1 PLANT BREEDING: AN INTRODUCTION

From the beginning of human civilization vis-a-vis agriculture, with the development of scientific knowledge, consciously or unconsciously man has developed a new branch of science and technique, the **Plant Breeding** for the improvement of crop quality.

Smith (1967) has defined **plant breeding as the art and science of improving the genetic pattern of plants in relation to their economic use.**

Frankel (1968) has defined **plant breeding as the genetic adjustment of plants to the social, cultural, economic and technological aspects of the environment.**

Technically plant breeding is an exercise in exploiting and manipulating the genetic system for improvement in relation to crop production. The science of plant breeding deals with the principles and methods required for favourable changes in the genetic constitution of crop plants, which are more suitable in one or more aspects than the existing ones.

1.1 HISTORY OF PLANT BREEDING

The process of plant breeding is assumed to be initiated nearly 7000 years ago with the beginning of human civilization. Bringing a wild species under human management as the source of food which can be referred to as the process of **domestication.** Movement of man from one place to another also helped the movement of cultivated plant species. In this way the **introduction** of new plant species or varieties into new area from other parts of the world became an integral part of plant breeding today. Furthermore man has started the process of **selection** by selecting the best seeds or good grains from the field to be planted in future. The first artificial **hybridization** procedure to get the hybrid was carried out by Knight and described **hybrid vigour.**

1.3 SCOPE AND OBJECTIVES OF PLANT BREEDING

The different methods of plant breeding for the improvement of crop are directed in the following aspects:

(i) **Higher productive capacity**: This is the first and foremost objective of plant breeding programme, but this higher yield is associated with many other criteria like responsiveness to fertilizer, tillering capacity, resistance to disease or adverse situation, etc.

(ii) **Improved quality**: Besides quantitative characters, the quality of food grains is considered in plant breeding programme keeping an eye to market value, feeding quality and seed quality. High protein content, vitamin content, good amino acid profile, palatability, texture, large and bold grains, good colour– all are qualitative characters.

(iii) **Disease resistance**: In contrast to chemical control of diseases and pests, genetic resistance conferred by resistant crop varieties is stable, safest and cheapest which is highly desirable. The disease resistance can be categorized like insect, fungus, bacteria and virus resistant.

(iv) **Adaptive ability**: The plant breeding programme aims at developing the resistance or tolerance property against adverse environmental situation such as drought, flood, cold, high salinity, etc. All these qualities are influenced and altered by genotype – environment interaction.

(v) **Agronomic properties**: Most of the agronomic properties are often desirable as those are associated with some other characters linked with higher yield, such as dwarfness of cereal crop is associated with lodging resistance; more number of tillers is associated with more yield.

(vi) **Change in maturity duration and synchronous maturity**: The duration for maturity of particular crop can be reduced which helps in multiple cropping and permits new crop rotation. Synchronous maturity is needed mainly in food crop for good harvesting.

(vii) **Physiological properties**: Development of insensitivity against photoperiod and temperature is very much desirable in case of crops like rice, wheat, etc., so that the same variety can be cultivated in different areas and in different seasons.

Dormancy is another criteria which is desirable in case of crop plants because if there is rain at the time of maturity, the seeds get germinated in field before harvesting. But in some other cases it is desirable to remove dormancy.

(viii) **Varieties for new seasons**: The crops cultivated in India can be broadly subdivided into two categories like Rabi and Kharif. But if the crop can be adjusted to grow in new season then the same crop may be cultivated throughout the year.

(ix) **Varieties for new areas**: Newer varieties are developed by plant breeders which are adapted to wider areas and newer agroclimates. Many of the temperate crops by continued selection can be adapted to tropical or sub-tropical conditions.

(x) **Some other desirable properties specific to crop**: In case of leguminous crop non-shattering is one of the desirable characters. Elimination of toxic substances from particular crop sometimes become essential such as khesari seeds have neurotoxin chemical, *Brassica* seeds contain undesirable erucic acid. Removal of these substances increase the nutritional value of crop.

QUESTIONS

1. Define plant breeding. Discuss its scope and objectives.
2. What do you mean by domestication? Discuss the origin of crop plants — rice, wheat, cotton, tea.
3. Write short notes on centre of origin of crop plants and domestication.

2 REPRODUCTIVE SYSTEMS IN CROP PLANTS

2.1	Mode of reproduction — Vegetative or Asexual, Apomixis, Sexual; Significance in generating and fixing genotypic variation
2.2	Breeding systems — Self pollinated crops, Cross pollinated crops, Occasional cross pollinated crops
2.3	Pollination control — Incompatibility and Male sterility — Types and use in plant breeding

In plant breeding programme it is necessary to know about the reproductive system in plant on which the goal of breeding methods and genetic constitution of a plant could be assumed.

2.1 MODE OF REPRODUCTION

The mode of reproduction in crop plants may be broadly grouped into three categories: **Vegetative**, **Apomictic** and **Sexual**.

A. Vegetative or Asexual

In this type of reproduction the vegetative parts of the plants act as propagule in place of seed. This mode is mostly found in all those plants where there is no seed set, long reproduction cycle and heterozygosity exists. The following organs can act as propagule:

1. **Modified stem**: Underground modified stems like rhizome (ginger, turmeric, banana), tuber (potato), bulb (onion, garlic), corn (colocasia, yam), stolon (strawberry), sucker (chrysanthemum, mentha) are used for propagation.
2. **Stem cutting**: In many of the fruit crops the artificially produced clones or stem cuttings are used as propagative material. In sugarcane the nodal portions of stems, in fruit crops like mango, litchi, lemon, grapes – the different methods like layering, grafting, budding are applied to get the stem clone.
3. **Normal or modified root**: Normal roots of woodapple, citrus and many such trees are used as units for propagation. Modified roots such as tuberous root (sweet potato), fasciculated root (dahlia, asparagus) are used as propagule.
4. **Bulbils**: In some plants the flower bud modified into globose bulb which are called bulbils can be used as multiplication unit.

Significance: Asexual or vegetative reproduction leads to perpetuation of the same genotype with great conservation. It is very much advantageous because large number of genetically identical individuals can be obtained irrespective of the degree of heterozygosity of the genotype. At any stage of breeding programme if a breeder gets any desirable clone it can be maintained through vegetative means.

Mutation breeding, i.e., the search for desirable mutants both through natural and artificially induced mutation is very much helpful in case of vegetatively reproducing plants as the sexual reproduction can be avoided.

The method of polyploid breeding is also useful as the induced bud can be used as propagule and polyploidy can be maintained without the intervention of meiotic segregational disturbances.

B. Apomixis

Apomixis is the phenomenon where there is no normal fertilisation of the egg cell, hence no normal development of embryo from the egg cell. However, embryo may develop from an unfertilised egg cell or from a cell other than the egg cell within the embryo sac or from the cell outside the embryo sac (Fig. 2.1). The plants produced by apomixis are called apomictic which are of two types: obligate, producing only apomictic embryos, and facultative, producing both apomictic and normal embryos. This phenomenon where the substitution of sexual process occurs by asexual methods is known as **apomixis** (*apo* = away from, *mixis* = act of mixing), the plants are called **apomictic**.

Types of Apomixis

Non-recurrent Apomixis (haploid seed/plant formation)

Here the seed/plant develops from the unfertilised egg cell or any other unfertilised haploid cell of embryo sac. In this type of apomixis the first event of normal sexual cycle, meiosis takes place, the embryo sac is formed normally, but due to various reasons the fertilisation does not take place. The reasons may be – (i) absence of pollen tube; (ii) inability of the tube to discharge its contents; (iii) no attraction between male and female nuclei; (iv) early degeneration of sperms; (v) maturation of egg and sperm is not synchronised.

(a) **Haploid parthenogenesis:** Here a haploid embryo develops from an unfertilised egg cell of the embryo sac, e.g., in *Orchis maculata, Platenthera chlorantha, Cephalanthera damasonium* – the pollen tube enters but fails to fertilize.

(b) **Haploid apogamy:** It is the development of haploid embryo from any haploid cell of the embryo sac other than the egg cell. In *Lilium martagon, Erythraea centaurium* – two proembryos are formed, one is from fertilized egg (zygotic cell) and another from the synergid cell (haploid cell).

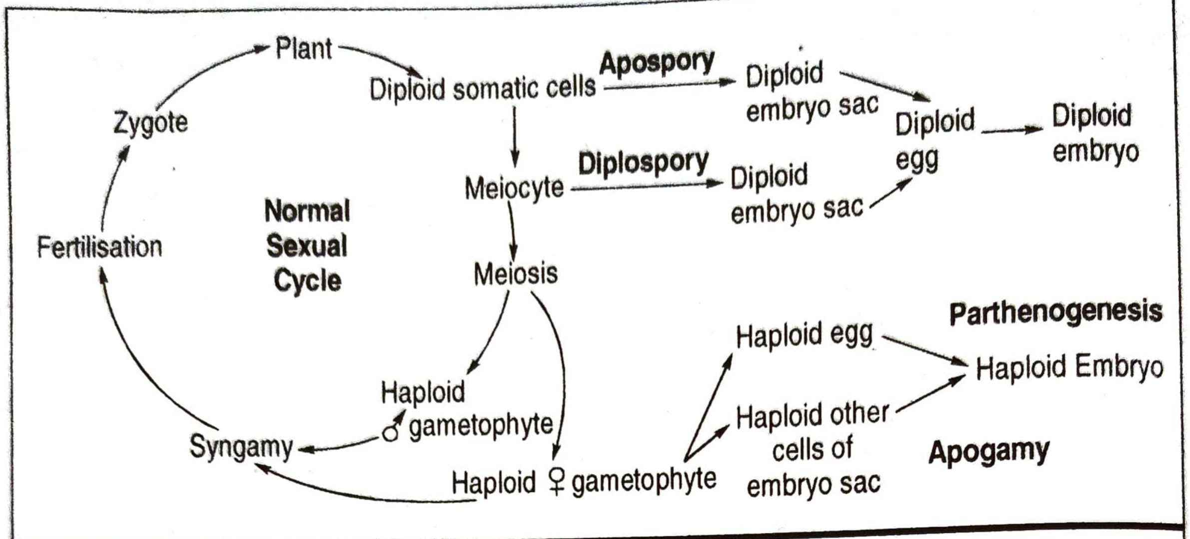

Fig. 2.1: Sexual and apomictic reproduction

Recurrent Apomixis

Here the meiotic event does not take place either in any somatic cell or the meiocyte cell fails to undergo meiosis, thereby produces the embryo sac with diploid cells only. These diploid cells directly give rise to diploid embryos, called **apospory** (Fig. 2.2).

(a) **Generative apospory**: The diploid egg cell develops into embryo without fertilisation, one particular variety of *Parthenium argentatum* exhibits.

(b) **Somatic apospory**: The diploid cell of nucellus or integument develops directly into diploid embryo sac and the diploid embryo is developed from the diploid unfertilised egg cell. This phenomenon is found in *Allium, Meliss, Crepis* etc.

Agamospermy

This term is used to categorise the plants which has the seed habit for propagation but not through normal sexual cycle, either meiosis or syngamy or both are eliminated. This includes either the embryos which may develop from cell of the unreduced female gametophyte or directly from the diploid sporophytic cell of the ovule, such as nucellus or integuments. Diplospory, apospory and adventive embryony, all are included within this category.

Adventive Embryony

In this case the gametophytic generation is completely eliminated. It is very much close to vegetative propagation, but the plants here retained the seed habit, i.e., the diploid embryo is developed from any diploid cell outside the embryo sac but matures into embryo within the embryo sac, zygotic embryo degenerates or competes with apomictic embryo. This kind of embryos are found in *Citrus*, mango, etc.

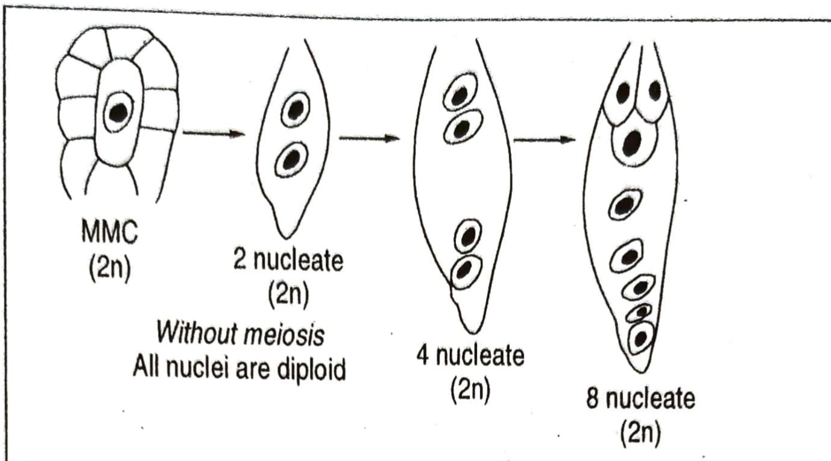

Fig. 2.2a: Aposporous embryo sac in *Eupatorium*

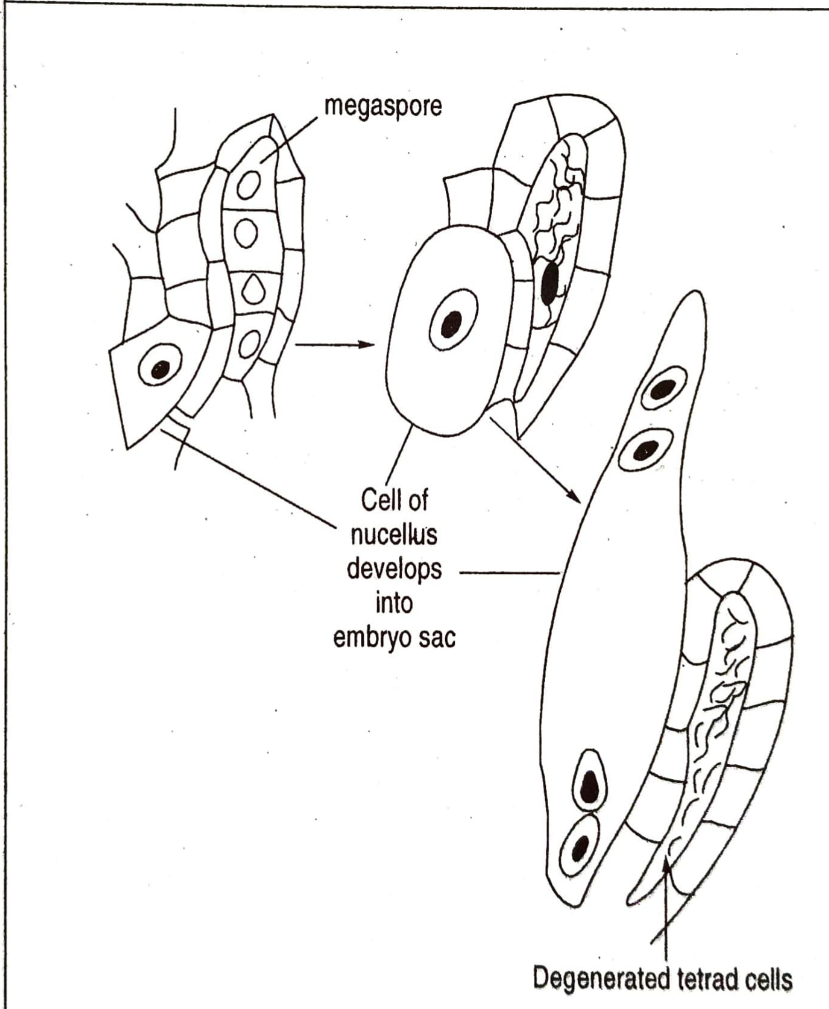

Fig. 2.2b: Aposporous embryo sac in *Hieracium*

Diplospory

Here the MMC differentiates into sexual ovules, but it does not enter into meiosis, it produces the embryo sac directly by mitotic division, all the cells within the embryo sac are diploid, and the embryos are formed.

C. Sexual

This process of reproduction involves the fusion of male and female gametes and formation of seed, so it is called the process of **amphimixis**. Depending on the nature of pollination the plants can be categorised as self pollinated and cross pollinated. Sexually reproducing crop plants produce a special structure, called flower which bears the essential whorls like androecium and gynoecium. Androecium consists of stamen and gynoecium consists of carpel. The male and female gametes are produced in microspores and megaspores respectively.

Sporogenesis: Production of microspores and megaspores is known as sporogenesis. In anther lobes there are pollen sacs which contain numerous PMC (Pollen mother cell) undergoing meiosis, produces microspores or pollen, the process is called **microsporogenesis**. Inside the ovary the ovules are present in which the MMC (Megaspore mother cell) undergoes meiosis and produces 4 megaspores out of which 3 degenerate and one survives, this process is called **megasporogenesis**.

Gametogenesis: During maturation of pollen, the microspore nucleus divides mitotically to produce generative and vegetative nucleus. The generative nucleus then divides to form male gametes or sperms. The pollen along with pollen tube and sperms is called microgametophyte and the production of sperms is known as **microgametogenesis**.

The nucleus of functional megaspore divides mitotically three consecutive times to produce eight nuclei, which get arranged in the embryo sac. The embryo sac contains generally one egg cell, two synergids, two central nuclei and three antipodals. All these cells are haploid and this process is called as **megagametogenesis**.

Fertilisation: Fusion of one of the two sperms with the egg cell, to produce a diploid zygote, is known as **fertilisation,** and the fusion of the remaining sperm with the secondary nucleus leading to the formation of primary endosperm nucleus known as **double fertilisation** or triple fusion. The zygote divides mitotically to produce diploid embryo. The primary endosperm nucleus produces endosperm by mitotic division, it may be absorbed completely in legumes or may form endospermous seed in cereals.

1.8. SOME IMPORTANT ACHIEVEMENTS

The present-day crop plants are very different from the wild species, mostly weeds, from which they originated. This change has been brought about by man through plant breeding. The extent of this change is often so great that it is difficult to realise that the cultivated plants did come from the weedy wild species. This can be appreciated by comparing the cobs of a local variety of maize (*S. mays*) with those of 'Ganga 101', an improved maize variety. Clearly, the present-day crop plants were virtually reconstructed by man from weedy wild plants.

1.8.1. Semidwarf Wheat and Rice

One of the most important developments of modern agriculture has been the production of semidwarf cereal varieties, particularly of wheat and rice. The semidwarf wheat varieties were developed by N.E. Borlaug and his associates at CIMMYT (International Centre for Wheat and Maize Improvement), Mexico. They used a Japanese variety Norin 10 as the source of dwarfing genes. In 1963, ICAR introduced several semidwarf selections from CIMMYT. Kalyan Sona and Sonalika were selected from these materials. For more than one decade, these varieties were the most popular wheat varieties in India. A great majority of the wheat varieties now grown in the country are semidwarf. These semidwarf wheat varieties are lodging resistant, fertilizer responsive and high yielding. They are generally resistant to rusts and other major diseases of wheat due to the incorporation of resistance genes into their genotypes. This has greatly increased and stabilised wheat production in the country. These varieties are photoinsensitive and many of them are suitable for late planting. This has enabled cultivation of wheat in nontraditional areas like West Bengal.

Studies based on isogenic lines at CIMMYT, Mexico have revealed that wheat dwarfing genes *Rht1*, *Rht2* or *Rht1* + *Rht2* lead to an yield increase by at least 15% over the tall isogenic lines. Semidwarf wheat varieties also show a marked increase in harvest index (HI) as compared to that of tall varieties, but this is regarded as a side effect of *Rht* genes rather than their main effect. In contrast to *Rht1* and *Rht2*, *Rht3* and *Rht8* do not significantly increase yield, but they may provide a good degree of lodging tolerance. The semidwarf wheats are also photoperiod insensitive due to genes *Ppd1* and *Ppd2*. The best combinations of *Rht* and *Ppd* genes appear to be as follows : *Rht1* + *Ppd1* or *Ppd2*, and *Rht2* + *Ppd1* or *Ppd2*. When both *Ppd1* and *Ppd2* are present together in a wheat line, the yield of such a line is generally low.

Similarly, the development of semidwarf rice varieties has revolutionised rice cultivation. These varieties were derived from Dee-geo-woo-gen, a dwarf, early-maturing variety of *japonica* rice from Taiwan. Taichung Native 1 (TN1), developed in Taiwan, and IR8, developed at IRRI (International Rice Research Institute), Philippines, were introduced in India in 1966. They were extensively grown for few years, but were later replaced by superior semidwarf varieties developed in India, *e.g.*, Jaya, Ratna, etc. The semidwarf rice varieties are lodging resistant, fertilizer responsive, high yielding and photoinsensitive. Photoinsensitivity has allowed rice cultivation in nontraditional areas like Punjab. Even in traditional areas, rice—wheat rotation has become possible only due to these varieties.

1.8.2. Noblisation of Indian Canes

Another noteworthy achievement is noblisation of sugarcane. The Indian canes were of *Saccharum barberi* origin and were largely grown in North India. They were hardy, but poor in yield and sugar content. The tropical noble canes of *Saccharum officinarum* origin had thicker stem and higher sugar content. But they performed badly in North India primarily due to low winter temperatures in this region. C.A. Barber, T.S. Venkataraman and others at the Sugarcane Breeding Institute, Coimbatore, transferred the thicker stem, higher sugar content and other desirable characters from the noble canes to the Indian canes. This is commonly referred to as ***noblisation of Indian canes***. They also crossed *Saccharum spontaneum* (vern., kans), a wild species, to transfer disease resistance and other desirable characteristics to the cultivated varieties. Several high yielding varieties with high sugar content and well adapted to local climate have resulted from this breeding programme. At present, sugarcane breeding all over the world is based on the noblisation technique.

1.8.3. Hybrid Millets

The development of hybrid varieties of maize, jowar and bajra deserves a special mention. A programme to develop hybrid maize began in India over four decades ago in collaboration with Rockefeller and Ford Foundations. Several hybrid varieties have been released since then. The Ganga series of hybrids, *e.g.*, Ganga Safed 2, and Deccan, are a few examples. Similarly, Several hybrids have been released in jowar, *e.g.*, CSH 1, CSH 2, CSH

3, CSH 4, CSH 5, CSH 6, CSH 9, CSH 10, CSH 11 etc., and in bajra, *e.g.*, PHB10, PHB14, BJ104 and BK560. For certain reasons, hybrid maize varieties could not become popular with the farmers. But in some states like Karnataka, hybrid varieties occupy large areas. More recently, composite varieties are being developed to overcome the difficulties encountered with the hybrid varieties. For example, Manjari, Vikram, Sona, Vijay and Kisan are some of the notable maize composite varieties. Some recently released composites are CO1, NLD, Renuka, Kanchan, and Diara. The composite varieties often yield as much as the hybrid varieties and do not have the drawbacks of the latter. More notably, the farmers need not replace the seed every year in the case of composite varieties.

1.8.4. Hybrid Cotton

India has achieved the distinction of commercially exploiting heterosis in cotton. The first hybrid variety of cotton was H4 (a hybrid from two *G. hirsutum* strains); it was developed by the Gujarat Agriculture University (Surat Station) and released for commercial cultivation in 1970. Since then, several other hybrid varieties, *e.g.*, Jk Hy 1, Godavary, Sugana, H6 and AKH468 (all within *G. hirsutum*), Varalaxmi, CBS156, Savitri, Jayalaxmi and H2HC (all *G. hirsutum* × *G. barbadense*), have been released for cultivation. The hybrid varieties are high yielding, and have high ginning outturn and good fiber quality. They are becoming increasingly popular with the farmers; according to an estimate, they occupy about 70% of the total area under irrigated cotton (this came to about 1.5 million hectares in 1985-86). It is noteworthy that the farmers are more than willing to pay the high cost of the hybrid seed (around Rs. 50.00 per kg), which is produced by hand emasculation and hand pollination. Efforts to utilize cytoplasmic male sterility (CMS) for hybrid seed production have been successful and a hybrid based on CMS has been released. Hand pollination is essential for seed set on the CMS line. The cost of seed production is expected to be reduced to 10% of that incurred by hand emasculation and pollination technique. Recently, two hybrid varieties of desi cotton, *viz.*, G-cot. Dh-7 and G-cot. Dh-9, have been released.

These are only a few examples of the achievements of plant breeding in India. If we consider the achievements in other countries as well, the examples will be far too many to be listed. (1) The improved varieties generally yield 50-80 per cent more than the existing local varieties; often the yields are much higher. Further, (2) due to resistance to diseases the improved varieties save the cost of plant protection; they also stabilise crop yields. In addition, (3) they offer numerous other advantages (consider the points listed under *objectives of plant breeding*). Thus plant breeding is of immense economic importance to a nation, especially to that with an agriculture-based economy, like India. This fact is well appreciated by the government of India. This is evident from the elaborate All India Coordinated Crop Improvement Projects for most of the important crops.

1.9. UNDESIRABLE CONSEQUENCES

Crop improvement leads to many desirable changes in crop species, which make these crops more useful to man. However, it also generates some undesirable effects, which include (1) genetic erosion, (2) narrow genetic base and (3) increased susceptibility to previously minor diseases.

1.9.1. Genetic Erosion

In general, improvement in the yield of a crop species is accompanied with a reduction in variability among the cultivated varieties of that species. This reduction is produced by the following two potent factors: (1) replacement of heterogeneous local varieties by few dominant, more homogeneous improved varieties, and (2) use of similar/related varieties as parents in breeding programmes. The improved varieties are commonly purelines (self-pollinated species) or hybrids (cross-pollinated species), which are much more homogeneous than the unimproved local and open-pollinated varieties. A few improved varieties become predominant and rapidly replace the local varieties leading to a rapid depletion of genetic variability (***genetic erosion***). This, in turn, limits the prospects of further improvement in the species since variability is the prerequisite for any modification in the characteristics of a crop species. Is it not ironical that successful crop improvement has depleted the very basic resource that is so essential for its continued success. *Germplasm collections aim at minimising the detrimental effects of genetic erosion by collecting and preserving the variability in crops and their related species.*

1.9.2. Narrow Genetic Base

Many of the improved varieties have one or more parents (immediate or somewhat removed in the ancestry) in common with each other. For example, many semidwarf varieties of rice have IR8 or TN1 as one of their parents; IR8 and TN1 are related to each other by the common parent Dee-geo-woo-gen, the source of their semidwarfing gene. Similarly, almost all the semidwarf wheat varieties have *Rht1, Rht2* or both these genes for reduced height; these genes have been derived from a single wheat variety, Norin 10. Thus the improved varieties of a crop species are becoming increasingly similar to each other due to the commonness of one or more parents in their ancestry. This has led to the narrowing down of the genetic base of these varieties. ***Genetic base*** refers to the genetic variability present among the cultivated varieties of a crop species. The narrow genetic base has created ***genetic vulnerability***, which refers to the susceptibility of most of the cultivated varieties of a crop species to a disease, insect pest or some other stress due to a similarity in their genotypes.

An example of genetic vulnerability is the outbreak in epidemic proportions of *Helminthosporium* (now, *Drechslera maydis*) leaf blight of maize in the 1970s in U.S.A. This occurred due to the extreme susceptibility of most of the commercial hybrids to a new race, T-race, of the leaf blight pathogen, *D. maydis*; this susceptibility was produced by the Texas male sterility cytoplasm (CMS-T) present in these hybrids. In 1970, about 75-80% of maize acreage in U.S.A. was occupied by hybrids based on Cms-T. A similar case in India is the susceptibility of early bajra hybrids to downy mildew and ergot; again this susceptibility was contributed by the male sterile parent of these hybrids, Tift 23A or its dwarf derivative, Tift $23D_2A$. But in this case, the susceptibility was due to some nuclear genes and not due to the male sterile cytoplasm itself. *Genetic vulnerability can be avoided by using diverse and unrelated parents in breeding programmes, and by using unrelated sources of male sterility, semidwarfness, etc.* Breeders are becoming increasingly aware of this problem and they are making conscious efforts to broaden the genetic base of cultivated varieties of various crop species.

1.9.3. Increased Susceptibility to Minor Diseases

Another problem has been generated by the lopsided emphasis on breeding for resistance to major diseases and insect pests only. This has often resulted in an increased susceptibility to thus far minor diseases. As a result, these diseases have gained in importance and, in some cases, produced severe epidemics. A case in point is the epidemic caused by *Botrytis cinerea* (grey mold) in chickpea during 1980-81 and 1981-82 crop seasons in Punjab, Haryana and parts of U.P. and Bihar. Another example is the severe infection by Karnal bunt (*Tilletia* sp.) on some wheat varieties, *e.g.*, WL711. This problem is difficult to overcome since resource constraints may never permit a breeder to screen his material against all the diseases and pests of a crop species. We may probably have to, so to say, learn to live with this problem and tackle it as and when it arises.

Sooner or later, the variability for yield in a crop species is exhausted and no further yield increases are obtained through breeding, *i.e.*, the yield reaches a plateau. Such plateaus were evident in wheat and rice yields before the exploitation of semidwarfing genes, and are being experienced once again. In such cases, new variability has to be introduced in the breeding programmes in order to break the plateau. There is an increasing evidence that wild relatives of cultivated species may provide 'yield genes' for breaking the yield plateaus. In some cases, a novel breeding approach may be useful in raising crop yields beyond the plateau, *e.g.*, hybrid rice.

1.10. FUTURE PROSPECTS

The past achievements of plant breeding fully illustrate its future possibilities. Modifications in the genetic make-up of crops, therefore, may be expected to be quite rewarding in the future as well. As the variability present in the cultivated species would be exhausted, a greater emphasis will be placed on the utilization of genes from related species. Genetic engineering is gaining importance, and we already have genetically engineered varieties in commercial cultivation. 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*.

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PLANT BREEDING

Principles and Methods

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