

DEPARTMENT OF GENETICS AND PLANT BREEDING

1. Course No. : GBPR 311
2. Course Title : **Breeding of Field and Horticultural Crops**
3. Credit Hours : 3 (2+1)

References

- Allard, R.W. 1960. *Principles of Plant Breeding*. John Wiley and Sons, New York.
- Chopra, V.L. and Paroda, R.S. 1986. *Approaches for Incorporating Drought Salinity Resistance in Crop Plants*. Oxford and IBH, Publishing Co., New Delhi.
- Kaloo, G. 1994. *Vegetable Breeding*. Panima Educational Book Agency, New Delhi.
- Kumar, N. 2006. *Breeding of Horticultural Crops – Principles and Practices*. New India Publishing Agency, New Delhi.
- Phundan Singh, 1996. *Essentials of Plant Breeding*. Kalyani Publishers, New Delhi.
- Poehlman, J.M. and Borthakur, D. 1995. *Breeding Asian Field Crops*. Oxford and IBH Publishing Co., New Delhi.
- Sharma, J.R. 1994. *Principles and Practice of Plant Breeding*. Tata McGraw Hill, Publishing Company Ltd., New Delhi.
- Singh, B.D. 1983. *Plant Breeding: Principles and Methods*. Kalyani Publishers, New Delhi.

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.

Objectives of Plant Breeding :

- **Higher yield :** The ultimate aim of plant breeding is to improve the yield of “**economic produce on economic part**”. 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.
- **Improved quality:** Quality of produce is another important objective in plant breeding. The quality characters vary from crop to crop. Eg. grain size, colour, milling and baking quality in wheat. Cooking quality in rice, malting quality in barley, 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.
- **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.
- **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.
- **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.
- **Determinate Growth :** Development of varieties with determinate growth is desirable in crops like mung, pigeon pea (*Cajanus cajan*), cotton (*Gossypium sp.*), etc.
- **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.
- **Desirable Agronomic Characteristics :** It includes plant height, branching, tillering capacity, growth habit, erect or trailing habit etc., is often desirable. For example, dwarfness in cereals is generally associated with lodging resistance and better fertilizer response. Tallness, high tillering and profuse branching are desirable characters in fodder crops.
- **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 – lentil (*Lathyrus 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.
- **Non-shattering characteristics:** The shattering of pods is serious problem in green gram. Hence resistance to shattering is an important objective in green gram.
- **Synchronous Maturity :** It refers to maturity of a crop species at one time. The character is highly desirable in crops like greengram, cowpea, castor and cotton where several pickings are required for crop harvest.

- **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.
- **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.
- **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.

Scope of plant breeding (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. Since the population is increasing at an alarming rate, there is need to strengthened the food production 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*.

Undesirable effects

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 :** 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 man made 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 in Punjab and Haryana. The severe infection by Karnal bunt (*Tilletia sp.*) on some wheat varieties, infestation of mealy bugs in Bt cotton.

Concepts of breeding Self pollinated, Cross pollinated and asexually propagated crops

The mode of pollination and reproduction play an important role in plant breeding. Based on this, crop plants are divided into three groups viz.

1. Self Pollinated
2. Cross pollinated
3. Vegetatively propagated

Self Pollinated Species:

These are all self fertilizing species. In these species development of seed take place by self pollination (autogamy). Hence self pollinated species are also known as autogamous species or inbreeders. Various plant characters such as homogamy, cleistogamy, chasmogamy, bisexuality etc. favour self fertilization.

Some important features of autogamous species are

1. They have regular self pollination
2. They are homozygous and have advantage of homozygosity, means they are true breeding.
3. Inbreeders do not have recessive deleterious genes, because deleterious genes are eliminated due to inbreeding by way of gene fixation.
4. Inbreeding does not have any adverse effects on inbreeders.
5. In autogamous species, new gene combinations are not possible due to regular self pollination.
6. Inbreeders are composed of several component (homozygous) lines. Hence variability is mostly among component lines.
7. Inbreeders have generally narrow adaptation and are less flexible.

Methods of Breeding in Autogamous Species

1. Plant introduction
2. Pureline selection
3. Mass selection
4. Pedigree method
5. Bulk method
6. Single seed descent method
7. Backcross method
8. Heterosis breeding
9. Mutation breeding
10. Polyploidy breeding
11. Distant hybridization
12. Transgenic breeding

Four breeding approaches viz., recurrent selection, disruptive selection, diallel selective mating and biparental mating are used for population improvement.

Cross pollinated species

This group refers to cross fertilizing species these species produce seed by cross pollination (allogamy) hence, referred to as allogamous species or out breeders. Various plant characters which promote cross pollination which include dichogamy, monoecy, dioecy, heterostylely, herkogamy, self incompatibility and male sterility.

Some important features of out breeders are

1. They have random mating. In such population, each genotype has equal chance of mating with all other genotypes
2. Individuals are heterozygous and have advantage of heterozygosity
3. Individuals have deleterious recessive gene which are concealed by masking effect of dominant genes.
4. Out breeders are intolerant to inbreeding. They exhibit high degree of inbreeding

depression on selfing.

5. Cross pollination permits new gene combinations from different sources.
6. In these species, variability is distributed over entire population.
7. They have wide adaptability and more flexibility to environmental changes due to heterozygosity and heterogeneity.

Methods of Breeding Allogamous species

1. Plant introduction
2. Mass and progeny selection
3. Back cross method.
4. Heterosis breeding
5. Synthetic breeding
6. Composite breeding
7. Polyploidy breeding
8. Distant hybridization
9. Transgenic breeding
10. Mutation breeding (rarely)

Three breeding approaches viz., recurrent selection, disruptive mating and biparental mating are used for population improvement.

Asexually propagated species

Some crop plants propagate by asexual means i.e. by stem or root cuttings or by other means. Such species are known as asexually propagated species or vegetatively propagated species. Such species are found in both self and cross pollinated groups. Generally asexually propagated species are highly heterozygous and have broad genetic base, wide adaptability and more flexibility.

Methods of breeding Asexually propagated species

1. Plant introduction
2. Clonal selection
3. Mass selection (rarely used)
4. Heterosis breeding
5. Mutation breeding
6. Polyploidy breeding
7. Distant hybridization
8. Transgenic breeding

BREEDING POPULATIONS

The genetic constitution of plants is determined by mode of pollination. Self pollination leads to homozygosity and cross pollination results in heterozygosity to exploit homozygosity in self pollinated crops and heterozygosity in cross pollinated species, because inbreeders have advantage of homozygosity and outbreeders have advantage of heterozygosity. Based on genetic constitution, breeding populations are of four types viz.,

1. Homogenous
2. Heterogenous
3. Homozygous
4. Heterozygous

1. Homogenous population

Genetically similar plants constitute homogenous populations. Examples of homogeneous populations are pure lines, inbred lines, F_1 hybrid between two pure line or inbred lines and progeny of a clone. Pure lines and inbred lines generally have narrow adoption.

2. Heterogenous populations

Genetically dissimilar plants constitute heterogenous populations. Examples are land races, mass selected populations, composites, synthetics and multilines. Heterogenous populations have wide adaptability and stable performance under different environments.

3. Homozygous populations

Individuals with like alleles at the corresponding loci are known as homozygous. Such individuals do not segregate on selfing. Thus non-segregating genotypes constitute homozygous populations. Examples are pure lines, inbred lines and mass selected populations in self-pollinated plants. Thus pure lines and inbred lines are homozygous and homogeneous and mass selected varieties of self-pollinated crops and multi lines are homozygous and heterogenous, because they are mixtures of several pure lines.

4. Heterozygous populations

Individuals with unlike alleles at the corresponding loci are referred to as heterozygous. Such individuals segregate into various types on selfing. This includes F_1 hybrids, composites and synthetics. Thus F_1 hybrids are heterozygous but homogeneous and composites and synthetics are heterozygous and heterogenous population. Such populations have greater buffering capacity to environmental fluctuations.

Different types of genetic populations in plant breeding

population	Brief description / definition	Examples
Homogeneous	Genetically similar population	Purelines, inbred line, F_1 hybrids progeny of a clone
Heterogeneous	Genetically dissimilar population	Land races, composites synthetics and multilines. Purelines, inbred lines mass selected autogamous varieties and multilines
Homozygous	Non-segregating populations	
Heterozygous	Populations segregate on selfing	F_1 hybrids, composites, synthetics and a clone
COMBINATIONS Homogeneous and Homozygous	Genetically similar and non segregating populations	Purelines and inbred lines
Homogeneous and heterozygous	Genetically similar but segregating on selfing	F_1 hybrids between inbred lines and progeny of a clone
Heterogeneous and homozygous	Genetically dissimilar but non segregating populations	Multilines and mass selected varieties in autogamous species
Heterogeneous and Heterozygous	Genetically dissimilar and segregating populations	Composites and synthetics

Plant Genetic Resources

Germplasm may be defined as the sum total of hereditary material i.e., all the alleles of various genes present in a crop species and its wild relatives.

Also known as gene pool or genetic stock or germplasm or genetic resources.

Germplasm or gene pool is the basic material with which a plant breeder has to initiate his breeding programme.

Important features of plant genetic resources are

1. Gene pool represents the entire genetic variability or diversity available in a crop species.
2. Germplasm consists of land races, modern cultivars, obsolete cultivars, breeding stocks, wild forms and wild species of cultivated crops.
3. Germplasm includes both cultivated and wild species or relatives of crop plants.
4. Germplasm is collected from the centres of diversity, gene banks, gene sanctuaries, farmers fields, markets and seed companies.
5. Germplasm is the basic material for launching a crop improvement programme.
6. Germplasm may be indigenous (collected within country) or exotic (collected from foreign countries)

Kinds of Germplasm

The germplasm consists of various plant materials of a crop such as

- | | |
|------------------------|--|
| (1) land races | (4) advanced (homozygous), breeding materials, |
| (2) obsolete cultivars | (5) wild forms of cultivated species |
| (3) modern cultivars | (6) wild relatives |
| | (7) mutants |

These are briefly discussed below :

1. Land races

These are nothing but primitive cultivars which were selected and cultivated by the farmers for many generations without systematic plant breeding efforts.

- Land races were not deliberately bred like modern cultivars. They evolved under subsistence agriculture.
- Land races have high level of genetic diversity which provides them high degree of resistance to biotic and abiotic stresses.
- Land races have broad genetic base which again provides them wider adaptability.
- The main drawbacks of land races are that they are less uniform and low yielders.
- Land races were first collected and studied by N.I. Vavilov in rice.

2. Obsolete Cultivars

These are the varieties developed by systematic breeding effort which were popular earlier and now have been replaced by new varieties. Improved varieties of recent past are known as obsolete cultivars.

- Obsolete varieties have several desirable characters they constitute an important part of gene pool. Example : Wheat varieties K65, K68, pb 591 were most popular traditional tall varieties before introduction of high yielding dwarf Mexican wheat varieties. Now these varieties are no more cultivated. They are good genetic resources and have been widely used in wheat breeding programmes for improvement of grain quality. Now such old varieties are found in the genepool only.

3. Modern cultivars

The currently cultivated high yielding varieties are referred to as modern cultivars. They are also known as improved cultivars or advanced cultivars.

- These varieties have high yield potential and uniformity as compared to obsolete varieties and land races.
- They constitute a major part of working collections and are extensively used as parents in the breeding programmes.

As these are good sources of genes for yield and quality, can be introduced in a new area and directly released.

- However, these have narrow genetic base and low adaptability as compared to land races

4. Advanced breeding lines

These are pre-released plants which have been developed by plant breeders in modern scientific breeding programmes. These are known as advanced lines, cultures and stocks. This group includes, nearly homozygous lines, lines derived from biotechnology programmes i.e. transgenic plants and mutant lines etc. These lines which are not yet ready for release to farmers. They often contain valuable gene combinations.

5. Wild forms of cultivated species

Wild forms of cultivated species are available in many crop plants. Such plants have generally high degree of resistance to biotic and abiotic stresses and are utilized in breeding programmes. They can easily cross with cultivated species. Wild forms of many crop species are extinct.

6. Wild Relatives

Those naturally occurring plant species which have common ancestry with crops and can cross with crop species are referred to as wild relatives or wild species. Wild relatives include all other species, which are related to the crop species by descent during their evolution. Both these groups are sources of valuable genes for biotic and abiotic stress and for quality traits and yield.

7. Mutants

Mutation breeding is used when the desired character is not found in the genetic stocks of cultivated species and their wild relatives. Mutations do occur in nature as well as can be induced through the use of physical and chemical mutagens. The extra variability which is created through induced mutations constitutes important components of gene pool. Mutant for various characters sometimes may not be released as a variety, but they are added in the gene pool. The germplasm includes those carrying gene mutations, chromosomal aberrations and marker genes etc. are considered special genetic stocks. They are useful in breeding programmes.

The gene pool system of classification

The pool of a crop includes all cultivars, wild species and wild relatives containing all the genes available for breeding use.

Based on degree of relationship, the gene pool of crops can be divided into three groups (Harland and Dewet, 1971), viz., 1. Primary gene pool 2. Secondary Gene pool 3. Tertiary gene pool

These are briefly discussed below:

1. **Primary gene pool (GP1)** : This is also known as gene pool one (GP1). The gene pool in which intermating is easy and leads to production of fertile hybrids is known as primary gene pool. It includes plants of the same species or of closely related species which produce completely fertile offspring on intermating. In such gene pool, genes can be exchanged between lines simply by making normal crosses. This is the material of prime breeding importance.

2. **Secondary gene pool (GP2) :** This type of gene pool is also known as gene pool two (GP2). The genetic material that leads to partial fertility on crossing with GP1 is referred to as secondary gene pool. It includes plants that belong to related species. Such material can be crossed with primary gene pool, but usually the hybrids are sterile and some of the progeny to some extent are fertile. Transfer of gene from such material to primary gene pool is possible but difficult.
3. **Tertiary gene pool (GP3) :** The genetic material which leads to production of sterile hybrids on crossing with primary gene pool is termed as tertiary gene pool or gene pool three (GP3). It includes material which can be crossed with GP1, but the hybrids are sterile. Transfer of genes from such material to primary gene pool is possible with the help of special techniques.

Types of seed collections

Based on the use and duration of conservation, seed collections are of three types

1. Base collections
 2. Active collections
 3. Working collections
1. **Base collections:** It is also known as principal collection. These consist of all the accessions present in the germplasm of a crop. They are stored at about -18°C or -20°C with $5 \pm 1\%$ moisture content; they are disturbed only for regeneration. When the germination of an accession falls below, usually, 95% of its germination at the start of storage, the accession is regenerated. For reasons of safety, duplicates of base collections should be conserved in other germplasm banks as well. High quality orthodox seeds can maintain good viability upto 100 years.
 2. **Active collections :** The accessions in an active collection are stored at temperatures below 15°C (often near 0°C), and the seed moisture is kept at 5%. The storage is for medium duration, i.e., 10-15 years. These collections are actively utilized in breeding programme. These collections are used for evaluation, multiplication and distribution of the accessions. They are usually maintained by multiplying the seeds of their own accessions. But from time to time, base collection material should be used for regeneration of these collections. Germination test is carried out after every 5-10 years to assess the reduction in seed viability.
 3. **Working collections :** The accessions being actively used in crop improvement programmes constitute working collection. Their seeds are stored for 3-5 years at less than 15°C and they usually contain about 10% moisture. These collections are maintained by the breeders using them.

Core collection

The concept of core collection was proposed by Frankel it refers to a subset of base collection which represents the large collection. Or a limited set of accessions derived from an existing germplasm collections.

Germplasm activities

There are six important activities related to plant genetic resources.

- | | |
|-------------------------------|------------------------------------|
| 1. Exploration and collection | 4. Documentation |
| 2. Conservation | 5. Multiplication and Distribution |
| 3. Evaluation | 6. Utilization |

Exploration

Exploration refers to collection trips and collection refer to tapping of genetic diversity from various sources and assembling the same at one place.

The exploration and collection is a highly scientific process. This process takes into account six important items, viz, (1) sources of collection, (2) priority of collection, (3) agencies of collection, (4) methods of collection, (5) methods of sampling and (6) sample size.

Merits and Demerits

There are several merits and demerits of exploration and collection of germplasm, some of which are as discussed below:

Merits

1. Collection helps in tapping crop genetic diversity and assembling the same at one place.
2. It reduces the loss of genetic diversity due to genetic erosion.
3. Sometimes, we get material of special interest during exploration trips.
4. Collection also helps in saving certain genotypes from extinction.

Demerits

1. Collection of germplasm especially from other countries, sometimes leads to entry of new diseases, new insects and new weeds.
2. Collection is a tedious job.
3. Collector, sometimes has encounter with wild animals like elephants, tigers etc.
4. Transportation of huge collections also poses difficulties in the exploration and collection.

2. Germplasm conservation

Conservation refers to protection of genetic diversity of crop plants from genetic erosion.

There are two important methods of germplasm conservation or preservation. Or Germplasm conservation refers to maintain the collected germplasm in such a state that there is minimum risk for its loss and that either it can be planted directly in the field or it can be prepare for planting with relative ease whenever necessary.

There are two important methods of germplasm conservation or preservation viz.,

1. In situ conservation
2. Ex situ conservation

1. *In situ* conservation

Conservation of germplasm under natural habitat is referred to as in situ conservation. This is achieved by protecting this area from human interference : such an area is often called as natural park, biosphere reserve or gene sanctuary. A gene sanctuary is best located within the centre of origin of crop species concerned, preferably covering the microcenter with in the centre of origin. NBPGR, New Delhi is making attempts to establish gene sanctuaries in Meghalaya for Citrus and in the North-Eastern region for *Musa*, *Citrus*, *Oryza*, *Saccharum* and *Megifera*.

This method of preservation has following main disadvantages

- 1) Each protected area will cover only very small portion of total diversity of a crop species, hence several areas will have to be conserved for a single species.
- 2) The management of such areas also poses several problems.
- 3) This is a costly method of germplasm conservation

Merits : Gene sanctuaries offer the following two advantages.

1. A gene sanctuary not only conserves the existing genetic diversity present in the population, it also allows evolution to continue. As a result, new alleles and new gene combinations would appear with time.

2. The risks associated with ex situ conservation are not operative.

2. *Ex situ* conservation

Conservation of germplasm away from its natural habitat is called ex situ germplasm conservation. This method has following three advantages.

- 1) It is possible to preserve entire genetic diversity of a crop species at one place.
- 2) Handling of germplasm is also easy
- 3) This is a cheap method of germplasm conservation

Preservation in the form of seed is the most common and easy method, relatively safe, requires minimum space and easy to maintain. Glass, tin or plastic containers are used for preservation and storage of seeds. The seed can be conserved under long term, medium term and short term storage conditions.

Roberts in 1973 classified seeds on the basis of their storability, into two major groups.

viz., 1. Orthodox seeds 2. Recalcitrant seeds

1. Orthodox Seeds : Seeds of this type can be dried to low moisture content of 5% and stored at a low temperature without losing their viability are known as orthodox seeds. Most crop seeds belong to this category. Such seeds can be easily stored for long periods; their longevity increases in response to lower humidity and storage temperature. Eg. Wheat, Rice, Corn, Chickpea, Cotton, Sunflower

2. Recalcitrant seeds : The viability of this group of seeds drops drastically if their moisture content is reduced below 12-30%. Seeds of many forest and fruit trees, and of several tropically crops like Citrus, cocoa, coffee, rubber, oil palm, mango, jackfruit, etc. belong to this group. Such seeds present considerable difficulties in storage. They require *in situ* conservation.

3. Evaluation

Evaluation refers to screening of germplasm in respect of morphological, genetical, economic, biochemical, physiological, pathological and entomological attributes. Evaluation requires a team of specialists from the disciplines of plant breeding, physiology, biochemistry, pathology and entomology. First of all a list of descriptors (characters) for which evaluation has to be done is prepared. This task is completed by a team of experts from IPGRI, Rome, Italy. The descriptors are ready for various crops. The evaluation of germplasm is done in three different places, viz., (1) in the field, (2) in green house, and (3) in the laboratory.

4. Documentation

It refers to compilation, analysis, classification storage and dissemination of information. In plant genetic resources, documentation means dissemination of information about various activities such as collection, evaluation, conservation, storage and retrieval of data. Now the term documentation is more appropriately known as information system. Documentation is one of the important activities of genetic resources. Large number of accessions are available in maize, rice, wheat, sorghum, potato and other major crops. About 7.3 million germplasm accessions are available in 200 crops species. Handling of such huge germplasm information is only possible through electronic computers.

5. Distribution

The specific germplasm lines are supplied to the users on demand for utilization in the crop improvement programmes.

1. Distribution of germplasm is the responsibility of the gene bank centres
2. The germplasm is usually supplied to the workers who are engaged in research work of a

particular crop species.

3. Supplied free of cost to avoid cumbersome work of book keeping.
4. The quantity of seed samples depends on the availability of seed material and demands
5. Proper records are maintained about the distribution of material.
6. It helps in acclimatization and purification of the material.

6. Utilization

It refers to use of germplasm in crop improvement programmes. The germplasm can be utilized in various ways. The uses of cultivated and wild species of germplasm are briefly discussed below:

a) Cultivated Germplasm

It can be used in three main ways: (1) as a variety, (2) as a parent in the hybridization, and (3) as a variant in the gene pool.

b) Wild Germplasm

it is used to transfer resistance to biotic and abiotic stresses, wider adaptability and sometimes quality such as fibre strength in cotton.

Organizations associated with germplasm

IPGRI – International Plant Genetic Resources Institute

NBPGR – National Bureau of Plant Genetic Resources

Gene Sanctuaries

The genetic diversity is sometimes conserved under natural habitat. The areas of great genetic diversity are protected from human interference. These protected areas in natural habitat are referred to as gene sanctuaries. Gene sanctuary is also known as natural park or biosphere reserve. Gene sanctuary is generally established in the centre of diversity or microcenter. India has setup its first gene sanctuary in the Garo Hills of Assam for wild relatives of citrus. Efforts are also being made to setup gene sanctuaries for Banana, Sugarcane, Rice and Mango. In Ethiopia gene sanctuary for conservation of wild relatives of coffee was setup in 1984.

Gene sanctuaries have two main advantages.

1. It protects the loss of genetic diversity caused by human intervention.
2. It allows natural selection and evolution to operate.
3. The risks associated with *ex situ* conservation are not operative There

are two main drawbacks of gene sanctuary.

1. Entire variability of a crop species can not be conserved.
2. Its maintenance and establishment is a difficult task.
3. It is a very good method of *in situ* conservation.

Genetic Erosion

Genetic erosion refers to loss of genetic diversity between and within populations of the same species over a period of time. Gradual reduction in genetic diversity in the populations of a species, due to elimination of various genotypes, is called genetic erosion. Thus genetic erosion leads to reduction of the genetic base of a species due to human intervention and environmental

changes. There are five main reasons of genetic erosion.

Replacement of land races with improved cultivars :

The main features of modern cultivars are high yield, uniformity, narrow genetic base and narrow adaptability. On the other hand land races and primitive cultivars have more genetic diversity, broad genetic base, wider adaptability and low yield potential. Thus replacement of land races with modern cultivars has resulted in reduction in genetic diversity because land races are disappearing.

1. **Modernization of agriculture :** Clean and modern agriculture , Improved crop management practices has resulted in the elimination of wild and weedy forms of many crops. These weedy forms enhance the genetic diversity through introgression of genes from crop to weedy forms and weedy forms to crop plants.
2. **Extension of farming into wild habitats :** It has resulted in destruction of wild relatives of various crops resulting in reduction of their genetic diversity.
3. **Grazing into wild habitats :** Grazing of animals in the wild habitat also reduces genetic diversity by destroying the wild and weedy forms of crop plants.
4. Developmental activities like Hydroelectric projects, growth of towns, cities, roads, air ports and industrial areas also lead to genetic erosion of crop plants, because vast areas are cleaned for such activities.

Extinction

Extinction refers to permanent loss of a crop species due to various reasons.

Introgression

Transfer of few genes from one species into the full diploid chromosome complement of another species.

Gene banks

Gene bank refers to a place or organization where germplasm can be conserved in living state. Gene banks are also known as germplasm banks. The germplasm is stored in the form of seeds, pollen or *in vitro* cultures, or in the case of a field gene banks, as plants growing in the field. Gene banks are mainly of two types, viz.,

1. Seed gene banks
2. Plant or field gene banks
3. Meristem gene banks
4. Cell and organ gene banks and
5. DNA gene banks

These are briefly discussed below :

1. Seed gene banks :

A place where germplasm is conserved in the form of seeds is called seed gene banks. Seeds are very convenient for storage because they occupy smaller space than whole plants. However, seeds of all crops can not be stored at low temperature in the seed banks. The germplasm of only orthodox species (whose seed can be dried to low moisture content without losing variability) can be conserved in the seed banks. In the seed banks, there are three types of conservation, viz., (1) short term, (2) medium term, and (3) long term. Base collections are conserved for long term (50 years or more) at -18 or -20°C . Active collections are stored for medium term (10-15 years) at zero degree Celsius and working collection are stored for short term (3-5 years) at $5-10^{\circ}\text{C}$. The main advantages of gene banks are as follows.

- 1) Large number of germplasm samples or entire variability can be conserved in a very small space.
- 2) In seed banks, handling of germplasm is easy
- 3) Germplasm is conserved under pathogen and insect free environment

There are some disadvantages of germplasm conservation in the seed banks.

- 1) Seed of recalcitrant species can not be stored in seed banks
- 2) Failure of power supply may lead to loss of viability and there by loss of germplasm
- 3) It requires periodical evaluation of seed viability. After some time multiplication is essential to get new or fresh seeds for storage.

2. Field Gene banks

Field gene banks also called plant gene banks are areas of land in which germplasm collections of growing plants are assembled. This is also *ex situ* conservation of germplasm. Those plant species that have recalcitrant seeds or do not produce seeds readily are conserved in Field gene banks. In field gene banks, germplasm is maintained in the form of plants as a permanent living collection. Field gene banks are often established to maintain working collections of living plants for experimental purposes. Field gene banks have been established in many countries for different crops.

Field gene banks in some countries

Name of country	Crop species for which field gene bank is established
Malaysia	Oil palm has been conserved on 500 hectares
Indonesia	Earmarked 1000 hectare area for coconut and other perennial crops
Philippines	South East Asia germplasm of banana has been conserved
India	Global collection of coconut has been conserved in Andman & Nicobar

Field gene banks have some advantages and disadvantages.

Advantages

1. It provides opportunities for continuous evaluation for various economic characters.
2. It can be directly utilized in the breeding programme

Disadvantages

1. Field gene banks can not cover the entire genetic diversity of a species. It can cover only a fraction of the full range of diversity of a species.
2. The germplasm in field gene banks is exposed to pathogens and insects and sometimes is damaged by natural disasters such as bushfires, cyclones, floods, etc.
3. Maintenance of germplasm in the field gene banks is costly affair

Meristem gene banks

Germplasm of asexually propagated species can be conserved in the form of meristems. This method is widely used for conservation and propagation of horticultural species. *In vitro* method can be used in two ways. First for storage of tissues under slow growth conditions. Second, for long term conservation of germplasm by cryopreservation. In cryopreservation, the tissues are stored at a very low temperature i.e. at -196°C in liquid nitrogen. At this temperature, all biological processes virtually come to a stop.

Shoot Tip Gene Banks

In such gene banks, germplasm is conserved as slow growth cultures of shoot-tips and

nodal segments. Their regeneration consists of sub-culturing the cultures, which may be done every 6 months to 3 years. The chief merits for the conservation of germplasm of vegetatively propagated crops and tree species.

1. Genotypes of the accessions can be conserved indefinitely free from diseases and pests.
2. They can be used for such crops, which either do not produce seeds or produce recalcitrant seeds.
3. Subculture becomes necessary only after relatively long periods (every 6-36 months).
4. Regeneration i.e., subculturing, requires a comparatively very short time.

In addition, cuttings, bulbs and tubers can be maintained under controlled humidity and temperature conditions; however, this approach is practical for the short and medium term storage, and it should be used in conjunction with a field gene bank.

Cell and Organ Gene Banks

A germplasm collection based on cryoprest (-196°C in liquid nitrogen) embryogenic cell cultures, shoot-tips and or somatic/zygotic embryos may be called cell and organ bank. The techniques for cryopreservation of plant cells and tissues are being rapidly refined, and some such banks have been established, e.g., for potato in Germany.

DNA Gene Banks

In these banks, DNA segments from the genomes of germplasm accessions are maintained as cosmid clones, phage lysates or pure DNA (the last one being for relatively short periods). These DNA segments can be evaluated and the desired ones may be used to produce transgenic plants. This approach is applicable to the conservation of genetic materials of already extinct species since DNA extracted from well preserved herbarium specimens can often be cloned. However, it is very expensive and highly sophisticated. A world-wide network of DNA banks for threatened / endangered species has been established.

IDEOTYPE BREEDING

Crop ideotype refers to model plants or ideal plant type for a specific environment. In broad sense an ideotype is a biological model which is expected to perform or behave in a predictable manner within a defined environment. More specifically, crop ideotype is a plant model which is expected to yield greater quantity of grains, fibre, oil or other useful product when developed as a cultivar. The term ideotype was first proposed by Donald in 1968 working on wheat.

Ideotype Breeding

Ideotype breeding can be defined **as a method of crop improvement which is use to enhance genetic yield potential through genetic manipulation of individual plant character.**

Main features of ideotype breeding are

1. Emphasis on individual trait

In ideotype breeding, emphasis is given on individual morphological and physiological trait which enhances the yield. The value of each character is specified before initiating the breeding work.

2. Includes yield enhancing traits

Various plant characters to be included in the ideotype are identified through correlations analysis. Only those characters which exhibit positive association with yield are included in the model.

3. Exploits physiological variation

Genetic differences exist for various physiological characters such as photosynthetic efficiency, photo respiration, nutrient uptake, etc. Ideotype breeding makes use of genetically controlled physiological variation in increasing crop yields, besides various agronomic traits.

4. Slow progress

Ideotype breeding is a slow method of cultivar development, because incorporation of various desirable characters from different sources into a single genotype takes long time. Moreover, sometimes undesirable linkage affects the progress adversely.

5. Selection

In ideotype breeding selection is focused on individual plant character which enhance the yield

6. Designing of model

In ideotype breeding, the phenotype of new variety to be developed is specified in terms of morphological and physiological traits in advance.

7. Interdisciplinary approach

Ideotype breeding is in true sense an interdisciplinary approach, it involves scientist from the disciplines of genetics, breeding, physiology, pathology, entomology etc.

8. A continuous process

Ideotype breeding is a continuous process, because new ideotypes have to be developed to meet changing and increasing demands.

Differences between traditional and ideotype breeding

<i>S. No.</i>	<i>Traditional Breeding</i>	<i>Ideotype Breeding</i>
1.	The main objective is defined before initiating the breeding work.	The conceptual theoretical model is prepared before initiation of breeding work
2.	Selection is focused on yield and some other characters.	Selection is focused on individual plant characters.
3.	It usually includes various morphological and economic characters.	It includes various morphological, physiological and biochemical plant characters
4.	Value of each character is not fixed in advance	Value of each trait is defined in advance.

5.	This is a simple and rapid method of cultivar development	This is a difficult and slow method of cultivar development.
6.	The phenotypic of a new variety is not specified in advance	Phenotype of new variety to be developed is specified in advance.

STEPS IN IDEOTYPE BREEDING

Ideotype breeding consists of four important steps,

1. Development of Conceptual Model

The values of various morphological and physiological traits are specified to develop a conceptual theoretical model. For example, values for plant height, maturity duration, leaf size, leaf number, angle of leaf, photosynthetic rate etc., are specified. Then efforts are made to achieve this model.

2. Selection of Base Material

Selection of base material is an important step after development of conceptual model of ideotype. Genotypes to be used in devising a model plant type should have broad genetic base and wider adaptability. Genotypes for plant stature, maturity duration, leaf size and angle and resistance are selected from the global gene pool of the concerned crop species. Genotypes resistant or tolerant to drought, soil salinity, alkalinity, diseases and insects are selected from the gene pool with the cooperation of physiologist, soil scientist, pathologist and entomologist.

3. Incorporation of Desirable Traits

The next important step in combining of various morphological and physiological traits from different selected **genotypes into single genotype**. Various breeding procedures, viz single cross, three way cross, multiple cross, backcross, composite crossing, intermating, mutation breeding, heterosis breeding etc., are used for the development of ideal plant types in majority of field crops.

4. Selection of Ideal Plant Type

Plants combining desirable morphological and physiological traits are selected in segregating populations and intermated to achieve the desired plant type. Morphological features are judged through visual observations and physiological parameters are recorded with the help of sophisticated instruments. Screening for resistance to drought, soil salinity, alkalinity, disease and insects is done under controlled conditions.

PRACTICAL ACHIEVEMENTS

Ideotype breeding has significantly contributed to enhanced yields in cereals (wheat and rice) and millets (*Sorghum* and pearl millet) through the use of dwarfing genes, resulting in green revolution. Semidwarf varieties of wheat and rice are highly responsive to water use and nitrogen application and have wide adaptation. The Norin 10 in wheat and Dee-geo-Woo-gen in rice are the sources of dwarfing genes. The genic cytoplasmic male sterile systems in *Sorghum* and pearl millet laid the foundation of green revolution in Asia (Swaminathan, 1972). Thus ideotype breeding has been more successful for yield improvement in cereals and millets than in other crops.

BREEDING FOR BIOTIC STRESS RESISTANCE DISEASE RESISTANCE

Stress: Constraining influence, force, pressure or adverse conditions for crop growth caused by biological or environmental factors.

Biotic (living) : Adverse effects due to pests and diseases abiotic stresses **Abiotic**

(non living) : Adverse effects on host due to environmental factors eg: Drought, water logging, heat, cold, salinity, alkalinity and air pollution etc.

Host : Plant effected by a disease or which can accommodate pathogen.

Pathogen : An organism that produces the disease

Disease : an abnormal conditions in the plant caused by an organism (pathogen)

Pathogenicity : The ability of a pathogen to infect a host strain

Virulence : Capacity of a pathogen to incite a disease

Avirulence : The inability of a pathogen to cause or incite a disease

Physiological race : Strains of a single pathogen species with identical or similar morphology but differ in pathogenic capabilities.

Pathotype : Strains of a pathogen classified on the basis of their virulence to known resistance genes present in the host.

Epidemic : Severe and sudden out break of disease beginning from a low level of infection.

Variability in fungal pathogens:

- a) **Hybridization:** Recombination of genes of the two parental nuclei takes place in the zygote, and the haploid nuclei or gametes resulting after meiosis are different both from gametes that produced the zygote and from each other.
Thus every diploid pathogen individual is genetically different from any other pathogen even within the same species and variability of the new individual pathogens is continued indefinitely.
e.g., Phytophthora infestans.
- b) **Heterokaryosis:** Condition in which fungal hyphae that are genetically different come together in the same cell to form heterokaryons.
- c) **Parasexualism** : Parasexuality – re-assortment of genetic material both in haploid and diploid condition, ready for natural and artificial selection.
Mixtures of races grown together on a susceptible host combine genetically to produce new races *e.g. phytophthora infestans*
- d) **Mutation:** The rate at which new variants of a pathogen are produced will depend on the mutation rate of the genes at a particular locus. The mutation rate varies from gene to gene and from pathogen to pathogen.
e.g. Melampsora lini – new race produced with UV rays (Flor 1956)
- e) **Cytoplasmic adaptation:** There are several examples of cytoplasmic inheritance of important characteristics such as growth rate and virulence (Jinks 1966).
Virulence of *P.graminis f. sp. Avenae*, carrying gene E, is maternally inherited and may be controlled by single plasma gene (Johnson *et al* 1967)

MECHANISMS OF DISEASE RESISTANCE:

There are different ways of disease resistance *viz.*, disease escape, disease endurance or tolerance disease resistance and immunity

1. **Disease escape** : The ability of susceptible host plants to avoid attack of disease due to environmental conditions factors, early varieties, change in the date of plating, change in the site of planting; balanced application of NPK etc.
Eg. Early varieties of groundnut and potato may escape ‘Tikka’ and ‘Late blight’ diseases respectively since they mature before the disease epidemic occurs.
Changing planting season in sugarcane from June to October has successfully escaped leaf-rust.
Virus free seed potato is produced by sowing the crop in October in Jullundher and other places instead of November, the normal planting time.
2. **Disease endurance or tolerance** : The ability of the plants to tolerate the invasion of the pathogen without showing much damage. This endurance is brought about by the influence of external

characters. Generally, tolerance is difficult to measure since it is confounded with partial resistance and disease escape. To estimate tolerance the loss in yield and some other trait of several host varieties having the same amount of disease eg., leaf area covered by disease etc., is compared.

- Eg. In Barley the variety Proctor shows 13% yield loss as compared to 20% loss in the varieties Zephy and Sultan.
 - Wheat varieties when fertilized with potash and phosphorus are more tolerant to the rust and mildew infection.
 - The Rice crop fertilized with silicate is resistant to blast infection in Japan.

3. **Disease Resistance** : The ability of plants to withstand, oppose or overcome the attack of pathogens. Resistance is a relative term and it generally refers to any retardation in the development of the attacking pathogen. In case of resistance, disease symptoms do not develop and the rate of reproduction is never zero i.e., $r > 0$ but it is sufficiently lower than 1 (the rate of reproduction on the susceptible variety) to be useful. The inhibition of growth of the pathogen is believed to be nutritional in nature and in some cases chemical growth inhibitors may be involved.

Resistance is largely controlled by inherited characters

- i) may be controlled by single dominant gene in Ottawa 770 B, Newland flax variety, wheat all rusts NP 809
4. **Immunity**: When the host does not show the symptoms of disease it is known as immune reaction. Immunity may result from prevention of the pathogen to reach the appropriate parts of the host e.g. exclusion of spores of ovary infecting fungi by closed flowering habit of wheat and barley. It is more generally produced by hypersensitive reaction of the host usually immediately after the infection was occurred. In immune reaction the rate of reproduction is zero i.e. $r = 0$
5. **Hypersensitivity**: Immediately after the infection several host cells surrounding the point of infection are so sensitive that they will die. This leads to the death of the pathogen because the rust mycelium cannot grow through the dead cells. This super sensitivity (hypersensitivity) behaves as a resistant response for all practical purposes. Phytoalexins are specific polyphenolic or terpenoid chemicals and are produced by the host in response to the infection by a pathogen. More than 30 different phytoalexins have been identified. Phytoalexins are either fungicidal or fungistatic. Eg. Rust fungi and virus attack.

Factors for disease resistance (Causes of Disease resistance)

The disease resistance may be caused due to

1. Morphological, structural and functional characteristics which prevents the entrance of the pathogen i.e. prevents the first stage of infection.
2. Biochemical or anatomical properties of tissue which prevent the establishment of parasitic relationship.

a. Morphological characters

Certain morphological features of the host may prevent infection.

- Eg. Resistance to Jassid attack in cotton has been shown to be correlated with the hairiness of varieties : hairy type resists the attack more, than glabrous types.
Failure to germinate rust spores on the leaves of the barley due to waxy coating.
Young sugarbeet leaves practically immune to attack of the circo-spora because the stomata size is very small.

b. Physiological characters

Protoplasmic factors or chemical interactions :

By virtue of its chemical composition the protoplasm may exert an inhibitory influence on the pathogen bringing about the desired resistance in the plant.

Eg. : Resistance of grape to powdery mildew is highly correlated with the acidity of cell sap.

Presence of toxic substance in the red pigment in the coloured onions. The outer scales resist the smudge fungus attack when the scales are removed they become susceptible.

- c. Anatomical**: More secondary thickening of the cell walls of resistant potato varieties which resists the

mechanical puncture of the invading *Pythium* pathogen.

- d. Nutritional factors :** Reduction in growth and in spore production is generally supposed to be due to unfavourable physiological conditions within the host. Most likely a resistant host does not fulfill the nutritional requirements of the pathogen and thereby limits its growth and reproduction.
- e. Environmental factors :** In addition to the above the environmental factors have marked effect on the pathogen attack. Temperature, moisture, humidity and soil P^H and fertility status of the soil effects the pathogen reaction greatly.

Genetic basis of disease resistance

The first study on genetics of disease resistance was done by Biffen in 1905. He reported the inheritance of resistance to leaf rust of wheat variety Rivet in crosses with some susceptible varieties. In F₂ there were 3 susceptible : 1 resistant plants indicating that resistance was controlled by a single recessive gene. Most of the earlier studies were conducted without taking into consideration the physiological specialization (pathotype differentiation) of the pathogen which can materially influence the conclusions drawn. It is now recognized that disease resistance may be inherited in three different ways :

Oligogenic Polygenic and
Cytoplasmic inheritance

Oligogenic inheritance:

The disease resistance is governed by one or few major genes and resistance is generally dominant to the susceptible reaction. The action of major resistance genes may be altered by modifying genes in many cases. Eg. bunt resistance in Wheat. Oligogenes generally produce immune reaction. The chief characteristic of the oligogenic disease resistance is pathotype - specificity, i.e. resistant gene is effective against some pathogens, while it is ineffective against the others. In most cases, there are a number of major genes that determines resistance to a particular disease Eg. more than 20 different resistance genes are known for leaf rust of wheat, while those for stem rust resistance exceed 30. The genetics of oligogenic resistance has advanced by two events viz.,

1. Discovery of a resistance gene to the prevalent pathotype and
2. Evolution of a pathotype virulent to the new resistance gene.

Oligogenic resistance is synonymous to vertical resistance.

Gene for gene hypothesis:

The concept of gene for hypothesis was first developed by Flor in 1956 based on his studies of host pathogen interaction in flax rust caused by *Malampsora lini*. The gene for gene hypothesis states that for each gene controlling resistance in the host, there is a corresponding gene controlling pathogenicity in the pathogen. The resistance of host is governed by dominant genes and virulence of pathogen by recessive genes. The genotype of host and pathogen determine the disease reaction. When genes in host and pathogen match for all the loci, then only the host will show susceptible reaction. If some gene loci remain unmatched, the host will show resistant reaction. Now gene-for -gene relationship has been reported in several other crops like potato, *Sorghum*, wheat etc. The gene for gene hypothesis is known as "Flor Hypothesis".

A simple scheme to explain gene for gene relationship hypothesis (Fehr, 1987)

Varieties	Host genotype	Pathogen genotypes	Disease Reaction
1. One gene pair	AA	Aa	Susceptible
	Aa		
	BB	Bb	Susceptible
2. Two gene pair	Bb AA CC	Aa	Resistant
	Aa CC	Cc	Resistant
	Aa Cc	Aacc	Susceptible
	AA BB CC	aa bb	Resistant

	AA BB CC Aa Bb Cc	aa cc aabbcc	Resistant susceptible
--	----------------------	--------------	-----------------------

Note: Dominant genes in the host are responsible for resistance and recessive genes in the pathogen for virulence.

Vertifolia Effect : Vander plank introduced the term vertifolia effect and refers to epidemic development in a variety carrying vertical resistance genes (oligogenes) leading to heavy economic losses. Total failure of vertical resistance leading to a disease epidemic is known as vertioalia effect. This failure occurs because of two reasons :

- The level of horizontal resistance in varieties carrying oligogenes is usually low and
- The pathogen is able to evolve new virulent pathotypes.

Polygenic inheritance

In this type the disease resistance is governed by many genes with small effects and a continuous variation for disease reaction is produced. The genes show additive and non additive effects and the environmental effect is also observed. The polygenic resistance does not show pathotype-specificity as against the oligogenic resistance. It is almost same as horizontal resistance. In some cases the polygenic inheritance may have a oligogenic component, the oligogenes acting in an additive manner eg. bacterial blight resistance in cotton

Cytoplasmic inheritance :

Resistance in some cases is determined by cytoplasmic genes or plasma gene(s).

Eg. The T-male sterilize cytoplasm (cms-T) in maize is extremely susceptible to *Helmin thosporium* leafblight, while the non-T cytoplasms are resistant to this disease.

Vertical and Horizontal Resistance (Vander plank)

<i>Feature</i>	<i>Vertical resistance</i>	<i>Horizontal resistance</i>
1. Pathotype – specificity	Specific	Non specific
2. Nature of gene action	Oligogenic	Polygenic; rarely oligogenic
3. Response to pathogen	Usually, hypersensitive	Resistant response
4. Phenotypic expression	Qualitative	Quantitative
5. Stage of expression	Seedling to maturity	Expression increases as plant matures
Selection and evaluation	Relatively easy Present	Difficult
Host pathogen interaction		Absent
8. Commonly used, synonyms	Major: gene, race -specific seedling, monogenic, pathotype specific resistance	Polygenic, race nonspecific, pathotype-nonspecific, mature plant, adult plant, field uniform resistance
9. Efficiency	Highly efficient against specific races	Variable, but operates against all races

Sources of Disease Resistance

Resistance to diseases may be obtained from four different sources :

1. A known variety
2. Germplasm collection
3. Related species
4. Through mutations

1. **A known variety:** Disease reactions of most of the cultivated varieties are documented and a breeder may find the resistance he needs in a cultivated variety. Resistant plants were also latered from commercial varieties as in the case of cabbage yellows in cabbage curlytop resistance etc. These provide the basis for new resistance varieties.
2. **Germplasm collection :** When resistance to a new disease or a new pathotype of a disease is not known in a cultivated variety germplasm collection should be screened. Several instances disease

resistance were found from the germplasm collections.

Eg. resistance to neckblotch in barley resistance to wilt in watermelon

3. **Related species** : Often the resistance to a disease may be found in related species and transferred through interspecific hybridization.

Eg. Resistance to stem, leaf & stripe rusts of wheat

4. **Mutation**: Resistance to diseases may be obtained through mutation arising spontaneously or induced through mutagenic treatments.

Eg.

1. Resistance to Victoria blight in oats was induced by irradiation with x-rays or thermal neutrons / also produced spontaneously
2. Resistance to stripe rust in wheat
3. Resistance to brown rust in oats
4. Resistance to mildew in barley
5. Resistance to rust in linseed
6. Resistance to tikka leaf spot and stem root in groundnut

Vertical and Horizontal Resistance (Van der plank)

Vertical Resistance is generally determined by major genes and is characterized by pathotype specificity. Clearly immune or susceptible response in the case of vertical resistance depends on the presence of virulent pathotype. When virulent pathotype becomes frequent, epidemics are common in the cases of vertical resistance. Thus an avirulent pathotype will produce an immune response i.e. $r=0$ or close to 0 but the virulent pathotype will lead to susceptible reaction i.e. $r=1$. It is also known as race specific, pathotype specific or simply specific resistance.

Horizontal Resistance

Race non-specific, pathotype non-specific and partial, general or field resistance. Horizontal resistance is generally controlled by polygenes i.e. many genes with small effects and it is pathotype nonspecific. In this case, the reproduction rate is not zero but it is less than one. Poly genes, govern horizontal resistance.

Methods of Breeding for Disease Resistance

The methods of breeding for disease resistance are essentially same as those used for other agronomic traits. They are :

1. Introduction
2. Selection
3. Hybridization
4. Budding & Grafting
5. Mutation Breeding
6. Biotechnological methods.

1. **Introduction** : Resistant varieties may be introduced for cultivation in a new area. Eg.

- Early varieties of groundnut introduced from USA have been resistant to leaf spot (Tikka) , Kalyanasona and Sonalika wheat varieties originated from segregating material introduced from CIMMYT, Mexico, were rust resistant. African bajra introductions have been used in developing downy mildew resistant cms lines.

2. **Selection** : Selection of resistant plants from commercial varieties is easiest method.

Eg.

- Kufri Red potato is selection from Darjeeling Red round
- Pusa Sawani behind (yellow mosaic) selection from a collection obtained from Bihar
- MCU I was selection from CO4 for black arm resistance in cotton

3. **Hybridization** : Transferring disease resistance from one variety or species to the other.

Pedigree method is quite suitable for horizontal resistance. Artificial disease

epiphytotics are produced to help in selection for disease resistance. Eg. In wheat Kalyana Sona, Sonalaka, Malvika 12 Malvika 37, Malavika 206, Malavika 234 Laxmi in Cotton (Gadag 1 x CO2) for leaf blight resistance

Backcross method is used to transfer resistance genes from an undesirable agronomic variety to a susceptible, widely adoptable and is agronomically highly desirable variety.

If the resistant parent is a wholly unadapted variety, backcross method is a logical choice.

If resistant variety also possess some good qualities then chose pedigree method of handling segregating material.

4. **Budding & Grafting** : The disease resistance in vegetatively propagated material is transferred by adopting either by budding or grafting. By grafting or budding the resistant material, the resistance can be transferred.

5. **Mutation Breeding** : When adequate resistance is not available in the germplasm ; Mutation breeding is resorted to induce resistance. This is also used to break the linkages between desirable resistant genes and other desirable genes.

Precautions

1. The donor parent must possess the required amount of resistance
2. It must be simply inherited without any linkage
3. The recovery in the recipient parent should be more
4. Proper condition for full expression of the resistant genes has to be provided

Advantages with breeding for disease resistance

1. Helps in reducing the losses caused by pathogens
2. Reduces the high cost of disease control by chemical treatment
3. Helps to avoid the use of poisonous fungicides
4. Only method available to some specific diseases like viruses, wilt etc.

Limitations

1. Linkage of resistant genes with genes of inferior quality
2. Occurrence of physiological races of varying capacities
3. Self sterility in host plants

Utilization and achievements

1. Rice ADT 10 x Co4 (resistant to blast)
2. Potato *Solanum tuberosum* x *Solanum demissum* (susceptible to late blight) (wild resistant to late blight)
F₁ backcrossed with *Sol. tuberosum*
Resistant variety

INSECT RESISTANCE

Global average loss due to insect pests is 14%. Estimated losses in individual crops vary from 5% in wheat to 26.7% in rice and still more in crops like cotton & sugarcane.

Insect Resistance :

1. The ability of a plant to withstand, oppose or overcome the attack of an insect is known as insect resistance.
2. It is the property of a variety or a host crop due to which it is attacked by an insect pest to a significantly lower degree than are other varieties of the same host.

Biotypes : Strains of a species of an insect pest, differing in their ability to attack different varieties of the same host species (syn: Physiological races)

Host Habitation :

1. Polyphagy
2. Oligophagy
3. Seasonal Oligophagy
4. Monophagy

1. Polyphagy : Insects feed on a wide range of hosts avoiding few plant species. Eg. Scales & moths.
2. Oligophagy : Live on one taxonomic unit only. Eg. Hessianfly on wheat
3. Seasonal oligophagy : Insects may live on many species in one part of the year and on few in another part of the year. Eg : Aphids.
4. Monophagy : Avoid all hosts except one particular species or variety Eg. Boll weevil on cotton.

Mechanism of Insect Resistance :

Insect resistance is grouped into four categories :

- | | |
|-------------------|---------------|
| 1. Non preference | 2. Antibiosis |
| 3. Tolerance | 4. Avoidance |

1. **Non preference** : Host Varieties exhibiting this type of resistance are unattractive or unsuitable for colonization, oviposition or both by an insect pest. This type of resistance is also termed as non-acceptance and anti-xenosis. Non preference involves various morphological and biochemical features of host plants such as – color, hairiness, leaf angle, taste etc.
2. **Antibiosis** : Antibiosis refers to an adverse effect of feeding on a resistant host plant on the development and/or reproduction of the insect pest. In severe cases, it may even lead to the death of the insect pest. Antibiosis may involve morphological, physiological or biochemical features of the host plant; some cases of insect resistance involve a combination of features. Eg. Resistance to BPT is due to antibiosis & non preference
3. **Tolerance** : An insect tolerant variety is attacked by the insect pest to the same degree as a susceptible variety. But at the same level of infestation, a tolerant variety produces a higher yield than a susceptible variety. Ability of the host plant to withstand the insect population to a certain extent which might have damaged a more susceptible host. Tolerance is mainly a host character and it may be because of greater recovery from pest damage. Eg. Rice varieties tolerant to stem borer/gall midge produce additional tillers to compensate yield losses (as in stem borer in sorghum) or due to the ability of host to suffer less damage by the pest eg. aphid tolerance in Sugarbeet & Brassica spp.
Inheritance of tolerance is complex in many cases and is supposed to be governed by polygenes.
4. **Avoidance** : Pest avoidance is the same as disease escape, and as such it is not a case of true resistance. Mostly insect avoidance results from the host plants being at a much less susceptible developmental stage when the pest population is at its peak.
 - Eg. 1. Early maturing cotton varieties escape pinkboll worm infestation, which occurs late in the season.

Nature of Insect Resistance / Factors for insect-resistance

1. Morphological
 2. Physiological (or)
 3. Biochemical features of the host plant
1. **Morphological features** : Morphological factors like, hairiness, colour, thickness and toughness of tissues etc. are known to confer insect resistance.
 - a) Hairiness of leaves is associated with resistance to many insect pests leaf beetle in cereals, in cotton to Jassids, in turnip to turnip aphid.
 - b) Colour of plant : Color may contribute to non preference in some cases.
For example : Red cabbage, Red leaved brussels sprouts are less favored than green varieties by butterflies and certain Lepidoptera for oviposition. Boll worms prefer green cotton plants to red ones.
 - c) Thickness and Toughness of plant – Tissues prevent mechanical obstruction to feeding and oviposition and thereby lead to non-preference as well as antibiosis.
Eg.
 - Thick leaf lamina in cotton contributes to Jassid resistance
 - Solid stem in wheat confers resistance to wheat stem sawfly
 - Thick and tough rind of cotton bolls makes it difficult for the boll worm larvae to bore holes and enter the bolls.

Other characters: also contribute to insect resistance.

- Eg. 1. *Gossypium arboreum* varieties with narrow lobed and leathery leaves are more resistant to Jassids than are those with broad lobed and succulent leaves.
- 2. Cotton varieties with longer pedicels are more resistant to boll worms.

2. **Physiological Factors** : Osmotic concentration of cell sap, various exudates etc; may be associated with insect resistance.

Eg.

- Leaf hairs of some *solanum* *sps.* secrete gummy exudates. Aphids and colorado beetles get trapped in these exudates.
- Exudates from secondary trichomes of *Medicago disciformis* leaves have antibiotic effects on alfalfa weevil.
- Cotton- High osmotic concentration of cell sap is associated with Jassid resistance.

3. **Biochemical Factors** : Several biochemical factors are associated with insect resistance in many crops. It is believed that biochemical factors are more important than morphological and physiological factors in conferring non-preference and antibiosis.

Eg.

- High concentrations of gossypol is associated with resistance in several insect pests in cotton.
- In rice – high silica content in shoots gives resistance to shoot borer

Genetics of Insect Resistance

Insect resistance is governed by -

1. Oligogenes
2. Polygenes
3. Cytoplasmic genes

1. **Oligogenic Resistance** : Insect resistance is governed by one or few major genes or oligogenes, each gene having a large and identifiable individual effect on resistance. Oligogenic resistance may be conditioned by the dominant or the recessive allele of the concerned gene. The differences between resistant and susceptible plants are generally large and clear-cut. In several cases, resistance is governed by a single gene (monogenic resistance)

Eg. In wheat to green bugs

In cotton to Jassids

In apple to woolly aphis

In rice to plant & leaf hopper

2. **Polygenic Resistance**: It is governed by several genes, each gene producing a small and usually cumulative effect. Such cases of resistance.

- Involve more than one feature of the host plant
 - Are much more durable than the cases of oligogenic resistance.
 - Difference between resistance & susceptible plants are not clear cut
 - Transfer of resistance is much more difficult
- Examples for polygenic resistance : In wheat to cereal leaf beetle

4. Testing in a particular season when the infestation is very high. Eg. Rice stem borer in off season.
5. Transferring manually equal number of eggs or larvae to each test plant.

Glass house screening

Result from glass house tests are much more reliable than those from field tests since both the environment and the initial level of infestations are more or less uniform for all the plants being tested.

Problems in Breeding for Insect Resistance :

1. Breeding for resistance to one insect pest may lead to the susceptibility to another pest. Eg. Glabrous strains of cotton are resistant to bollworms but susceptible to Jassids.
2. Reduction in quality or make unfit for consumption.
3. Linkage between desirable & undesirable genes. Inter specific varieties are generally low yielding and their produce is often of inferior quality.
4. Screening for resistance is the most critical and difficult step in a breeding programme it necessitates a close co-ordination among scientists belonging to different disciplines.
5. It is a long term programme

Achievements

INDIA

1. India – cotton varieties – G 27, MCU 7, LRK 516 – resistant to boll worms.
2. Rice – variety vijaya – resistant to leaf hopper
Rice – TKM
6, Ratna – Stem borer
Rice – Vajram, chaitanya, Pratibha – BPH

BREEDING FOR ABIOTIC STRESS RESISTANCE DROUGHT RESISTANCE

Drought: Scarcity of moisture (soil moisture) which restricts the expression of full genetic yield potential of a plant.

Drought resistance: The ability of crop plants to grow, develop and reproduce normally under moisture stress.

Mechanisms of drought resistance

There are 4 mechanisms of drought resistance.

1. **Drought Escapes:** It is due to ability of a genotype to mature early, before occurrence of drought. Drought escape is most common in plants grown in desert region.
Eg. Early maturing varieties of sorghum, maize, bajra, wheat, rice etc; give more yield than late maturing under drought.
2. **Drought Avoidance (Dehydration avoidance):** It is due to the ability of plants to maintain favorable water balance even under stress. The plants which avoid drought retain high moisture content in their tissues and lose less water. This is possible either because of :
 1. Increased water uptake (due to increase in root development) plants are called water spenders.(or)
 2. Reduced water loss (due to reduction in growth of aerial parts are called water savers (i.e. to avoid transpiration) Dehydration avoidance is interpreted as the ability of genotypes to maintain high leaf water potential when grown under soil moisture stress: Several traits contribute to dehydration avoidance Such as : Leaf rolling, folding and reflectance narrow leaves, increased pubescence on aerial organs , presence of awns, osmotic adjustment of stomata, cuticular wax, increased water uptake ;
Reduced Transpiration: Increase in concentration of Abscisic Acid (ABA), closure of stomata, ABA plays a role in reduction of leaf expansion, Promotion of root growth etc.
3. **Drought Tolerance (Dehydration tolerance):** Ability of plants to produce higher yield even under 'low water potential'. In cereals drought tolerance generally occurs during reproductive phase. Tolerant cultivars exhibit better germination, seedling growth and photosynthesis.
4. Drought tolerance may be because of
 - i. high proline accumulation
 - ii. maintenance of membrane integrity
5. **Drought Resistance:** It is the sum total of avoidance and Tolerance. It refers to the genetic ability of plants to give good yield under moisture stress conditions.

Various morphological, physiological and biochemical features / parameters associated with drought resistance

a. Morphological

1. Earliness
2. Reduced tillering
3. Leaf characters : Leaf rolling , Leaf folding, Leaf shedding, Leaf reflectance
4. Reduced leaf area :Narrow leaf, Change in leaf angle
5. Hairiness (presence of hairs on leaf and other parts, lowers leaf temperature and reduce transpiration)
6. Colour of leaves
7. Wax content
8. Awns (eg. wheat and barley)
9. Root system (rooting depth and intensity)

b. Physiological

1. Photosynthesis (efficient system like C4) under stress, photosynthetic efficiency is reduced due to chloroplast damage.
2. Reduced Transpiration and reduced respiration losses
3. Stomatal behavior (closure of stomata, also change in size and number of stomata)
4. Osmotic adjustment
5. Leaf enlargement (increase in thickness)
6. Leaf cuticle wax (increases)

c. Biochemical

1. Accumulation of proline and betaine
2. Increase in Abscisic acid (barley) and Ethylene (maize & wheat)
3. Protein synthesis (increases under stress)
4. Nitrate – reductase activity

Sources of drought resistance

1. Cultivated varieties
2. Land (old or desi primitive varieties)
3. Wild relatives (reported in several crops)

4. Transgenes :

Eg. 'Rab' (Responsive to abscisic acid) in rice

Screening / Evaluation

- Field Env. Highly desirable
- Green house Env. More precisely controlled than field

Breeding Methods and Approaches

It is important that drought resistance be incorporate in material with high genetic potential for yield.

- Yield and yield components are best evaluated under non stress / optimal environments, while
- Drought resistance must be evaluated under water stress.

Breeding methods: Methods are same as for yield and other economic characters. Breeding for drought resistance refers to breeding for yield under moisture stress, i.e. developing varieties which can give high yields under stress. The common methods are

1. Introduction
2. Selection
3. Hybridization
4. Mutation
5. Biotechnology

Limitations:

- Generally resistant varieties have low yield
- Do not have much wider adaptability (as abiotic resistant is location specific)
- Drought resistant genes may have linkage with undesirable genes.
- Transfer of resistant genes from wild types may post problem.
- Drought resistance is a consequence of a combination of characters and single character can be used for selection.

Measurement of many drought resistant traits is difficult and problematic, since virtually all the useful drought resistant traits are under polygenic control. (So pedigree method most common). But if resistant genes are from agronomically inferior race then 1-2 backcrossing with cultivated type in made. If resistance gene is from wild species-go for backcrossing breeding.

Generally selection is performed on individual plant progenies instead of individual plants (i.e. similar to line breeding)

1. Creation of controlled moisture stress Environments
2. Selection require considerable resources

COLD TOLERANCE

When temperatures remain above-freezing *i.e.* $>0^{\circ}\text{C}$ to $<10^{\circ}\text{C}$ - 15°C it is called chilling. When temperature remains below freezing *i.e.* $<0^{\circ}\text{C}$ it is called Freezing.

A. Chilling Resistance:

Chilling sensitive plants are typically tropical plants. Temperate plants are generally tolerant to chilling injury.

Effects of chilling stress on plants :

- Reduced germination
- Poor seedling establishment
- Stunted growth
- Wilting
- Chlorosis
- Necrosis
- Pollen sterility
- Poor fruit set / seed formation
- Reduced root growth
- Locked open stomata
- ABA accumulation

At subcellular level

- Reduces membrane stability
- Poor chlorophyll synthesis (affected)
- Reduced photosynthesis & respiration
- Toxicity due to H_2O_2 formation

Chilling Tolerance

Ability of some genotypes to survive / perform better under chilling stress than other genotypes is called chilling tolerance. It is because of chilling hardening, *i.e.* an earlier exposure to a near chilling temperature for a specific period as a result of which chilling tolerance of the concerned plants increases.

Mechanisms of chilling tolerance:

- Membrane lipid unsaturation
- Reduced sensitivity of photosynthesis
- Increased chlorophyll accumulation
- Improved germination
- Improved fruit / seed set
- Pollen fertility

Sources of chilling Tolerance :

- Late adopted breeding populations *eg.* maize

- Germplasm (eg. That collected from high altitude , low temperature geographic regions)
- Induced mutants for cold tolerance
- Cold tolerant somaclonal variants
- Related wild species eg. Tomato

Genotype – Environment – Interaction and Adaptation

It is established that $P = G + E$,

Phenotype (p) is the function of the genotype (G) and environment (E). this is relevant to an individual subjected to a particular environmental condition. When the same individual is subjected to more than one kind of environment, its phenotypic expression for any trait may often change. Then, the differences in phenotypic expression for any trait cannot be accounted for by G and E alone, since $P > G + E$.

This lack of correspondence between heritable and non-heritable effects, or the remainder of 'P' that cannot be accounted for by 'G and 'E', is attributed to the interaction of G with E (i.e. $G \times E$).

Then

$$P = G + E + (G \times E)$$

This holds true for all the individuals or populations which tend to behave differentially in diverse environmental conditions due to genotype x environment interaction.

Genotypes, Environments and their Interaction

1. Genotypes (G) : Comprises all the crop varieties (cultivars), improved or unimproved, homogeneous or heterogeneous, under domestication, and genetic stocks in the breeder's nursery.

2. Environments (E) : Plants surrounded and influenced by physical, chemical and biological conditions of their habitat. All these conditions constitute an environment. These conditions might vary over time (years or seasons) and space (locations or altitudes).

