk Population Method

1. It is simple and convenient to conduct.
2. Natural selection may increase frequency of desirable genotypes by the end of the bulking period.
3. Artificial or natural epigenetics eliminates undesirable types and increases the frequency of desired types.

Demerits of Bulk Population Method

1. This method takes longer time to develop new variety
2. Superior genotypes may be lost to natural selection, while undesirable ones are promoted during the early generations

3. The procedure is lengthy, but cannot take advantage of off-season planting.

7.5 Back Cross Method

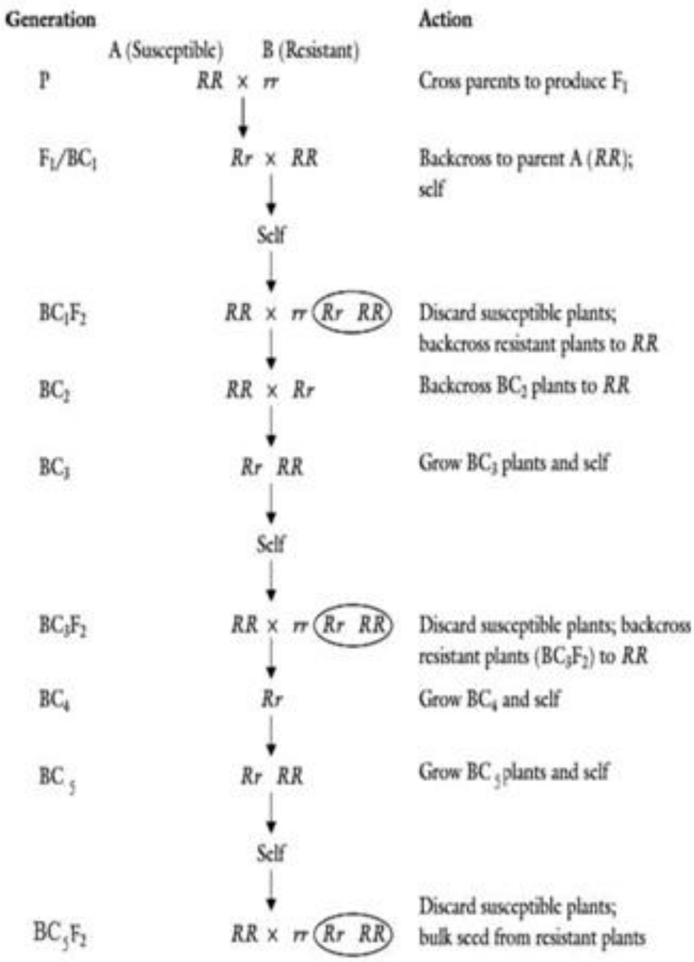


Figure 5: Backcross method for Dominant Gene transfer (created in Microsoft PowerPoint Presentation) (Jain, H. K., *2012)*

The Backcross Method is a plant breeding technique used to transfer a specific trait or traits from one plant (known as the donor or parent) to another plant (known as the recurrent or recipient parent) while maintaining the genetic background of the recurrent parent as much as possible. It is commonly used to introduce desirable traits, such as disease resistance or specific quality attributes, into elite cultivars or varieties.

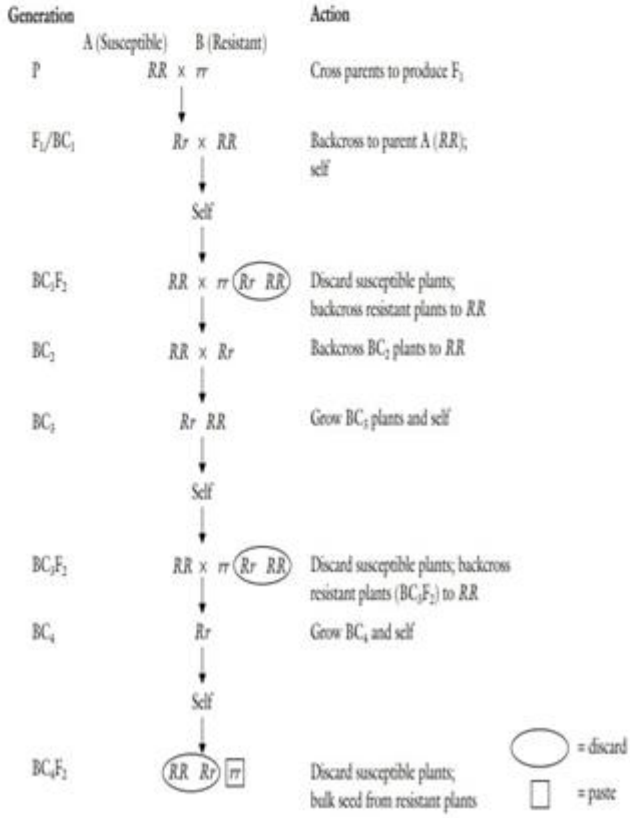


Figure 6: Backcross Method for Recessive Gene Transfer (Created in Microsoft Power Point Presentation) (Singh, B.D. *1990)*

Merits of Backcross Method

1. Cross-breeding program independent of the environment (off-season nurseries and greenhouse facilities can be used to establish breeding programs)
2. Outbreeding is reproducible. If the same parent plant is used, it is possible to recover the backcross cultivar.
3. It is useful for introgressing specific genes from wide crosses.
4. Much smaller population are needed.

Demerits of Backcross Method

1. Backcross is not effective in transferring quantitative traits. Traits should be highly heritable and easily identifiable in each generation.
2. The newly developed variety cannot generally be superior to the old parent variety, except for the transferred trait.
3. The presence of undesirable linkages may prevent the cultivar being improved from attaining the performance of the original recurrent parent.

VIII. SELECTION IN CROSS-POLLINATED CROPS

8.1 Recurrent Selection

Recurrent selection is a plant breeding method that involves multiple cycles of selection and intermating to improve a population or variety over time. It is particularly effective for improving complex traits controlled by multiple genes and is commonly used in both self- pollinated and cross-pollinated crops. Recurrent selection aims to increase the frequency of favourable alleles and enhance the overall genetic potential of the population. Here the 4 types of recurrent selection are discussed:

1. **Simple Recurrent Selection:** This is similar to mass selection with one or two years per cycle. The procedure does not involve the use of a tester. Selection is based on phenotypic scores. This procedure is also called phenotypic recurrent selection.

2. **Recurrent Selection for General Combining Ability:** This is a half-sib progeny test procedure in which a wide genetic based genotype (e.g., a cultivar) is used as a tester. The test cross performance is evaluated in replicated trials prior to selection.

3. **Recurrent Selection for Specific Combining Ability:** This scheme uses an inbred line (narrow genetic base) for a tester. The test cross performance is evaluated in replicated trails before selection.

4. **Reciprocal Recurrent Selection:** This scheme is capable of exploiting both general and specific combining ability. It entails two heterozygous populations, each serving as a tester for the other. Two genetically different populations are altered to improve their crossbred mean. To achieve this, individual plants from two populations (A and B) are selfed and also crossed with plants from the reciprocal female tester population (B and A, respectively).

8.1.1 Simple Recurrent Selection

A number of desirable plants are selected and self pollinated. Separate progeny rows are grown from the selected plants in next generation. The progenies are intercrossed in all possible combination by hand. Equal number of seed from each cross is mixed to raise next generation. This completes original selection cycle. From this, several desirable plants are selected and self pollinated. Progeny rows are grown and inter crosses made. Equal number of seeds are composited to raise next generation. This forms the first recurrent selection cycle.

8.1.2 Recurrent Selection for General Combining Ability

Recurrent selection for general association was proposed by Jenkins in 1935. The progeny werecrossed with a test strain with a broad genetic basis. Thus, trees selected based on the superior performance of their X-tree test subgenus will have a superior GCA.

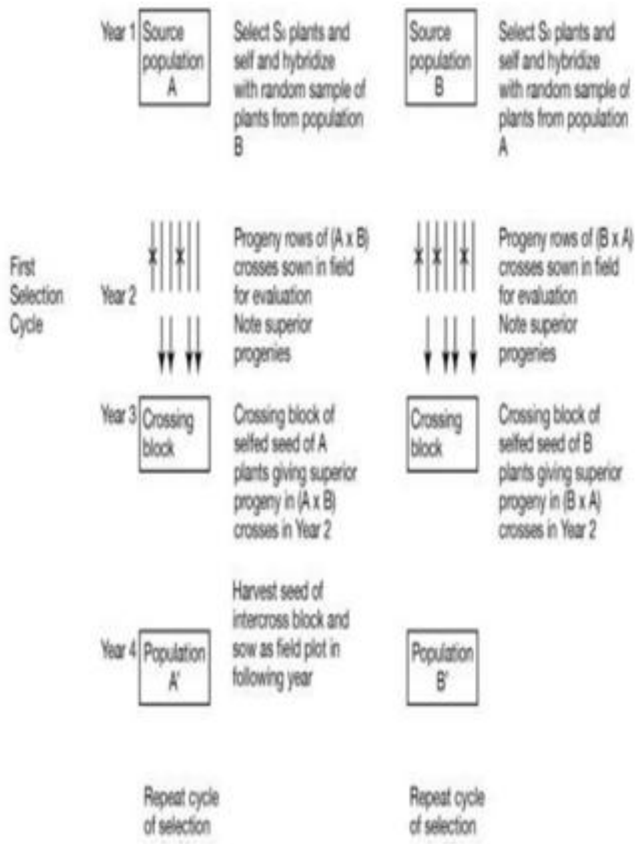


Figure 7: Generalized steps in Simple recurrent selection (created in Microsoft PowerPoint Presentation) (Jain, H. K., 2012)

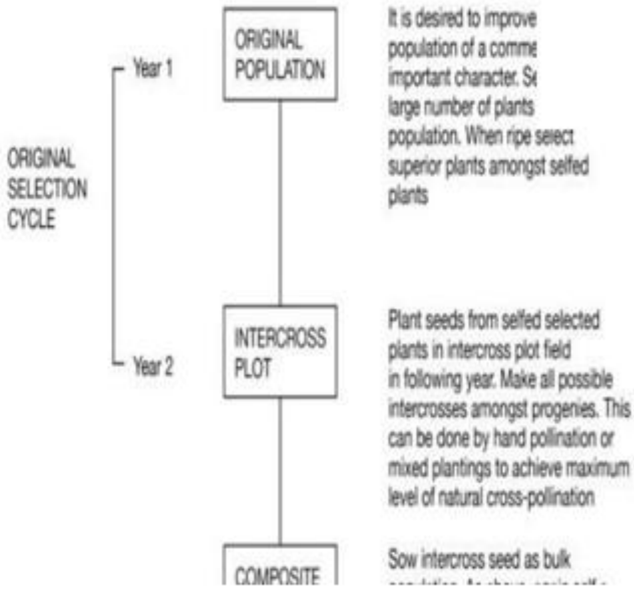


Figure 8: Generalized steps in reciprocal recurrent selection (created in Microsoft PowerPoint Presentation) (Jain, H. K., 2012)

8.2 Selection in Clonally Propagated Crops

Some agricultural crops and a large number of horticultural crops are propagated asexually. Some common asexual crops are sugarcane *(S. officinarum)*, potato *(S.tuberosum)*, sweet potato *(I. batatas)*, Colocasia *(Taro)*, Arum, Dioscorea *(yam)*, Mentha, ginger *(Zingiber sp.)*, turmeric *(C. domestica)*, banana *(Musa paradisiaca)*, etc., most fruit plants such as mango *(Mangifera indica)*, lemon *(Citrus spp.)*, apple *(P. malus)*, pear *(P.communis)*, peach (*P. persica)*, lychee *(Litchi chinensis)*, loquat *(Eriobotrya japonica)* and many kinds of grasses and ornamental plants. Many of these crops exhibit reduced flowering like sugar cane, potatoes, sweet potatoes, bananas, etc., and some of these crops do not show flowering at all. However, a significant number of these crops bloom consistently and yield adequate seeds. The progeny of a single plant obtained by asexual reproduction is called clonal. The process of selecting superior clones from a mixed population of cloned cultures is known as clonal selection. Cultures that are propagated asexually or vegetatively are called clonal propagation or vegetative propagation or clonal culture.The main reasons of asexual reproduction are:

- Non flowering in many cases,
- Reduced flowering and seed set,
- To avoid inbreeding depression in certain crops and
- Apomixis in some species.

Sources of Clonal Selection

1. Local Varieties
2. Introduced Material
3. Hybrids
4. Segregating Populations

Clonal Selection Procedure: Based on these considerations, in the early stages of clonal propagation, when propagating against individual plants or plots, the focus is on eliminating weak and undesirable clones or plants. Breeders cannot reasonably expect to identify dominant genotypes at this stage. At later stages, when repeated trials form the basis of selection, emphasis is placed on identifying and selecting superior clones. The various steps involved in clonal selection are briefly described below and described in Fig 9

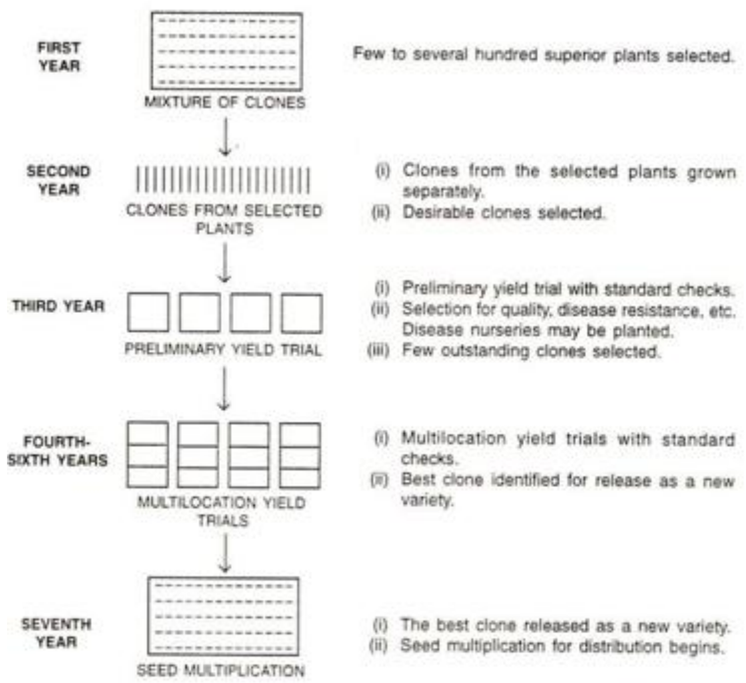


Figure 9: Generalized steps in Clonal Selection (created in Microsoft PowerPoint Presentation) (Jain, H. K., 2012)

Merits of Clonal Selection

1. Stable variety, easy to care for
2. Prevent inbreeding depression
3. Clonal selection, combined with hybridization, produces the variation necessary for some selections.

4. Hybrid vitality is easy to use. Selection can be used to maintain clone purity.

Demerits of Clonal Selection

1. Selection uses natural variability already present in the population.
2. Sexual reproduction is necessary for the generation of sources of variation by hybridization.
3. Only applicable to vegetatively propagated plants.

Achievement through clonal selection:

1. Kufri Red from Darjeeling Red Round
2. Kufri Safed from phulwa
3. Bombay green banana is a selection of shoots from the Cavendish dwarf species, pidimonthan de Monthan.

8.3 Hybridization

8.3.1 History of Hybridization: Thomas Fairchild 1717 was the first to perform outcrossing. It creates a hybrid between two species of Dianthus

Dianthus caryophyllus (Carnation) x *Dianthus barbatus* (Sweet william)
The intergenerational hybrid was created in 1928 by Karpechenko, a Russian scientist. Raphano brassica is a diploid form of the cross between a radish *(Raphanus sativus)* and a cabbage *(Brassica oleraceae).* Triticale was produced by Rimpau in 1890. Triticale is a diploid derived from the cross between wheat and rye. Another example is the preciousness of Saccharum in relation to three species.

8.3.2 Introduction

During the 20th century, planned crosses between carefully selected parents became dominant in the breeding of self-pollinated species. The goal of crossbreeding is to combine desired genes found in two or more different breeds to produce purebred offspring that are superior in many respects to the parental type. Hybridization relies heavily on sexual mating between the same species of two genetically distant lineages, but the existence of different reproductive barriers restricts mating to sexually compatible groups, limiting gene flow and limiting opportunities to improve genotypes of the crops.

Based on the nature & relationship of plants to be crossed, hybridization can be-Inter-varietal – Cross between plants of two difference variety of same species. Intra-varietal – Cross between two plants of difference genotypes but same variety. Inter-specific – Cross between two species of genus - Eg. Wheat, Cotton, Tobacco Inter-generic – Cross between two diff. genera. Eg. Sugarcane X Bamboo, Wheat X Rye, Radish X Cabbage.

Objectives

1. To evolve a variety with desirable characters. Eg. High yield, good quality, disease resistance, drought tolerance, etc.
2. To produce useful variations by introducing recombination of characters.
3. To produce and utilize hybrid vigour.

8.3.3 Procedure of Hybridization

1. Selection of parents

a. First step of hybridization.
b. Select the desired male and female plants.
c. Parent plants must be healthy and strong.
d. Parents must be isolated and self-pollinated to become homozygous for the desired trait.
e. Keep in mind all the important characters you need to combine.
f. Both parents must mature at the same time

2. Selfing of parents or artificial self-pollination:

a. Second stage of hybridization.
b. Make your parents pure of character.
c. Made by artificial self fertilization.
d. Pollination - Cover with paper bags prior to flowering to prevent natural cross- pollination.
e. Self-pollination will occur inside the paper bag.
f. In cross-pollinated crops, male and female flowers are packaged separately before flowering.
g. When the stigma becomes receptive, pollen grains are collected and applied to the stigma. This is artificial pollination.
h. This process continues until the parent is homozygous or pure for a particular trait.

3. Emasculation

a. 3rd step in hybridization.
b. Exclusion of stamens from female parent earlier they burst & shed pollen.

c. Done to prevent self-pollination.
d. Prepare for flower buds that open in next day.
e. These buds can be identified by their unenlarged corollas.
f. Hand Emasculation or Forceps or Scissor Method
g. Hot Water Treatment
h. Cold Water Treatment
i. Alcohol Treatment Method
j. Suction Method
k. Male Sterility or Self-incompatibility Method
l. Chemical Gametocides.

4. **Bagging:** After emasculation, the flower buds are kept sealed in a plastic bag, cellophane or paper bag of the ideal size. The Bags are tied by thread, wire, pins, etc. This process is called bagging. Both male & female flowers - bagged separately to prevent contamination of any foreign pollen. Bagging is usually done before anthesis.

5. **Tagging:** Emasculated flowers are labelled immediately after packaging. A commonly used round tag of about 3 cm or a rectangular tag of about 3 x 2 cm is used. The tag is attached with thread to the base of the flower or inflorescence.

6. **Crossing:** It is the sixth step. It can be defined as artificial cross-pollination between genetically dissimilar plants. In this method, mature, fertile, viable pollen from the male parent is placed on the receptive stigma of a castrated flower to induce fertilization. Pollen grains are collected in petridishes (e.g., wheat, cotton, etc.) or paper bags (e.g., corn) and applied to the soluble stigma using a camel hair brush, paper sheet, toothpick or tweezers.

7. **Harvesting and Storing the F1 Seeds:** The pods or pods of the desired plant are harvested, completely dried and then threshed. Seeds are stored properly with original tags. They may exhibit hybrid vigour – increased growth, size, yield, function, etc. over the parents.

8. **Raising the F1 Generation:** The next season, the stored seeds are sown separately to grow the F1 generation. Plants of the F1 generation are hybrids as they are descendants of seed crosses.

8.3.4 Hybridization in Cross Pollinated Crops

Common cross-pollinated crops include maize, rye, cucurbits, fruit trees, and fodder crops with desirable traits scattered across different pure lines (inbreds). The characters can be combined in any of the following ways- Single cross, three way cross, Synthetic cross, Doublecross and Top cross.

Single Cross: It is the cross between two inbreeds (pure lines) Eg. A X B or C X D. The produced hybrids are directly distributed to farmers for cultivation purpose.

Double Cross: It is a cross between the F1 hybrids of two different single crosses, each involving two different inbreeds.

1st single cross A X B & C X D 2nd single cross
F1 hybrid AB X CD F1 Hybrid
ABCD Double cross hybrid.

Three Way Cross: Here Cross between F1 hybrid of a single cross & an inbred which is used as male parent.

A X B Single cross
AB F1 Hybrid
AB X C Three way cross

8.3.5 Difficulties in Conducting Hybridization

1. **Isolation of Suitable Parents:** The most difficult part of hybridization is to isolate the desirable inbreds to be used as parents and the hybrids to establish the variety. This requires extensive careful observation, thorough field testing & keeping records, etc.

2. **Different times of Maturity:** Usually plants grown in the same season are selectedforcrossing but they may not flower together due to differences in their time of maturity. This can be modified byaltering the sowing period in such a way that both male and female plants flower at once. In some cases, pollen grains are well-preserved.

3. **Incompatibility and Sterility:** This are common in both inter specific and intergeneric crosses. Lack of pollen germination& failure of fertilization

may be due to incompatibility. Hybrid pollen sterility is the main handicap in inter generic crosses duetogene imbalance.

4. **Flower Injury during Emasculation:** In some cases, flowers may be damaged or damaged during emasculation, resulting in hybridization failure.

IX. CONCLUSION

This chapter has summarised conventional breeding methods in plant, which have been the backbone of agricultural advancements for centuries. These traditional approaches have played a vital role in developing new crop varieties that possess improved traits, such as higher yields, and better adaptation to specific environments. Through the process of selective breeding, plant breeders have successfully manipulated the genetic composition of plants to enhance desirable characteristics. Techniques like mass selection, pedigree breeding, recurrent selection & backcross method have provided valuable tools for breeders to achieve their goals. These methods rely on careful observation, rigorous selection, and controlled crosses to achieve desired outcomes. Genetic diversity serves as a reservoir of potentially beneficial traits, offering breeders the opportunity to tap into a wider range of genetic resources for crop improvement. Maintaining and preserving genetic diversity is crucial to ensure the resilience and adaptability of cultivated plants in the face of changing environmental conditions and emerging challenges.

While conventional methods have proven effective in the past, they do have limitations. They can be time-consuming and labour-intensive, requiring several generations of breeding before desired traits are fully fixed. In recent years, advancements in molecular biology and genetic engineering have led to the emergence of alternative breeding techniques, such as marker-assisted selection and transgenic approaches. These methods offer new opportunities for precise trait manipulation and accelerated breeding progress. However, it is essential to recognize that conventional breeding methods still hold tremendous value. They provide a solid foundation for plant breeding practices and remain relevant, particularly in regions with limited access to advanced technologies or concerns regarding the acceptance of genetically modified organisms (GMOs). Conventional breeding methods have played a significant role in shaping our agricultural landscape and have contributed to enhancing crop productivity. To ensure that we can continue to feed future generations, it's important to find a balance between conventional and modern farming methods. By combining the strengths of both approaches, we can meet the challenges of a changing world and ensure food security. As newer techniques develop, it's crucial to remember the importance of conventional methods while also embracing new innovations. This will help us achieve sustainable and reliable food production for the future.

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Self Assessment

1. Which of the following related to plant breeding?
   a. enhance the yield of crops
   b. Purposeful manipulation of crop
   c. Develop disease and pest resistant plants
   d. **All of the above**

2. Pollen grains are transferred from the anthers of a flower to the stigma of the same flower is known as
   a. in vitro fertilization
   b. Xenogamy
   c. **Autogamy**
   d. Geitonogamy

3. Find the monocotyledonous plant in following options
   a. Ground nut
   b. Rice
   c. Black gram
   d. Berseem

4. Which of the following is not involved in classical plant breeding practices?
   a. The hybridization of pure lines
   b. Artificial selection of plants
   c. Desirable traits of higher yield
   d. **Molecular biology**

5. Which is not genetically modified crops.
   a. BT-Brinjal
   b. Golden rice
   c. BT-Cotton
   d. BN-Hybrids

6. Pusa Gaurav develop by breeding for disease resistance against aphids is a variety of:
   a. cowpea
   b. BN hybrids
   c. Okra
   d. Rape seed mustard

7. Heritabilty of a character within a pure line is :
   a. 50%
   b. Zero
   c. **100%**
   d. 75%

8. Who demonstrated that gene are located in the chromosomes?
   a. Meselson and Stahl
   b. Franklin
   c. Chargaff
   d. Morgan

9. Term addition decay was coined by:
   a. Riley and Kimber
   b. E.R. Sears
   c. Unrau et a.
   d. Driscoll

10. Hardy Weinberg law is applicable for maintenance of genetic purity in
    a. Inbreds
    b. Composites
    c. Hybrids
    d. Pure line