Fundamentals of Plant Breeding

Plant breeding is an art and science of changing the genetics of plants for the benefit of humankind. Plant breeding can be accomplished through many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to more complex molecular techniques Plant breeding has been practiced for thousands of years, since near the beginning of human civilization. It is now practiced worldwide by individuals such as gardeners and farmers, or by professional plant breeders employed by organizations such as government institutions, universities, crop-specific industry associations or research centers.

International development agencies believe that breeding new crops is important for ensuring food security by developing new varieties that are higher-yielding, resistant to pests and diseases, drought-resistant or regionally adapted to different environments and growing conditions.

Nature of Plant Breeding

Plant breeding is an art or science and is as old as agriculture, started since man learnt to cultivate the plants. In earlier days, man depends on his skill and judgement in selecting better plants. His knowledge about the plant was very limited. He knew nothing about the inheritance of characters, role of environment in producing them and the basis of variation in various plant characters. His method of selection was designed without the understanding of the principle of inheritance. Therefore, during primitive time plant breeding was largely an art and very less science was involved in that, but the present breeding methods are entirely based on the scientific principles of plant sciences, particularly of genetics a cytogenetic. Thus, plant breeding is purely science with very little art involved. Science is the knowledge gathered through scientific method. The scientific method consists of observation, formulation of hypothesis, experimentation and conclusion either to accept or reject the hypothesis.

Plant breeding is considered as the current phase of crop evolution. As the knowledge of genetics and other related science progresses plant breeding become less art and more science. Especially discovery of Mendel's work in 1900, added lot to the knowledge of science. Selection of desirable plant even today is an art it depends on the skill of a person but alone skill is not enough, modern plant breeding is based on through understanding and use of genetics principles. To be successful, a plant breeder must know each and everything

about the crop with he is working. He should have an understanding of principles of difference disciplines viz. Genetics, Cytology, Morphology and Taxonomy, Plant Physiology, Plant Pathology, Entomology, Agronomy, and Soil Science, Biochemistry, Statistics, and Biometrics, Computer and Plant biotechnology. Thus, plant breeding is an art science and a technology of developing genetically superior plants in terms of the economics utility for the mankind.

Objectives of Plant Breeding:

Plant breeding aims to improve the characteristics of plants so that they become more desirable agronomically and economically. The specific objectives may vary greatly depending on the crop under consideration.

1. Higher yield: The ultimate aim of plant breeding is to improve the yield of economic produce. It may be grain yield, fodder yield, fibre yield, tuber yield, cane yield or oil yield depending upon the crop species. Improvement in yield can be achieved either by evolving high yielding varieties or hybrids.

2. Improved quality: Quality of produce is another important objective in plant breeding. The quality characters vary from crop to crop. e.g. grain size, colour, milling and backing quality in wheat. Cooking quality in rice, malting quality in barley, size, colour and size of fruits, nutritive and keeping quality in vegetables, protein content in pulses, oil content in oilseeds, fibre length, strength and fineness in cotton.

3. Abiotic resistance: Crop plants also suffer from abiotic factors such as drought, soil salinity, extreme temperatures, heat, wind, cold and frost, breeder has to develop resistant varieties for such environmental conditions.

4. Biotic resistance: Crop plants are attacked by various diseases and insects, resulting in considerable yield losses. Genetic resistance is the cheapest and the best method of minimizing such losses. Resistant varieties are developed through the use of resistant donor parents available in the gene pool.

5. Change in maturity Duration / Earliness: Earliness is the most desirable character which has several advantages. It requires less crop management period, less insecticidal sprays, permits new crop rotations and often extends the crop area. Development of wheat varieties suitable for late planting has permitted rice-wheat rotation. Thus, breeding for early maturing crop varieties, or varieties suitable for different dates of planting may be an important objective. Maturity has been reduced from 270 days to 170 days in cotton, from 270 days to 120 days in pigeonpea, from 360 days to 270 days in sugarcane.

6. Determinate Growth: Development of varieties with determinate growth is desirable in crops like Mung, Pigeon Pea (*Cajanus cajan*), Cotton (*Gossypium sp*.), etc.

7. Dormancy: In some crops, seeds germinate even before harvesting in the standing crop if there are rains at the time of maturity, e.g., Greengram, Blackgram, Barley and Pea, etc. A period of dormancy has to be introduced in these crops to check loss due to germination. In some other cases, however, it may be desirable to remove dormancy.

8. Desirable Agronomic Characteristics: It includes plant height, branching, tillering capacity, growth habit, erect or trailing habit etc., is often desirable. For example, dwarf ness in cereals is generally associated with lodging resistance and better fertilizer response. Tallness, high tillering and profuse branching are desirable characters in fodder crops.

9. Elimination of Toxic Substances: It is essential to develop varieties free from toxic compounds in some crops to make them safe for human consumption. For example, removal of neurotoxin in Khesari (*Lathyruys sativus*) which leads to paralysis of lower limbs, erucic acid from Brassica which is harmful for human health, and gossypol from the seed of cotton is necessary to make them fit for human consumption. Removal of such toxic substances would increase the nutritional value of these crops.

10. Non-shattering characteristics: The shattering of pods is serious problem in green gram. Hence resistance to shattering is an important objective in green gram.

11. Synchronous maturity: It refers to maturity of a crop species at one time. The character is highly desirable in crops like Greengram, Cowpea, and Cotton where several pickings are required for crop harvest.

12. Photo and Thermo insensitivity: Development of varieties insensitive to light and temperature helps in crossing the cultivation boundaries of crop plants. Photo and thermo-insensitive varieties of wheat and rice has permitted their cultivation in new areas. Rice is now cultivated in Punjab, while wheat is a major *rabi* crop in West Bengal.

13. Wider adaptability: Adaptability refers to suitability of a variety for general cultivation over a wide range of environmental conditions. Adaptability is an important objective in plant breeding because it helps in stabilizing the crop production over regions and seasons.

14. Varieties for New Seasons: Traditionally Maize is a *kharif* crop. But scientists are now able to grow Maize as *rabi* and *zaid* crops. Similarly, mung is grown as a summer crop in addition to the main kharif crop.

Major achievements of Plant Breeding

Development of dwarf and semi dwarf cereal varieties

Many dwarf and semi dwarf varieties are developed in crop like wheat and Rice. Dr. Borlaug used a Japanese variety NORIN-10 as a source of dwarfing gene, in wheat at CIMMYT (Mexico). In 1963, ICAR has introduced some dwarf selection from CMMYT. Variety Kalyansona and Sonalika were selected from these materials. In India, majority of the wheat varieties grown are semi dwarf, and are resistant to water lodging, responsive to fertilizer doses etc. Similarly, the development of semi dwarf varieties of rice has revolutionized rice cultivation. These varieties were developed by introducing the gene Dee-Geo-Woo-Gene. e.g. TN1 variety developed at Taiwan and IR-8 at IRRI Philippines, both were introduced in India in 1966.

Noblisation of Indian Canes

The Indian canes were of *Saccharum barberi,* largely grown in North India. They were hardy but poor in yield and sugar content, while tropical cane of *Saccharum officinarum* had thicker stem and higher sugar content but, it performed badly in North India due to low winter temperature. C.A. Barber and T.S Venkatraman at Sugarcane Breeding Institute, Coimbtore transferred thick stem higher sugar content and other desirable characters from the noble cane to Indian cane is commonly referred as nobilization on of Indian canes.

Development of Hybrid and Synthetic varieties in millets

Development of hybrid varieties in maize, sorghum and pearl millet enhanced the production of these crops in the country. First maize hybrid was released in India in 1957.

a) Maize- Canga series of hybrid, Ganga safed-2, African Tall, Manjari, Deccan etc.

b) Sorghum -CSH-1,2,3,4,5,6,7,8,910,12,14 and 15 R.

c) Bajra-WCC-75, PHB-10, ICTP-8203, Shradha and Saburi.

Hybrid cotton

First cotton hybrid was developed in India in 1970 named H4 at Surat station of Gujrat Agriculture University. After that many intervarietal and interspecific cotton hybrids were developed which further increased the area under hybrid cotton and enhanced the production of cotton in the country. e.g. H-4, Varalaxmi, Savitri, NH-44, Jaylaxmi, etc.

Molecular Breeding

Use of molecular biology techniques to supplement conventional plant breeding further enhanced the efficiency of various breeding methods. **Marker assisted selection** or **marker aided selection (MAS)** is a process whereby a marker (morphological, biochemical or one based on DNA/RNA variation) is used for indirect selection of a genetic determinant or determinants of a trait of interest (i.e. productivity, disease resistance, abiotic stress tolerance, and/or quality). Many varieties in rice, maize and wheat were developed with help of MAS

and released for commercial cultivation in India. e.g. Improved Pusa Basmati1, Improved Samba Mahsuri in rice, maize hybrid Vivek QPM9 etc.

Transgenic varieties

Recombinant DNA technology is most powerful tool for creating crops with novel desired phenotypes or designer crops. Genetic modification of plants is achieved by adding a specific gene or genes to a plant, or by knocking out a gene with RNAi, to produce a desirable phenotype. The plants resulting from adding a gene are often referred to as transgenic plants. Genetic modification can produce a plant with the desired trait or traits faster than classical breeding because the majority of the plant's genome is not altered.

The majority of commercially released transgenic plants, are currently limited to plants that have introduced resistance to insect pests and herbicides. Insect resistance is achieved through incorporation of a gene from *Bacillus thuringiensis* (*Bt*) that encodes a protein that is toxic to some insects. For example, the cotton bollworm, a common cotton pest, feeds on Bt cotton it will ingest the toxin and die. Herbicides usually work by binding to certain plant enzymes and inhibiting their action. The enzymes that the herbicide inhibits are known as the herbicides *target site*. Herbicide resistance can be engineered into crops by expressing a version of *target site* protein that is not inhibited by the herbicide. This is the method used to produce glyphosate resistant crop plants Genetic modification of plants that can produce pharmaceuticals (and industrial chemicals), sometimes called *pharma crops*, is a rather radical new area of plant breeding.

Undesirable consequences

Plant breeding has several useful applications in the improvement of crop plants. However, it has five main undesirable effects on crop plants.

1. Reduction in diversity/Genetic erosion: Modern improved varieties are more uniform than land races. Thus, plant breeding leads to reduction in diversity. The uniform varieties are more prone to the new races of pathogen than land races which have high genetic diversity.

2. Narrow genetic base: Uniform varieties have narrow genetic base. Such varieties generally have poor adaptability.

3. Danger of uniformity: Most of the improved varieties have some common parents in the pedigree which may cause danger of uniformity.

4. Undesirable combinations: Sometimes, plant breeding leads to undesirable combinations. The examples of manmade crops having undesirable combination of characters are Raphanobrassica and Pomato.

5. Increased susceptibility to minor diseases and pests: Due to emphasis on breeding for resistance to major diseases and insect pests often resulted in an increased susceptibility to minor diseases and pests. These have gained importance and, in some cases, produced severe epidemics. The epidemic caused by *Botrytis cinerea* (grey mold) in chickpea during 1980-82 Punjab, Haryana. The severe infection by Karnal bunt (*Tilletia sp*.) on some wheat varieties, infestation of mealy bugs in Bt cotton.

Future Prospects

From times immemorial, the plant breeding has been helping the mankind. With knowledge of classical genetics, number of varieties have been evolved in different crop plants. In order to combat the global alarm created by population explosion, the food front has to be strengthened which is serious challenge to those scientists concerned with agriculture. Advances in molecular biology have sharpened the tools of the breeders, and brighten the prospects of confidence to serve the humanity. The application of biotechnology to field crop has already led to the field testing of genetically modified crop plants. Genetically engineered Rice, Maize, Soybean, Cotton, Oilseeds Rape, Sugar Beet and Alfalfa cultivars are expected to be commercialized before the close of 20th century. Genes from varied organisms may be expected to boost the performance of crops especially with regard to their resistance to biotic and abiotic stresses.

In addition, crop plants are likely to be cultivated for recovery of valuable compounds like pharmaceuticals produced by genes introduced into them through genetic engineering. It may be pointed out that in Europe hirudin, an anti-thrombin protein is already being produced from transgenic *Brassica napus*.

Different phases of Plant Breeding

1. Domestication

The process of bringing a wild species under human management is referred to as domestication. Domestication may be the most basic method of plant breeding. Domestication continuous today and is likely to continue for some time in future.

During the long period of historic cultivation, natural selection has definitely acted on the domesticated species. Movement of man from one place to another brought about the movement of his cultivated plant species. This map shows the sites of domestication for a number of crops. Places where crops were initially domesticated are called centers of origin

Plant breeding in certain situations may lead the domestication of wild plants. Domestication of plants is an artificial selection process conducted by humans to produce plants that have more desirable traits than wild plants, and which renders them dependent on artificial (usually enhanced) environments for their continued existence. The practice is estimated to date back 9,000-11,000 years. Many crops in present day cultivation are the result of domestication in ancient times, about 5,000 years ago in the Old World and 3,000 years ago in the New World. In the Neolithic period, domestication took a minimum of 1,000 years and a maximum of 7,000 years. Today, all of our principal food crops come from domesticated varieties.

A plant whose origin or selection is due primarily to intentional human activity is called a cultigen, and a cultivated crop species that has evolved from wild populations due to selective pressures from traditional farmers is called a landrace. Landraces, which can be the result of natural forces or domestication, are plants (or animals) that are ideally suited to a particular region or environment. An example are the landraces of rice, *Oryza sativa* subspecies *indica*, which was developed in South Asia, and *Oryza sativa* subspecies *japonica*, which was developed in China.

2. Selection

i.) Mass selection

ii.) Pureline selection

iii.) Recurrent selection

3. Hybridization

i.) Intervarietal/Intraspecific

ii.) Distant Hybridization

a) Interspecific/Intrageneric
b) Intergeneric
c) Somatic hybridization

4. Creation of novel genetic variations

i) Mutation

ii.) Polyploidy

iii.) Somaclonal variation

iv.) Gametoclonal variation

5. Genetic engineering/Recombinant DNA technology

Activities of Plant Breeding

The desired changes in the 'genotypes of crop species mi the consequent benefits to the farmers are brought about by a series interrelated and largely interdependent activities. Major activities of plant breeding are following;

1. Creation - variation
2. Selection
3. Evaluation
4. Release
5. Multiplication
6. Distribution of the new variety

Creation of variation: Genetic variation is a prerequisite for any improvement in a crop. Therefore, in any breeding programme, this is always the first step unless variation pre-exists. Genetic variation can be created by domestication, germplasm collections, plant introduction, hybridization, mutation, polypolidy, somaclonal variation and genetic engineering.

Selection: The next step consists of identification and isolation of plants having the desirable combinations of characters, and growing their progeny, this is called selection. Selection is necessarily based on phenotype. The efficiency of this activity determines the success of a breeding programme. Various breeding methods have been designed to increase the efficacy of selection. Selection finally yields an improved line/ stream of population.

Evaluation: The newly selected lines/strains/population are tested for yield and other traits and their performance is compared with the existing best varieties called checks. Evaluation

is a stepwise process, ordinarily conducted at several locations for three or more years under the concerned. All India coordinated crop improvement project. If the new line/strain/population is superior to the checks, it is released and notified as the new variety and its seed can now be multiplied and, more importantly, certified by a seed certification agency for quality.

Multiplication: This step concerns with the large scale production of certified seed of the released and notified variety. Seed production is usually done by seed production agencies in a step wise manner, and the seed is certified by a seed certification agency.

Distribution: Certified seed is ultimately sold to the farmers who use it for commercial crop cultivation. This activity alone makes it possible to reap the economic benefits from the above activities in form of: (i) an enhanced and (ii) Stable production of (iii) Superior produce (iv) often at a lower cost.

MODE OF REPRODUCTION

Knowledge of the mode of reproduction and pollination is essential for a plant breeder, because these aspects help in deciding the breeding procedures to be used for the genetic improvement of a crop species. Choice of breeding procedure depends on the mode of reproduction and pollination of a crop species.

Reproduction refers to the process by which living organisms give rise to the offspring of similar kind (species). In crop plants, the mode of reproduction is of two types: viz. 1) Asexual reproduction and 2) Sexual reproduction

I. Asexual reproduction

Multiplication of plants without the fusion of male and female gametes is known as asexual reproduction. Asexual reproduction can occur either by vegetative plant parts or by vegetative embryos which develop without sexual fusion (apomixis). Thus, asexual reproduction is of two types: viz. a) vegetative reproduction and b) apomixis.

Vegetative reproduction refers to multiplication of plants by means of various vegetative plant parts. Vegetative reproduction is again of two types: viz. i) natural vegetative reproduction and ii) artificial vegetative reproduction.

Natural vegetative reproduction

In nature, multiplication of certain plants occurs by underground stems, sub aerial stems, roots and bulbils. In some crop species, underground stems (a modified group of stems) give rise to new plants. Underground stems are of four types: viz. rhizome, tuber, corm and bulb. The examples of plants which reproduce by means of underground stems are given below:

Rhizome: Turmeric (*Curcuma domestica),* Ginger (*Zingiber officinale)*

Tuber: Potato *(Solanum tuberosum)*

Corm: Arvi *(Colocasia esculenta*), Bunda (*C. antiquorum*)

Bulb: Garlic (*Allium sativum),* onion (*A. cepa)*

Rhizome: Turmeric

Tuber: Potato

Bulb: Onion

Sub aerial stems include runner, sucker, stolon, etc. These stems lead to vegetative reproduction in mint (*Mentha spp*) rose, strawberry, banana, etc.

Bulbils are modified forms of flower. They develop into plants when fall on the ground. Bulbils are found in garlic.

Artificial vegetative reproduction

Multiplication of plants by vegetative parts through artificial method is known as artificial vegetative reproduction. Such reproduction occurs by cuttings of stem and roots, and by layering and grafting. Examples of such reproduction are given below:

Stem cuttings: Sugarcane (*Saccharum* sp.) grapes (*Vitis vinifera*), roses, etc.

Root cuttings: Sweet potato, citrus, lemon, etc.

Layering and grafting are used in fruit and ornamental crops.

Significance of Vegetative Reproduction

Vegetatively reproducing species offer unique possibilities in breeding. A desirable plant may be used as a variety directly regardless of whether it is homozygous or heterozygous. Further, mutant buds, branches or seedlings, if desirable, can be multiplied and directly used as varieties.

Apomixis

Apomixis refers to the development of seed without sexual fusion (fertilization). In apomixis embryo develops without fertilization. Thus apomixis is an asexual means of reproduction. Apomixis is found in many crop species. Reproduction in some species occurs only by apomixis. This apomixis is termed as **obligate apomixis**. But in some species sexual reproduction also occurs in addition to apomixis. Such apomixis is known as **facultative apomixis**.

There are two types of apomixis: *viz*.

A) Adventive embryony

B) Gametophytic apomixis

a) Apospory

b) Diplospory

i) Pathenogenesis

ii) Peudogamy

Adventive embryony

The development of embryo directly from the diploid cells of ovule lying outside the embryosac belonging to either nucellus or integuments is referred to as adventive embryony.

Gametophytic apomixis

In this form of apomixis, embryo develop without fertilization from egg cell or other cells of embryo sacs. In recurrent apomixis, unreduced embryo sacs are produced by a process of apomeiosis, which is a collective term used for various substitutes for meiosis that give rise to unreduced embryo sacs. Apomeiosis is of two main types:

Apospory

Some vegetative cells of ovule develop into unreduced embryo sacs through a series of mitotic divisions and without meiosis, e.g., in some species of *Malus*, orchids etc.

Diplospory

Embryo sac is produced from the megaspore, which may be haploid or, more generally, diploid. In apomictic species, the meiosis is so modified that the megaspore remain diploid. In all such cases, either meiosis is omitted altogether or restitution of unreduced chromosome number occur during first meiotic division. The embryos in such embryo sacs may arise by either i) Parthenogenesis ii) Pseudogamy

i) Parthenogenesis

Embryo develop from the embryo sac without pollination. Parthenogenesis is of following two types:

Gonial parthenogenesis: Embryo develop from egg cell.

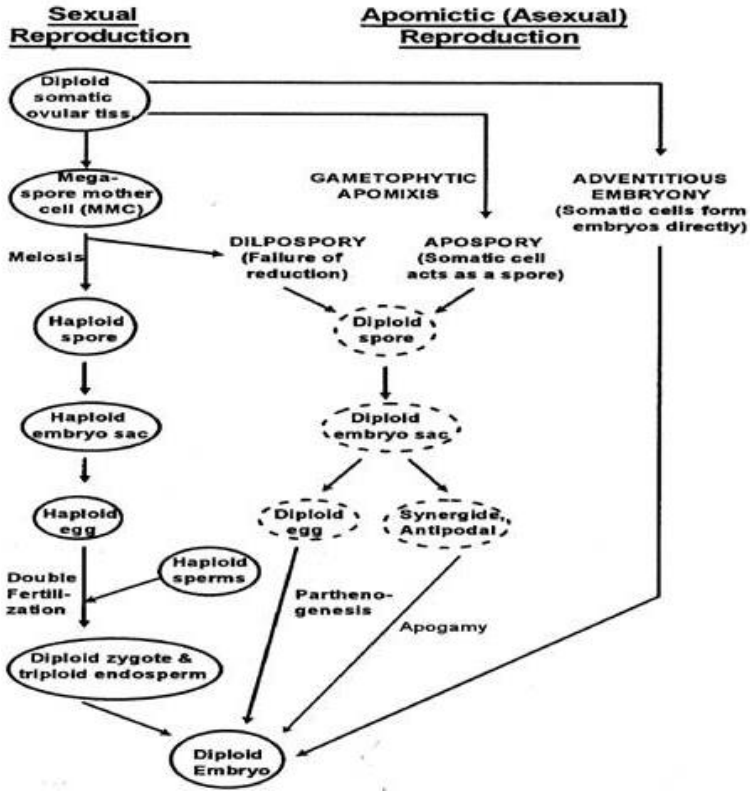
Somatic parthenogenesis: Embryo develop from some other cells of embryo sac.

ii) Pseudogamy

In such cases, pollination is necessary for embryo development, but fertilization of egg cell does not take place. Fertilization of the secondary nucleus, however, does occur and is necessary for endosperm development. Pseudogamy is also of two types:

Gonial pseudogamy: Embryo develop from egg cell

Somatic pseudogamy: Embryo develop from some other cells of embryo sac.



Significance of Apomixis

Apomixis is a nuisance when the breeder desires to obtain sexual progeny, i.e., selfs or hybrids. But it is of great help when the breeder desires to maintain varieties. thus in breeding of apomictic species, the breeder has to avoid apomictic progeny when he is making crosses or producing inbred lines. But once a desirable genotype has been selected, it can be multiplied and maintained through apomictic progeny. This would keep the genotype of a variety intact. Asexually reproducing crop species are highly heterozygous and show severe inbreeding depression. Therefore, breeding methods in such species must avoid inbreeding.

II SEXUAL REPRODUCTION

Sexual reproduction involves fusion of male and female gametes to form a zygote, which develops into an embryo. In crop plants, male and female gametes are produced in specialised structures known as flowers.

Flower

A flower usually consists of sepals, petals (or their modifications), stamens and/or pistil. A flower containing both stamens and pistil is a perfect or hermaphrodite flower. If it contains stamens, but not pistil, it is known as staminate, while a pistillate flower contains pistil, but not stamens. Staminate and pistillate flowers occur on the same plant in a monoecious species, such as maize, *Colocasia*, castor (*Ricinus communis*), coconut, etc. But in dioecious

species, staminate and pistillate flowers occur on different plants, e.g., papaya, date palm (*Phoenix dactylifera*), pistachio (*Pistacia vera*), etc. In "crop plants, meiotic division of specific cells in stamen and pistil yields microspores and megaspores, respectively. This is followed by mitotic division of the spore nuclei to produce gametes; the male and female gametes are produced in microspores and megaspores, respectively.

Sporogenesis

Productions of microspores and megaspores is known as sporogenesis. Microspores are produced in anthers (microsporogenesis), while megaspores are produced in ovules (megasporogenesis).

Microsporogenesis

Each anther has four pollen sacs, which contain numerous pollen mother cells (PMCs). Each PMC undergoes meiosis to produce four haploid cells or microspores. This process is known as microsporogenesis. The microspores mature into pollen grains mainly by a thickening of their walls.

Megasporogenesis

Megasporogenesis occurs in ovules, which are present inside the ovary. A single cell in each ovule differentiates into a megaspore mother cell. The megaspore mother cell undergoes meiosis to produce four haploid megaspores. Three of the megaspores degenerates leaving one functional megaspore per ovule. This completes megasporogenesis.

Gametogenesis

The production of male and female gametes in the microspores and the megaspores, respectively, is known as gametogenesis. Microgametogenesis. This refers to the production of male gamete or sperm. During the maturation of pollen, the microspore nucleus divides mitotically to produce a generative and a vegetative or tube nucleus. The pollen is generally released in this binucleate stage. When the pollen lands onto the stigma of a flower, it is known as pollination. Shortly after pollination, the pollen germinates. The pollen tube enters the stigma and grows through the style. The generative nucleus now undergoes a mitotic division to produce two male gametes or sperms. The pollen, along with the pollen tube, is known as microgametophyte. The pollen tube finally enters the ovule through a small pore, micropyle, and discharges the two sperms into the embryo sac.

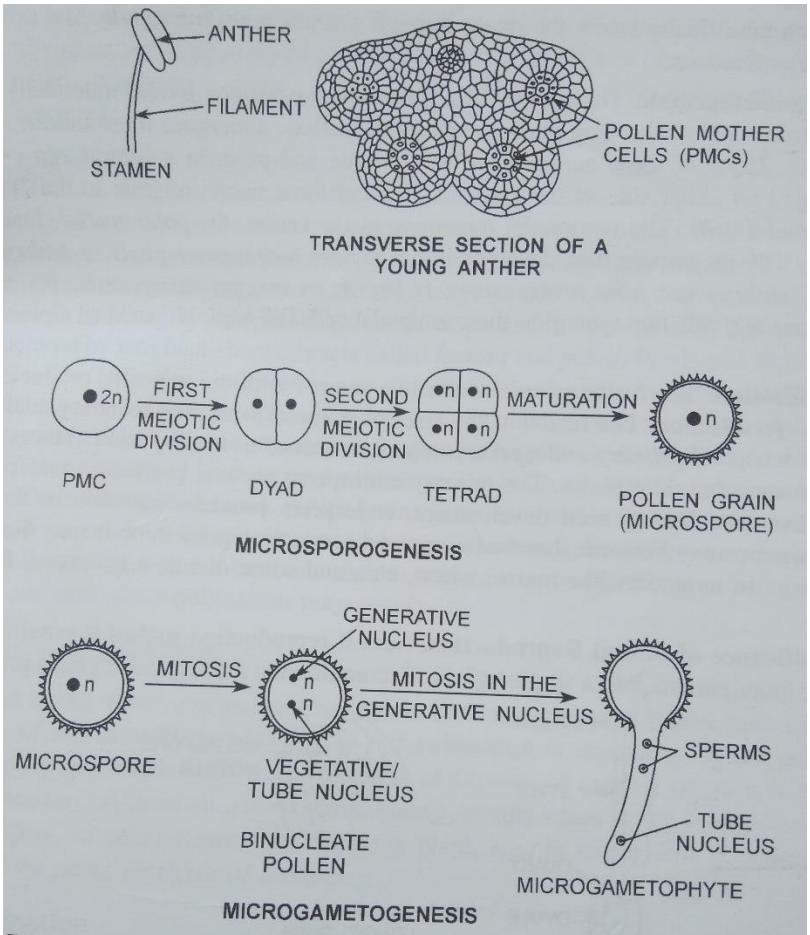


FIG. 4.1. Microsporogenesis and microgametogenesis (a generalised scheme).

Megagametogenesis

The nucleus of a functional megaspore divides mitotically to produce four or more nuclei. The exact number of nuclei and their arrangement vary considerably from one species to another. In most of the crop plants, megaspore nucleus undergoes three mitotic divisions to produce eight nuclei. Three of these nuclei move to one pole and produce a central egg cell and two synergid cells; one synergid is situated on either side of the egg cell. Another three nuclei migrate to the opposite pole to give rise to antipodal cells. The two nuclei remaining in the centre, the polar nuclei, fuse to form a secondary nucleus. The megaspore thus develops into a mature megagametophyte or embryo sac. The development of embryo sac from a megaspore is known as megagametogenesis. The embryo sac generally contains one egg cell, two synergids, three antipodal cells (all haploid), and one diploid secondary nucleus.

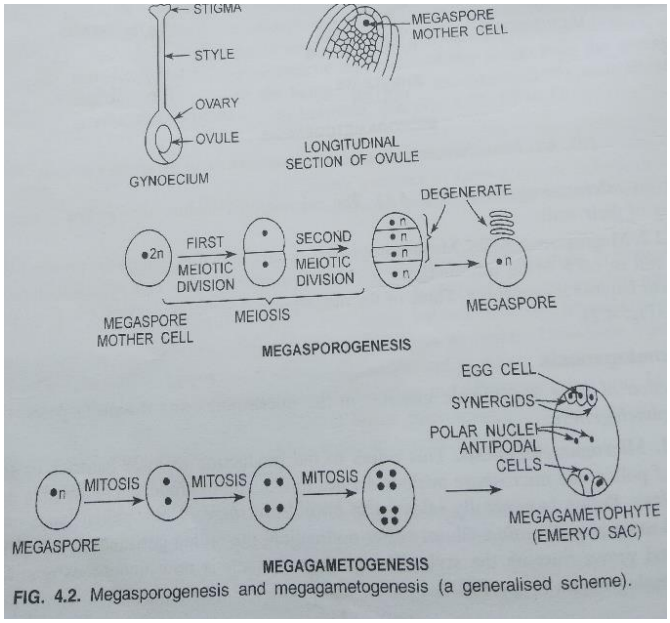
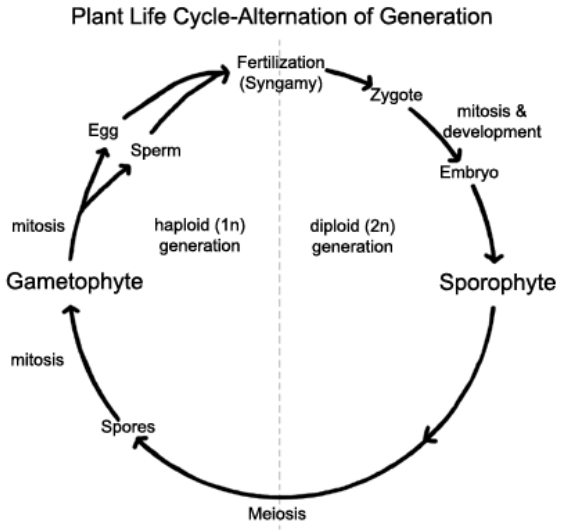


FIG. 4.2. Megasporogenesis and megagametogenesis (a generalised scheme).

Fertilization:

The fusion of one of the two sperms with the egg cell producing a diploid zygote is known as fertilization. The fusion of the remaining sperm with the secondary nucleus leading to the formation of a triploid primary endosperm nucleus is termed as **triple fusion**. The primary endosperm nucleus after several mitotic divisions develops into mature **endosperm**, which nourishes the developing embryo.



Significance of Sexual Reproduction

Sexual reproduction makes it possible to combine genes from two parents into a single hybrid plant. Recombination of these genes produces a large number of genotypes. This is an essential step in creating variation through hybridization. Almost the entire plant breeding is

based on sexual reproduction. Even in asexually reproducing species, sexual reproduction, if it occurs, is used to advantage, e.g., in sugarcane, potato, sweet potato etc.

Mode of pollination

The process by which pollen grains are transferred from anthers to stigma is referred as pollination. Pollination is of two types: viz. 1) Autogamy or self-pollination and 2) Allogamy or cross pollination.

I. Autogamy

Transfer of pollen grains from the anther to the stigma of same flower is known as autogamy or self-pollination. Autogamy is the closest form of inbreeding. Autogamy leads to **homozygosity**. Such species develop homozygous balance and do not exhibit significant inbreeding depression.

Mechanism promoting self-pollination

1. Bisexuality. Presence of male and female organs in the same flower is known as bisexuality. The presence of bisexual flowers is a must for self-pollination. All the self-pollinated plants have **hermaphrodite** flowers.

2. Homogamy. Maturation of anthers and stigma of a flower at the same time is called homogamy. As a rule, homogamy is essential for self-pollination.

3. Cleistogamy. When pollination and fertilization occur in unopened flower bud, it is known as cleistogamy. It ensures self-pollination and prevents cross pollination. Cleistogamy has been reported in some varieties of wheat, barley, oats and several other grass species.

4. Chasmogamy. Opening of flowers only after the completion of pollination is known as chasmogamy. This also promotes self-pollination and is found in crops like wheat, barley, rice and oats.

5. Position of Anthers. In some species, stigmas are surrounded by anthers in such a way that self-pollination is ensured. Such situation is found in tomato and brinjal. In some legumes, the stamens and stigma are enclosed by the petals in such a way that self-pollination is ensured. Examples are greengram, blackgram, soybean, chickpea and pea.

Genetic Consequences of Self-Pollination

Self-pollination leads to a very rapid increase in homozygosity. Therefore, populations of self-pollinated species are highly homozygous, self-pollinated species do not show inbreeding depression, but may exhibit considerable heterosis. Therefore, the aim of breeding methods generally is to develop homozygous varieties.

II. Allogamy

Transfer of pollen grains from the anther of one plant to the stigma of another plant is called allogamy or cross pollination. This is the common form of out-breeding. Allogamy leads to heterozygosity. Such species develop heterozygous balance and exhibit significant inbreeding depression on selfing.

Mechanism promoting cross-pollination

1. Dicliny. It refers to unisexual flowers. This is of two types: viz. i) monoecy and ii) dioecy. When male and female flowers are separate but present in the same plants, it is known as **monoecy**. In some crops, the male and female flowers are present in the same inflorescence such as in mango, castor and banana. In some cases, they are on separate inflorescence as in maize. Other examples are cucurbits, grapes, strawberry, cassava and rubber. When staminate and pistillate flowers are present on different plants, it is called **dioecy**. It includes papaya, date palm, spinach, hemp and asparagus.

2. Dichogamy. (from the Greek *dikho*-apart and *gamous*-marriage) It refers to maturation of anthers and stigma of the same flowers at different times. Dichogamy promotes cross pollination even in the hermaphrodite species. Dichogamy is of two types: viz. i) protogyny and ii) protandry. When pistil matures before anthers, it is called **protogyny** such as in pearl millet. When anthers mature before pistil, it is known as **protandry**. It is found in maize, sugarbeet and several other species.

3. Heterostyly. When styles and filaments in a flower are of different lengths, it is called heterostyly. It promotes cross pollination, such as linseed.

4. Herkogamy. Hinderance to self-pollination due to some physical barriers such as presence of hyline membrane around the anther is known as herkogamy. Such membrane does not allow the dehiscence of pollen and prevents self-pollination such as in alfalfa.

5. Self-incompatibility: The inability of fertile pollens to fertilize the same flower is referred to as self-incompatibility. It prevents self-pollination and promotes cross pollination. Self-incompatibility is found in several crop species like *Brassica, Radish, Nicotiana,* and many grass species. It is of two types **sporophytic** and **gametophytic**.

6. Male sterility: In some species, the pollen grains are not functional. Such condition is known as male sterility. It prevents self-pollination and promotes cross pollination. It is of three types: viz. **genetic, cytoplasmic** and **cytoplasmic genetic**. It is a useful tool in hybrid seed production.

Study of **floral biology** and aforesaid mechanisms is essential for determining the mode of pollination of various crop species. Moreover, if selfing has adverse effects on seed setting

and general vigour, it indicates that the species is cross pollinated. If selfing does not have any adverse effect on these characters, it suggests that the species is self-pollinated.

The percentage of cross pollination can be determined by growing a seed mixture of two different varieties together. The two varieties should have marker characters say green and pigmented plants. The seeds are harvested from the recessive (green) variety and grown next year in separate field. The proportion of pigmented plants in green variety will indicate the percentage of **outcrossing** or cross pollination.

Genetic Consequences of Cross-Pollination

Cross-pollination preserves and promotes heterozygosity in a population. Cross-pollinated species are highly heterozygous and show mild to severe inbreeding depression and a considerable amount of heterosis. The breeding methods in such species aim at improving the crop species without reducing heterozygosity to an appreciable degree. Usually, hybrid or synthetic varieties are the aim of breeder wherever the seed production of such varieties is economically feasible. Often Cross-Pollinated Species

Often Cross-Pollinated Species

In many crop plants, cross-pollination often exceeds 5 per cent and may reach 30 per cent. Such species are generally known as often cross-pollinated species, e.g., Jowar, Cotton, arhar, safflower etc. The genetic architecture of such crops is intermediate between self-pollinated and cross-pollinated species. Con-sequently, in such species breeding methods suitable for both of them may be profitably applied. But often hybrid varieties are superior to others.

Significance of pollination

The mode of pollination plays an important role in plant breeding. It has impact on five important aspects *viz*. 1) gene action, 2) genetic constitution, 3) adaptability, 4) genetic purity and 5) transfer of genes.

Classification of crop plants based on mode of pollination and mode of reproduction

Mode of pollination and reproduction	**Examples of crop plants**
A. Autogamous Species	
1. Seed Propagated	Rice, Wheat, Barley, Oats, Chickpea, Pea, Cowpea, Lentil, Green gram, Black gram, Soybean, Common bean, Moth bean, Linseed, Sesame, Khesari, Sunhemp, Chillies, Brinjal, Tomato, Okra, Peanut, etc.
2. Vegetatively Propagated	Potato

B. Allogamous Species	
1. Seed Propagated	Corn, Pearlmillet, Rye, Alfalfa, Radish, Cabbage, Sunflower, Sugarbeet, Castor, Red clover, White clover, Safflower, Spinach, Onion, Garlic, Turnip, Squash, Muskmelon, Watermelon, Cucumber, Pumpkin, Kenaf, Oilpalm, Carrot, Coconut, Papaya, etc.
2. Vegetatively propagated	Sugarcane, Coffee, Cocoa, Tea, Apple, Pears, Peaches, Cherries, grapes, Almond Strawberries, Pine apple, Banana, Cashew, Irish, Cassava, Taro, Rubber, etc.
C. Often Allogamous Species	Sorghum, Cotton, Triticale, Pigeonpea, Tobacco.

SELF-INCOMPATIBILITY

More than 300 species belonging to 20 families of angiosperms show self-incompatibility. Self-incompatible pollen grains fail to germinate on the stigma of the flower that produced them. If some pollen grains do germinate, pollen tubes fail to enter the stigma. In many species, the pollen tubes enter the style, but they grow too slowly to effect fertilization before the flower drops. Sometimes, fertilization is affected, but the embryo degenerates at a very early stage. Self-incompatibility appears to be a biochemical reaction, but the precise nature of these reactions is not clearly understood. The genetic control of incompatibility reactions is relatively simple. Lewis (1954) has suggested various classifications of self-incompatibility; a relatively simple classification is as follows:

1. Heteromorphic system,
2. Homomorphic system,

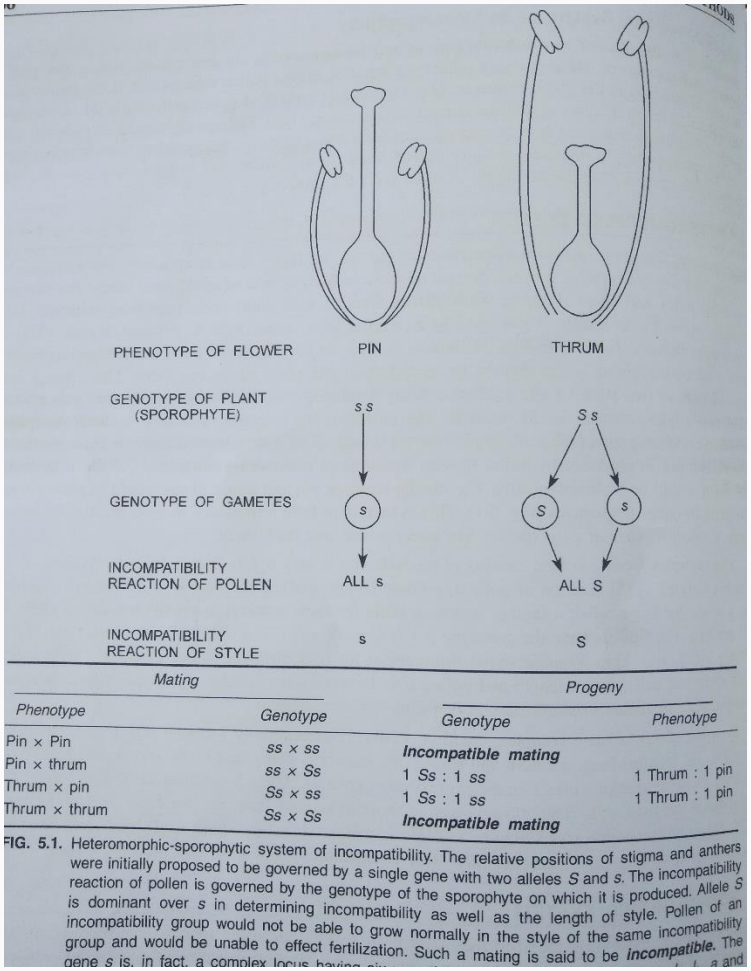
(2a) Gametophytic control, and

(2b) Sporophytic control

Heteromorphic System

In this system, flowers of different incompatibility groups are different in morphology. For example, in *Primula* there are two types of flowers, pin and thrum. Pin flowers have long styles and short stamens, while thrum flowers have short styles and long stamens. This situation is referred to as distyly. Tristyly is known in some plant species, e.g. *Lythrum*; in such cases, the style of a flower may be either short, long or of medium length. In the case of distyly, the only compatible mating is between pin and thrum flowers. This characteristic is governed by a single gene *s*; *Ss* produces thrum, while *ss* produces pin

flowers. The incompatibility reaction of pollen is determined by the genotype of the plant producing them. Allele *S* is dominant over *s*. The incompatibility system, therefore, is heteromorphic-sporophytic. The pollen grains produced by pin flowers, would all be *s* in genotype as well as incompatibility reaction. The pollen produced in thrum flowers would be of two types genotypically, *S* and *s*, but all of them would be *S* phenotypically. The mating between pin and thrum plants would produce *Ss* and ss progeny in equal frequencies. This system is of little importance in crop plants; it occurs in sweet potato and buckwheat.



Mating		Progeny	
Phenotype	*Genotype*	*Genotype*	*Phenotype*
Pin × Pin	*ss* × *ss*	***Incompatible mating***	
Pin × thrum	*ss* × *Ss*	1 *Ss* : 1 *ss*	1 Thrum : 1 pin
Thrum × pin	*Ss* × *ss*	1 *Ss* : 1 *ss*	1 Thrum : 1 pin
Thrum × thrum	*Ss* × *Ss*	***Incompatible mating***	

FIG. 5.1. Heteromorphic-sporophytic system of incompatibility. The relative positions of stigma and anthers were initially proposed to be governed by a single gene with two alleles *S* and *s*. The incompatibility reaction of pollen is governed by the genotype of the sporophyte on which it is produced. Allele *S* is dominant over *s* in determining incompatibility as well as the length of style. Pollen of an incompatibility group would not be able to grow normally in the style of the same incompatibility group and would be unable to effect fertilization. Such a mating is said to be ***incompatible.*** The gene *s* is, in fact, a complex locus having

Homomorphic System

In the homomorphic system, incompatibility is not associated with morphological differences among flowers. The incompatibility reaction of pollen may be controlled by the genotype of the plant on which it is produced or by its own genotype.

Gametophytic System

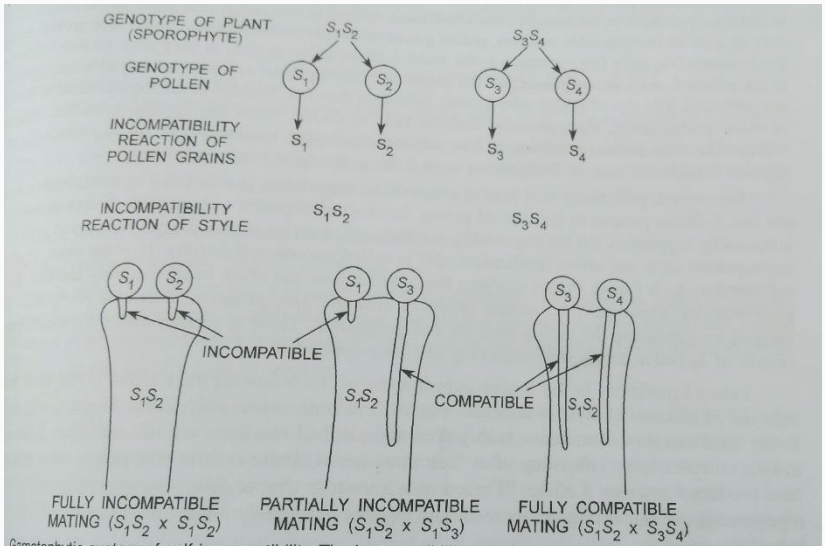
Gametophytic incompatibility was first described by East and Mangelsdorf in 1925 in *Nicotiana sanderae*. The incompatibility reaction of pollen is determined by its own

genotype, and not by the genotype of the plant on which it is produced. Generally, incompatibility reaction is determined by a single gene having multiple alleles, e.g., *Trifolium, Nicotiana, Lycoperscion, Solanum, Petunia* etc. Pollen tube grows very slowly in the style containing the same *S* allele as the pollen, and fails to effect fertilization. Therefore, all the plants are heterozygous at the *S* locus. In a single gene system, there are three types of mating:

i) Fully incompatible, e.g., *S1S2* x *S1S2*

ii) Fully compatible, e.g., *S1S2* x *S3S4*

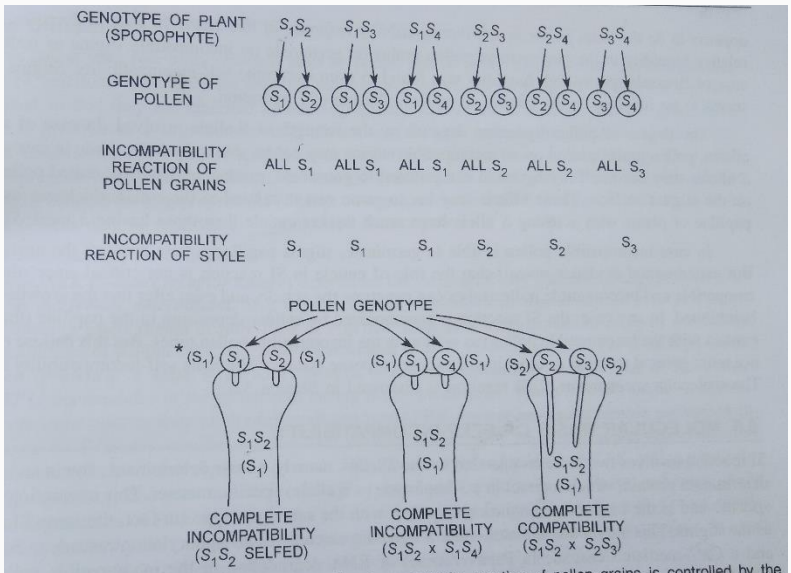
iii) Partially (i.e., 50% of the pollen) compatible, e.g., *S1S2* x *S2S3*



Gametophytic system of self-incompatibility. The incompatibility reaction of pollen is governed by the genotype of pollen itself. The incompatibility reaction of style is determined by its own genotype and, generally, the two alleles show codominance.

Sporophytic System

In the sporophytic system also, the self-incompatibility is governed by a single gene, *S*, with multiple alleles; more than 30 alleles are known in *Brassica oleracea*. In general, the number of *S* alleles is considerably larger in the gametophytic than in the sporophytic system. The incompatibility reaction of pollen is governed by the genotype of the plant on which the pollen is produced, and not by the genotype of the pollen. It was first reported by Hughes and Babcock in 1950 in *Crepis foetida*, and by Gerstel in *Parthenium argentatum* (in the same year). In the sporophytic system, the *S* alleles may exhibit dominance, individual action (codominance) or competition. In many cases, different *S* alleles vary in their activity leading to varying degrees of self-incompatibility, e.g., *B. oleracea*. Polygenes (modifying genes) are known to increase as well as decrease the activities of *S* alleles both in the gametophytic as well as sporophytic systems.



Sporophytic system of self-incompatibility. The incompatibility reaction of pollen grains is controlled by the genotype of plant (sporophyte) on which they are produced, while that of style is governed by its own genotype. For simplicity, it is assumed that the incompatibility alleles (*S* alleles) show complete dominance in the manner $S_1 > S_2 > S_3 > S_4$ ...., etc. The actual situation is much more complicated and several different types of allelic relationships are encountered. *The letters within parenthesis, *e.g.*, (S_1) and (S_2), denote the incompatibility reactions of pollen grains and styles.

Mechanism of Self-Incompatibility

The mechanism of self-incompatibility is quite complex and is poorly understood. The various phenomena observed in self-incompatible matings are grouped into three broad categories:

(1) pollen-stigma interaction,

(2) pollen tube-style interaction, and

(3) pollen tube-ovule interaction.

Pollen-Stigma Interaction

These interactions occur just after the pollen grains reach the stigma and generally prevent pollen germination. At the time they reach stigma, pollen grains generally have two nuclei in the gametophytic system, while they have three nuclei in the sporophytic system. This was once considered to be the basis for the two incompatibility systems, but the available evidence indicates otherwise. However, the structure of stigmatic surface appears to be definitely involved in the differences between the two systems. In the gametophytic system, the stigma surface is plumose having elongated receptive cells and is commonly known as 'wet' stigma. Incompatible pollen grains generally germinate on reaching the stigma; the incompatibility reaction occurs at a later stage.

In the sporophytic system, the stigma is papillate and dry, and is covered with a hydrated layer of proteins known as 'pellicle'. There is evidence that the pellicle is involved in

incompatibility reaction. Within few minutes of reaching the stigmatic surface, the pollen releases an exine exudates which is either protein or glycoprotein in nature. This exudate induces immediate callose formation in the papillae (which are in direct contact with the pollen) of incompatible stigma. Often callose is also deposited on the young protruding pollen tubes preventing any further germination of the pollen. Thus, in the sporophytic system, stigma is the site of incompatibility reaction; once the pollen tube crosses the stigmatic barrier, there is no further inhibition of pollen tube growth.

In the homomorphic sporophytic system, the incompatibility reaction of pollen is probably due to the deposition of some compounds from anther tapetum on to the pollen exine.

Pollen Tube-Style Interaction

In most cases of the gametophytic system, pollen grains germinate and pollen tubes penetrate the stigmatic surface. But in incompatible combinations, the growth of pollen tubes is retarded within the stigma, e.g., in Oenothera, or a little later in the style, e.g., in *Petunia*, *Lycopersicon*, *Lilium* etc. In the latter case, there is a cessation of protein and polysaccharide synthesis in the pollen tubes, which leads to the degeneration of tube wall and the bursting of pollen tube.

Pollen Tube-Ovule Interaction

In some cases, e.g., *Theobromo cacao*, pollen tubes reach the ovule and effect fertilization. However, in incompatible combinations, embryos degenerate at an early stage of development.

Exploitation of self-incompatibility in hybrid production

Self-incompatibility may be used in hybrid seed production. For this purpose,

(1) two self-incompatible, but cross-compatible, lines are interplanted; seed obtained from both the lines would be hybrid seed.

(2) Alternatively, a self-incompatible line may be interplanted with a self-compatible line. from this scheme, seed from only the self-incompatible line would be hybrid.

(3) Schemes for the production of double cross and triple cross hybrids have also been proposed and their feasibility has been demonstrated in the case of brassicas. The gametophytic system has been used, to a limited extent, for hybrid seed production in clover, *Trifolium* (Leguminosae). In Solanaceae, the cultivated species are generally self-fertile, and self-incompatibility is confined to wild species.

The sporophytic system has been exploited for hybrid seed production in brassicas (Cruciferae), primarily by the Japanese seed companies. In Compositae, another

economically important family showing sporophytic self-incompatibility, the cultivated varieties are generally self-fertile.

The use of self-incompatibility in hybrid seed production is hampered by several problems mentioned below:

(1) Production and maintenance of inbred lines by hand pollination is tedium and costly.

(2) This raises the cost of hybrid seed.

(3) Continued selfing leads to a depression in self-incompatibility, and it unintentionally, but unavoidably, selects for self-fertility.

(4) In the gametophytic system, continued inbreeding gives rise to new incompatibility reactions, which may limit the usefulness of such inbreds as parents. (5) Environmental factors, e.g., high temperature and high humidity etc., reduce or even totally overcome self-incompatibility reaction leading to a high (30% or more) proportion of selfed seed.

(6) Bees often prefer to stay within a parental line, particularly when the parental lines differ morphologically. This, in turn, increases the proportion of selfed seed.

7) Transfer of *S* alleles from one variety or, more particularly, species into another variety or species is tedious and complicated. This has prevented the use of self-incompatibility in hybrid seed production in Solanaceae and Compositae.

MALE STERILITY

Male sterility is characterized by non-functional pollen grains, while female gametes function normally. It occurs in nature sporadically, perhaps due to mutation. Male sterility is classified into three groups:

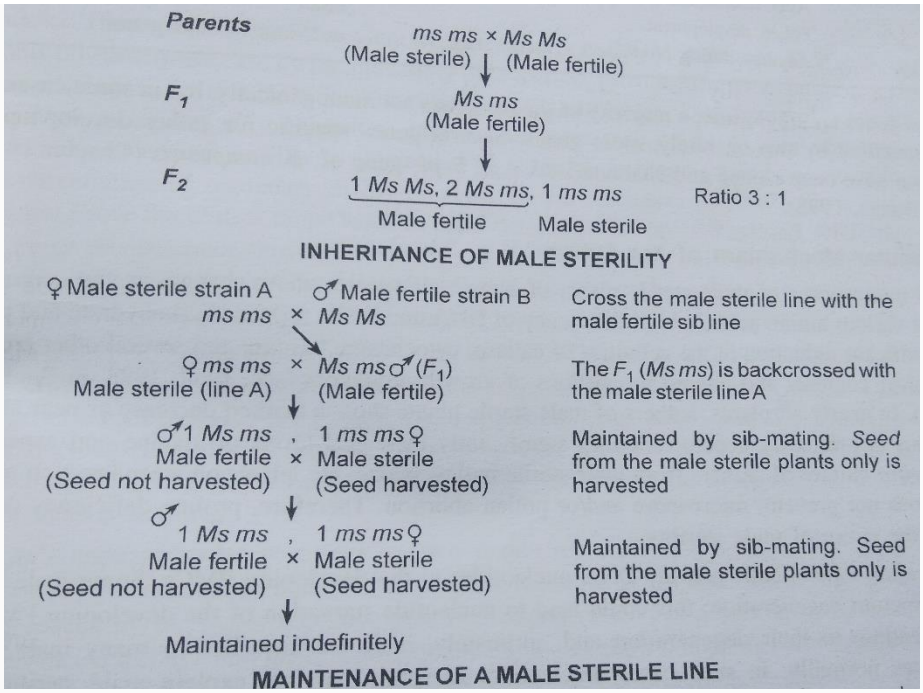
(1) Genetic,

(2) Cytoplasmic, and

(3) Cytoplasmic-genetic.

Genetic Male Sterility

Genetic male sterility is ordinarily governed by a single recessive gene, *ms*, but dominant genes governing male sterility are also known, e.g., in safflower. Male sterility alleles arise spontaneously or may be artificially induced. A male sterile line may be maintained by crossing it with heterozygous male fertile plants. Such a mating produces 1:1 male sterile and male fertile plants.



Utilization in Plant Breeding

Genetic male sterility may be used in hybrid seed production. The progeny from *ms ms* x *Ms ms* crosses are used as female, and are interplanted with a homozygous male fertile (*Ms Ms*) pollinator. The genotypes of *ms ms* and *Ms ms* lines are identical except for the *ms* locus, i.e., they are isogenic; they are known as male sterile (A) and maintainer (B) lines, respectively. The female line would, therefore, contain both male sterile and male fertile plants; the latter must be identified and removed before pollen shedding. This is done by identifying the male fertile plants in seedling stage either due to the pleiotropic effect of the *ms* gene or due to the phenotypic effect of a closely-linked gene. Pollen dispersal from the male (pollinator) line should be good for a satisfactory seed set in the female line. however, generally pollen dispersal is poor and good, closely-linked markers are rare. Rouging of male fertile plants from the female lines is costly as a result of which the cost of hybrid seed is higher. Due to these difficulties, genetic male sterility has been exploited commercially only in a few countries. In USA it is used in Castor. In India it was being used in Redgram, but presently it is being used in safflower. Marker genes which are linked to male sterility/fertility can be used to identify the male fertile plants before flowering stage. For example, in Maize there is a gene, pigmented hypocotyl (P) and green hypocotyl (P) which is closely linked with sterility locus

PS - Pigmented & Sterile

PF – Green & Fertile

At seedling stage all the green plants are to be removed and pigmented plants are retained, as they are sterile.

Suggestions have been made for its use in several other crops, e.g., Cotton, barley, tomato, sunflower, cucurbits etc., but it is not yet practically feasible.

Cytoplasmic Male Sterility

This type of male sterility is determined by the cytoplasm. Since the cytoplasm of a zygote comes primarily from egg cell, the progeny of such male sterile plants would always be male sterile. Nuclear genotype of male sterile line would be almost identical to that of the recurrent pollinator strain. The male sterile line is maintained by crossing it with the pollinator strain used as the recurrent parent in the backcross programme since its nuclear genotype is identical with that of this new male sterile line. such a male fertile line is known as the maintainer line or B line as it is used to maintain the male sterile line is also known as the A line, there is considerable evidence that the gene or genes conditioning Cytoplasmic male sterility, particularly in Maize, reside in mitochondria, and may be located in a plasmic like elements.

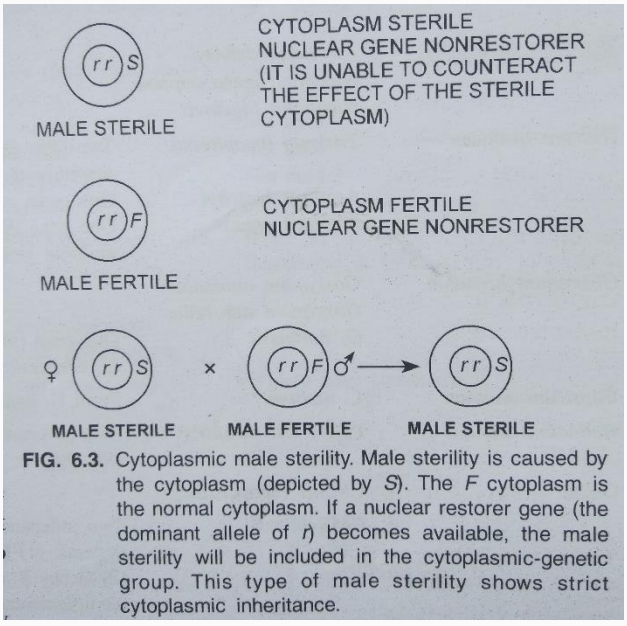


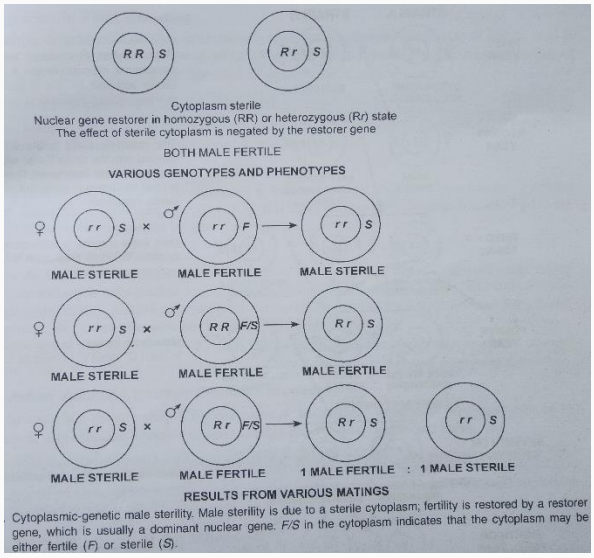
FIG. 6.3. Cytoplasmic male sterility. Male sterility is caused by the cytoplasm (depicted by *S*). The *F* cytoplasm is the normal cytoplasm. If a nuclear restorer gene (the dominant allele of *r*) becomes available, the male sterility will be included in the cytoplasmic-genetic group. This type of male sterility shows strict cytoplasmic inheritance.

Utilization in Plant Breeding

Cytoplasmic male sterility may be utilized for producing hybrid seed in certain ornamental species, or in species where a vegetative part is of economic value. But in those crop plants where seed is the economic part, it is of no use because the hybrid progeny would be male sterile. Eg: Onion, Fodder Jowar, Cabbage, Palak etc.

Cytoplasmic-Genetic Male Sterility

This is a case of Cytoplasmic male sterility where a nuclear gene for restoring fertility in the male sterile line is known. The fertility restorer gene, *R*, is dominant and is found in certain strains of the species, or may be transferred from a related species, e.g., in wheat. This gene restores male fertility in the male sterile line, hence it is known as restorer gene.



Cytoplasmic-genetic male sterility. Male sterility is due to a sterile cytoplasm; fertility is restored by a restorer gene, which is usually a dominant nuclear gene. *F/S* in the cytoplasm indicates that the cytoplasm may be either fertile (*F*) or sterile (*S*).

The cases of Cytoplasmic male sterility would be included in the Cytoplasmic-genetic system as and when restorer genes for them would be discovered. It is likely that a restorer gene would be found for all the cases of Cytoplasmic male sterility if a thorough search were made. This system is known in Maize, Jowar, bajra, sunflower, rice, wheat, etc. Plant would be male sterile in the presence of male sterile cytoplasm if the nuclear genotype were *rr*, but would be male fertile if the nucleus were *Rr* or *RR*. New male sterile lines may be developed following the same procedure as in the case of Cytoplasmic system. For the production of hybrid seed, removal of anthers before fertilization is essential to avoid selfing. Manually removing of anthers is very tedious and time-consuming process in almost all the crops except in Maize and Castor which are monoecious. The pre-requisites for successful hybrid seed production in large quantities are:

1. Existence of male sterility or self-incompatibility through which hand emasculation can be avoided.
2. Sufficient cross-pollination should be there to get good seed set.

Breeding Methods

The following are the methods of breeding self-pollinated crop plants.

1. Introduction
2. Selection a) Pure line selection b) Mass selection
3. Hybridization and selection i) Inter varietal a) Pedigree Method b) Bulk Method. c) Single Seed Descent Method. d) Modified Bulk Method e) Mass - Pedigree Method.
   ii) Interspecific hybridization
4. Back cross method
5. Multiline varieties
6. Population approach
7. Hybrids.
8. Mutation breeding
9. Polyploidy breeding
10. Innovative techniques

Plant introduction

Taking a genotype or a group of genotypes in to a new place or environment where they were not grown previously. Thus, introduction may involve new varieties of a crop already grown in that area, a wild relative of the crop species or totally a new crop species for that area.

E.g. a) Introduction of lRRl rice varieties.

b) Introduction of sunflower wild species from Russia

c) Introduction of oilpalm in to Tamil Nadu.

Plant introduction may be of two types. 1. Primary Introduction and 2. Secondary Introduction

1. Primary Introduction

When the introduced crop or variety is well suited to the new environment, it is directly grown or cultivated without any alteration in the original genotype. This is known as primary introduction. E.g. IR. 8, IR 20, IR 34, IR 50 rice varieties; oil palm varieties introduced from Malaysia and Mashuri rice from Malaysia.

2. Secondary Introduction

The introduced variety may be subjected to selection to isolate a superior variety or it may be used in hybridization programme to transfer some useful traits. This is known as secondary Introduction.E.g. In soybean EC 39821 introduced from Taiwan is subjected to selection and variety Co 1 was developed. In rice ASD 4 is crossed with IR 20 to get Co 44 which is suited for late planting.

Objectives of Plant Introduction

1. To introduce new plant species there by creating ways to build up new industries. E.g. Oil palm
2. To introduce high yielding varieties to increase food production. E.g. Rice and wheat.
3. To enrich the germplasm collection. E.g. Sorghum, Groundnut.
4. To get new sources of resistance against both biotic and abiotic stresses. E.g. NCAC accessions to have rust resistance in groundnut. Dasal rice variety for saline resistance.
5. Aesthetic value – ornamentals are introduced for aesthetic value.

Plant Introduction Agencies

Most of the introductions occurred very early in the history. In earlier days the agencies were invaders travellers, traders, explorers, pilgrims and naturalists Muslim invaders introduced in India cherries and grapes. Portuguese introduced maize, ground nut, chillies, potato, sweet potato, guava, pine apple, papaya and cashew nut. East India Company brought tea. Later Botanic gardens played a major role in plant Introduction.

A centralized plant introduction agency was initiated in 1946 at IARI, New Delhi. During 1976 National Bureau of Plant Genetic Resources (NBPGR) was started. The bureau is responsible for introduction and maintenance of germplasm of agricultural and horticultural plants.

Similarly, Forest Research Institute, Dehradun has a plant introduction organization, which looks after introduction, maintenance and testing of germplasm of forest trees. Besides NBPGR the Central Research Institutes of various crops also maintain working germplasm. All the introductions in India must be routed through NBPGR, New Delhi. The bureau functions as the central agency for export and introduction of germplasm.

At International level International Board of Plant Genetic Resources (IBPGR) with headquarter at Rome, Italy is responsible for plant introduction between countries.

Procedure for plant Introduction

The scientist / University will submit the requirement to NBPGR. If the introduction is to be from other countries, NBPGR will address IBPGR for effecting supply. The IBPGR will assign collect the material from the source and quarantine them, pack them issue phytosanitary certificate suitably based on the material and send it to NBPGR. The NBPGR will assign number for the material, keep part of the seed for germplasm and send the rest to the scientist. There are certain restrictions in plant introduction. Nendran banana from Tamil Nadu should be not be sent out of state because of bunchy top disease. Similarly, we cannot import Cocoa from Africa, Ceylon, West Indies, Sugarcane from Australia, Sunflower from Argentina.

Functions of NBPGR

1. Introduction maintenance and distribution of germplasm
2. Provide information about the germplasm through regular publications.
3. Conduct training courses to the scientist with regard to introduction and maintenance of germplasm.
4. Conduct exploratory surveys for the collection of germplasm.
5. To set up Natural gene sanctuaries.

Purpose of plant introduction

The main purpose of plant introduction is to improve the plant wealth of the country. The chief objectives of plant introduction may be grouped as follows:

To obtain an entirely new crop plant

Plant introductions may provide an entirely new crop species. Many of our important crops, e.g., Maize, potato, tomato, Tobacco, etc., are introductions. Some recently introduced crops are Soybean, gobhi sarson, oil palm etc.

To serve as new varieties

Sometimes introductions are directly released as superior commercial varieties. The Maxican semidwarf wheat varieties Sonora 64 and Lerma Rojo, semidwarf rice varieties TN 1, IR-8 and IR-36 are more recent examples of this type.

To be used in crop improvement

Often the introduced material is used for hybridization with local varieties to develop improved varieties. Pusa Ruby tomato was derived from a cross between Meeruty and Sioux, an introduction from U.S.A.

To save the crop from diseases and pests

Sometimes a crop is introduced into a new area to protect it from diseases and pests. Coffee was introduced in South America from Africa to prevent losses from leaf rust.

Hevea rubber, on the other hand, was brought to Malaya from South America to protect it from a leaf disease.

For scientific studies

Collections of plants have been used for studies on biosystematics, evolution and origin of plant species. N.I. Vavilov developed the concept of centres of origin and that of homologous series in variation from the study of a vast collection of plant types.

For aesthetic value

Ornamentals, shrubs and lawn grasses are introduced to satisfy the finer sensibilities of man. These plants are used for decoration and are of great value in social life.

Varieties selected from introductions

Many varieties have been developed through selection from introductions. Two varieties of wheat, Kalyan Sona and Sonalika, were selected from introductions from CIMMYT, Mexico.

Varieties Developed through Hybridization

Introductions have contributed immensely to the development of crop varieties through hybridization. All the semidwarf wheat varieties are derived from crosses with Mexican semi-dwarf wheats. All but few semidwarf rice varieties possess the dwarfing gene from Dee-geo-woo-gen through either TN1 or IR 8. Thus, almost all these semi-dwarf wheat and rice varieties have been developed from crosses involving introductions. All the sugarcane varieties have been derived from the introduced noble canes.

Other examples of varieties developed through hybridization with introductions are Pusa Ruby tomato obtained from a cross between Meeruti and Sioux; Pusa Early Dwarf Tomato derived from the cross Meeruti x Red Cloud; Pusa Kesar carrot, Pusa Kanchan turnip etc.

Merits of plant introduction

1. It provides new crop varieties, which are high yielding and can be used directly
2. It provides new plant species.
3. Provides parent materials for genetic improvement of economic crops.
4. Enriching the existing germplasm and increasing the variability.
5. Introduction may protect certain plant species in to newer area will save them from diseases. E.g. Coffee and Rubber.

Demerits

1. Introduction of new weed unknowingly. E.g. *Argemone mexicana*, *Eichornia* and *Parthenium*

2. Introduction of new diseases: Late blight of potato from Europe and Bunchy top of banana from Sri Lanka

3. New pests: Potato tuber moth came from Italy

4. Ornamentals becoming weeds: *Lantana camara*

5. Introduction may cause ecological imbalance. E.g. *Eucalyptus*.

Acclimatization

When superior cultivars from neighbouring or distant regions are introduced in a new area, they generally fail initially to produce a phenotypic expression similar to that in their place of origin. But later on they pickup and give optimal phenotypic performance, in other words they become acclimatized to the new ecological sphere. Thus, acclimatization is the ability of crop variety to become adapted to new climatic and edaphic conditions. The process of acclimatization follows an increase in the frequency of those genotypes that are better adapted to the new environment. Factors affecting acclimatization are:

i. Mode of pollination
ii. Amount of variability present in original population
iii. Life cycle of crop plant and
iv. Mutation

SELECTION

Selection is basic to any crop improvement. Isolation of desirable plant types from the population is known as selection. It is one of the two fundamental steps of any breeding programme viz., 1. creation of variation and 2. Selection. There are two agencies involved in carrying out selection: one is Nature itself (Natural selection) and the other is man artificial selection. Though both may complement each other in some cases, they are mostly opposite in direction since their aims are different under the two conditions (nature and domestication). The effectiveness of selection primarily depends upon the degree to which phenotype reflects the genotype. Before domestication, crop species were subjected to natural selection. The basic for natural selection was adaptation to the prevailing environment. After domestication man has knowingly or unknowingly practiced some selection. Thus, crop species under domestication were exposed to both natural and artificial selection i.e. selection by man. For a long period, natural selection played an important role than selection by man. But in modern plant breeding methods natural selection is of little importance and artificial selection plays an important role.

Basic Principles of Selection: Notwithstanding the highly complex genetic situation imposed by linkage and epistasis, there are just three basic principles of selection (Walker, 1969):

1. Selection operates on existing variability: The main function of the selection exercise is to discriminate between individuals. This is possible only when sufficient variation is present in the material subjected to selection pressure. Thus, selection acts on the existing variation it cannot create new variation.

2. Selection acts only through heritable differences: only the selected individuals are permitted to contribute to the next genetion / progenies. Therefore, should there be greater influence of non-heritable agencies on the individuals selected, the parentprogeny correlation will be greatly vitiated. Hence the variation among individuals to be selected must be genetic in nature, since it is the genetic variation that tends to close the gap between phenotype and genotype. Environmental variability cannot be of any use under selection.

3. Selection works because some individuals are favoured in reproduction at the expense of other : As a consequence of its past evolutionary history and breeding structure, a population or a crop consists of highly genetically variable individuals with regards to such diverse phenomena as differential viability, differential maturity, differences in mating tendencies, fecundity, and duration of reproductive capacity. Hence some individuals tend to become superior to others for some or other traits desirable under domestication. These superior individuals are retained for reproduction while others discarded under selection.

Selection has two basic characteristics *viz*. 1. Selection is effective for heritable differences only,

2. Selection does not create any new variation. It only utilizes the variation already present in a population.

The two basic requirements for select on to operate are:

1. Variation must be present in the population.

2. The variation should be heritable.

Selection intensity: Parcentage of plants selected, to be advanced to next generation, from a population.

Mass Selection

Large number of plants having similar phenotype are selected and their seeds are mixed together to constitute a new variety. Thus, the population obtained from selected plants

will be more uniform than the original population. However, they are genotypically different.

Steps:

First year: From the base population select phenotypically similar plants which may be 200 - 2000. Harvest the selected plants as a bulk.

Second year: The bulk seed is divided into smaller lots and grown in preliminary yield trial along with control variety. Dissimilar phenotypes are rejected. High yielding plots are selected.

Third to sixth year: The variety is evaluated in coordinated yield trials at several locations. It is evaluated in an initial evaluation (IET) trial for one year. If found superior it is promoted to main yield trials for 2 or 3 years.

Seventh year: If the variety is proved superior in main yield trials it is multiplied and released after giving a suitable name.

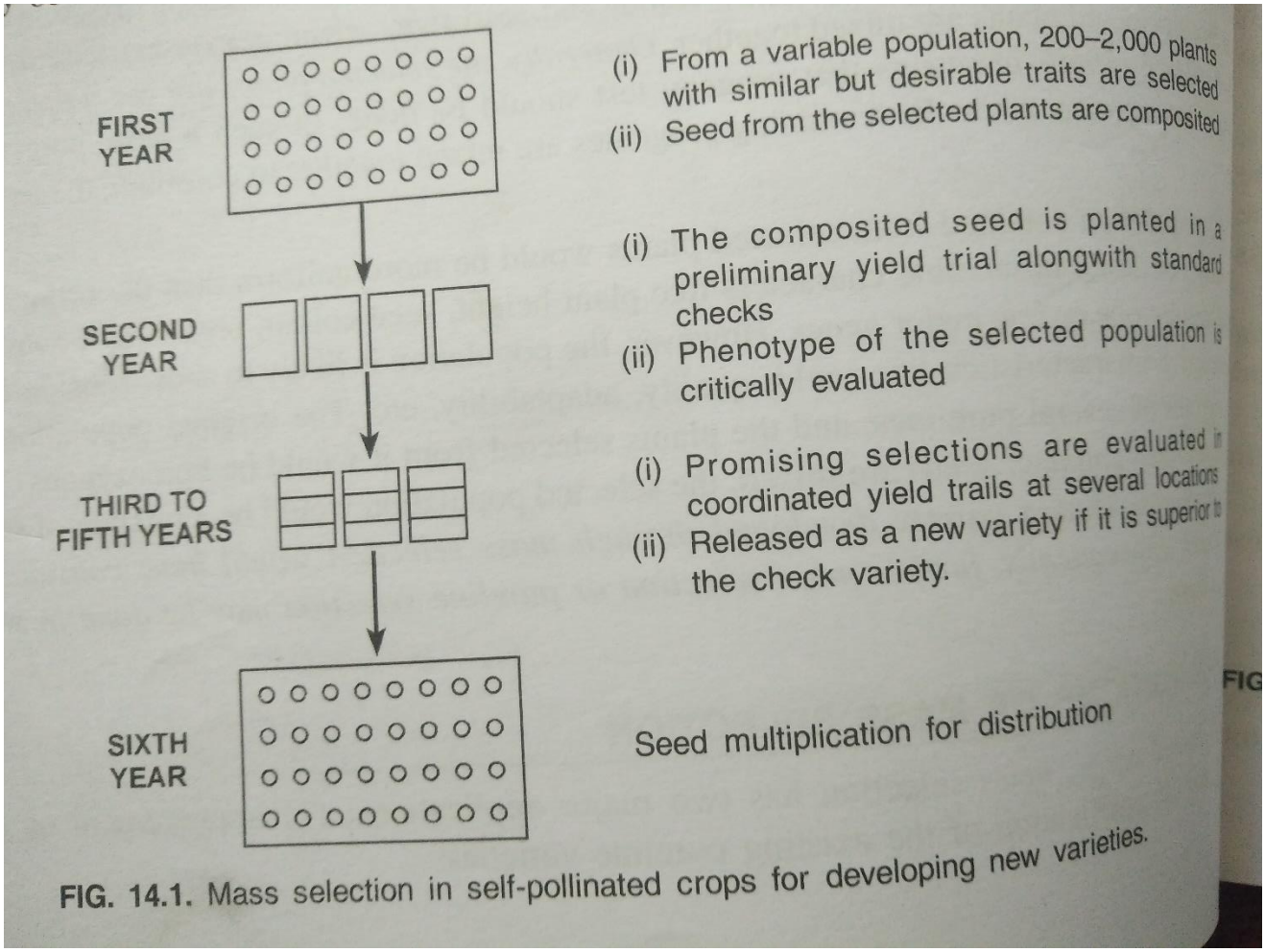


FIG. 14.1. Mass selection in self-pollinated crops for developing new varieties.

Schematic representation of Mass selection

Merits of mass selection

1. Since large number of plants are selected, the variety developed has wider adaptability as compared to variety developed through Pureline selection.
2. Often extensive yield trials are not necessary. This reduces the time and cost for developing new variety.
3. Mass selection retail considerable genetic variability in the new variety. Therefore, another round of mass selection after few years would be effective in improving variety further.
4. It is less demanding method so that breeders can devote more time to other breeding programmes.

Demerits of mass selection

1. The varieties developed through mass selection show variation and are not as uniform as Pureline varieties. Therefore, such varieties are less liked than pureline varieties.
2. Improvement through mass selection is less than that could be achieved through pureline selection, because some progenies will be poorer in performance as compared to the best progeny/pureline present in new variety.
3. In the absence of progeny test it is difficult to find out whether selected plants are homozygous as there may be some degree of cross pollination in self-pollinated crops, some of the selected plants may be heterozygous.
4. Varieties developed through mass selection are more difficult to identify than pureline varieties in seed certification programmes.
5. Mass selection utilizes variability already present in a variety or population, and it can not generate variability.

Pureline theory given by Johannsen (1903)

- Pureline is the progeny of a single self-fertilized homozygous plant.
- The concept of Pureline was proposed by Johannsen on the basis of his studies with beans (*Phaseolus vulgaris*) variety called Princess. He obtained the seeds from the market and observed that the lot consisted of a mixture of larger as well as smaller size seeds. Thus, there was variation in seed size. Johannsen selected seeds of different sizes and grown them individually. Progenies of larger seeds produced larger seeds and progenies from smaller seeds produced small seeds only.
- This clearly showed that there is variation in seed size in the commercial lot and it has a genetic basis. He studied nineteen lines altogether. He concluded that the market lot of the beans is a mixture of purelines. He also concluded whatever variation observed with in a line is due to environment only.

- Confirmatory evidence was obtained in three ways. In line 13 which is having 450 mg seed weight he divided the seeds on weight basis. He divided the line into seeds having 200, 300, 400 and 500 mg weights and studied the progenies.
- Ultimately, he got lines having weight ranging from 458 to 475. Thus, the variation observed is purely due to environment. The second evidence was that selection with in a Pureline is ineffective. From a Pureline having 840 mg selection was made for large as well as small seeds.
- After six generations of selection the line for large seed as well as for small seed gave progenies having 680-690 mg. did not change further. Thus, it was proved that section within a Pureline is ineffective. In third evidence when parent - offspring regression was worked in line thirteen found be to zero indicating that variation observed is non heritable and it is due to environment only.

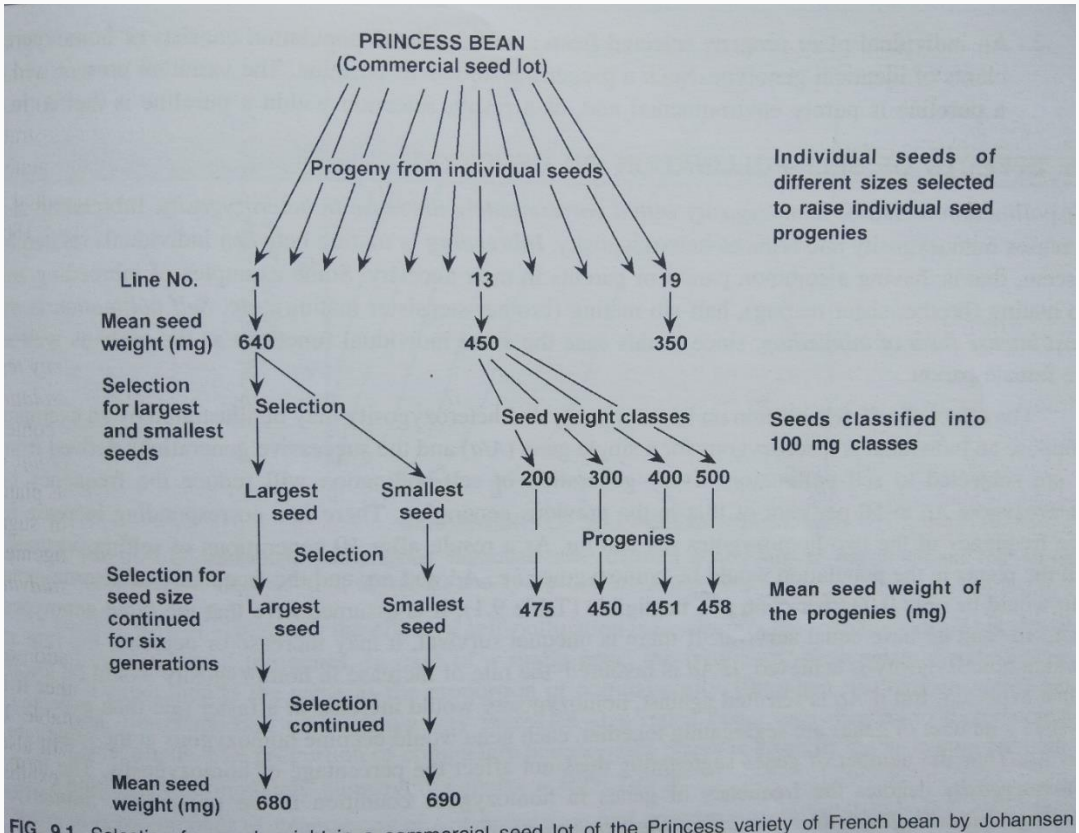


FIG. 9.1. Selection for seed weight in a commercial seed lot of the Princess variety of French bean by Johannsen (1903).

Confirmatory evidence was obtained in three ways

In the first case, he classified the seed from each pureline into 100 mg classes, and grew them separately. The mean seed weight of progenies from different seed weight class of a single pure line were comparable with each other, and with that of the parent pureline. For example, line no 13 had seed size classes of 200, 300, 400, and 500 mg. The mean seed weights of the progenies derived from these seed weight classes were 475, 450, 451 and 458 mg respectively.

The second line of evidence came from selection within a pureline. From each pureline, the largest and the smallest seeds were selected to raise the next generation. In the subsequent generations, large seeds were selected in the progenies obtained from large seeds while in these from small seeds selection was done fro small seeds. Six generations of selection was ineffective in increasing or decreasing the seed size. For example, after 6 generations of selection, the mean seed weight in Line No 1 was 690 and 680 mg in the progenies selected for small and large seeds respectively. Thus, selection within a pureline was ineffective.

The third approach was to estimate parent offspring correlation. The value of parent offspring correlation within line no 13 was – 0.018+ 0.038, that is, zero, while it was 0.336 + 0.008 in the original seed lot of the Princess which is highly significant. The parent-offspring correlation will be zero when the variation is nonheritable, while it will be significantly greater than zero when the variation has a genetic basis, i.e., is heritable.

These observations reveal that the variation for seed size in the original seed lot of Princess had a genetic basis and was heritable. But the variation within the purelines obtained from the single seeds selected from this seed lot was purely due to the environment and, therefore, non-heritable.

The two main conclusions from the Johannsen's experiment are:

1. A self-fertilized population consists of a mixture of several homozygous genotypes. Variation in such a population has a genetic component, and therefore selection is effective.
2. Each individual plant progeny selected from a self-fertilized population consists of homozygous plants of identical genotype. Such a progeny is known as pureline. The variation within a pureline is purely environmental and, as a result, selection within a pureline is ineffective.

Origin of variation in pure lines

Pure lines show genetic variation after some time because of the following reasons:

1. Mechanical Mixture: During cultivation, harvesting threshing and storage, other genotypes may get mixed up.

2. Natural hybridization: Through pure lines are produced in self-pollinated crops, some amount of natural cross pollination occurs in them also can be avoided by isolation and rouging. 3. Mutation: occur spontaneously in nature at random

Characteristics of purelines

1. All the plants within a pureline have the same genotype
2. The variation within a pureline is environmental and non-heritable
3. Purelines are stable

Progeny test

Evaluation of the worth of plants on the basis of performance of their progenies is known as progeny test. This was developed by Louis de Vilmorin and so it is also known as the Vilmorin Isolation principle. Vilmorin worked on sugar beet plants. The progeny test serves two valuable function:

1. Determines the breeding behaviour of a plant i.e. whether it is homozygous or heterozygous.
2. Whether the character for which the plant was selected is heritable i.e. is due to genotype or not. Selections have to be based or phenotype and so it is necessary to know the genotype of the selected plant.

Pureline selection

Pureline selection has been the most commonly used method of improvement of self-pollinated crops. Almost all the present day varieties of self-pollinated crops are purelines. Pureline selection has several applications in improvement of self-pollinated crops. It is used to improve:

1. Local varieties
2. Old pureline varieties and,
3. Introduced varieties

Procedure of Pureline selection

First year:

- An old variety or landrace is used for Pureline selection. Population they selected for pureline selection is homozygous. Single plant is selected and harvested separately superior plants must be selected from the mixed population. About 1000-2000 plants are selected depending on the available resources.

Second year:

- The individual progenies are grown separately with proper spacing the top 15-20 progenies are selected and they are bulked. Poor, defective, weak and segregating

progenies are discarded. Selection should be based on simply inherited character like plant type, Plant height, grain type, flowering and maturity duration disease resistance this process may be repeated

Third year:

- Seed of the individual plant progenies are not enough to conduct a replication trail. So, they are grown in unreplicated trial with check. Here yield of progenies are taken as a criteria for selection.

Fourth year:

- Replicated yield trials are conducted using the best available check variety. This may be repeated for 2-3 year. All the observations are recorded

Fifth to Eighth year:

- Promising strains are evaluated at several locations along with strains or check. The best progeny / strain is released as a new variety and its seed multiplication in initiated for distributed to the farmer.

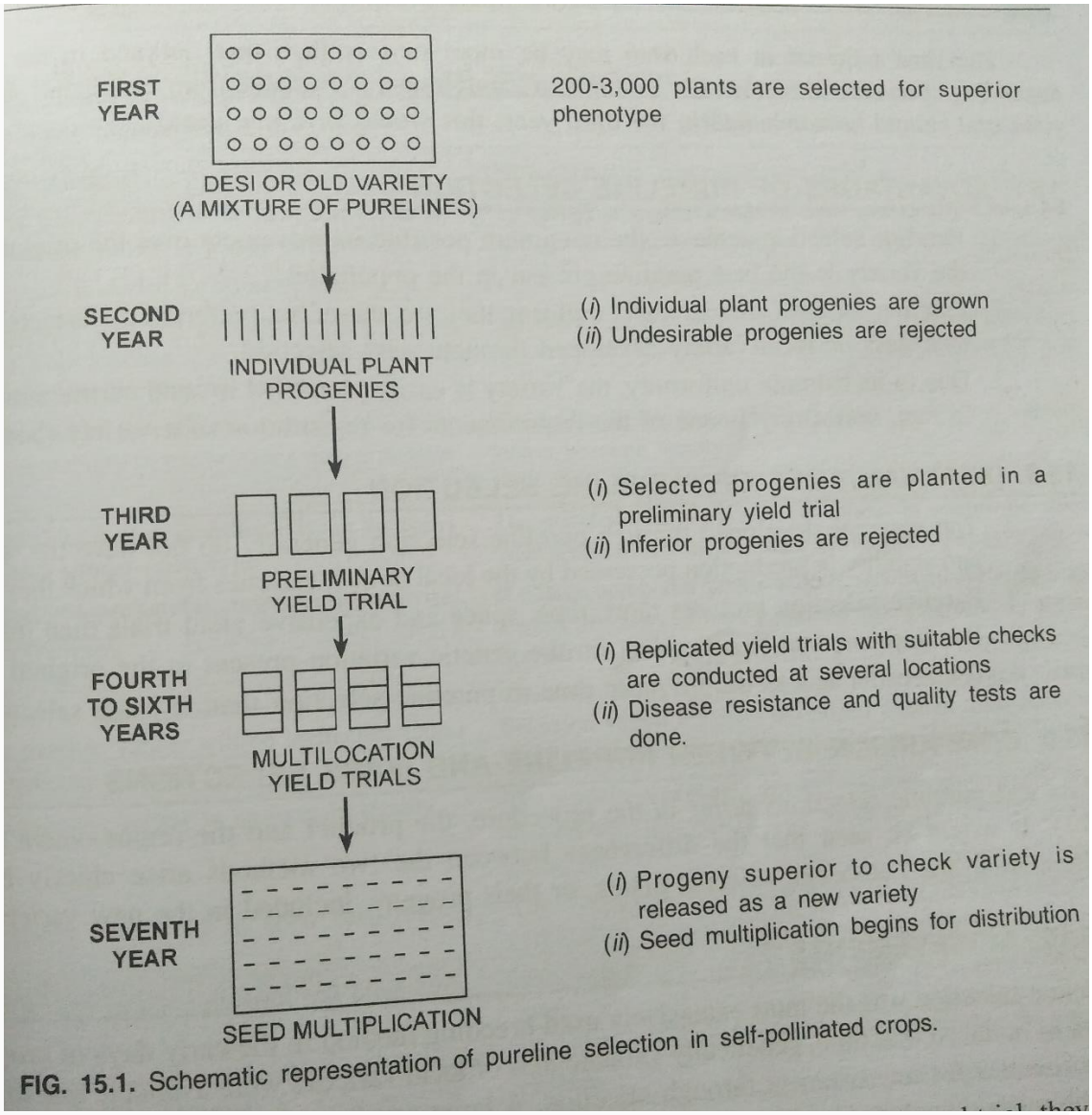


FIG. 15.1. Schematic representation of pureline selection in self-pollinated crops.

Advantages:

- Maximum possible improvement over original variety.
- Pureline varieties are extremely uniform and therefore, more preferred by farmers and consumers
- Due to uniformity, the variety is easily identified in seed certification programmes.

Disadvantages:

- This method can isolate only superior genotypes, it cannot create new genotypes. And not applicable in cross pollinated crop.
- Poor adaptability due to narrow genetic base vulnerable for new diseases and pests.
- Pureline selection requires more time, space and expensive yield trials than mass selection.
- Improvement is dependent on genetic variation present in the original population.

- The breeder has to devote more time to pureline selection than mass selection.

Comparison between pureline and mass selection

	Pure line selection	**Mass selection**
1	The new variety is a pureline	The new variety is a mixture of purelines.
2	The new variety is highly uniform. In fact, the variation within a pureline variety is purely environmental.	The variety has genetic variation of quantitative characters, although it is relatively uniform in general appearance.
3	The selected plants are subjected to progeny test.	Progeny test is generally not carried out.
4	The variety is generally the best pureline present in the original population. The pureline selection brings about the greatest improvement over the original variety.	The variety is inferior to the best pureline because most of the purelines included in it will be inferior to the best pureline.
5	Generally, a pureline variety is expected to have narrower adaptation and lower stability in performance than a mixture of purelines.	Usually the variety has a wider adaptation and greater stability than a pureline variety.
6	The plants are selected for the desirability. It is not necessary they should have a similar phenotype.	The selected plants have to be similar in phenotype since their seeds are mixed to make up the new variety.
7	It is more demanding because careful progeny tests and yield trials have to be conducted.	If a large number of plants are selected, expensive yield trials are not necessary. Thus, it is less demanding on the breeder.

Hybridization

- Natural variability in self-pollinated population is exhausted during selection, for further improvements new genetic variability has to be created by crossing two different pure lines. Hybridization means the mating or crossing of two plants or lines of dissimilar genotypes.

- The seeds as well as the progeny resulting from the hybridization are known as hybrid or F1. The progeny of F1 obtained by self or inter mating of F1 plants and the subsequent generations are called segregating generations. Today hybridization is the most common method of crop improvement and the majority of the crop varieties have originated from hybridization.
- One of the objectives of hybridization is to create genetic variation. Two genotypically different plants are crossed together to obtain F1 generation. F1 is advanced to generate F2 generation. The degree of genetic variation in F2 and subsequent generation depend on number of heterozygous genes in F1.

Aims of hybridization

1. To transfer of one or few qualitative characters.
2. Improvement in one or more quantitative character.
3. F1 Hybrid as variety.

I. Combination breeding:

This method is used for the transfer of one or more character into or single variety from another variety. Eg: improving the yield by correcting the defect. i.e. disease resistance. The other parent selected for hybridization must have a sufficient intensity of a character under transfer.

II. Transgressive breeding:

It aims at improving yield or its contributing character through transgressive segregation. It refers to the appearance of such plants in F_2 generation that are superior to both the parents for one or more character. It is due to accumulation of plus or favourable genes from the parents as a consequence of recombination. The parents used for crossing must combine very well and are genetically diverse. So, pedigree breeding followed by population approach are designed for production of transgressive segregants.

III. Hybrid varieties:

In self-pollinated crops F_1 is more vigorous and high yielding than the parents. Two parents should combine well to produce outstanding F_1 hybrid.

Types of hybridization

- Inter-varietal Hybridization / Intra specific: Parents involved in hybridization belong to the same species. They may be two strains, varieties or races.
- Varietal crosses may be simple crosses or complex crosses

a.) Simple crosses: Two parents are crossed to produce F_1 (A x B)

b.) Complex crosses: More than two parents are crossed to produce the hybrid (A x B) x C x F_1

Procedure of hybridization:

The breeder has clear cut objective in developing the variety. He has to select the variety accordingly.

1. Choice of parents*:* One of the parents involved in crosses should be a well-adapted and proven variety in the area. The other variety should be having the character that are absent in this variety. Combining ability of the parents serves as useful guides in the selection of parents, which produce superior F_1 and F_2.

2. Evaluation of parents: Parents are evaluated for their combining ability.

3. Emasculation: The removal of stamens/anther without affecting the female reproductive organs, hand emasculation is mostly followed.

4. Bagging: Immediately after emasculation the flowers are enclosed in suitable bags to prevent cross pollination.

5. Tagging: The emasculated flowers are tied with a thread. The information on date of emasculation, date of pollination, names of female and male parents are recorded in the tag with pencil. The name of the female parent is written first then male parent.

6. Pollination: Mature fertile and viable pollen from the male parent should be placed on receptive stigma of emasculated flowers to bring about fertilization. Pollen grain is collected, allowed for dehiscence and pollination is carried out with camel hair brush.

7. Harvesting and storing of F_1 seeds: The crossed heads/pods should be harvested and threshed. The seeds should be dried and properly stored to protect them from storage pests.

8. Rising the F_1 generation: Identify the selfed seeds in the F_1 generation by using dominant marker gene. Larger F_1 population is desirable, because both the genes are present in heterozygous condition.

9. Selfing: To avoid cross pollination and to ensure self-pollination. In often cross-pollinated crops, they are bagged to prevent cross pollination.

Distant Hybridization

When crosses are made between two different species or between two different genera, they are generally termed as distant hybridization (or) wide hybridization

History

Thomas Fairchild 1717 was the first man to do distant hybridization. He produced a hybrid between two species of Dianthus *Dianthus caryophyllus* (Carnation) x *D. barbatus* (Sweet william)

Inter generic hybrid produced by Karpechenko, a Russian Scientist in 1928. Raphano brassica is the amphidiploid from a cross between Radish (*Raphanus sativus*) and cabbage (*Brassica oleracea*). Triticale was produced by Rimpau in 1890 itself. Triticale is an amphidiploid obtained from cross between wheat and rye. Another example is *Saccharum* noblisation involving three species.

Hybrids in self-pollinated crops - problems and prospects

Exploitation of heterosis through F1 hybrids has hitherto been the prerogative of cross-pollinated crops, chiefly due to their breeding systems favouring allogamy. However, possibilities of working for such a proposition have recently been realized in self-pollinated corps also. Indeed, exploitation of hybrid vigour in autogamous/ self-pollinated crops is easy and less time consuming as homozygous inbreds are already available. There is practically no difference with regard to hybrid breeding between self and cross-pollinated crops. But the prospects of hybrids in self-pollinated crops are dependent on three major considerations:

1. How high a heterotic effect can be gained under optimal production conditions.

2. In fact, a breeder's main concern is the magnitude rather than the frequency of occurrence of heterosis in crops. Thus, the consideration is whether or not it is possible to obtain economically viable heterosis.

3. How much of the yield surplus due to high heterosis can offset the extra seed cost? In major self-pollinated crops like wheat, barley, rice, etc., the seed rate per unit area is exorbitant and hence the hybrid seed requirement is also more.

4. How efficient and effective is the mechanism of cross-pollination in self-pollinated crops? By nature, self-pollinated crops are shy pollinators with very poor pollen manoeuvrability (or movability to effect allogamy). Therefore, the efficiency (degree of allogamy) with which cross pollination can take place on a commercial scale is the true determinant of the success of a hybrid programme in self-pollinated crops.

5. Among self-pollinated crops, F_1 hybrids have been graduated into the farmer's field in rice, barely, tomato, Sorghum (often-cross-pollinated) and wheat.

Pedigree method of handling segregating generations

- In pedigree method individual plants are selected from F_2 and their progenies are tested in subsequent generations. A record of the entire parent off spring relationship is maintained and known as pedigree record. The pedigree may be defined as a description of the

ancestor of an individual and it generally goes back to some distant ancestor. So, each progeny in every generation can be traced back to the F_2 plant from which it is originated.

- This method used for selection from segregating population of crosses in self-pollinated crops. It is used for combination or transgressive breeding.

Procedure:

1. Hybridization: The selected parents are crossed to produce a simple / complex cross (F_1 seed)
2. F_1 generation: F_1 seeds are space planted to each produces maximum number of F_2 seed. 15-30 F_1plants are sufficient to produce good F_2 populations.
3. F_2 generation: 200-10000 plants are space planted and 100-500 plants are selected and their seeds are harvested separately. He should select as many as F_2 plants as he can handle efficiently. The selection depends on skill of the breeder and his ability to judge to select F_2 which produce good progeny.
4. F_3 generation: Individual plant progeny are space planted. Individual plant with desirable characters from superior progenies is selected.
5. F_4 generation: Individual plants progenies are space planted desirable pants are selected undesirable progenies are rejected. Progenies are compared visually and more plants are selected from superior progenies. Selection of desirable plants from superior progenies selection is practiced within / between family.
6. F_5 generation: Many families have reached homozygous and may be harvested in bulk. The breeder has to assess the yielding potential of progenies, 25-100 progenies are advanced and tested in preliminary yield trial.
7. F_6 generation: Multi row plots and evaluated visually progenies harvested bulk and they have become homozygous.
8. F_7 generation: Preliminary yield trail with replication to identify the superior progenies. Progenies are evaluated for other component character 2-5 outstanding lines superior to check are advanced to multi location testing.
9. F_8 –F_{10} generation: Replicated yield trial at several locations. They are tested for yield as well as for resistance.
10. F_{11} generation: Seed multiplication and release.

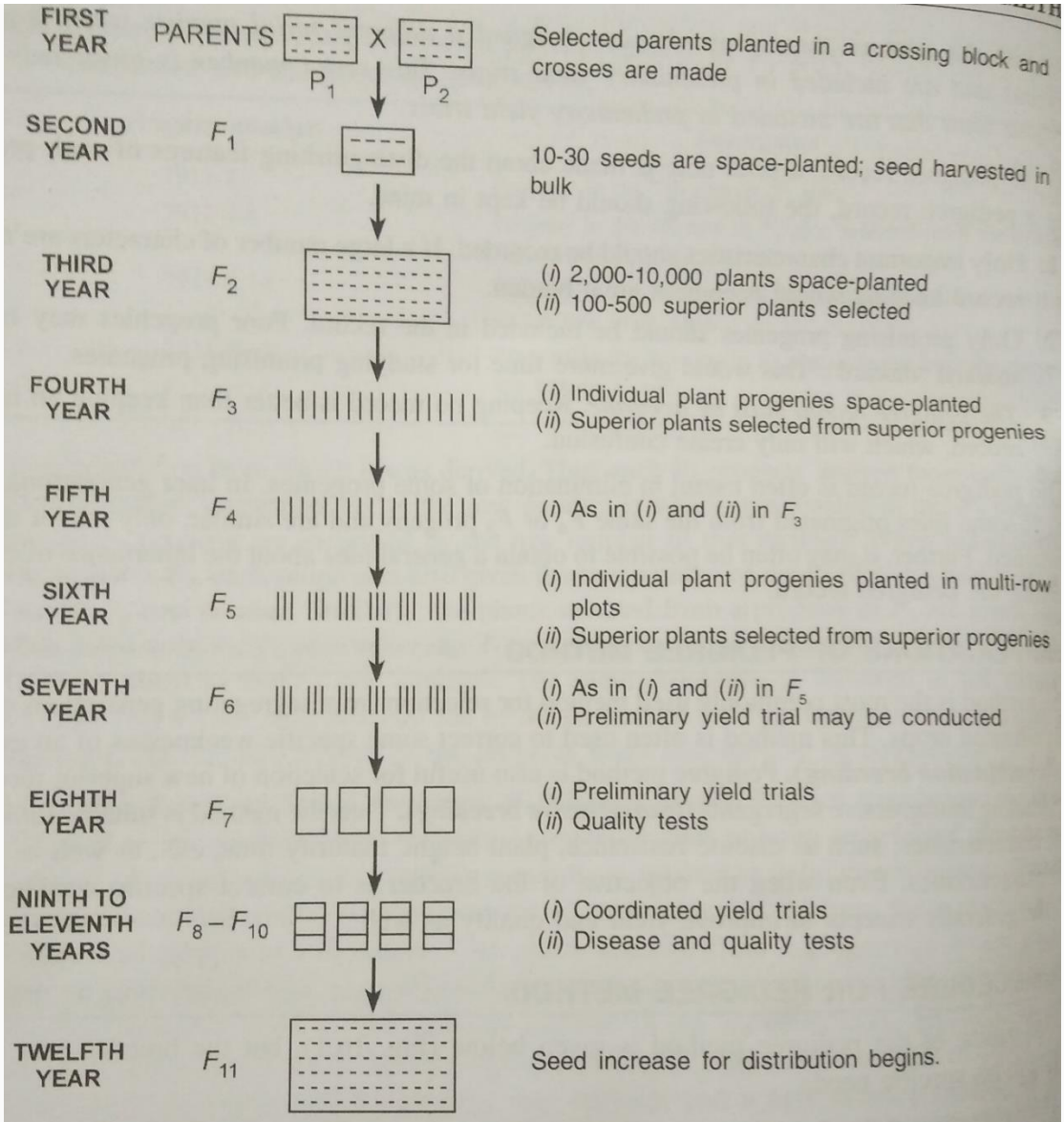


FIG. 16.1. A simplified schematic representation of pedigree method.

Merits:

1. Maximum opportunity for the breeder to use his skill and judgment for the selection of plants in segregating generation.
2. It provides information about the inheritance of qualitative character from the pedigree record.
3. Chances of recovering transgressive segregants is more.
4. Plants and progenies with visible defects and weaknesses are eliminated at an early stage.
5. Well suited for the improvement of easily identified and simply inherited characters.

Demerits:

1. Maintenance of accurate pedigree record is tedious and takes up valuable time

2. Selection of progenies in every generation laborious, time consuming. Difficult to handle many crosses.
3. No opportunity for natural selection.
4. Possibility of losing the valuable genotype is early segregating generation.
5. The success of this method largely depends on skill of the breeder.

Bulk method

Bulk method was first used by Nilsson Ehle in 1908. F_2 and the subsequent generations are harvested as bulks to raise the next generation. At the end of bulking period individual plants are selected and evaluated in a similar manner as in the pedigree method. The duration of bulking may vary from 7-30 generation artificial selection may seldom be practiced

1. Isolation of homozygous lines

It is used for the isolation of homozygous lines with a minimum of effort and expense. The population is carried to F_6-F_7 as Bulk, where it reaches homozygosity. Individual plants are selected and evaluated to derive pure line. So preliminary yield trails are conducted to derive homozygous lines.

2. Waiting for the opportunity for selection:

Selection for resistance to disease, lodging and cold depends upon the presence of suitable environmental conditions favouring epidemic. Waiting till such environment do occur so the segregating generations are carried as bulk in such environment. Individual plants are selected and handled as in pedigree method. The duration of bulking depends upon the occurrence of the concerned environment. This is known as mass pedigree method of Harlan.

3. Opportunity for natural selection:

Maintenance of bulk is inexpensive and without much efforts. Some bulk populations are carried up to F_{20} to F_{30} to provide an opportunity for natural selection to act on their composition. Up to F_6 generation the population is heterozygous and after F_7 generation natural selection to act on homozygous plants and would change the frequency of homozygous genotypes present in the population. It is assumed that natural selection would favour higher yielding genotypes and eliminate poorer genotypes.

Procedure of bulk method:

1. Hybridization: Parents are selected and crossed
2. F_1 generation: F_1 is space planted more than 200 F_1 plants

3. F_2-F_6 Generation: Planted at commercial seed rate, spacing and harvested as bulk, during this period. Frequency of population changes due to outbreak of disease or pest.
4. F_7 generation: 50000 plants are space planted about 1000-5000 plants with phenotype is selected and the seeds are harvested separately.
5. F_8 generation: Individual plant progenies are single/multi row plants, since progenies are homozygous and harvested in bulk weak and inferior progenies are rejected and 100-300 individual plant progenies with desirable characters.
6. F_9 generation: Preliminary yield trial with standard check, yield and quality parameter is taken for selection.
7. F_{10}---F_{12} generations: Replicated yield trails are conducted. Yield and its component characters are evaluated along with the check. Superior progenies are released as variety
8. F_{13} generation: Seed multiplication of the newly released variety and distribution to farmers.

Merits

1. Simple, convenient and inexpensive method
2. Natural selection is likely to increase the frequency of superior genotypes in the population. Therefore, progenies selected from long term bulks are likely to be superior to those selected from F_2 or short bulks.
3. Little work and attention are required in F_2 and subsequent generations, and no pedigree record is to be kept. This save time and labour, and the breeder can concentrate more on other breeding projects.
4. Since large populations are grown, chances of getting transgressive segregants are more.
5. Individual plant selection is done when population has become homozygous. Therefore, selection is expected to be more effective than in F_2 and F_3 generations.
6. Particularly suited to small grain crops grown in high crop densities.
7. Natural selection is expected to improve characters like adaptation to prevailing environment which are otherwise difficult to assess and select for.

Demerits

1. The major disadvantage of bulk method is longer time taken to develop a new variety. Natural selection becomes important only after F_{10} generation and bulking may have to be done up to F_{20} or more which is considerably longer than the time taken in pedigree method
2. In short term bulks, natural selection has little effect on the genetic composition of populations. But short-term bulks are useful for isolation of homozygous lines.

3. It provides little opportunity to breeders to exercise their skill in selection.
4. A large number of progenies have to be handled at the end of the bulking period.
5. Information on inheritance of characters cannot be obtained
6. Off season and green house facilities cannot be used to advance the generation since environment at such locations may be markedly different from that in target location.

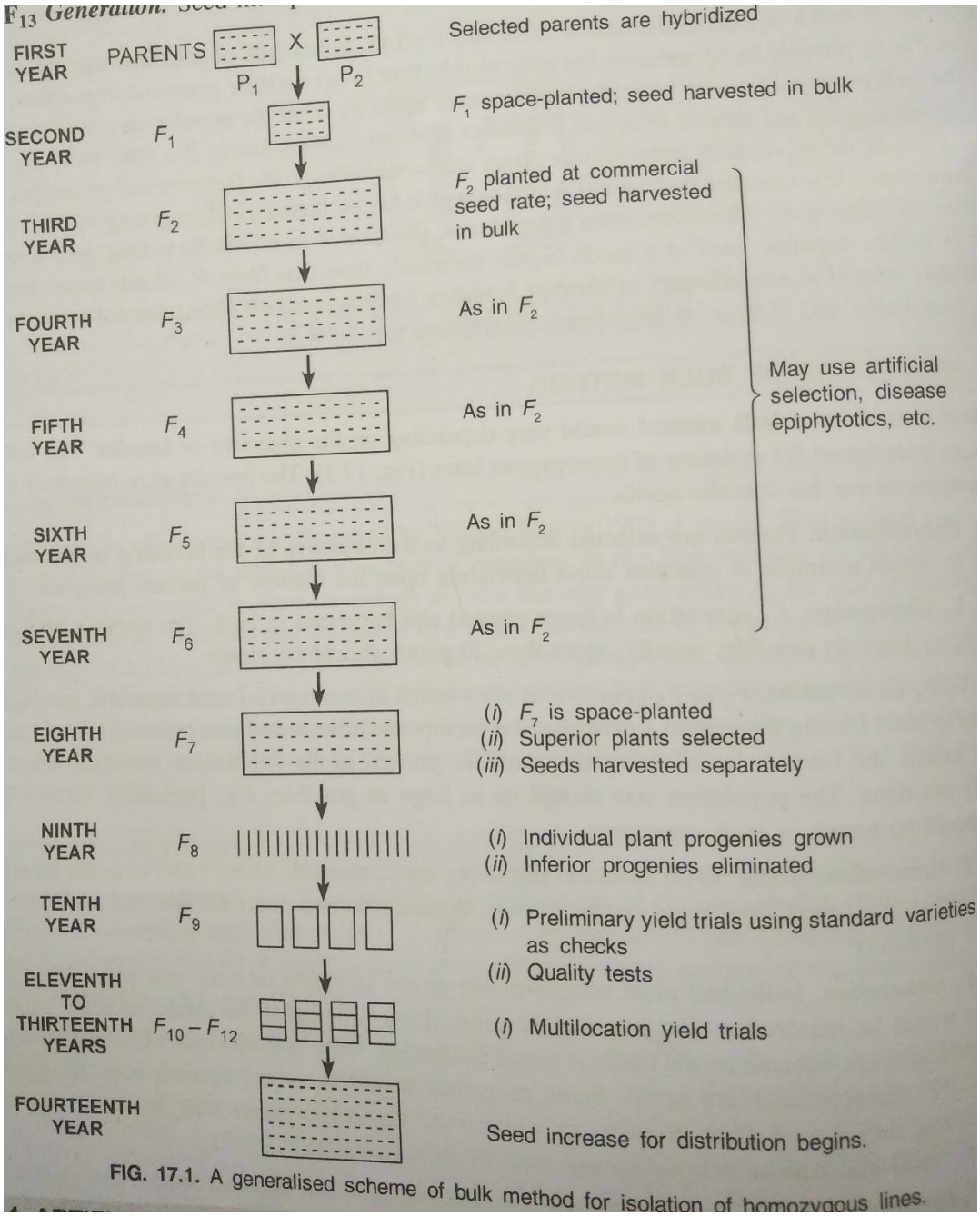


FIG. 17.1. A generalised scheme of bulk method for isolation of homozygous lines.

Single seed decent method

- Single seed descent method This method is a modification of bulk method

- Single seed from each F_2 plants is bulked to raise the F_3 generation. Similarly, F_3, F_4, F_5 generation when the plants are homozygous plant progenies are advanced to next generation. Selection is done mainly among the progenies and number of progenies is sufficiently reduced to permit replicated trail. Individual plants may be selected from outstanding families showing segregation. So preliminary yield trial and quality tests begin in F_7 to F_8.

Objectives

1. Rapidly advance of generation of crosses.
2. F_2 and subsequent generation are grown with a very high plant density.
3. F_2 plant is represented equally in the end population.
4. Off season nursery/green house facilities are utilized.
5. Maximum possible speed.
6. Require very little space/effort/ labour.
7. Do not permit any form of selection during the segregating generation.
8. In each successive generation the population size become small due to poor generation and death of plants due to disease/pest.

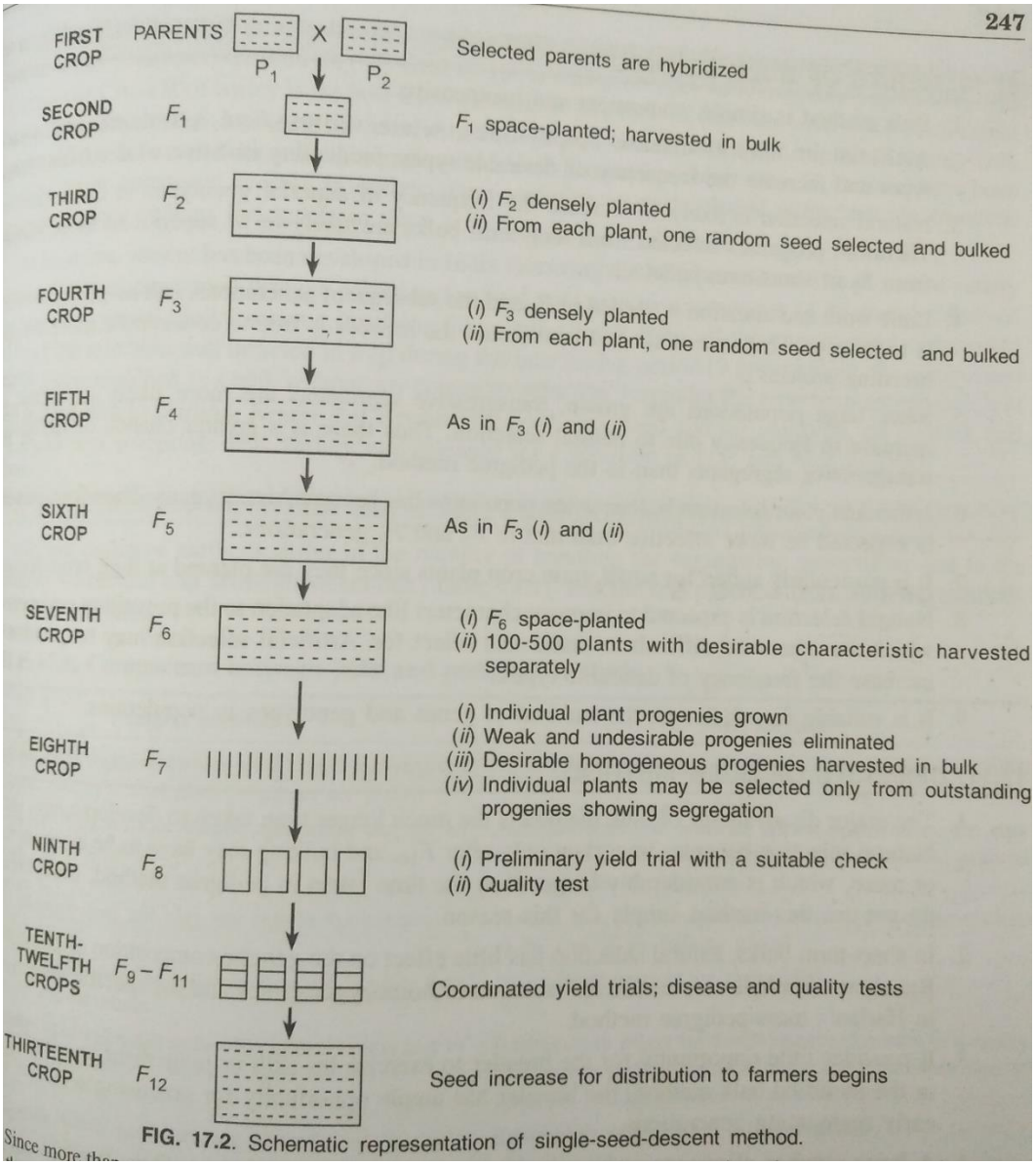


FIG. 17.2. Schematic representation of single-seed-descent method.

Since more than

Pedigree Method	**Bulk Method**
Individuals plants are selected in F_2 and Segregation generation and individual plant progenies are grown	F_2 and the subsequent generation are maintained as bulk
Artificial selection, Artificial disease epidemics are an integral part	Artificial selection, artificial disease epidemic can be created to assist natural selection.
No role of Natural section	Natural selection determines the composition of population.
Pedigree record have to be maintained which is laborious and time consuming	No pedigree records are maintained
It takes 12 years to develop new variety	More than 12 years bulk population > 10

	years for effective natural selection
Widely used method	Limited use
Needs close attention from F_2 onwards	It is simple convenient.
Segregating generation are space planted to permit individual plant selection	Bulk population are planted at commercial planting rate
Population size is small	Larger population are grown and the natural selection expected to the increase the chances recovery of transgressive segregants

Back cross method

A Crossing between a F_1 hybrid or its segregating generation with one of its parents is known as Back cross. The hybrid and its progenies in the subsequent generations are repeatedly back crossed to one of their parents. As a result, the genotype of back cross progeny becomes increasingly similar to that parent to whom the back crosses are made. At the end of 6-8 back crosses, the progeny would be almost identical with the parent involved in back crossing.

Objective:

1. To improve one or two specific defects of a high yielding variety and a well-adapted variety with desirable character.

2. The characters lacking in this variety are transferred to it from a donor parent without changing the genotype of this variety except for the genes being transformed.

Requirements of back cross breeding

1. Suitable recurrent parent must be available which lacks in one or two characteristics.

2. A suitable donor parent must be available; the character must be highly intense.

3. The character(s) to be transferred must have high heritability and preferably, should be governed by one or few genes

4. A sufficient number of back crosses should be made so that genotype of recurrent parent is recovered in full. Ordinarily, 6-7 backcrosses are sufficient for the purpose.

Applications of back cross breeding

1. Inter varietal transferring of simply inherited traits. Characters governed by one or two genes like disease resistance are successful.
2. Inter varietal transfer of quantitative characters and highly heritable quantitative characters like earliness, plant height, seed size and seed shape are transferred.

3. Inter specific transfer of simply inherited characters: Disease resistance is transferred from related species to cultivated species. Inter specific transfer of genes are easy when the chromosome of the two species pair regularly.
4. Transferring of cytoplasm: wild species cytoplasmic are transferred to cultivated species transfer of male sterility. The variety or species from which the cytoplasm is to be transferred is used as the female parent. The parent to which the cytoplasm is to be transferred is used as the male parent in the original cross and back cross. After 6-8 back crosses the progeny would have the nuclear genotype of the recurrent parent and the cytoplasm from the donor parent.
5. Transgressive segregation: F1 is back crossed to one or two times to the recurrent parent leaving much heterozygosity for transgressive segregation to appear. In the second modification two or more recurrent parent may be used in the back-cross progeny to accumulate genes from them into the back cross. Progeny of the new variety is not exactly like any one of the recurrent parents.
6. Production of isogenic lines: Isogenic lines are identical in their genotype except for one gene
7. Germplasm conversion: When valuable germplasm cannot be utilized in breeding programmes and may be used as recurrent parent in separate back cross programme these lines are called converted lines.

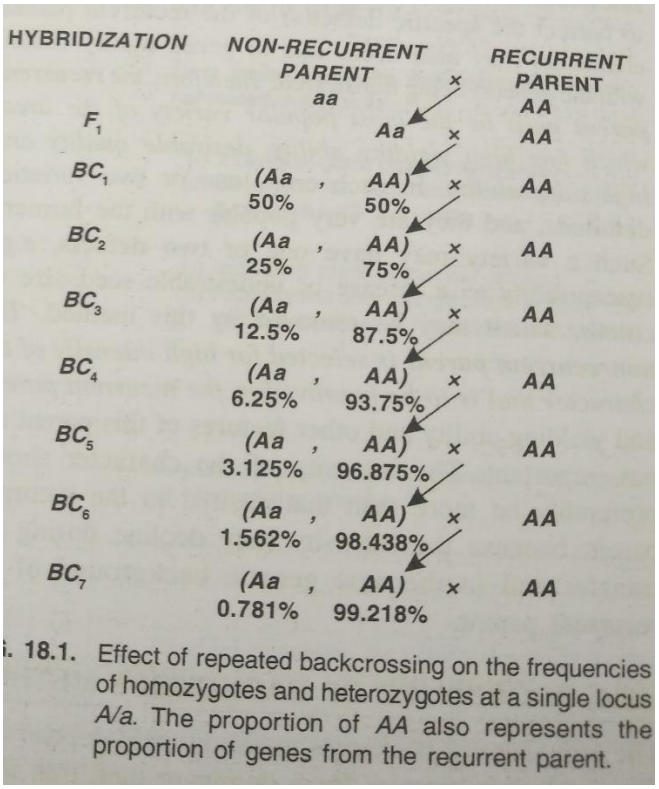
Procedure for transfer to dominant gene

E.g. High yielding and widely adapted wheat variety A is susceptible to stem rust another variety B is resistance to stem rust. Stem rust is dominant to susceptibility.

1. Hybridization: Variety A is crossed to variety B. Generally, variety A should be used as female parent. This would help in identification of selfed plants.

2. BC_1 generation: F_1 plants are back crossed to variety A. Since all the F_1 are heterozygous for rust resistance, selection for rust resistance is not necessary.

3. First BC_1 generation: Half of the plants in BC_1 generation are resistant and the remaining half would be susceptible to stem rust. Rust resistant plants are selected and back crossed to variety A.



. 18.1. Effect of repeated backcrossing on the frequencies of homozygotes and heterozygotes at a single locus *A/a*. The proportion of *AA* also represents the proportion of genes from the recurrent parent.

4. BC_2 to BC_5 generation: Segregation would occur for rust resistance. Rust resistant plants are selected and back crossed to variety A.

5. BC_6 generation: BC_6 plants will have 99 percent genes from variety A Rust resistant plants are selected and selfed, their seeds are harvested separately

6. BC_6F_2 generation: Individual plants progeny from the selfed seeds of the selected plants are grown. Rust resistant plant similar to the plant type of variety A are selected and they are selfed. Seeds are harvested separately.

7. BC_6 F_3 generation: Individual plants progeny are grown. Progenies homozygous for rust resistant and similar to plant type of variety Aare harvested in bulk. Several similar progenies are usually mixed to constitute the new variety.

Merits:

1. Back cross method retains all desirable character of a popular adapted varieties and replaces undesirable allele at particular locus

2. Useful for the transfer of disease resistance and incorporation of quality traits into a variety

3. This is used for the development of isogenic lines,

4. Extensive tests are not required 2-3 generation can be raised in off season nurseries greenhouses; it would save time.

5. This is the only method for the inter specific gene transfer and transfer of cytoplasm.

6. Male sterility and fertility restoration genes can be transferred to various back ground.

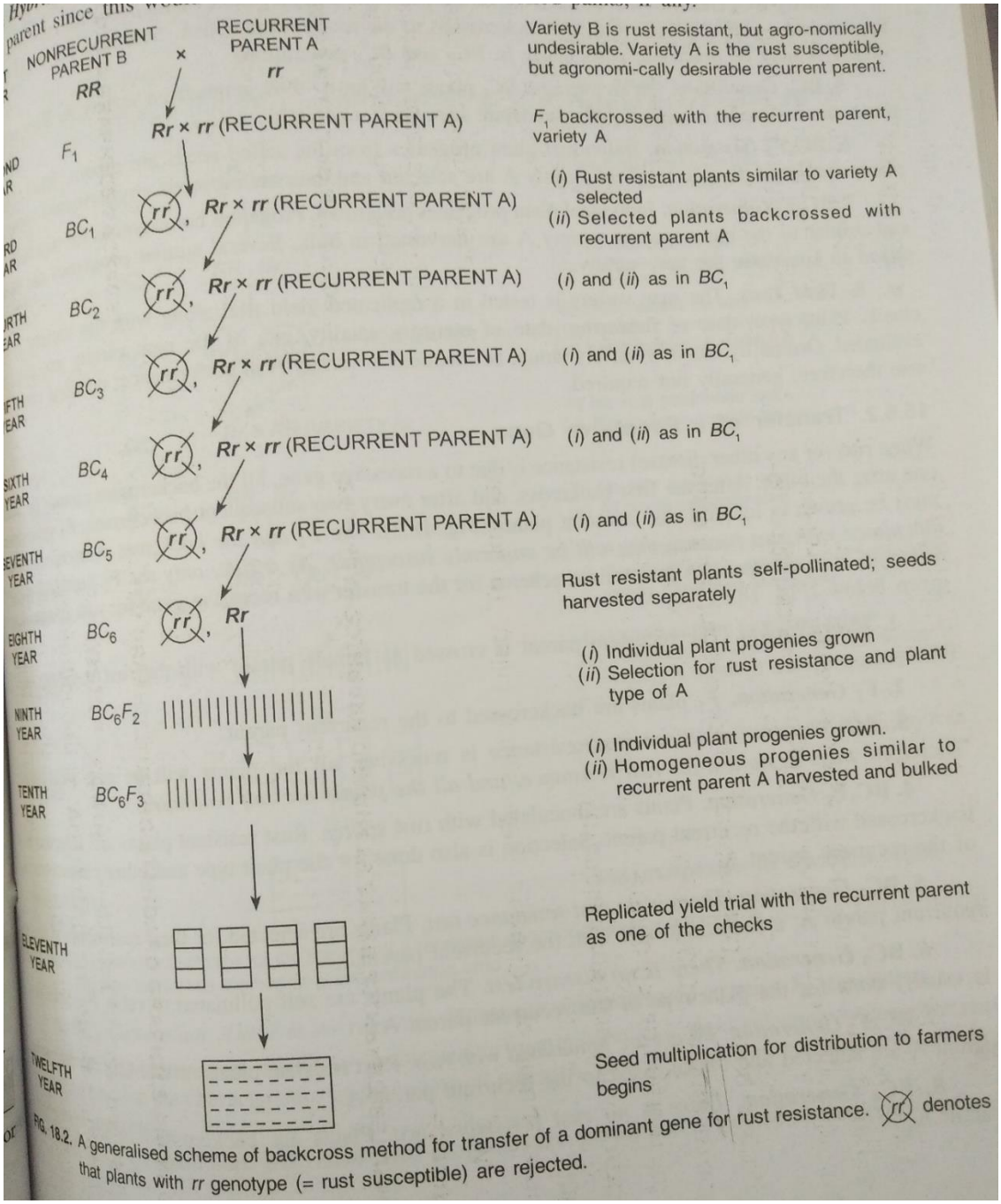


FIG. 18.2. A generalised scheme of backcross method for transfer of a dominant gene for rust resistance. (rr) denotes that plants with *rr* genotype (= rust susceptible) are rejected.

Demerits:

1. New variety cannot be superior to recurrent parent except for the character transferred
2. It involves lot of crossing work. 6-8 back cross is often difficult and time consuming.
3. Sometime undesirable gene linked with desirable also may be transferred.
4. By the time the back cross programme the recurrent parent may have been replaced by other varieties superior in yield and other character.

Multiline Varieties

Generally, pureline varieties are highly adapted to a limited area, but poorly adapted to wider regions. Further, their performance is not stable from year to year because of changes in weather and other environmental factors. Purelines often have only one or a few major genes for disease resistance, such as, rust resistance, which make them resistant to some races of the pathogen. New races are continuously produced in many pathogens, which may overcome the resistance present in the pureline varieties. For example, Kalyan Sona wheat (*T. aestivum*) originally resistant to brown rust (leaf rust), soon became susceptible to new races of the pathogen. To overcome these limitations, particularly the breakdown of resistance to disease, it was suggested to develop multiline varieties.

Multiline varieties are mixtures of several purelines of similar height, flowering and maturity dates, seed colour and agronomic characteristics, but having different genes for disease resistance. The purelines constituting a multiline variety must be compatible, i.e., they should not reduce the yielding ability of each other when grown in mixture.

In 1954, Borlaug suggested that several purelines with different resistance genes should be developed through back cross programmes using one recurrent parent. This is done by transferring disease resistance genes from several donor parents carrying different resistant genes to a single recurrent parent. Each donor parent is used in a separate backcross programme so that each line has different resistant gene or genes. Five to ten of these lines may be mixed depending upon the races of the pathogen prevalent in the area. If a line or lines become susceptible, they would be replaced by resistant lines. New lines would be developed when new sources of resistance become available. The breeder should keep several resistant lines in store for future use in the replacement of susceptible lines of multiline verities.

Merits of Multiline varieties

1. All the lines are almost identical to the recurrent parent in agronomic characteristics, quality etc. Therefore, the disadvantages of the pureline mixtures are not present in the multiline varieties.

2. Only one or a few lines of the mixture would become susceptible of the pathogen in anyone season. Therefore, the loss to the cultivator would be relatively low.

3. The susceptible line would constitute only a small proportion of the plants in the field. Therefore, only a small proportion of the plants would be infected by the pathogen. Consequently, the disease would spread more slowly than when the entire population was susceptible. This would reduce the damage to the susceptible line as well.

Demerits of Multiline Varieties

1. The fanner has to change the seed of multiline varieties every few years depending upon the change in the races of the pathogen.

2. There is a possibility that a new race may attack all lines of a multiline variety.

Achievements

Multiline variety appears to be a useful approach to control diseases like rusts where new races are continuously produced. In India, three multiline varieties have been released in wheat (*T. aestivum*). Kalyan Sona, one of the most popular varieties in the late sixties, was used as the recurrent parent to produce these varieties. Variety 'KSML 3' consists of 8 lines having rust resistance genes from Robin, Ghanate, Kl, Rend, Gabato, Blue Brid, Tobari etc. Multiline 'MLKS 11' is also a mixture of 8 lines; the resistance is derived from E 6254, E 6056, E 5868, Frecor, HS 19, E 4894 etc. The third variety, KML 7406 has 9 lines deriving rust resistance from different sources.

Dirty Multiline

This term is used when a multiline is having one or two susceptible lines also. The idea of including susceptible lines is to prevent race formation.

Hardy Weinberg Law

- Cross pollinated crops are highly heterozygous due to the free inter mating among them so these are random mating populations. Because each individual of the population has equal opportunity of mating with any other individual. It is also known as mendelian/panmictic population. A Mendelian population may be thought of having a gene pool consisting of all gametes produced by the population. So, gene pool may be defined as the sum total of all genes present in the population. A population consists of all such individuals that share the same gene pool has an opportunity to inter mate with each other and contribute to the next generation of the population.
- Each generation of a Mendelian population may be considered to arise from a random sample of gametes from the gene pool of previous generation. Hence, it is not easy to follow the inheritance of a gene in a Mendelian population. It cannot be estimated by using the techniques of classical genetics. So, to understand the genetic makeup of such population a population genetics has been developed.
- This law is independently developed by Hardy (1908) in England and Weinberg (1909) in Germany. The law states that the gene and genotype frequencies in a Mendelian population remain constant from generation after generation if there is no selection, mutation, migration or random drift.

- The frequencies of these genotypes for a locus with two alleles A and a would be P^2(AA), 2pq (Aa)and q^2(aa)

  Where, p= Frequency of 'A' allele in the population.

- q= Corresponding frequency 'a' allele in the population the sum of p+q is equal=1

Such a population would be at equilibrium since the genotypic frequencies would be stable, that is, would not change from one generation to the next. This equilibrium is known as Hardy Weinberg equilibrium.

Migration: Migration is the movement of individual into a population from a different population. Migration may introduce new alleles into the population or may change the frequency of existing allele. The amount of change in gene frequency 'q' will primarily depend upon two factors.

a. Ratio of migrant individuals to those of the original population.

b. The Magnitude of difference between the values of q in the population and in the migrants.

So, in plant breeding migration is by inter varietal crosses or poly crosses.

Mutation: mutation is a sudden heritable change in an organism and is generally due to a structural change in a gene. It may produce a new allele not present in the population or may change the frequency of existence allele that 10^{-6} mutation is detected. So, such effects in breeding population may be ignored.

Random drift or genetic drift: It is a random change in gene frequency due to sampling error. Random drift is more in small population than larger. Ultimately, the frequency of one of the alleles becomes zero and that of the other allele becomes one. The allele with the frequency one is fixed in the population because there would be no change in the frequency. So, all genes become homozygous. The genetic drift can be reduced by handling large population.

Inbreeding: Mating between individuals sharing a common parent in their ancestry inbreeding reduces the proportion of the heterozygosity and increase the frequency of homozygosity by the rate of decrease in heterozygosity is equal to ½ N (N- Number of plants in the population) per generation in monoecious or hermaphrodite species. In dioecious species and monoecious species where self-pollination is prevented the decrease in heterozygosity is low. In small population, even with strict random mating / strict cross pollination the frequency of homozygotes increases while that of heterozygotes decreases due to inbreeding

Selection: The selection in a random mating population is highly effective in increasing or decreasing the frequency of allele, but it is unable to either fix or eliminate them. However, in combination with a system of inbreeding, selection is highly efficient in the fixation and elimination of an allele.

Inbreeding

It is mating between individuals related by descent or having common ancestry. The highest degree of inbreeding is obtained by selfing. Inbreeding depression refers to decrease in fitness and vigour due to inbreeding. The degree of inbreeding is measured by the inbreeding coefficient.

History of inbreeding:

In breeding depression has been recognised by man for a long time. Knowing the consequences of inbreeding many societies have prohibited marriages between closely related individuals. Darwin in 1876 published a book "cross and self-fertilization in vegetable kingdom" in which he concluded that progenies obtained from self-fertilization were weaker in maize. Detailed and precise information on inbreeding in maize was published by East in 1908 and Shull in 1909.

The different effects of inbreeding are:

1. Appearance of Lethal and Sublethal Alleles: IB results in appearance of lethal; sublethal and sub vital characters. e.g.: Chlorophyll deficiencies, rootless seedlings, flower deformities – They do not survive, they lost in population.

2. Reduction in vigour: General reduction in vigour size of various plant parts.

3. Reduction in Reproductive ability: Reproductive ability of population decreases rapidly. Many lines reproduce purely that they cannot be maintained.

4. Separation of the population into distinct lines: Population rapidly separates into distinct lines i.e. due to increase in homozygosity. This leads to random fixation of alleles in different lines. Therefore, lines differ in genotype and phenotype. It leads to increase in the variance of the population.

5. Increase in homozygosity: Each line becomes homozygous. Therefore, variation within a line decreases rapidly. After 7-8 generations of selfing the line becomes more than 99% homozygous. These are the inbreds which have to be maintained by selfing.

6. Reduction in yield: Inbreeding leads to loss in yield. The inbreds that survive and maintained have much less yield than the open pollinated variety from which they have been developed.

Degrees of inbreeding depression

Various plant species exhibit different degrees of inbreeding depression. The depression may be from very high to nil. Based on degree of depression, the plant species can be grouped into 4 broad categories.

1. High inbreeding depression: E.g. Lucerne, Carrot. Inbreeding leads to severe depression and exhibit lethal effects. After 3 or 4 generations of selfing it is hard to maintain lines.

2. Moderate inbreeding depression: E.g. Maize, Jowar, Bajra. Though lethal effects are there, lines can be separated and maintained.

3. Low inbreeding depression: E.g. Cucurbits, Sunflower. Only a small degree of inbreeding depression is observed.

4. No inbreeding depression: The self-pollinated crops do not show inbreeding depression.

Heterosis

The term heterosis was first used by Shull in 1914. Heterosis may be defined as the superiority of an F1 hybrid over both of its parents in terms of yield or some other character. Generally, heterosis is manifested as an increase in vigour, size, growth rate, yield or some other characteristic.

History

Koelreuter is first reported hybrid vigour in tobacco produced artificial hybrids. In 1876, Darwin concluded that hybrids form unrelated plant type were highly vigorous. Most of our present knowledge on heterosis comes from the work on maize. Crossing inbred lines rather than open pollinated varieties produces the commercial maize hybrids. Hybridization between inbreds developed from the same variety or from closely related varieties produced only a small degree of heterosis.

- But a vast majority of the cases of heterosis are cases of superiority of hybrids over their parents. Hybrid vigour describes only superiority of hybrids over the parents. The few cases where F1 hybrids are inferior to their parents may also be regarded as cases of hybrid vigour in the negative direction.

Heterosis is the superiority of a hybrid over its parents.

1. Increased yield: Heterosis is generally expressed as an increase in the yield of hybrids. The yield may be measured in terms of grain, fruit, seed, leaf, tubers or the whole plant.
2. Increased reproductive ability: More number of flowers/fruits/seeds. Increase in Size and General Vigour: The hybrids are generally more vigorous, i.e., healthier and faster growing and larger in size than their parents.

3. Better quality: In many cases, hybrids show improved quality. For example, many hybrids in onion show better keeping quality, but not yield, than open-pollinated varieties.
4. Earlier flowering and maturity: In many cases hybrids are earlier in flowering and maturity than the parents. But earliness is highly desirable in many situations particularly in vegetables.
5. Greater resistance to disease and pest: Some hybrids are known to exhibit a greater resistance to insect or diseases than their parents.
6. Greater adaptability: Hybrids are generally more adapted to environmental changes than inbreds.
7. Faster growth rate: In some cases, hybrids show a faster growth rate than their parents. But the total plant size of the hybrids may be comparable to that of parents. In such cases, a faster growth rate is not associated with a larger size.
8. Increase in the number of a plant part: In some cases there is an increase in the number of nodes, leaves and other plant parts, but the total plant size may not be larger.

Estimation of heterosis

1. Average heterosis:

It is the heterosis where F_1 is superior to mid parent value. In other words, superior to average of two parents.

$$\frac{F_1 - MP}{MP} \times 100$$

Where F_1 = Mean of hybrid

MP = Mid parental value.

$$MP = \frac{(P_1 + P_2)}{2}$$

where P_1 = Parent 1; P_2 = Parent 2

This type of heterosis is of no use in agriculture since the superiority is below the better parent value

2. Heterobeltiosis:

Superiority of F_1 over the better parent.

$$\frac{F_1 - BP}{} \times 100$$

BP

Where BP = Mean of Better Parent.

3. Economic heterosis:

Superiority of the F_1 compared to the high yielding commercial variety in a particular crop.

F_1 - CV

--------- x 100

CV

Where CV = Mean of Commercial Variety.

4. Negative heterosis:

Performance of F_1 inferior to better parent / mid parent value. - e.g. Duration.

Breeding Methods for Cross Pollinated Crops

Populations of cross-pollinated crops are highly heterozygous. When inbreeding is practiced, they show severe inbreeding depression. So, to avoid inbreeding depression and its undesirable effects, the breeding methods in the crop is designed in such a way that there will be a minimum inbreeding. The breeding methods commonly used in cross pollinated crops may be broadly grouped into two categories.

I. Population improvement

2. Hybrids

3. Synthetics and Composites

Population Improvement

In cross pollinated crops, population improvement is used to enhance the frequency of desirable alleles in a population.

Population improvement without progeny test: Mass selection,

Population improvement with progeny testing includes Recurrent selection

Mass selection

This is similar to the one, which is practiced, in self-pollinated crops. A number of plants are selected based on their phenotype and open pollinated seed from them are bulked together to raise the next generation. The selection cycle is repeated one or more times to increase the frequency of favourable alleles. Such a selection is known as phenotypic recurrent selection.

Merits

i) Simple and less time consuming

ii) Highly effective for character that are easily heritable. Eg. Plant height, duration.

iii) It will have high adaptability because the base population is locally adapted one.

Demerits

1. Selection is based on phenotype only which is influenced by environment

2. The selected plants are pollinated both by superior and inferior pollens present in the population.

3. High intensity of selection may lead reduction in population there by leading to inbreeding.

Recurrent selection

This is one of the breeding methods followed for the improvement of cross-pollinated crop. Here single plants are selected based on their phenotype or by progeny testing. The selected single plants are selfed. In the next generation they are intermated (cross in all possible combinations) to produce population for next cycle of selection. The recurrent selection schemes are modified forms of progeny selection programmes. The main difference between progeny selection and recurrent selection:

i) The manner in which progenies are obtained for evaluation.

ii) Instead of open pollination, making all possible inter crosses among the selected lines.

The recurrent selection schemes are of 4 different types:

i. Simple Recurrent Selection
ii. Recurrent Selection for GCA
iii. Recurrent Selection for SCA
iv. Reciprocal Recurrent Selection

1. Simple recurrent selection

In this method 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 amount 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 amount of seeds are composited to raise next generation. This forms the first recurrent selection cycle.

First Year:

i) Several superior plants are selected.

ii) Selected plants selfed.

iii) Harvest the single plants.

iv) Seeds are evaluated, superior plants are identified.

Second Year:

i) Progeny rows raised

ii) Inter crosses are made in all combination by hand.

iii) Equal amount of seed bulked from each cross.

Third Year:

i) Composited seeds raised

ii)Repeat the operation as in first year

Fourth Year:

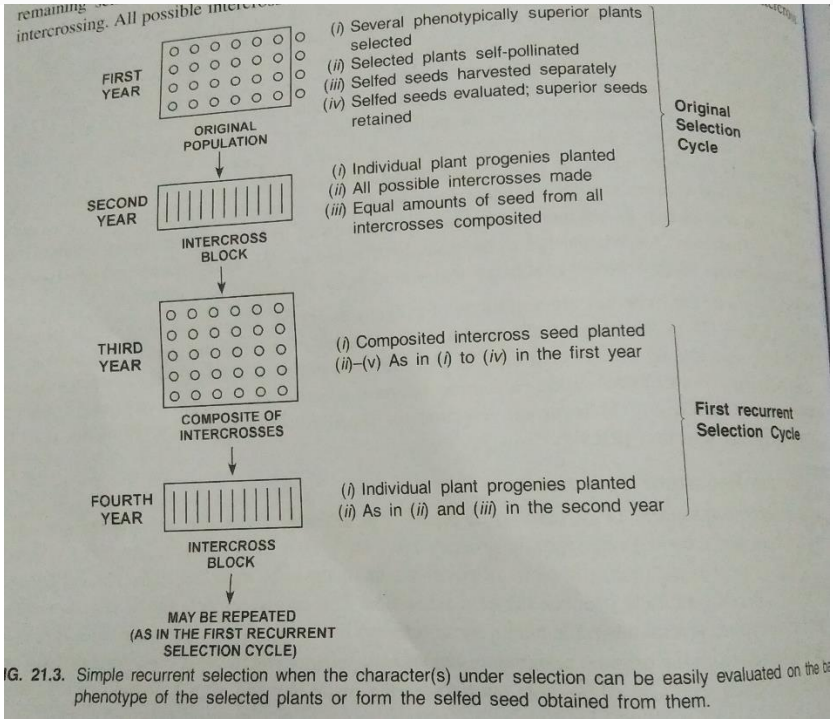
Repeat as in second year.

i) Recurrent selection is effective in increasing the frequency of desirable genes in the population

ii) Most suited for characters having high heritability.

iii) Inbreeding is kept at minimum.

Eg: oil content, protein content and high heritability traits are effective for increasing the frequency of desirable genes in the selected populations



IG. 21.3. *Simple recurrent selection when the character(s) under selection can be easily evaluated on the b phenotype of the selected plants or form the selfed seed obtained from them.*

Merits of recurrent selection

i) Recurrent selection is effective in increasing the frequency of desirable genes in the population ii) Most suited for characters having high heritability

iii) Inbreeding is kept at minimum.

2. Hybrids

They are the first generation from crosses between two pure lines, inbreds, open pollinated varieties of other populations that are genetically not similar. Pure line hybrids: Tomato. Inbred hybrids: Maize, bajra.

Kinds of hybrids

1. Single cross hybrids (A x B)

Crossing two inbreeds or pure lines.

2. Three-way cross hybrid (A x B) x C

A cross between a single cross hybrid and an inbred.

3. Double cross hybrid (A x B) x (C x D)

cross between two F_1s.

4. Double Top Cross hybrid

Double cross hybrid crossed with open pollinated variety.

Operation in production of hybrids:

In production of hybrids inbreds are preferred rather than open pollinated varieties for the following reasons:

1. Inbreds can be maintained without a change in the genotype. Whereas open pollinated variety cannot be maintained pure. They may alter genotypically due to natural selection etc.
2. The hybrids derived from inbreds will be uniform where as it may not be in case, of open pollinated variety.
3. The inbreds are homogenous and their performance can be predicted whereas open pollinated variety are heterogenous and their prediction in performance cannot be made.

Development of inbreds

1. By inbreeding, selfing etc.
2. Development of inbreds from haploids - rice, sorghum, maize.

Evaluation of inbreds

a) Phenotypic evaluation

Based on phenotypic performance. Highly suitable for characters with high heritability.

b) Top cross test

Top cross test provides a reliable estimate of GCA. The selected inbreds will be crossed to a tester parent with wide genetic base i.e. open pollinated variety. The cross progenies will be evaluated in replicated progeny rows. Based on results better inbreds can be selected.

c) Single cross evaluation

The developed inbreds can be crossed and the single crosses can be estimated in replicated trial. Outstanding hybrids tested over years in different locations, then released.

d) Prediction of double cross performance

'The predicted performance of any double cross is the average performance of the four non parental single crosses involving the four parental inbreds. Inbreds: A, B, C, D.

6 possible single crosses = A x B, A x C, A x D, B x C, B x D, C x D.

From these 3 double crosses produced = (A x B) x (C x D), A x C) x (B x D), (A x D) x (B x C)

The performance of these anyone double cross can be predicted from performance of the four single crosses not involved in producing that particular hybrid.

(A x B) x (C x D) = [(A x C) + (A x D) + (B x C) + (B x D)]/4

Production of Hybrids

Methods

I. Hand emasculation and dusting - Cotton, Tomato, Chillies, Bhendi

2. Use of male sterile lines

a) Cytoplasmic male sterility – ornamentals

b) Genic male sterility - Redgram, Castor.

c) Cytoplasmic - genic male sterility Jowar, Bajra, Rice

3. Use of self in compatibility

By planting cross compatible lines hybrids are produced. Here both are hybrids. E.g. *Brassicas*.

Success of hybrids

a) Easy hand emasculation

b) Abundant seed set to compensate cost of hand emasculation.

c) Stable male sterile lines.

d) Effective restorers.

e) Effective pollen dispersal.

3. Synthetic Varieties

A synthetic variety is produced by crossing in all combinations a number of inbreds (4-6) that combine well with each other. The inbreds are tested for their GCA. Once synthesised, a synthetic is maintained by open pollination. The lines that make up a synthetic may be usually inbred line but open pollinated variety, or other population tested for general combining ability are also be used.

Synthetic varieties are common in grasses, clover, maize and sugar beets. The normal procedure is equal amounts of seeds from parental lines (Syn_0) is mixed and planted in isolation. Open pollination is allowed. The progeny obtained is Syn_1. This is distributed as synthetic variety or it may be grown in isolation for one more season and Syn_2 is distributed.

Merits

1. Less costly compared to hybrids.

2. Farmer can maintain his synthetic variety for more seasons which is not possible in hybrids.

3. Because of wider genetic base the synthetics are more stable over years and environments.

4. Seed production is more skilled operation in hybrids where as it is not so in synthetics.

Demerits

1. Performance is little bit lower compared to hybrids because synthetics exploit only GCA while hybrids exploit both GCA and SCA.

2. The performance may not be good when lines having low GCA are used.

4. Composite varieties

It is produced by mixing seeds of phenotypically outstanding lines and encouraging open pollination to produce crosses in all possible combinations among mixed lines. The lines used to produce a composite are rarely tested for combining' ability. So, the yield of composite varieties cannot be predicted easily. Like synthetics, composites are commercial varieties and are maintained by open pollination.

Synthetic variety	Composite variety
Parental components are generally inbreds tested for their GCA	It is not so in composite. The lines are not tested for their GCA.
No of parental lines are limited to 4 - 6 inbreds	No such limit
Synthetic produced with inbreds can be reconstituted	It is not possible to reconstitute composite variety
Yield performance can be predicted	Yield performance cannot be predicted

Combining ability

Ability of a strain to produce superior progeny when crossed with other strains.

General combining ability (GCA)

Average performance of a strain in a series of cross combinations. The GCA is estimated from the performance of F_1 S from the crosses. The tester will have a broad genetic base.

Specific combining ability (SCA)

Deviation in performance of a cross combination from that predicted on the basis of general combining ability of the parents involved in the cross. The testing will be on inbred.

Breeding methods for vegetatively propagated crops

Some agricultural crops and a large number of horticultural crops are asexually propagated. Some common asexually propagated crops are sugarcane (*S. officinarum*), potato (*S. tuberosum*), sweet potato (*I. batatas*), *Colocasia* (Taro), Arum, *Dioscorea* (yams), Mentha, ginger (*Zingiber* sp.), turmeric (*C. domestica*), banana (*Musa paradisiaca*), etc., almost all the fruit trees, e.g., mango (*Mangifera indica*), citrus (Citrus spp.), apples (P. malus), pears (*P.communis*), peaches (*P. persica*), litchi (*Litchi chinensis*), loquat (*Eriobotrya japonica*), etc:, and many ornamentals and grasses. Many of these crops show reduced flowering and seed set, 'e.g., sugarcane, potato, sweet potato, banana, etc., and some varieties of these crops do not flower at all. But many of these crops flower regularly and show satisfactory seed set. However, they are propagated asexually to avoid the ill effects of segregation and recombination, both being the inevitable consequences of sexual reproduction.

Segregation and recombination produce new gene combinations due to which the progeny differ from their parents in genotype and phenotype. Asexual reproduction, on the other hand, produces progeny exactly identical to their parents in genotype because the progeny is derived from vegetative cells through mitosis.

The advantage of asexual reproduction is immediately clear. It preserves the genotype of an individual indefinitely. It must be noted that this does not depend on the homozygosity of the genotype of an individual. Any genotype is preserved and. maintained through asexual reproduction. In contrast self-pollination preserves and maintains only homozygous genotypes giving rise to purelines.

Characteristics of Asexually Propagated Crops

 A great majority of them are, perennial, e.g., sugarcane, fruit trees, etc. The annual crops are mostly tuber crops, e.g., potato, cassava (*M. utilissima*), sweet potato, etc.

 Many of them show reduced flowering-and seed set. Many varieties do not flower at all. Only the crops grown for fruit, particularly where good fruit set depends upon seed formation, show regular flowering and satisfactory seed set.

 They are invariably cross-pollinated.

 These crops are highly heterozygous and show severe inbreeding depression.

 A vast majority of asexually propagated crops are either polyploids, eg., sugarcane, potato, sweet potato, etc., or have polyploid species or varieties.

 Many species are interspecific hybrid, eg., Banana (*M. paradisiaca*), sugarcane, *Rubus*, etc. These crops consist of a large number of clones, that is, progeny derived from a single

plant through asexual reproduction. Thus, each variety of an asexually propagated crop is a clone.

Clone

A clone is group of plants produced from a single through asexual reproduction. Thus, asexually propagated crops consist of large number of clones, and they are often known as clonal crops. All the members of a clone have the same genotype as the parent plant. As a result, they are identical with each other in genotype. Consequently, the phenotypic differences within a clone do not have a genetic basis and are purely due to the environmental effects. A selection within a clone is thus useless. The various characteristics of a clone are summarised below.

Identical Genotype

All the individuals belongings to a single clone are identical in genotype. This is so because a clone is obtained through asexual reproduction, which involves mitotic cell division only. Genetic variation in the progeny of a plant is produced chiefly by segregation and recombination, which occur during meiosis only. Thus, the genotype of a clone is maintained indefinitely without any change.

Lack of genetic variation

The phenotypic variation present within a clone is due to the environment only. This is so because all the individuals belonging to a single clone have the same genotype. The phenotype of a clone is due to the effects of genotype (G), the environment (E) and the genotype X 'environment interaction (G x E) the population mean (μ). Thus, the phenotype (P) of a clone may be expressed as follows:

$P = \mu + G + E + GE$

Thus, the phenotypic differences among clones would be partly due to E and GE components. Hence the efficiency of selection among clones, as among purelines, would depend upon the precision with which the E and GE components of phenotype are estimated.

Immortality

Theoretically, clones are immortal i.e., a clone can be maintained indefinitely through asexual reproduction. But clones usually degenerate due to viral or bacterial infection. A clone may become extinct due to its susceptibility to diseases or insect pests. Further, genetic variation may arise within a clone changing its characteristics.

Severe Inbreeding Depression

Generally, clones are highly heterozygous and show severe loss in vigor due to inbreeding.

Clonal Selection

The phenotypic value of a plant or clone is due to the effects of its genotype (G), the environment (E) and genotype x environment (G x E) interaction. Of these, only the G effects are heritable. The environmental and interaction effects are non-heritable and cannot be selected for. Therefore, a selection for quantitative characters based on observations on single plants is highly unreliable. In fact, plants selected in this way may be no better than a random sample.

Further, a selection for characters like yielding ability, etc. on the basis of unreplicated clonal plots would often be misleading and unreliable. Therefore, the value of a clone can be reliably estimated only through replicated yield trials. However, selection for highly heritable characteristics, such as plant height, days to flowering, color, disease resistance, etc., are easy and effective even on the basis of individual plants or single plots. Clearly, these situations are the same as those in the case of sexually reproducing crops.

Selection Procedure

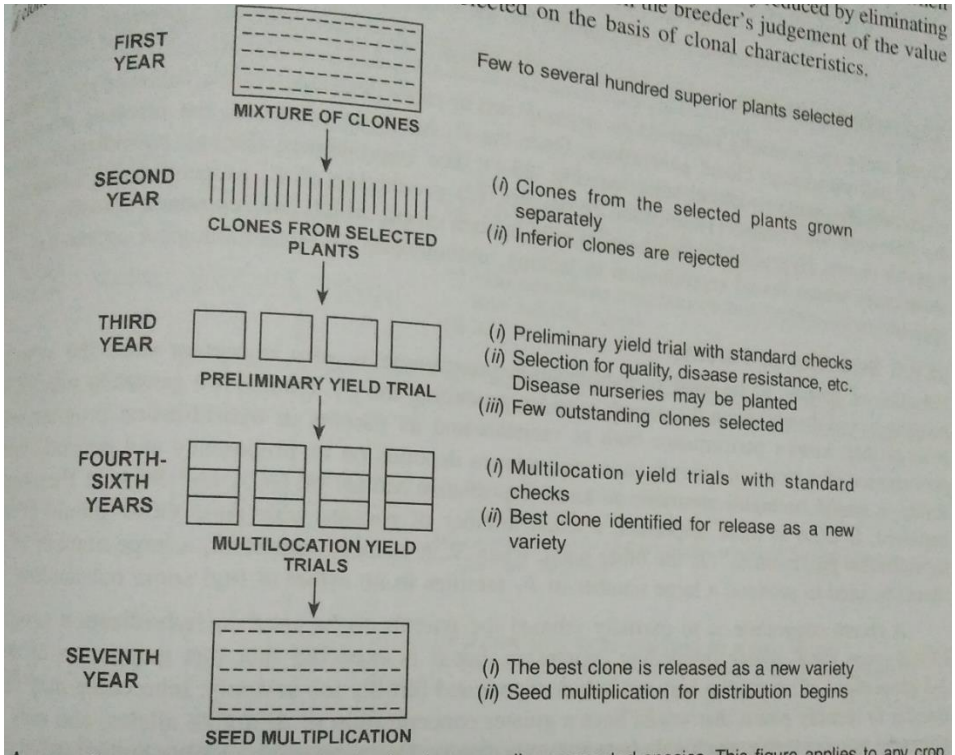
In view of these considerations, in the earlier stages of clonal selection, when selection is based on single plants or single plots, the emphasis is on the elimination of weak and undesirable plants or clones. The breeder cannot reasonably hope to identify superior' genotypes at this stage. In the later stages, when replicated trials are the basis of selection, the emphasis is to identify and select the superior clones. The various steps involved in clonal selection are briefly described below and are depicted in Fig:

1. First Year

From a mixed variable population, few hundreds to few thousand desirable plants are selected. A rigid selection can be done for simply inherited characters with high heritability. Plants with obvious weaknesses are eliminated.

2. Second Year

Clones from the selected plants are grown separately, generally, without replication This is done in view of the limited supply of the propagating material for each clone, and because of the large number of clones involved. The characteristics of clones will be clearer now than in the previous generation when the observations were based on individual plants. The number of clones is drastically reduced and inferior clones eliminated. The selection is based on visual observations and on the basis of clonal characteristics. Fifty to one hundred clones may be selected on the basis of clonal characteristics.



A generalised scheme for clonal selection in asexually propagated species. This figure applies to any crop, in which one generation does not take more than one year.

3. Third Year

Replicated preliminary yield trial is conducted. Suitable, checks included for comparison. Few superior performing clones with desirable characteristics selected for multilocation trials. At this stage, selection for quality is also done. If necessary, separate disease nurseries may be planted to evaluate the disease resistance of selected clones.

4. Fourth to Sixth Years

Replicated yield trials are conducted at several locations along with a suitable check. The yielding ability, quality and disease resistance, etc. of the clones are rigidly evaluated. The best clone that is superior to the check in one or more characteristics is identified for release as a new variety.

5. Seventh Year

The superior clone is multiplied released as a new variety.

Merits of Clonal Selection

 It is the only method of selection applicable to clonal crops. It avoids inbreeding depression, and preserves the gene combinations present in the clones.

 Clonal selection, without any substantial modification, can be combined with hybridization to generate the variability necessary for selection.

 The selection scheme is useful in maintaining the purity of clones.

Demerits of Clonal Selection

 This selection method utilizes the natural variability already present in the population; it has not been devised to generate variability.

 Sexual reproduction is a prerequisite for the creation of variability through hybridization

Clonal Hybridization

Clonal crops are generally improved by crossing two or more desirable clones, followed by selection in the F_1 progeny and in the subsequent clonal generations. Once the F_1 has been produced, the breeding procedure is essentially the same as clonal selection. The improvement through hybridization involves the following three steps:

1. Selection of parents,
2. Production of F_1 progeny, and
3. Selection of superior cones.

Hybridization can be used only in such crops, which can reproduce sexually. In case of those crops where sexual reproduction is lacking, mutagenesis or biotechnological approaches can be applied.

Selection of Parents

Selection of the parents to be used in hybridization is very important since the value of F_1 progeny would depend upon the parents used for producing the F_1. Parents are generally selected on the basis of their known performance both as varieties and as parents in hybridization programmes. The performance of a strain in hybridization programmes depends on its prepotency and general combining ability. It would be highly desirable to know the relative values of CGA and SCA in the crop to be improved. If GCA is more important, a small number of parents with good should be used in hybridization programmes. On the other hand, when SCA is more important, a large number of parents should be used to produce a large number of F_1 families in an effort to find some outstanding crosses.

A recent suggestion is to partially inbreed the parents to be used in hybridization programmes. Clonal crops show severe inbreeding depression, but it is expected that one generation of selfing or 2-3 generations of sib-mating may not reduce vigour and fertility too severely. Inbreeding may enable the breeder to identify plants that would have a greater concentration of desirable alleles. These plants may be more prepotent as parents than the highly heterozygous clones. The practice is gaining some favour with plant breeders.

Production of F_1 progeny

Generally, clonal crops are cross-pollinated and they may show self-incompatibility. The selected parents may be used to produce single crosses involving two parents or an equivalent of a polycross involving more than two parents.

Selection among F_1 Families

When the breeding value of parents is not known, and the relative contributions of GCA and SCA is not available, a large number of crosses have to be made in order to ensure that at least some of the crosses would produce outstanding progeny in F_1. This is particularly true in a species where crop improvement has not been done or has been done at a small scale. In such cases, it would be cumbersome to evaluate a large number of F_1 progeny in detail. To avoid this, generally small samples of several F_1 populations are grown. The general worth of individual F_1 populations is estimated visually. The presence of outstanding individuals in the F_1, populations is also noted, and inferior F_1's are eliminated. Promising F_1's with outstanding individuals are then grown at a much larger scale for selection. The procedure is designed to save time, space and labour by planting only small populations of a large number of crosses at the preliminary stage.

Selection within F_1 Families

The selection procedure within F_1 populations is essentially the same as that in the case of clonal selection. The various steps involved in the breeding of clonal crops through hybridization are briefly described below. From second year onward, these should be read along with the steps described in clonal selection.

First Year

Clones to be used as parents are grown and crosses are made to produce F_1 progeny.

Second Year

Sexual progeny from the cross, i.e., seedlings obtained from seeds, are grown. Undesirable plants are eliminated. Few hundred to few thousand desirable plants are selected.

Third Year

Clones from the selected individual plants are grown separately. Poor and inferior clones are eliminated. Up to 200 superior clones may be selected for preliminary yield trial.

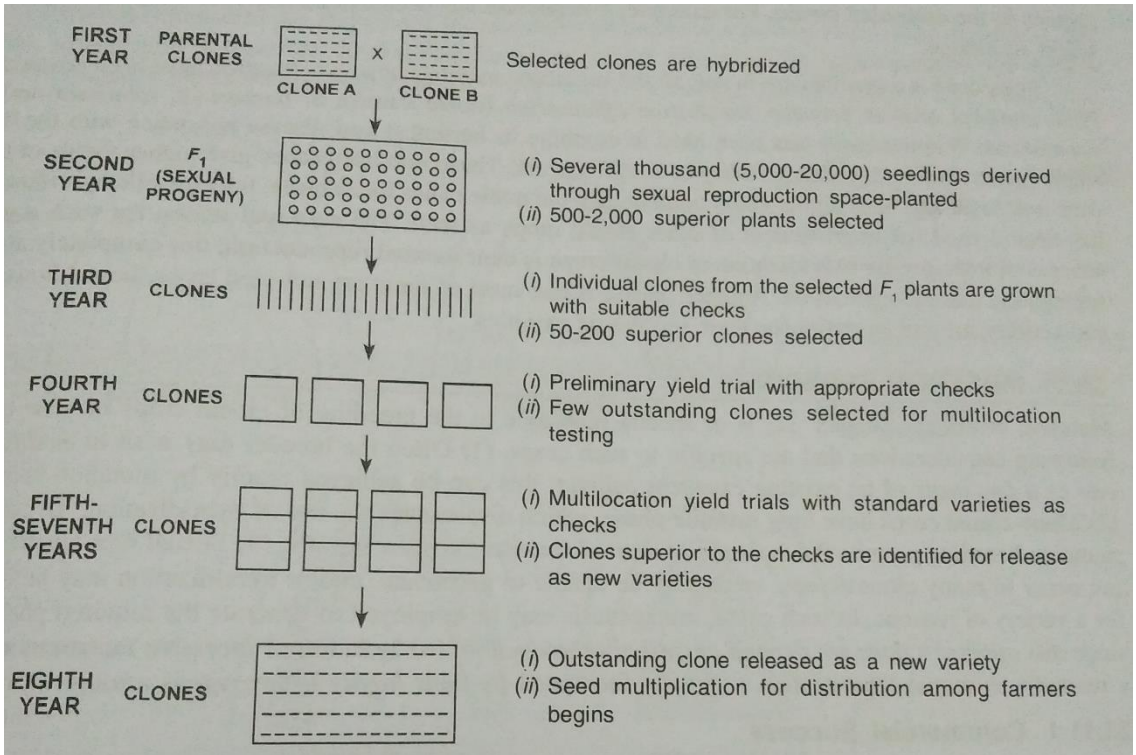
Fourth Year

A replicated preliminary yield trial is conducted in which suitable checks are included for comparison. Few outstanding clones are selected for trials at several locations.

Fifth to seventh year

Replicated yield trials are conducted at several locations. Suitable checks are included for comparison. One or a few outstanding clones are identified and released as new varieties.
Eighth year

The clones released as varieties are multiplied and distributed among farmers.



2. A generalised scheme for breeding of annual asexually propagated species through hybridization. This figure applies to a crop in which one generation is completed in one year.

MUTATION BREEDING

The term mutation was coined by Hugo De Vries in 1900 for the first time and the word is derived from the latin word 'MUTARE' means to change. Mutation is the sudden heritable change other than the Mendelian segregation and gene recombination in an organism.

Mutation may be the result of a change in a gene, a change in chromosome that involves several genes or a change in plasma gene. Mutations produced by changes in the base sequence of genes are known as gene or point mutations some mutations may be produced by changes in chromosome structure or even in chromosome number they are termed as chromosomal mutation. There are three types of mutations based on genetic basis of heritable change:

1. Gene mutations: These are produced by change in the base sequence of genes. The change may be due to base substitutions, deletion or addition.

2. Chromosomal mutation: These arise due to change in chromosome number that may leads to polyploidy or aneuploidy or change in chromosome structure that result in deletions duplication, inversion and translocation.

3. Cytoplasmic or plasma gene mutation: These are due to change in the base sequence of plasma genes. The plasma genes are present in mitochondria or chloroplast. Here the mutant character occurs in buds or somatic tissues which are used for propagation in clonal crops.

Classification of mutations:

A. Based on origin, the mutations are classified as spontaneous and induced mutations.

1. **Spontaneous mutations**: Mutations occur in natural populations at a low rate (10-6) but different genes may show different mutation rates. Here the different genes show different mutation rate. For example: in maize *R*-locus mutates at the frequency of 4.92 x 10-4 i.e. (1 in 20000 population), when as *Su* locus at 2.4 x 10 -6 (1 in 25 lakhs). The *Wx* locus considered to be highly stable. The difference in mutation rate may be due to

a) Genetic back ground i.e. presence of mutator genes

b) Genes themselves

c) Environment

2. Induced mutation: Mutations may be artificially induced by treatment with certain physical or chemical agents. Available evidence indicates that induced mutation rarely produces new alleles they produce alleles which are already known to occur spontaneously. Induced mutations are comparable to spontaneous mutations in their effects and in the variability they produce. Induced mutation occurs at a relatively higher frequency so that it is practical to work with them.

B. Based on magnitude of phenotypic effects mutation as classified as

Macro mutations: Oligogenic mutation – Large phenotypic effect and recognizable on individual plant basis and can be seen easily in M_2 generations. e.g. Ancon breed in sheep, pod maize to cob maize

Micro mutations: Polygenic mutations – Small phenotypic effect which cannot be recognized on individual plant basis but can be recognize only in a group of plants. Selection should be done in M_3 or later generations.

Characteristic features of mutations

1. Mutations are generally recessive but dominant mutations also occur
2. Mutations are generally harmful to the organism. Most of the mutations have deleterious effects but small proportion (0.1%) of them are beneficial.
3. Mutations are random i.e. they may occur in any gene. However, some genes show high mutation rates than the others.
4. Mutations are recurrent
5. Induced mutations commonly show pleiotropy often due to mutation in closely linked genes. **Procedure for irradiation**: The plant material may be treated in any of the following source. 1. Seeds, 2. Seedlings, 3. Flowers, 4. Cuttings

1. Seeds: Seeds are used after soaking to get greater frequency of induced mutations than air dried.
2. Seedlings: At any stage of life cycle can be subjected to radiation but usually seedlings neither too young nor too old are irradiated due to their convenience in handling in pots transportation from nursery easily.
3. Flowers: Meiotic cells have been found more sensitive than the mitotic cells and therefore plants are irradiated in the flowering stage in order to affect the developing gametes.
4. Cuttings: In case of fruit tree when they are propagated by clones – the desirable cuttings are exposed to irradiation.

Selection of the variety for mutagen treatment

The variety selected for mutagenesis should be the best available in the crop.

Dose of the Mutagen

An optimum dose of the mutagen should be used. An optimum dose is the one which produces the maximum frequency of mutations and causes the minimum killing. Many workers feel that a dose close to LD_{50} should be optimum. LD_{50} is that dose of a mutagen, which would kill 50% of the treated individuals.

Mutation Breeding for oligogenic traits

The handling procedure described here is based on the selection for a recessive mutant allele of an oligogene.

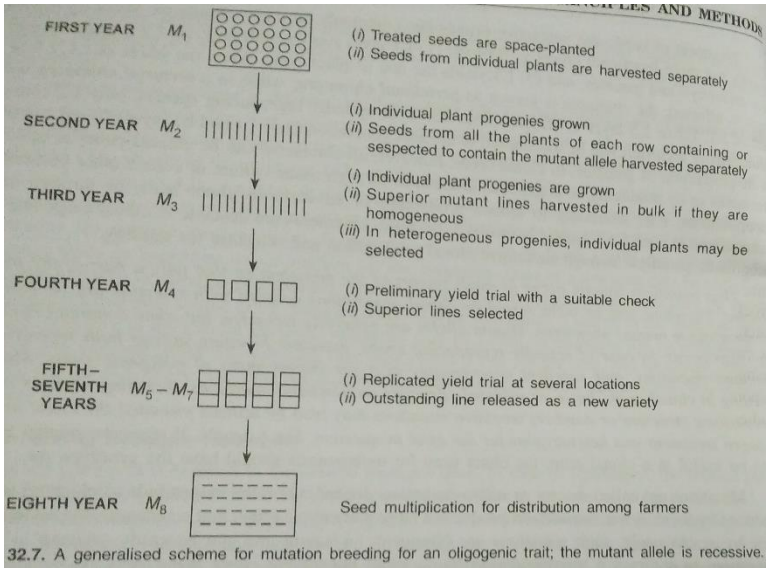
1. M_1 generation: Several hundred seeds are treated with a mutagen and are space planted. In general, the number of treated seeds is so adjusted as to give rise to 500 fertile M_1 plants at the harvest. Care should be taken to avoid outcrossing; this can be achieved either by planting the M_1 population in isolation or by bagging the inflorescence of M_1 plants or even the whole M_1 plants. M_1 plants will be chimeras for the mutations present in heterozygous state. About 20 to 25 seeds from each M_1 spike are harvested separately to raise the M_2 progeny rows.

2. M_2 generation: About 2,000 progeny rows are grown. Careful and regular observations are made on the M_2 rows. But only distinct mutations are detected in M_2 because the observations are based on single plants. All the plants in M_2 rows suspected of containing new mutations are harvested separately to raise individual plant progenies in M_3. if the mutant is distinct, it is selected for multiplication and testing. However, most of the mutations will be useless for crop improvement. Only 1-3 per cent of M_2 rows may be expected to have beneficial mutations.

3. M_3 generation: Progeny rows from individual selected plants are grown in M_3. Poor and inferior mutant rows are eliminated. If the mutant progenies are homogeneous, two or more M_3 progenies containing the same mutation may be bulked. Mutant M_3 rows are harvested in bulk for a preliminary yield trial in M_4.

4. M_4 generation: A preliminary yield trial is conducted with a suitable check, and promising mutant lines are selected for replicated multilocation trials.

5. M_5-M_7 generations: Replicated multilocation yield trials are conducted. The out-standing line may be released as a new variety. The low yielding mutant lines, however, should be retained for use in hybridization programmes.



32.7. A generalised scheme for mutation breeding for an oligogenic trait; the mutant allele is recessive.

Mutation breeding for polygenic traits: Mutagenesis does produce genetic variation in polygenic traits; this variation is usually as much as 50% of that generated in F_2 generation, but sometimes it may be as much as or even greater than the latter.

1. M_1 and M_2 generations: M_1 and M_2 generations are grown in the same way as in the case of oligogenic traits. In M_2 generation, vigorous, fertile and normal looking plants that do not exhibit a mutant phenotype are selected and their seeds are harvested separately to raise individual plant progeny rows in M_3.

2. M_3 generation: Progeny rows from individual selected plants are grown. Careful observations are made on M_3 rows for small deviations in phenotype from the parent variety. Inferior rows are discarded. Few rows may be homogeneous and would be harvested in bulk. Selection in done in M_3 rows showing segregation; a majority of M_3 rows would show segregation. Intensive and careful evaluation of a large number of M_3 progeny rows allows identification of mutants with altered quantitative traits, e.g., partial or horizontal disease resistance. Such mutants occur in high frequencies that approach 1% or even high, so that their isolation becomes quite cost effective.

3. M_4 generation: Bulked seed from homogeneous M_3 rows may be planted in a preliminary yield trial with a suitable check; superior progenies are selected for replicated multilocation yield trials. Individual plant progenies from M_3 are critically observed. Progenies showing segregation may be subjected to selection only if they are promising. Superior homogeneous progenies are harvested in bulk for preliminary yield tests in M_5.

4. M_5-M_8 generations: Preliminary yield trials and / or multi-location trials are conducted depending upon the stage when the progenies become homogeneous. Outstanding progenies may be released as new varieties.

Applications of Mutation Breeding

Mutation breeding has been used for improving both oligogenic as well as polygenic characters. Mutagenesis has been used to improve morphological and physiological characters including yielding ability. Various applications of mutation breeding are:

1. Induction of desirable mutant alleles which may not be available in the germplasm

2. It is useful in improving specific characteristics of a well-adapted high yielding variety.

3. Mutagenesis has been successfully used to improve various quantitative characters including yield.

4. F_1 hybrids from intervarietal crosses may be treated with mutagens in order to increase genetic variability by inducing mutation and to facilitate recombination of linked genes.

5. Irradiation of interspecific (distant) hybrids has been done to produce translocations.

Advantages:

1. Mutation create inexhaustible variation.

2. When no improvement is possible this method has to be adopted.

Limitations:

1. Frequency of desirable mutations is very low about 0.1 percent. To detect the desirable one in M_2 considerable time, labour & other resources are to be employed.

2. To screen large population, efficient quick and inexpensive selection techniques are needed. 3. Desirable mutations may be associated with undesirable side effects due to other mutations thus extending the mutation breeding programme.

4. Detection of recessive mutations in polyploids and clones is difficult and larger doses of mutagen have to be applied and larger populations are to be grown.

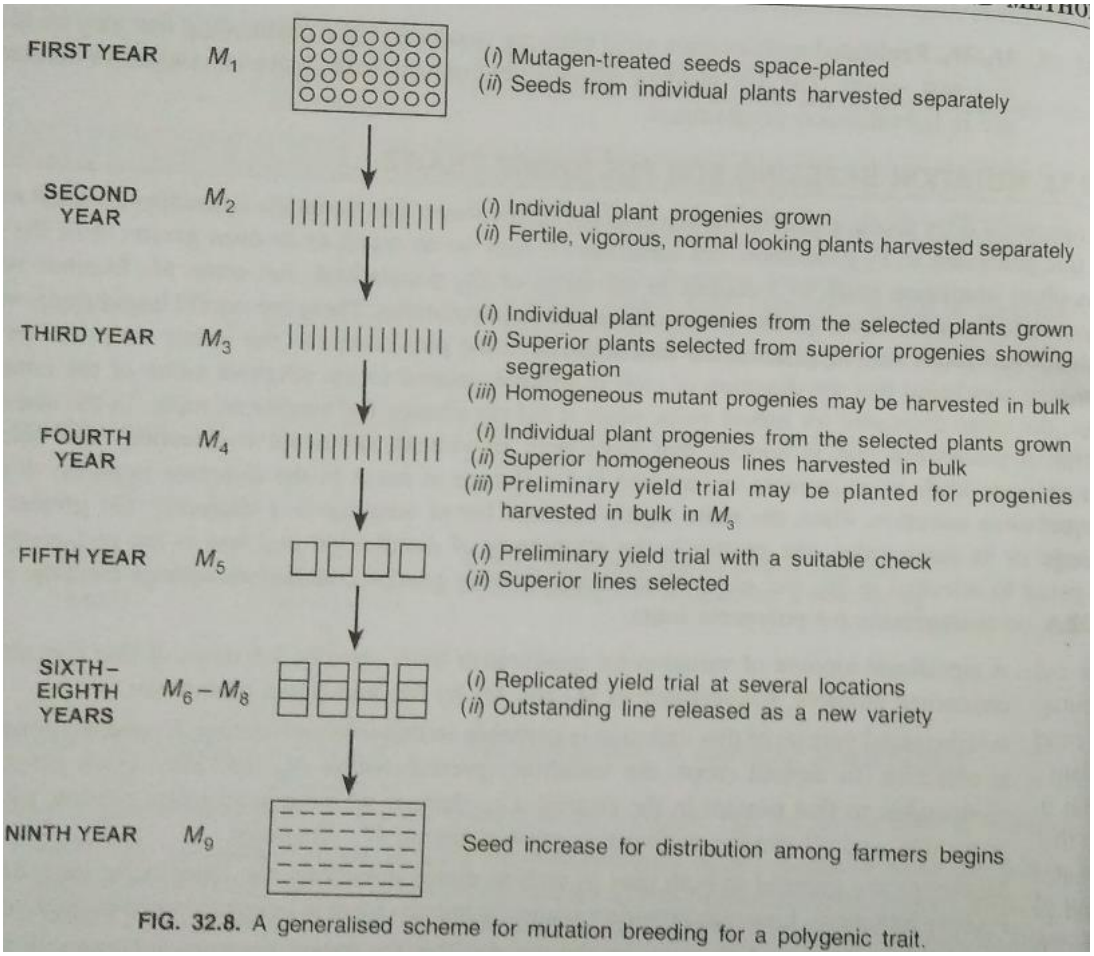


FIG. 32.8. A generalised scheme for mutation breeding for a polygenic trait.

Polyploidy Breeding

The somatic chromosome number of any species, whether diploid or polyploidy, is designated as 2n, and the chromosome number of gametes is denoted as n. An individual carrying the gametic chromosome number, n, is known as haploid. A monoploid, on the other hand, has the basic chromosome number, x. In a diploid species, n = x, one x constitutes a genome or chromosome complement. The different chromosomes of a single genome are distinct from each other in morphology and or gene content and homology; members of a single genome do not show a tendency of pairing with each other. Thus, a diploid species has two, a triploid has 3 and a tetraploid has 4 genomes and so on.

In euploids, the chromosome number is an exact multiple of the basic or genomic number. Euploidy is more commonly known as polyploidy.

When all the genomes present in a polyploidy species are identical, it is known as autopolyploid and the situation is termed as autopolyploidy.

In the case of allopolyploids, two or more distinct genomes are present.

Euploids may have 3(triploid), 4(tetraploid), 5 (pentaploid), or more genomes making up their somatic chromosome number.

In case of autopolyploidy, they are known as autotriploid, autotertaploid, autopentaploid, and so on, while in the case of allopolyploidy they are termed as allotriploid, allotetraploid, allopentaploid, etc.

Amphidiploid is an allopolyploid that has two copies of each genome present in it and, as a consequence, behaves as a diploid during meiosis.

A segmental allopolyploid contains two or more genomes, which are identical with each other, except for some minor differences.

Autopolyploids

Origin and production of doubled chromosome numbers:

1. Spontaneous: chromosome doubling occurs occasionally in somatic tissues and unreduced gametes are produced in low frequencies.

2. Production of adventitious buds: decapitation in some plants leads to callus development at the cut ends of the stem. Such a callus has some polyploid cells and some of the shoot buds regenerated from the callus may be polyploid. In Solanaceae 6-36% of adventitious buds are tetraploids.

3. Treatment with physical agents: Heat or cold treatment, centrifugation, x -ray or gamma ray irradiation may produce polyploids. Exposing the plants or ears of maize to a temperature of 38-45^{o}C at the time of the first division of zygote produce 2 -5 % tetraploid progenies.

4. Regeneration *in vitro*: polyploidy is a common feature of the cells cultured *in-vitro*.

5. Colchicine treatment: Colchicine treatment is the most effective and the most widely used treatment for chromosome doubling.

Autopolyploidy

In autopolyploidy, triploidy, tetraploidy and higher levels of ploidy are included.

Morphological and cytological features of auto polyploids:

The general features are summarised below:

1. Polyploids have larger cell size than diploids. Guard cells of stomata are larger and the number of stomata per unit area is less in polyploids than diploids.

2. Pollen grains of polyploids are generally larger than those of the corresponding diploids.

3. Polyploids are generally slower in growth and later in flowering.

4. Polyploids usually have larger and thicker leaves, and larger flowers and fruits which are usually less in number than in diploids.

5. Polyploids generally show reduced fertility due to irregularities during meiosis and due to genotypic imbalance leading to physiological disturbances.'

6. In many cases autopolyploidy leads to increased vigour and vegetative growth.

7. Different species have different levels of optimum ploidy. For sugar beet the optimum level is 3x, sweet potato 6x while for timothy grass it is between 8 -10x.

8. Autopolyploids generally have a lower dry matter content than diploids.

Application of autopolyploidy in crop improvement

Triploids

Triploids are produced by hybridization between tetraploid and diploid strains. They are generally highly sterile, except in a few cases. This feature is useful in the production of seedless watermelons. In certain species, they may be more vigorous than the normal diploids, e.g., in sugar beets. These two examples are described in some detail. Seedless watermelons are produced by crossing tetraploid (4x, used as female) and diploid (2x, used as male) lines, since the reciprocal cross (2x x 4x) is not successful. The triploid plants do not produce true seeds; almost all the seeds are small, white rudimentary structures like cucumber (*Cucumis sativus*) seeds. But few normal size seeds may occur which are generally empty. For good seed setting pollination is essential. For this purpose, diploid lines are planted in the ratio 1 diploid: 5 triploid plants. There are several problems *viz*. genetic instability of 4x lines, irregular fruit shape, a tendency towards hollowness of fruits, production of empty seeds and the labour involved in trioploid seed production.

1. Triploid sugar beets: Among root crops triploid sugar beets apparently represent the optimum level of polyploidy because 3n plants have longer roots than diploid and also yield more sugar per unit area.

2. Tetraploid rye: The advantage of tetraploid over its diploid counterpart are large kernel size, superior ability to emerge under adverse condition and higher protein content. Tetraploid rye varieties have been released for cultivation. e.g. Double steel, Tetra petkus.

Limitations of autopolyploidy:

1. Larger size autopolyploid generally contain more water and produce less dry matter content than diploids

2. High sterility with poor seed setting is observed

3. Due to complex segregation, progress through selection is slow

4. Monoploids and triploids cannot be maintained except through clonal propagation

5. The varieties cannot be produced at will

6. Effects of autopolyploidy cannot be predicted.

Allopolyploidy: Allopolyploids have genomes from two or more species production of allopolyploids has attracted considerable attention; the aim almost always was creation of new species. Some success has been evident from the emergence of triticale. *Raphano brassica* and allopolyploids of forage grasses.

Morphological and cytological features of allopolyploids

1. Allopolyploids combine the morphological and physiological characteristics of the parent species but it is very difficult to predict the precise combination of characters that would appear in the new species.
2. Many allopolyploids are apomictic eg: *Tulips, Solanum*
3. The chromosome pairing in the new species depends upon the similarities between the chromosomes of the parental species. Chromosomes with such similarities are known as homoeologous chromosomes. After chromosome doubling, the allopolyploid would have two homelegous chromosomes for each chromosome present in the F_1 hybrid, comparable to the diploid species. Such allopolyploid is referred as amphidiploid or Allotetraploid.
4. Fertility of Allopolyploids can be improved by hybridization and selection.

Application of allopolyploidy in crop improvement:

1. Utilization as a Bridging species: Amphidiploids serve as a bridge in transfer of characters from one species to a related species, generally from a wild species to cultivated species. An example of use of an amphidiploid as a bridging species in the use of synthetic *N. digluta* or transfer of resistance to tobacco mosaic virus from *N. glutinosa* to *N. tabacum*. The F_1 hybrid from the cross *N. tabacum* x *N. glutinosa* is sterile. Chromosome doubling of the F_1 hybrid produces the synthetic allohexaploid *N. digluta* which is reasonably fertile. *N. digluta* is backcrossed to the recipient species (*N. tabacum*) to produce a pentaploid having complete somatic chromosome complement of *N. tabacum* and one genome of *N. glutinosa*. The pentaploid is sufficiently fertile to be backcrossed to *N. tabaccum*. In the progeny *N. tabacum* like plants resistant to tobacco mosaic are selected and cytologically analysed.
2. Creation of new crop species: Triticales, Raphanobrassica
3. Widening the genetic base of existing allopolyploids: The genetic base of some natural allopolyploids may be narrow, and it may be useful to introduce variability in such cases by producing the allopolyploids afresh from their parental species. *B. napus* is a case in point; the genetic variability of this species is narrow and the only recourse available is to synthesize new allopolyploid *B. napus* to widen its genetic base. This is being done by crossing *B. campestris* (n=10, AA) with *B. oleracea* (n=9, CC), the parental diploid species, to produce the amphidiploid *B. napus* (n=19, AACC). The two species, *B. campestris* and *B.*

oleracea, have to be crossed as autotetraploids; the cross is very difficult and embryo culture has to be used; somatic hybridization is being used to get around these problems.

Limitations of Allopolyploidy

1. The effects of allopolyploidy cannot be predicted. The allopolyploids have some features from both the parental species, but these features may be the undesirable ones, e.g., Raphanobrassica, or the desirable ones, e.g., Triticale.
2. Newly synthesized allopolyploids have many defects, e.g., low fertility, cytogenetic and genetic instability, other undesirable features etc.
3. The synthetic allopolyploids have to be improved through extensive breeding at the polyploidy level. This involves considerable time, labour and other resources.
4. Only a small proportion of allopolyploids are promising; a vast majority of them are valueless for agricultural purposes.

Wide hybridization or Distant hybridization

Introduction

When individuals from two distinct species of the same genera are crossed, it is known as inter specific hybridization. e.g. Inter specific hybridization: *Oryza sativa* x *O. perennis*

When individuals being crossed belong to two different genera, it is referred to as inter generic hybridization. e.g. Wheat x rye.

Hybridization between individuals from different species belonging to the same genus or two different genera, is termed as distant hybridization or wide hybridization, and such crosses are known as distant crosses or wide crosses.

History

The first distant hybridization; hybrid between carnation (*Dianthus caryophyllus*) and sweet willian (*Dianthus barbatus*) by Thomas Fairchild in 1717 and the hybrid is called as Fairchilds' mule.

1. Most of the interspecific hybrids were of no agricultural value.

2. Many interspecific hybrids particularly in case ornamentals, served as commercial varieties. 3. An interesting inter generic hybrid Raphano brassica was an amphidiploid cross between radish and cabbage but it was useless.

The first inter generic hybrid with a great potential was TRITICALE

Objectives:

1. To transfer some desirable character from wild relatives that are not available in cultivated varieties. e.g. i) Many disease resistance and, insect resistance genes

ii. Wide adaptability: (i.e. drought-resistance, cold tolerance etc.)

iii. Quality improvement (e.g. Cotton (fibre), Tobacco (leaf)

iv. Yield improvement (e.g. Oats, Tobacco, Maize, Sugarcane)

v. Other characters (e.g. CMS, Earliness, dwarfness morphological characters)

2. Exploitation of luxuriance (heterosis) in vegetatively propagated / ornamental crops. Prolonged vegetative period, Prolonged blooming period

3. Creation of Novel genotypes: New species or F_1 hybrids hither to non – existent in nature.

Barriers to the production of distant hybrids

1. Failure of zygote formation / Cross incompatibility

2. Failure of zygote development / Hybrid inviability

3. Failure of F1 seedling development / Hybrid sterility

A variety of mechanisms may be responsible for each of these three difficulties:

1. Failure of zygote formation / cross incompatibility: Inability of the functional pollens of one species or genera to effect fertilization of the female gametes of another species or genera is referred to as cross incompatibility. It may be due to –

i. Failure of fertilization, because the pollen may not germinate.

ii. Pollen tube is unable to reach to embryo sac and hence sperms are not available for fertilization

iii. Pollen tube may burst in the style of another species. e.g. *Datura*.

iv. The style of the female parent may be longer than the usual length of the pollen tube growth therefore the pollen does not reach the embryo sac. e.g. *Zea mays* and *Tripsacum sp*.

v. Pollen tubes of polyploidy species are usually thicker than those of diploid species.

vi. When a diploid is used as female and a polyploidy as male, the polyploidy pollen tube grows at a slower rate in the diploid style than it would be in a polyploid style.

These barriers are known as pre-fertilization barriers.

Techniques to make wide crosses successful

1. Removal or scarification of stigma

2. Using short styled parent as female.

3. Using the diploid species as the male parent.

2. Failure of zygote Development / Hybrid inviability

The inability of a hybrid zygote to grow into a normal embryo under the usual conditions of development is referred to as hybrid inviability. This may be due to:

i.) Lethal genes: some species carry a lethal gene, which causes death of the interspecific hybrid zygote during early embryonic development. For e.g. *Aegilops umbellulata* carries a lethal gene with 3 alleles against diploid wheats.

ii.) Genetic disharmony between the two parental genomes: The genetic imbalance between the two parental species may cause the death of embryos. For e.g. in cotton - *G. gossypioides* x other *G. spp*., Brassica – *B. napus* x *B. oleracea*

iii.) Chromosome elimination: In some cases of distant hybridization, chromosomes are gradually eliminated from the zygote. This generally does not prevent embryo development, but the resulting embryo and the F_1 plants obtained from such crosses are not true interspecific hybrids since they do not have the two parental genomes in full. Generally, chromosomes from one are successively eliminated due to mitotic irregularities. For e.g. *Hordeum bulbosum* x *H. vulgare*, *Hordeum bulbosum* x *Triticum aestivum*, *Triticum aestivum* x *Zea mays*, chromosome of *H. bulbosum* and *Zea mays* are eliminated.

iv.) Incompatible cytoplasm: Embryo development may be blocked by an incompatibility between cytoplasm of the species used as female and the genome of the species used as male. Such an interaction, more generally, leads to hybrid weakness and male sterility in the hybrids or may sometimes leads to failure of embryo developments.

v.) Endosperm Abortion: Seeds from a large number of distant crosses are not fully developed and are Shrunken due to poorly developed endosperm. Such seeds show poor germination, and may often fail to germinate. When the endosperm development is poor or is blocked, the condition is generally known as endosperm abortion. For e. g.-

1. *Triticum sp*. x *Secale sp*. – Triticale. In this case the endosperm aborts at a much later stage so that a small frequency of viable seed is obtained.

2. *Hordeum bulbosum* x *Hordeum vulgare* – the endosperm aborts at an early stage so that viable seeds are not produced. In case of endosperm abortion - embryo rescue culture is practiced.

3. Failure of Hybrid seedling development / Hybrid sterility

Some distant hybrids die during seedling development or even after initiation of flowering. The mechanisms involved in the failure of seedling development most likely involve complementary lethal genes. For e.g.-

1. In cotton-certain interspecific hybrids appear normal, but die in various stages of seedling growth; some plants die at flowering.

2. Interspecific and intergeneric F_1 hybrids of wheat show both chlorosis and necrosis;

Hybrid sterility: Hybrid sterility refers to the inability of a hybrid to produce viable off spring. The main cause of hybrid sterility is lack of structural homology between the chromosomes of two species.

Applications of wide hybridization in crop improvement

1. Alien addition lines: Carries one chromosome pair from a different species in addition to somatic chromosome complement. For e.g. Disease resistance in Wheat, oats, tobacco

2. Alien substitution lines: has one chromosome pair from different species in place of the chromosome pair of the recipient parent.

3. Introgression of genes: Transfer of small chromosome segments with desirable genes. e.g.

i. Disease resistance: In Cotton transfer of black arm disease resistance from *G. arboreum* to *G. barbadense*

ii. Wider adaptation: Cold tolerance has been transferred from wild relatives to Wheat, onion, potato, tomato and grape.

iii. Quality: Oil quality in oil palm was improved by genes from wild relatives.

iv. Changing the mode of reproduction: 1. Self-incompatibility: S.I. genes from *B. campestris* to self-compatible *B. napus* for hybrid seed production.

v. Yield

vi. Other characters

4. **Development of New crop species:** e.g. Triticale

5. **Utilization as New hybrid varieties:** e.g. F_1 hybrids in cotton Varalaxmi cotton (*G. hirsutum x G. barbadense*)

Sugarcane: All the present day commercial varieties are complex interspecific hybrids involving *S. officinarum & S. spontaneum*

Limitations of Distant Hybridization:

1. Incompatible Crosses
2. F_1 Sterility
3. Problems in Creating New species
4. Lack of homoeology between Chromosomes of the Parental Species

5. Undesirable Linkages
6. Problems in the Transfer of Recessive Oligogenes and Quantitative Taits
7. Lack of Flowering in F_1
8. Problems in using Improved varieties in Distant Hybridization
9. Dormancy

Breeding for disease resistance

Disease is an abnormal condition in the plant produced by an organism

Host: Plant affected by disease.

Pathogen: Organism that produces the disease.

Damage due to disease

i) Reduces total Biomass leading to yield loss

ii) Stunted growth

iii) Sterility

Need for disease resistance breeding

i) To prevent yield loss

ii) High cost reduction

iii) Prevention of environmental pollution

Kinds of disease reaction:

i). Susceptible reaction: Disease reaction is profuse, if unchecked it may lead to total yield loss.

ii) Immune reaction: Host does not show the symptoms of a disease

iii) Resistance reaction: Infection and establishment takes place but growth of the pathogen in the host is restricted

iv). Tolerance: Host is attacked by the pathogen in the same manner as the susceptible variety but there may not be yield loss.

Vertical and horizontal resistance

These terms were introduced by Van der Plank.

Vertical resistance: It is also known as race specific, pathotype specific or specific resistance. Vertical resistance is generally determined by major genes and is characterised by pathotypic specificity. Pathotype specificity denotes that the host carrying a gene for vertical resistance is attacked only by that pathotype which is virulent towards the resistant gene, to all other pathotypes the host will be resistant.

Only two types of disease reaction can be seen i.e. immune or susceptible reaction. When virulent pathotype becomes frequent. There may be epidemics. Vertical resistance is not long lasting.

Horizontal resistance: It is race non-specific, pathotype non-specific or general resistance. Horizontal resistance is governed by polygenes, that is many genes with small effects and it is pathotype non-specific. Horizontal resistance does not prevent the development of symptoms but it slows down the rate of spread to the disease in the population. HR is more stable compared to VR.

Mechanism of disease resistance:

a) Mechanical: Certain mechanical or anatomical features of host may prevent infection. e.g. Closed flowering habit of wheat and barley prevents infection by spores of ovary infecting fungi.

b) Hypersensitivity: Immediately after infection several host cells surrounding the point of infection die. This leads to death of pathogen also. Phytoalexins present in plant body is responsible for hypersensitivity reaction.

c) Antibiosis: Presence of some toxic substance. This is more correct for insect resistance. E.g. Gossypol content in cotton.

d) Nutritional factors: The reduction in growth and spore formation may be due to nutritional factors of the host.

Genetics of disease resistance:

a) Oligogenic resistance: Resistance is governed by one or few major genes and resistance is generally dominant. The action of major genes may be altered by modifiers. Gene for gene relationship Flor (1956) proposed this based on his work in linseed rust. According to this for every resistance gene present in the host, the pathogen has a gene for virulence. Susceptible reaction will result when the pathogen is able to match all the resistant genes with virulence gene.

b) Polygenic inheritance: The genes show both additive and non - additive effects and there is large environmental effects.

c) Cytoplasmic inheritance: T cytoplasm - Maize Tift 23A cytoplasm - Cumbu Susceptible to disease. C and M cytoplasm of maize resistant to *Helminthosporium*. L 111A and 732, A cytoplasm resistant to downy mildew in cumbu.

Methods of disease resistance breeding

1. Plant introduction: Resistant varieties from other can be directly introduced for cultivation. e.g. IR 20 rice resistant to blast.

2. Selection: This may be from local land races or from introduced cultivars. e.g. Co 4 Gobi Anaikomban resistance to blast. NCAC 17090 ground nut resistant against leaf spot.

3. Hybridisation and Selection:

a) Intervarietal hybridization - Co37 Rice resistant to blast

b) Inter specific hybridization - Powdery mildew resistance in *Sesamum*

c) Inter generic - *Atylosia* for root rot in red gram. Depending on gene action the selection procedure may vary.

If the resistance is governed by polygenes, then pedigree method of selection is to be followed.

If the resistance is governed by major genes linked with other undesirable characters we have to go for back cross method of breeding. For dominant gene the back cross method is different from recessive gene governed traits.

4. **Mutation breeding**: Co2. Ground nut tolerant to late leaf spot disease.

5. **Polyploidy breeding**: *Nicotiana* crosses for resistance against leaf spot.

6. **Tissue culture method**: Resistance reaction can be screened easily in test tubes and resistant lines can be mass multiplied. e.g. Banana, *Cardamom*.

Screening techniques for disease resistance

Depending on mode of spread of disease the screening technique may differ. The screening can be done both at screen or glass house level and field level. The different screening techniques are as follows:

Soil borne diseases: Wilt and root rot are produced by soil borne fungi. In this case sick plot technique is followed. Susceptible varieties can be grown and infected plants can be ploughed *in situ* to maintain optimum condition for infection.

Air borne diseases: e.g. Rust, Smut, mildews, blights. For ground nut rust, infestor rows can be sown 15 days earlier as border rows and the disease will infest the susceptible infestor rows. After 15 days the varieties tested to be are to be sown. Spraying the spore suspension from affected leaves will also increase the load.

Seed borne disease: Smut, bunt etc. Artificial inoculation can be done by soaking the seeds in solution of pathogen under vacuum condition. Insect transmitted diseases.

Insect transmitted diseases: e.g. virus diseases, Red gram sterility mosaic virus.

Sap transmitted: Here the stapling technique is used. Leaves from affected plants can be stapled to the entries to be tested. The insect feeding in susceptible leaf will transmit virus to test entries.