CHAPTER 2

DOMESTICATION AND GERMPLASM CONSERVATION

2.1. DOMESTICATION

***Domestication** is the process of bringing wild species under human management.* The present-day cultivated plants have been derived from wild weedy species. Therefore, the first step in the development of cultivated plants was their domestication, which began ~10,000 years ago when man began agriculture. The first domesticated plants were cereals, legumes and other species used for their fruits or roots. Most of the crops were domesticated by the prehistoric man. Knowingly or unknowingly he must have selected for the characteristics that made the plants more suited to his needs. It is reasonable to assume that characters like seed shattering and dormancy were rapidly eliminated. Under domestication, the crop species have changed considerably as compared to the wild species from which they originated. The changes, brought about by selection by man as well as nature, are often so great that the crops are classified as distinct species. As a result, in many cases, the parental wild species of the cultivated plants are not definitely known. The domesticated species were selected for characteristics entirely different from those for which the wild species were selected in nature. Therefore, the two groups of plants developed in two different, often opposite, directions.

Domestication of wild species is still being done and is likely to continue for a long t in the future. This is because the human needs are likely to change with time. Consequent the wild species of little importance today may assume great significance tomorrow. This particularly true for microorganisms producing antibiotics, involved in nitrogen fixation, a producing other compounds of industrial or medical interest; forest trees producing timb and other commercial products; medicinal plants; and plants fulfilling specific needs. notable case of recent domestication is that of several members of Euphorbiaceae produc latex. The latex of these plants may be commercially used for the extraction of petrole products, including petrol and diesel. A large scale cultivation of these plants is being done USA and Japan. The Department of Science and Technology, Government of India, h initiated a project for cultivation of jojoba (*Simmondsia* sp.) in the arid zones of Rajasth Gujarat, Maharashtra and Uttar Pradesh. Seeds of jojoba contain oil, which is comparable sperm whale oil and is highly suitable as an industrial lubricant. The plants producing late are gopher plant (*Hevea* sp.), milkweed (*Euphorbia lathyrus*), etc. They are hardy dese plants and their latex compares favourably with petroleum crude, and is being used for th extraction of petroleum products. As a result, fields of these plants are often called ***living o fields***. Kala jeera (*Bunium persicum*), a perennial spice, was domesticated during 1990s i Himachal Pradesh; it is being cultivated as an orchard crop.

2.1.1. Selection under Domestication

When different genotypes present in a population reproduce at different rates, it is called ***selection***. A ***population*** may be simply defined as the group of individuals, which mate or ca mate freely with each other. Thus a population consists of individuals of a single species growing in the same locality. Selection is grouped into two types, (1) natural and (2) artificial on the basis of the agency responsible for it.

2.1.1.1. Natural Selection. The selection that occurs due to natural forces like climate, soil, biological factors (*e.g.*, diseases, insect pests, etc.) and other factors of the environment is called ***natural selection***. It occurs in natural populations, *i.e.*, wild forms and wild species, and determines the course of their evolution. Generally, all the genotypes of the population reproduce, plants become more adapted to the prevailing environment and the population retains considerable genetic variability.

In 1962, Nichlson proposed that natural selection may be seen to operate through two mechanisms, *viz.*, (1) environmental selection and (2) competition. ***Environmental selection*** acts against all such genotypes that are unable to cope with the environmental stresses. As a result, the population consists, ultimately, of only those genotypes that are capable of surviving the prevalent environmental stresses and are also able to reproduce. ***Natural selection through competition*** occurs in crop populations where a plant takes up more water, nutrients or light than another at the expense of the other. Therefore, the more successful is a plant in exploiting resources, the greater will be its potential to be represented in the succeeding generations and it will be selected through competition.

2.1.1.2. Artificial Selection. In contrast, ***artificial selection*** is carried out by man. This type of selection is confined to domesticated species. It allows only the selected plants to reproduce, ordinarily makes plants more useful to man and generally leads to a marked

decline in genetic variability in the selected progenies/populations. Usually plants become less adapted to the natural environment, and they have to be grown under carefully managed conditions. *Our present-day crops are the products of continued artificial selection.*

2.1.2. Types of Selection

Selection is grouped into the following three types depending mainly on the type of phenotypic class favoured by it : (1) directional selection, (2) stabilizing selection and (3) disruptive selection. In plant breeding situations, selection is almost always directional aiming to achieve the maximal expression of targeted characters. In nature, however, selection would be either directional, stabilizing or disruptive depending on the state of evolution of the population. While a population is adapting to new environmental conditions (either in a new area where it has been introduced, or in the same region in which the environment has undergone a change), there will be directional selection to increase the fitness of the species. Once the population has become adapted, directional selection will be succeeded by stabilizing and disruptive selections.

2.1.2.1. Directional Selection. When individuals having the extreme phenotype for a trait or a group of traits are selected for, it is called ***directional selection.*** Directional selection usually selects for such gene combinations that produce a fully balanced phenotype; such a phenotype results in the maximum yield under artificial selection, and in the maximum fitness under the natural selection. Once such gene combinations are established, these co-adapted gene complexes are protected from further changes by genetic linkage, and sometimes also by a change in the mode of reproduction, *e.g.,* from cross-pollination to self-pollination. In case of cross-pollinated species, directional selection achieves the correct 'heterozygous balance', while in self-pollinators it establishes the correct 'homozygous balance.'

In cross-pollinated populations, directional selection will favour alleles showing dominance in the appropriate direction, and genes showing 'desirable' epistatic interactions will also be selected for. As a result, characters subjected to prolonged directional selection will show high directional dominance and/or epistasis.

2.1.2.2. Stabilizing Selection. When selection favours the intermediate phenotype and acts against the extreme phenotypes, it is termed as ***stabilizing selection.*** In nature, it follows directional selection, and strives to maintain the co-adapted gene complexes generated by the latter. It may be pointed out that for such characters that directly affect fitness, *e.g.*, viability and fertility, selection will always be directional. Therefore, stabilizing selection occurs only for those traits that do not affect fitness directly. The stabilizing selection favours those genotypes whose phenotypic expression clusters around the population mean. In such characters, therefore, the 'maximal' expression is not the 'optimal' expression, *e.g.*, flowering time in many crop species.

Stabilizing selection disfavours dominance; if dominance is present, it is bidirectional (some alleles show dominance in one direction, while some other show dominance in the opposite direction). Similarly, epistasis is also selected against. Thus stabilizing selection accumulates alleles showing additive gene action.

2.1.2.3. Disruptive Selection. This type of selection succeeds directional selection in such natural populations that are subjected to distinct ecological niches that may be spatial,

temporal (seasonal or long-term cycles) or functional (*e.g.*, males and females of species) i nature. In each 'ecological niche' a different 'phenotypic optima' is selected for so that t population ultimately consists of two or more recognizable forms; such a selection is calle ***disruptive selection***. The consequences of such a selection depend mainly on the followi two factors : (1) whether the different optimal phenotypes are independent of or depende on, each other for their maintenance or function, and (2) the rate of gene flow between the For example, the male and female forms of a single species are completely interdependent f function, *i.e.*, reproduction, and show 100% gene exchange. At the other extreme, a specie may occupy a habitat that is fragmented into two or more independent niches. In each niche different phenotypic optima is selected for. In such cases, if the selection pressure is hig enough and continued long enough, genetic barriers to crossing may arise leading to th genetic separation of these forms, and eventually to their evolution as distinct species.

Disruptive selection maintains polymorphism in a population. Further, it shows such features as frequency-dependence (*e.g.*, less frequent alleles being more favoured), density-dependence, cyclical nature, etc.; a discussion of these aspects is beyond the scope of this book. *Since disruptive selection is 'directional' in nature within each 'ecological niche' of the habitat, it favours dominance and epistasis. In addition, it often leads to the establishment of integrated 'supergenes', e.g., in case of male and female forms of a species. A* ***'supergene'*** is a set of closely linked genes that together lead to the development of a specific optimal phenotype, *e.g.*, a male or female form.

2.1.3. Changes in Plant Species under Domestication

The precise sequence of events during the evolution of crop plants under domestication is not known. Presumably in the initial stages, considerable genetic variability existed in each domesticated species. This variability was acted upon by both natural and artificial selections. It may be expected that man always tried to pick out the plant types, which better suited his needs. He would obviously have selected for larger fruits and seeds. Our record of planned and systematic selection goes only as far back as middle of the nineteenth century. Before this period, selection efforts were obviously unfocussed and primitive. But judging from the results, *i.e.*, the differentiation of crops from their wild prototypes, the then completely unscientific man was not a bad plant breeder at all. The domesticated species have undergone several important changes as a consequence of his efforts.

Domestication of crops is believed to have occurred independently in the following at least six regions : (*i*) Mesoamerica, (*ii*) the Southern Andes (including the eastern piedmonts), (*iii*) the Near East, (*iv*) Africa (probably the Sahel and the Ethiopian highlands), (*v*) South East Asia, and (*vi*) China. In spite of the geographical diversity of these centres, a remarkably similar set of traits seems to have been selected in widely different crops; these traits are called ***domestication syndrome traits*** (Table 2.1). The changes in crop traits under domestication have resulted from selection of spontaneous mutations. Almost all the characteristics of plant species have been affected under domestication. The characters that show more distinct changes are those that have been objects of selection and are still plant breeding objectives in many cultivated species. Some of the important changes that have occurred under domestication are briefly listed below.

TABLE 2.1
The different traits comprising domestication syndrome

Selection at growth stage	Selected trait		
	General feature	Specific trait	Example crop(s)
Seedling	Increased seedling vigour	Loss of seed dormancy	Many crops, *e.g.*, mungbean
Reproductive system	Increased rate of selfing	—	Tomato, sunflower, *B. juncea*
	Adoption of vegetative reproduction	—	Sugarcane, cassava, etc.
Harvest or after harvest	Increase in seed yield	Loss of seed dispersal	Legumes
		More compact growth habit	Legumes
		Increased number or size of inflorescence	Maize, wheat
		Increased number of grains/inflorescence	Maize
		Changed photoperiod sensitivity	Legumes, rice
		Colour, size, taste, texture	Many crops
		Reduction in toxic substances	Cassava, lima bean, cucurbits

1. ***Elimination of or reduction in shattering*** of pods, spikes, etc. has taken place in most of the cultivated species.
2. ***Elimination of dormancy*** has taken place in several crop species. Lack of dormancy has become a problem in crops like barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), mung (*Vigna radiata*), etc.
3. ***Decrease in toxins*** or other undesirable substances has occurred in many crops. The bitter principle of cucurbitaceous plants provides an example of this type.
4. ***Plant type*** has been extensively modified. The cultivated plants show altered tillering, branching, leaf characters, etc.
5. In several crop species, there has been a ***decrease in plant height,*** *e.g.*, cereals, millets, etc. This is often associated with a change from indeterminate to determinate habit.
6. In some species, on the other hand, there has been an ***increase in plant height*** under domestication, *e.g.*, jute (*Corchorus* sp.), sugarcane (*Saccharum officinarum*), forage grasses, etc.
7. ***Life cycle has become shorter*** in case of some crop species. This is particularly so in case of crops like cotton (*Gossypium* sp.), arhar (*Cajanus cajan*), etc.
8. Most of the crop plants show an ***increase in size of their grains or fruits.***

9. ***Increase in economic yield*** is the most noticeable as well as desirable change und domestication. This is self-evident in every crop species.
10. In many crop species, ***asexual reproduction has been promoted*** under domesticatio *e.g.*, sugarcane, potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), etc.
11. There has been a ***preference for polyploidy*** under domestication. Many of th domesticated plant species are polyploids, *e.g.*, potato, wheat, sweet potato, tobacc (*Nicotiana* sp.), etc., while diploid counterparts are present in nature.
12. In many species, there has been a ***shift in the sex form*** of the species. In man dioecious fruit trees, bisexual forms have developed under domestication. Self incompatibility has also been eliminated in many crop species.
13. ***Variability within a variety has drastically decreased*** under domestication. Th extreme case is represented by pureline varieties, which are completely homozygou and homogeneous genotypically.

2.2. PATTERNS OF EVOLUTION IN CROP PLANTS

It is apparent that selection by nature and man has been responsible for the evolution of cro plants. However, selection is effective in altering a species only when genetic variabilit exists in the populations of that species. There are three major ways in which genetic variability has arisen in various crop species, *viz.*, (1) Mendelian variation (generated mainly by gene mutation), (2) interspecific hybridization, and (3) polyploidy. The patterns o evolution of various crops may, therefore, be broadly classified according to the mode o origin of genetic variation crucial for evolution of that species.

2.2.1. Mendelian Variation

Many crops have evolved through variation generated by gene mutation, and by hybridization between different genotypes within the same species, followed by recombination. Ultimately, all the variability in any species originates from gene mutations. Most of the gene mutations are harmful and are eventually eliminated. But some mutations are beneficial and are retained in the population. The mutations may be grouped into two categories: (1) macromutation and (2) micromutation. *A **macromutation** produces a large and distinct morphological effect, and often affects several characters of the plant.* A single macromutation is believed to have led to the differentiation of modern maize (*Zea mays*) plant from the grassy pod corn. This mutation has affected the positions of male and female inflorescences, the habit of the plant and several other characters. Similarly, cabbage (*Brassica oleracea*), cauliflower (*B. oleracea*), broccoli (*B. oleracea*), and Brussel's sprouts (*B. oleracea*) have originated from a common wild species and they differ from each other with respect to a few major genes.

The greater part of variation, however, has resulted from *mutations with small and less drastic effects, i.e., **micromutations**.* Since micromutations have only small effects, they tend to be accumulated in a population. Natural selection would accumulate and select for more favourable gene combinations. Man would have selected from the populations desirable plant

types leading to the differentiation of domesticated species from the wild ones. Several important crops have evolved through Mendelian variation, *e.g.*, barley, rice beans (*Phaseolus* sp.), peas (*Pisum sativum*), tomatoes (*Lycopersicon esculentum*), linseed (*Linum usitatissimum*), jowar (*Sorghum bicolor*), bajra (*Pennisetum americanum*) and many other crops.

2.2.2. Interspecific Hybridization

***Interspecific hybridization** refers to crossing of two different species of plants.* The resulting F_1 is generally more vigorous than the parents. But segregation in F_2 and later generations produces a vast range of genotypes. This is because the parental species are likely to differ from each other for a large number of genes. Most of the recombinants in the segregating generations are likely to be weak and undesirable. Often interspecific hybrids are highly sterile and do not set seeds. There is little evidence to suggest that interspecific hybridization contributed to any great extent in the evolution of crop species.

But in some cases, the interspecific hybrids may have repeatedly backcrossed to one of the parental species. As a result, most of the genotype of that parental species, to which the hybrid had repeatedly backcrossed, would be recovered along with few or several genes from the other parental species. This process is known as ***introgressive hybridization;** it leads to the transfer of some genes from one species into another.* The modern maize is postulated to have developed through introgressive hybridization between the primitive maize and a wild grass, *Tripsacum*. It is supposed that some genes from *Tripsacum* were transferred to the primitive maize, which resulted in the origin of the modern maize.

Interspecific hybridization has led to the development of several strawberry varieties. The F_1 from a cross between two species of strawberries, *Fragaria virginiana* and *Fragaria chiloensis*, was backcrossed to the two parental species to produce many varieties of commercial value. In certain fruit trees, such as, pears, plums, cherries and grapes, and ornamentals, *e.g.*, irises (*Iris* sp.), roses (*Rosa* sp.), lilies (*Lillium* sp.), etc., vegetative propagation is commonly used. In such species, many varieties are interspecific hybrids (F_1).

2.2.3. Polyploidy

Generally, autopolyploidy leads to increased vigour, larger flowers and fruits, etc. over the diploid forms. Many varieties of ornamental plants are autopolyploids. The commercial banana (*Musa paradisiaca*) is an autotriploid ($3x$); it has larger and seedless fruits in comparison to the diploid banana. Triploid varieties are known in apples (*Pyrus malus*), watermelons (*Citrullus vulgaris*), sugarbeets (*Beta vulgaris*) and some other crops. The commonly grown potato (*S. tuberosum*) may be regarded as an autotetraploid, although interspecific hybridization may also be involved. *S. tuberosum* has $3x$, $2x$ and $4x$ types. Some of the $2x$ progeny obtained from the $4x$ potato are fully fertile and as vigorous as the $4x$ types, indicating that it is largely an autotetraploid. Other autopolyploid crop species are sweet potato ($6x$), oat (*Avena abyssinica*, $4x$) and alfalfa (*Medicago sativa*, $4x$). Thus autopolyploidy has played a limited role in crop evolution.

Allopolyploidy, in contrast, has been considerably more important in crop evolution. Allopolyploidy results from chromosome doubling of interspecific F_1 hybrids. About 50 per

cent of the crop plants are allopolyploids. Some of the important allopolyploid crop plants are wheat, tobacco, cotton, sugarcane, oats (*Avena* sp.), rai (*Brassica juncea*), rapeseed (*Brassica napus*), etc. Origins of wheat, tobacco, cotton, and oats have been extensively investigated. Common bread wheat (*Triticum aestivum*) is an allohexaploid, while cotton (*Gossypium hirsutum* and *G. barbadense*) and tobacco (*Nicotiana tabacum* and *N. rustica*) are allotetraploids. There is evidence to suggest that *N. tabacum* originated from chromosome doubling of the F_1 hybrid from *N. sylvestris* × *N. tomentosa*. *Triticale hexaploide* is a man made allopolyploid developed by chromosome doubling of the F_1 between rye (*Secale cereale*) and tetraploid wheats. Triticale has shown much promise particularly in areas of moisture or temperature stress.

2.3. GERMPLASM

The genes required for crop improvement are present in different lines, varieties, strains or populations of the crop species and their relatives. Some useful genes, often critical genes, are contributed by the wild relatives of crops. The various lines, strains, populations of a crop species and its related wild species constitute the germplasm of the crop. Thus the ***germplasm*** *of a crop 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.* Therefore, germplasm consists of the following five types of materials: (1) land races, (2) obsolete varieties, (3) varieties in cultivation, (4) breeding lines, and (5) wild forms and wild relatives.

2.3.1. Land Races

These are primitive varieties, which had evolved over centuries or even millenia through both natural and artificial selection, but without a systematic and sustained plant breeding effort. They are storehouses of genetic variability and, ordinarily, are adapted to the local soil type, climatic conditions, etc. They are sources of many valuable genes, including those for adaptation. Genetic variation is present both within and between varieties. They are adapted to survive under unfavourable conditions and have low but stable yields.

2.3.2. Obsolete Varieties

These varieties were developed by systematic breeding effort, were once commercially cultivated, but are no more grown. They, however, do have some desirable features. For example, wheat varieties K65, K68, Ph591, many NP series varieties, etc. are obsolete varieties.

2.3.3. Varieties in Cultivation

The varieties in cultivation are the easiest to use in breeding programmes. They form a major part of a working collection (Section 2.11.2.2). They are good sources of genes for yield, quality, etc. They can be introduced in a new area, and directly released for cultivation. These have been evolved through planned plant breeding, are ordinarily highly homogeneous and highly genetically variable.

2.3.4. Breeding Lines

These are lines/populations developed in breeding programmes. They often contain valuable gene combinations. This group includes nearly homozygous lines, mutant lines, lines derived from biotechnology programmes and, now, transgenic lines. These lines usually have narrow genetic base. These lines are ordinarily maintained as working collections by breeders.

2.3.5. Special Genetic Stocks

The germplasm in this category includes those carrying gene mutations, chromosomal aberrations and markers genes, etc. These stocks are useful in genetic analyses and may find use in breeding programmes as well. An example of such a material will be the set of monosomic lines or trisomic lines. These lines may have been obtained spontaneously or, often, induced artificially.

2.3.6. Wild Forms and Wild Relatives

Wild forms are the wild species from which crop species were directly derived. They are easy to cross with the concerned crop species. The ***wild relatives*** include all other species, which are related to the crop species by descent during their evolution. Wild relatives are much more difficult to hybridize with crops than are the wild forms. Both these groups are sources of valuable genes for insect and disease resistance, tolerance to abiotic stresses like drought, cold, salinity, etc., and even for quality traits and yield.

Germplasm is also termed as genetic resource. Genetic resources can be broadly grouped into two types (1) cultivated germplasm and (2) wild germplasm, depending on the state of their domestication. Alternatively, they may be termed as (i) indigenous (from the country in question) or exotic (from another country) based on their place of origin.

2.4. GENE POOL CONCEPT

The concept of gene pools was proposed by Harlan and De Wet in 1971. ***Gene pool*** consists of all the genes and their alleles present in all such individuals, which hybridize or can hybridize with each other. In some sense, gene pool describes a concept similar to germplasm. The gene pool is classified into three groups: (1) primary (GP_1), (2) secondary (GP_2) and (3) tertiary (GP_3) gene pools.

2.4.1. Primary Gene Pool (GP_1)

It includes all the strains of the concerned crop species. Crossing between members of GP1 is easy; the resulting hybrids are vigorous, show normal meiotic chromosome pairing and recombination, there is normal gene segregation, and seed fertility is complete. The members of primary gene pool are the most commonly used in breeding programmes; most groups base their breeding programmes primarily or entirely on this material.

2.4.2. Secondary Gene Pool (GP_2)

Members of secondary gene pool are all those species that hybridize with the members of the primary gene pool with some to considerable difficulty and the hybrids are at least

partially fertile. These species are difficult to hybridize with those of GP1 due to ploidy differences, chromosome alterations or genetic barriers. Gene transfers from GP_2 to GP_1 are possible but usually difficult. Members of this group are often used in breeding programmes.

2.4.3. Tertiary Gene Pool (GP_3)

The species belonging to this group represent the extreme outer limit of the potential germplasm; they cross with the members of primary gene pool with considerable to great difficulty, and hybrids, if produced, are anomalous, lethal or completely sterile. Gene transfers from this group to the primary gene pool are extremely difficult and require special techniques. Gene transfers from GP_3 to GP_2 are relatively easier. GP_3 is used only occasionally in breeding programmes, and that too by a group of researchers having the competence and the patience for tackling the associated problems.

2.5. GENETIC EROSION

The gradual loss of variability from cultivated species, and their wild forms and wild relatives is called ***genetic erosion.*** This variability had arisen in nature over an extremely long period of time. Therefore, if allowed to be lost, it would be impossible to create it again during a short period. Genetic erosion is a creation of man since, ironically, man's success in plant breeding is the chief cause of genetic erosion. The varieties created by man using the natural genetic diversity are destroying the latter. The main causes of genetic erosion are briefly summarized below.

1. *Replacement of genetically variable land races ('desi' varieties) by the improved, genetically uniform pureline or hybrid varieties.* This has caused the disappearance of many land races, open-pollinated varieties, etc., which were reservoirs of genetic variability.
2. Improved crop management practices have virtually eliminated the weedy forms of many crops. In several crops, they existed as the so called *crop-weed complexes* in which gene introgression occurred from weed to the crop and *vice-versa*. Thus these complexes were sources of considerable genetic diversity.
3. Increasing human needs have extended farming and grazing into forests, the habitats of most wild species. This has led to the extinction of many wild relatives of crops.
4. Developmental activities like hydroelectric projects, roads, industrial areas, railways, buildings, etc. have also disturbed the wild habitat. Often wild relatives of crops are destroyed due to these activities.
5. Sometimes, introduction (deliberate or accidental) of a weedy species may result in the invasion of wild habitats by this species and lead to the elimination of the native wild relatives of crop plants. Even the cultivated forms derived from such introduced species may contribute to genetic erosion.

It is impractical to curb human activities to the extent necessary for the prevention of genetic erosion. The only practical, though not ideal, solution to the problem of genetic erosion is collection and conservation of the germplasm of cultivated plant species.

2.6. GERMPLASM COLLECTIONS

A ***germplasm collection*** of a crop species consists of a large number of lines, varieties and related wild species of the crop. Such collections are also called ***gene banks.*** When a germplasm collection is sufficiently large to include entries or accessions from all over the world, it is called ***world collection***; some of the world collections are listed in Table 2.2. However, inspite of the urgent need and unquestioned value of germplasm collection and conservation, only less than 30% of the countries have formal national germplasm conservation programmes.

TABLE 2.2

Some important germplasm world collections

S. No.	*Germplasm world collection*	*Crop*
1.	Bambey, Senegal	Groundnut
2.	Beltsville, U.S.A.	Small grain crops
3.	Cambridge, U.K.	Potato
4.	Canal Point, Florida	Sugarcane
5.	Central Rice Research Institute, Cuttack, India	Rice (more than 15,000 entries)
6.	Ethiopia, Africa	Coffee
7.	Institute of Plant Industry, Leningrad (USSR)	Ca. 1,60,000 entries of crop plants
8.	International Centre for Potato, Lima, Peru	Potato
9.	International Rice Research Institute, Los Banos, Philippines	Rice (over 86,000 collections)
10.	Near Tashkent, USSR	Annual New World Cotton
11.	New Zealand	Sweet potato
12.	Royal Botanic Gardens, Kew, England	Over 45,000 entries of crop plants
13.	Wisconsin, U.S.A..	Potato

In India, N.B.P.G.R. (National Bureau of Plant Genetic Resources, New Delhi) maintains large collections of *Sorghum* sp., *Pennisetum* sp., wheat, barley, oat, rice, maize and other agricultural and horticultural crops. Some of the germplasm collections are maintained at other places as given in Table 2.3.

Ideally, each entry in a germplasm collection should be different from the rest. But in practice, considerable duplications are quite frequent. It was estimated that during 1980s, the total holdings of the world's gene banks were approximately 2,500,000 accessions; of these only 1,050,000 accessions were unique, while the rest (1,450,000 accessions) were duplicates. Thus the estimated average level of duplication in the world's gene banks is about 58%, but it varies considerably with the crop (Table 2.4).

The extent of representation of cultivars in gene banks varies considerably from crop to crop. The highest representation is for maize, where only 5% of the cultivars remained uncollected during the 1980s; the other major crops rank (in the decreasing order) as follows: rice = wheat > potato > sorghum > soybean > legumes (grain and oil) > sweet potato > yams. Wild relatives of most crops are deficient in coverage, except for those of wheat, maize, potato and tomato. The major concerns in gene banks relate to the following: (1) the

TABLE 2.3

Germplasm collections maintained in India at institutions other than NBPGR, New Delhi

S. No.	Institution	Germplasm collection
1.	Central Institute for Cotton Research, Nagpur	6,548 entries of cottons (1991)
2.	Central Plantation Crops Research Institute, Kasaragod	Plantation crops
3.	Central Potato Research Institute, Simla	Potato
4.	Central Tobacco Research Institute, Rajahmundry	Tobacco
5.	Central Tuber Crops Research Institute, Thiruvananthapuram	Tuber crops other than potato
6.	CRRI, Cuttack	More than 15,000 entries of rice
7.	Directorate of Oilseeds Research, Hyderabad	Oilseeds
8.	Directorate of Wheat Research, Karnal	Wheat
9.	Indian Agricultural Research Institute, New Delhi	Maize
10.	Indian Grassland and Fodder Research Institute, Jhansi	Forage and fodder crops
11.	Indian Institute of Horticultural Research, Bangalore	Horticultural crops
12.	Indian Institute of Pulses Research, Kalyanpur, Kanpur	Pulses
13.	National Research Centre for Groundnut, Junagarh	Groundnut
14.	National Research Centre for Sorghum, Hyderabad	Sorghum
15.	National Research Centre for Soybean, Indore	Soybean
16.	Sugarcane Breeding Institute, Coimbatore	Over 2,800 entries of sugarcane

TABLE 2.4

The status of world's germplasm collections of different food crops (upto 1980s)

Crop	Number of accessions in gene banks	Distinct accessions	Level of duplication (%)	Number of wild accessions	Per cent cultivars remaining uncollected	Major efforts needed for proper conservation
Legumes (grain and oil)	2,60,000	1,32,000	~ 50	> 10,000	30-50	Collection, evaluation, maintenance (peanut)
Maize	1,00,000	50,000	50	15,000	5	Maintenance, evaluation
Potato	42,000	30,000	~ 30	15,000	10-20	Collection, evaluation
Rice	2,50,000	1,20,000	52	5,000	10	Collection (wild species), evaluation, maintenance
Sorghum	95,000	30,000	~ 69	9,500	20	Evaluation, maintenance
Soybean	1,00,000	30,000	70	7,500	30	Collection (wild species), evaluation
Sweet potato	8,000	5,000	~ 38	550	> 50	Collection, evaluation
Wheat	4,10,000	1,25,000	~ 70	10,000	10	Evaluation, maintenance
Yams	8,200	3,000	~ 63	60	High	Collection

eco-genetic coverage of the collections, (2) the number of distinct accessions, and (3) the proportion of viable accessions. The total holdings (including duplicates) in the gene banks of some countries and most of the international research institutes are summarised in Table 2.5. Ideally, the different gene banks should (1) evaluate their germplasms to minimise (preferably eliminate) duplicate accessions (from within a gene bank) without the risk of losing distinct accessions or ecostrains, and (2) resort to judicious exchange of accessions among gene banks to fill their gaps and to ensure that each distinct collection is held in two or more gene banks in order to minimise the risk of loss. Ecological genetics is the study of genetics in natural populations.

2.6.1. Requisites for a Gene Bank

Gene banks are maintained so that they can supply viable and useful germplasm to users, *viz.*, breeders, agronomists, entomologists, plant pathologists, geneticists, plant physiologists, crop ecologists, soil scientists, production specialists and growers. In order to be able to achieve this objective, a gene bank must fulfill the following requirements/conditions.

1. The accession maintained in the gene bank should provide comprehensive and representative coverage of the germplasm of the concerned species.
2. It should have dependable and cost-effective preservation facilities.

TABLE 2.5

Estimated number of accessions present in the gene banks of some countries and in the international research institutes (upto 1980s)

Country/Inter-national research institute	*Crops*	*Number of accessions*
China	All crops	4,00,000
India	All crops	76,000
U.S.A.	All crops	5,57,000
U.S.S.R.	All crops	3,25,000
CIAT	Common bean, cassava, forages	66,000
CIMMYT	Wheat, maize	75,000
CIP	Potato, sweat potato	12,000
ICARDA	Cereals, legumes, forages	77,000
ICRISAT	Sorghum, millet, chickpea, peanut, pigeon pea	86,000
IITA	Cowpea, rice, root crops	40,000
IRRI	Rice	86,000

3. It should generate sufficient seed stocks for distribution and exchange.
4. It should publish/make available easily and freely accessible information on the accessions maintained in the bank.
5. It should enjoy adequate financial and technical support.
6. The staff of the gene bank should be technically capable and, more particularly, willing to perform their assigned duties.

Only a small number of gene banks in the world fulfil all these conditions. It has bee suggested that a global network of gene banks is essential to serve crop researche throughout the world.

2.6.2. Genetic Erosion in Gene Banks

Genetic erosion occurs in all gene banks due to the lack/deficiency of one or more of th following : refrigerated storerooms, field space, trained personnel, and administrative an financial support. Repeated regeneration in small plots also leads to undesirable effects i terms of genetic identity and population structure. Erosion is more frequent in gene banks i the tropics. An example of genetic erosion in gene banks is the loss of many Latin Americar maize races. The factors that lead to genetic erosion are as follows : (1) discontinuity i programme and/or personnel, (2) human neglect, (3) shifts in programme direction o methodology of maintenance, (4) poor storage facilities, (5) disappearance of some records and (6) lack of periodic monitoring of seed viability. Therefore, germplasm conservatio work calls for sustained support from governments, and vigilance and loving care from all the concerned workers.

2.6.3. Constraints of Gene Banks

1. The labour-intensive and costly component of seed regeneration is a serious constraint to all gene-banks.
2. In humid tropics, seed drying is the major problem.
3. In case of gene banks with limited financial support, power consumption is a major expenditure.
4. Availability of technically capable and dedicated personnel may be a problem for many gene banks.
5. Conservation of some types of germplasms, *e.g.*, unadapted to adverse environments, disease and pest susceptible accessions, those having relatively poor seed longevity, etc., may be difficult. Even IRRI, Philippines germplasm centre has lost hundreds of accessions for the above-mentioned reasons.
6. Adequate financial support for germplasm conservation programmes is a major problem. The estimated global requirement in 1990 was US $ 500 million per annum, while the funding for 1982 was merely US $ 55 million.

2.7. GERMPLASM REGENERATION

Germplasm collections have to be regenerated every few years since seeds of most species lose viability with the storage duration. ***Germplasm regeneration*** or ***rejuvenation*** consists of growing seeds of the various entries in field and harvesting fresh seeds for further storage. Generally, an accession is regenerated when its germination falls below 95% of its germination at the start of storage. The frequency of regeneration depends mainly on the storage conditions, and on the concerned crop species, in some crops like onion and lettuce, it also depends considerably on the varieties involved. Generally, (1) about 50–100 plants

should be grown per accession, but some workers may be satisfied with a smaller number. (2) Regeneration should be done under climatic conditions similar, if not identical, to those from which an accession was collected. The above precautions are essential to prevent genetic drift (in the case of the first precaution) and natural selection (in the case of second precaution). ***Random drift*** represents changes in gene and genotype frequencies of a sample/population entirely due to chance (small sample size, etc.). Therefore, routine germination checks are done every 5–10 years to decide if the regeneration of a sample had become necessary.

Periodical regeneration is essential for the maintenance of germplasm collections in their original constitution and in a healthy state. It may be pointed out that *old seeds with reduced viability show an increased frequency of spontaneous mutations. Sometimes a loss of 50% in seed viability may be accompanied with a mutation frequency in the surviving seeds equivalent to a 10 kR X-ray treatment.* The processes of rejuvenation and multiplication should be utilized to eliminate viral and other infectious diseases from the accessions; shoot-tip culture, etc. may be used to achieve this goal. But regeneration poses the following problems.

1. Growing, harvesting and storing of large collections is a costly affair requiring much time, labour, land and money.
2. There is risk of errors in labelling, and of accession loss due to natural disasters, pathogen attacks, etc.
3. The genotypic constitution of the entries may change, especially if they are grown in environments considerably different from those from which they were originally collected. This is particularly true in case of cross-pollinated species and for old local varieties or land races.

2.8. ACTIVITIES IN GERMPLASM CONSERVATION

The various activities in germplasm conservation can be grouped into the following categories: (1) collection of germplasm, (2) conservation, (3) evaluation, (4) cataloguing, *i.e.*, data storage and retrieval, (5) multiplication and distribution, and (6) utilization. These activities are considered in some detail in the following sections. In addition, (7) training of personnel and (8) global coordination are also integral activities of an effective germplasm conservation programme; IPGRI (International Plant Genetic Resources Institute), Rome looks after the last two activities.

2.9. COLLECTION OF GERMPLASM

The process of obtaining the various germplasm accessions for a germplasm collection is known as ***collection of germplasm.*** This can be done in two chief ways: (1) exploration and (2) procurement from other agencies, individuals, companies, etc.

2.9.1. Exploration and Collection

Explorations are trips for collection of various forms of crop plants and their related species. Therefore, cultivated forms like land races, open-pollinated varieties, etc., wild forms

and wild relatives are all collected. *Explorations are the primary source of all the germplasm present in various germplasm collections.*

2.9.1.1. Objectives. Explorations are planned to fulfil mainly the following two objectives.

1. *Collection of germplasm needed by breeders.* The germplasm accessions collected for this purpose possess the specific traits that are required by breeders either in the immediate future or in the foreseable future.
2. *Collection of the variability remaining in the crop plants and their relatives for its conservation.* For this purpose, germplasm samples are collected without any reference to the presence of specific traits; the consideration for collection is that as many diverse types are collected as possible.

2.9.1.2. Areas of Collection. The areas to be covered by explorations are usually the centres of origin (Section 2.10) of the concerned crops. In addition, collections should also be made from the peripheral regions of species distribution, and even in areas where it was introduced in comparatively recent times. This is because in these areas the crops are exposed to environmental stresses, and special mutations may have been selected for.

2.9.1.3. Sampling Sites. The locations of sampling sites within the collection area should be carefully planned in advance. This should be based on a consideration of the changes in ecological, agricultural and social conditions in the area; soil patterns and changes in agricultural practices should also be considered. If there is considerable variation for these factors, the sampling sites should be closer, otherwise they should be relatively farther apart. Generally, sites for cultivated materials would be scattered over the entire area, while those for wild materials would occur in clusters. A preliminary survey of the area may be done before the actual collection.

2.9.1.4. Collection Priorities. The species for which collection is to be done will be determined by the needs of the breeders, and by the level of threat to the concerned species. Thus the need-based priorities will depend on the country in question, while the threat-based priorities have been developed by FAO: the emergency situations are indicated by 'E', and the lower level priorities are denoted by I, II and III.

2.9.1.5. Sampling Procedure. The objective of sampling is to capture the maximum amount of genetic diversity with the minimum number and size of samples. The collection of plant materials from sampling sites may be (1) random or (2) selective. In random sampling, samples are collected without considering their distinctiveness, while in selective sampling distinct forms are collected. Random sampling is the most suited for conservation efforts and is expected to collect the whole range of variability present in a species. Selective sampling, on the other hand, may pick out morphological variants only, and may miss entirely such genes as those for adaptation, resistance to biotic and abiotic stresses, etc. Hence a combination of both sampling approaches has been advocated.

The collector should aim at the collection of as many diverse types as possible with the least (ideally little or no) duplication. This is very difficult to achieve as the genotypes of the various types can not be assessed at the time of collection. As a result, *duplications are quite common; this leads to an overcrowding in the germplasm collections.*

2.9.1.6. Sample Size. It has been suggested that 50-100 plants should be collected from each sample site. In addition, at least 50 seeds should be collected from each plant. Thus each sample should consist of 2,500 to 5,000 seeds.

2.9.1.7. Field Records. Adequate field records must be maintained during collection. For this purpose, minimum data sheets have been proposed, which can be used with some modifications, if necessary.

Indian scientists have undertaken several explorations. In 1955, the Botanic Survey of India sent a team to Bomdila, NEFA. In 1961, an expedition to central Nepal between Butwal and Pokhra and Muktinath was undertaken. Collections made during this expedition included cultivars of cereals, millets, pulses, mustards, etc. Wild species related to wheat, oat, barley, linseed, okra, and several other crops were also collected. Dr. H.B. Singh toured the country extensively in connection with germplasm collection. In addition, explorations were organised in tribal areas of Bihar, Orissa, Andhra Pradesh, in Lahaul and Spiti, in rainfed areas of Madhya Pradesh, Rajasthan and Gujarat, in the North-East region, in Indonesia and in certain parts of U.S.S.R.

2.9.1.8. Merits of Exploration. The chief merits of plant exploration are listed below.

1. It is the source of virtually all genetic diversity stored in gene banks.
2. It is the only means of collecting and conserving the threatened genetic diversity.
3. It often provides access to materials of special interest, *e.g.*, new genes (= alleles), new species, etc.

2.9.1.9. Limitations of Plant Explorations. The chief limitations of plant explorations are given below.

1. It is tedius, time-taking and expensive.
2. It poses various hardships to the collectors, *e.g.*, in boarding, transportation, etc., especially in remote areas.
3. There may even be a threat to life, especially from wild animals.

2.9.2. Procurement from other Agencies

Germplasm can be obtained from other agencies concerned with germplasm conservation, from research institutions, individuals or companies. Generally, this involves an import of the germplasm; it is therefore considered in a greater detail under plant introduction (Chapter 3).

2.10. CENTRES OF ORIGIN

There is considerable evidence that the cultivated plants were not distributed uniformly throughout the world. Even today, certain areas show far greater diversity than others in the forms of certain cultivated crops and their wild relatives. In 1926, N.I. Vavilov proposed that *crop plants evolved from wild species in the areas showing great diversity and termed them as* ***primary centres of origin.*** Later, crops moved to other areas primarily due to the activities of man. These latter areas generally lack the richness in variation found in the primary centres

of origin. *But in some areas, certain crop species show considerable diversity of forms although they did not originate there; such areas are known as* ***secondary centres of origin*** *of these species.*

The concept of centres of origin was given by Vavilov based on his studies of a vast collection of plants at the Institute of Plant Industry, Leningrad. He was director of this institute from 1916 till 1936. He also postulated the ***Law of Homologous Series in Variation:*** *this law states that characters found in one species also occur in other related species.* Thus diploid (2*x*), tetraploid (4*x*) and hexaploid (6*x*) wheats show a series of identical contrasting characters. Similarly, genus *Secale* duplicates the variation found in genus *Triticum*. Thus a character absent in a species, but found in a related species, is likely to be found in the collections of that species made from the centre of its origin.

Eight main centres of origin were originally proposed by Vavilov in 1926; these centres are (1) China, (2) Hindustan, (3) Central Asia, (4) Asia Minor, (5) Mediterranean, (6) Abyssinia, (7) Central and (8) South America (Table 2.6). Later, in 1935, Vavilov divided the Hindustan Centre of Origin into two centres, *viz., Indo-Burma* and *Siam-Malaya-Java Centres of Origin*. Similarly, the South American Centre was divided into three centres, namely, *Peru Chile* and *Brazil-Paraguay Centres of Origin.* Thus the eight main centres were regrouped into 11 centres of origin. At the same time, he introduced a new centre of origin, the *U.S.A. Centre of Origin.* Two plant species, sunflower (*Helianthus annuus*) and Jerusalem artichoke (*Helianthus tuberosus*), are believed to have originated in the U.S.A. Centre of Origin.

2.10.1. The China Centre of Origin

This centre consists of the mountainous regions of central and western China and the neighbouring lowlands. It is the largest and the oldest independent centre of origin. The crops that originated in this area (*primary centre of origin*) are, soybean (*Glycine max*), radish (*Raphanus sativus*), *Colocasia antiquorum* (bunda), *Panicum miliaceum* (proso millet) and some other species of millets, buckwheat (*Fagopyrum esculentum*), *Papaver somniferum* (opium poppy), several species of *Brassica* and *Allium, Solanum melongena* (brinjal), some species of *Cucumis* and *Cucurbita*, pears (*Pyrus communis*), peaches (*Prunus persica*), apricots (*Prunus armeniaca*), plums (*Prunus divaricata*), orange (*Citrus nobilis*), Chinese tea (*Camellia sinensis*) and naked oats (*Aveda nuda*).

In addition, it is *secondary centre of origin* for several crop plants, *e.g., Zea mays* (maize), *Phaseolus vulgaris* (rajma), cowpea (*Vigna anguiculata*), turnip (*Brassica rapa*) and sesame or til (*Sesamum indicum*).

2.10.2. The Hindustan Centre of Origin

This centre includes Burma, Assam, Malaya Archipelago, Java, Borneo, Sumatra and Philippines, but excludes North-West India, Punjab and North-Western Frontier Provinces. It is the *primary centre of origin* of rice (*Oryza sativa*), arhar or pigeonpea (*Cajanus cajan*), gram or chickpea (*Cicer arietinum*), cowpea, mung (*Vigna radiata*), brinjal, *Cucumis sativus* (cucumber), *Lactuca indica* (Indian lettuce), certain species of *Dioscorea* (yams), *Raphanus indicus* (Indian radish), *Saccharum officinarum* (noble canes), several species of cotton

(particularly, *Gossypium arboreum*), hemp (*Cannabis indica*), black pepper (*Piper nigrum*), indigo (*Indigofera* sp.), mango (*Mangifera indica*), orange, sour lime and some other *Citrus* species, coconut (*Cocos nucifera*), banana (*Musa sapientum*) and turmeric (*Curcuma domestica*).

TABLE 2.6

The centres of origin as proposed by N.I. Vavilov (1926, 1935)

Centre of origin	*Primary centre of origin*	*Secondary centre of origin*
Abyssynian Centre	Barley, *Triticum* spp., jowar, bajra, gram, lentil, sem (*Dolichos* sp.), pea, khesari, linseed, safflower, sesame, castor, coffee, onion, okra, etc.	Broad bean (*Vicia faba*)
Asia Minor Centre (*Syn.*, Near East or Persian Centre)	*Triticum* spp., rye, alfalfa, carrot, cabbage, oat, lettuce, apple, *Pyrus* spp., *Prunus* spp., grape, almonds, chestnut, pistachio nut, persian clover, etc.	*B. campestris, B. nigra*, turnip, apricot, etc.
Central American Centre (*Syn.*, Mexican Centre)	Maize, rajma (*P. vulgaris*), lima beans, melons, pumpkin, sweet potato, arrowroot, chillies, *G. hirsutum*, papaya, guava, avacado, etc.	
Central Asia Centre (*Syn.*, Afghanistan Centre)	*T. aestivum*, pea, mung, linseed, sesame, safflower, hemp, *G. herbaceum*, radish, musk melon, carrot, onion, garlic, spinach, pear, almond, grape, apple, etc.	Rye (*Secale cereale*)
China Centre	Soybean, radish, bunda (*Colocasia* sp.), proso millet, buckwheat, opium poppy, brinjal, pear, peach, apricot, plum, orange, chinese tea, etc.	Maize, rajma, cowpea, turnip, sesame (til)
Hindustan Centre [Divided into: (1) Indo-Burma, and (2) Siam-Malaya-Java Centres]	Rice, pigeonpea, chickpea, cowpea, mung, brinjal, cucumber, Indian radish, noble canes, *G. arboreum*, mango, orange, coconut, banana, etc.	
Mediterranean Centre	*Triticum* spp., barley, *Avena* spp., lentil, pea, broad bean, lupins, *Lathyrus* spp., chickpea, clovers, *Brassica* spp., onion, garlic, beets, lettuce, asparagus, lavender, peppermint, etc.	
South American Centre [Divided into: (1) Peru, (2) Chile, and (3) Brazil-Paraguay Centres]	Potato, maize, limabean, peanut, pineapple, pumpkin, *G. barbadense*, tomato, tobacco, guava, quinine tree, cassava, rubber, etc.	
U.S.A. Centre	Sunflower, Jerusalem artichoke	

FIG. 2.1. Centres of origin of cultivated plant species. 1. The China Centre, 2. The Hindustan Centre, 3. The Central Asia Centre, 4. The Asia Minor Centre, 5. The Mediterranean Centre, 6. The Abyssinian Centre, 7. The Central American Centre, and 8. The South American Centre (8. Peru, 8a. Brazil—Paraguay, and 8b. Chile).

2.10.3. The Central Asia Centre of Origin

It includes North-West India (Punjab, The North-West Frontier Provinces and Kashmir), all of Afghanistan, the Soviet Republics of Tadjikistan and Uzbekistan and Tian-Shan. It is also known as the *Afghanistan Centre of Origin.* The crops that originated in this centre (*primary centre of origin*) are, wheat (*Triticum aestivum*), club wheat (*Triticum compactum*), pea (*Pisum sativum*), broad bean (*Vicia faba*), mung, linseed (*Linum usitatissimum*), sesame, safflower (*Carthamus tinctorius*), hemp, cotton (*Gossypium herbaceum*), radish, musk melon (*Cucurbita moschata*), carrot (*Daucus carota*), onion (*Allium cepa*), garlic (*Allium satium*), spinach (*Spinacea oleracea*), pistachio nut (*Pistacia vera*), apricot, pear, almond (*Prunus amygdalus*), grape (*Vitis vinifera*) and apple (*Pyrus malus*). It is *secondary centre of origin* of rye (*Secale cereale*).

2.10.4. The Asia Minor Centre of Origin

This is also known as the *Near East* or the *Persian Centre of Origin.* It includes the interior of Asia Minor, the whole of Transcaucasia, Iran and Highlands of Turkmenistan. The crop species that originated in this region (*primary centre of origin*) include nine species of *Triticum,* rye, alfalfa (*Medicago sativa*), Persian clover (*Trifolium resupinatum*), carrot, cabbage (*Brassica oleracea*), oat (*Avena sativa*), species of *Allium,* lettuce (*Lactuca sativa*), fig (*Ficus carica*), pomegranate (*Punica granatum*), apple, several species of *Pyrus, Prunus,* grape, almonds, chestnuts (*Castanea* sp.) and pistachio nut. It is the *secondary centre of origin* of rape (*Brassica campestris*), black mustard (*Brassica nigra*), leaf mustard (*Brassica japonica*), turnip (*B. rapa*) and apricot.

2.10.5. The Mediterranean Centre of Origin

Many valuable cereals and legumes originated in this area. The species that originated in this centre (*primary centre of origin*) are, durum wheats (*Triticum durum*), emmer wheats (*Triticum dicoccum*), and other *Triticum* species, several species of *Avena*, barley (*Hordeum valgare*), lentil (*Lens esculenta*), several species of *Lathyrus*, pea, broad bean, lupins (*Lupinus* sp.), chickpea, clovers (*Trifolium* sp.), vetch (*Vicia sativa*), several species of *Brassica,* such as, rape, black mustard, cabbage and turnip, onion, garlic, beets, lettuce (*Lactuca sativa*), artichoke, asparagus (*Asparagus officinalis*), lavender, peppermint (*Mentha* sp.) and sage.

2.10.6. The Abyssinian Centre of Origin

It includes Ethiopia and hill country of Eritrea. It is the *primary centre of origin* for *H. vulgare* (barley), *Triticum durum, Triticum turgidum, Triticum dicoccum,* jowar (*Sorghum bicolor*), bajra (*Pennisetum americanum*), gram, lentil, sem (*Dolichos lablab*), pea, khesari (*Lathyrus sativus*), linseed, safflower, sesame, castor (*Ricinus communis*), coffee (*Coffea arabica*), onion and okra (*Abelmoschos esculentus*). It is the *secondary centre of origin* for broad bean (*Vicia faba*).

2.10.7. The Central American Centre of Origin

This includes the region of South Mexico and Central America. It is also referred to as the *Mexican Centre of Origin*. The plants that originated (*primary centre of origin*) here are, maize, rajma (*P. vulgaris*), lima bean (*Phaseolus lunatus*), melons, pumpkin (*Cucurbita melanosperma*), sweet potato (*Ipomoea batatas*), arrowroot (*Canna edulis*), chillies (*Capsicum annuum*), cotton (*G. hirsutum* and *G. purpureascens*), papaya (*Carica papaya*), guava (*Psidium guajava*) and avacado (*Persea americana*).

2.10.8. The South American Centre of Origin

This centre includes the high mountainous regions of Peru, Bolivia, Ecuador, Columbia, parts of Chile and Brazil, and whole of Paraguay. The crops that originated in this centre (*primary centre of origin*) are many species of potatoes, maize, lima bean, peanut (*Arachis hypogaea*), pineapple (*Ananas comosa*), pumpkin (*Cucurbita maxima*), Egyptian cotton (*Gossypium barbadense*), tomatoes, guava, tobacco (*Nicotiana tabacum* and other species), quinine tree (*Cinchona calisaya*), cassava (*Manihot utilissima*), and rubber (*Hevea* sp.).

2.10.9. Centres of Diversity

The concept that centres of diversity represent centres of origin has been seriously questioned. Plants of a species growing in different environments are likely to be different, *i.e.*, diverse. Thus a plant species is likely to show a greater variation in a region with varied climatic and other ecological conditions. Areas with mountains and valleys show considerable variation in the prevalent environment. Therefore, plant species would show a great variation in such areas. Interestingly, the centres of origin are situated in such mountain-valley areas. Further the centres of diversity of many species have shifted with time. This shift in diversity was brought about by a shift in the area of the greatest cultivation and due to the introduction of the concerned species into an area with a greater ecological diversity than where they existed before. These processes have given rise to the ***secondary centres of diversity.*** Consequently, several species have two or more centres of diversity and it is often difficult to determine, which one of them is the real centre of origin.

Thus the centres of origin may be more appropriately called ***centres of diversity.*** Zhukovsky, in 1965, recognized 12 mega-gene centres of crop plant diversity (Table 2.7), and a number of microgene centres of wild growing species related to our crop plants. The cultivated forms are believed to have first originated in these microgene centres. These centres may not be the centres of origin of the species concerned, but they are the areas of the maximum diversity of these species. This serves as an extremely useful guide to plant explorers as to where to search for variation in a given species. Within the large centres of diversity, small areas may exhibit a much greater diversity than the centre as a whole; these areas are known as ***microcentres.*** The crop evolution appears to proceed at a more rapid rate in such microcentres. The microcentres are important for plant collection as well as for an experimental study of the evolution of plants.

TABLE 2.7

The 12 regions of diversity of crop plants (based on Zeven and Zhukovsky, 1975, and Zeven and de Wet, 1982)

Centre of diversity	Crop plant
Chinese-Japanese region	Soybean, Adzuki bean, prosomillet, fox tail millet, naked oat, leafy mustard, orange/*Citrus*, peach apricot, litchi, bamboo, tea, etc.
Indochinese-Indonesian region	Rice, rice bean, winged bean, cucurbits/ash gourd, mango, banana, *Citrus*/lime, grape-fruit, bamboos, nutmeg, clove, ginger, taros and yams, betel nut, coconut, etc.
Australian region	*Eucalyptus*, *Acacia*, *Macadamia* nut
Hindustani region	Rice, little millet, black gram, green gram, moth bean, rice bean, *Dolichos* bean, pigeonpea, cowpea, chickpea, horse gram, jute, eggplant, okra, cucumber, taros and yams, *Citrus*, banana, mango, sesame, ginger, turmeric, cardamom, sugarcane, black pepper, etc.
Central Asian region	Wheat (bread/club/shot), rye, *Allium*/onion, garlic, spinach, peas, beetroot, faba bean, lentil, chickpea, apricot, plum, pear, walnut, almond, melon, grape, carrot, sesame, etc.
Near-Eastern region	Wheat (einkorn, durum, bread), barley, rye, faba bean, chickpea, French bean, lentil, pea, *B. oleracea*, *Allium*, melon, grape, apple, safflower, sesame, flax, lupins, etc.
Mediterranean region	Wheat (durum, turgidum), oats, *B. oleracea*, lettuce, beetroot, faba bean, radish, olive, berseem, lupins, grape, fennel, cumin, linseed, celery, *Crocus*, colza
African region	Wheat (durum, emmer, bread), African rice, sorghum, pearl millet, finger millet, cowpea, bottle grourd, okra, cucumber, yams, castor, sesame, niger, oil palm, safflower, cotton, coffee, groundnut, date palm, melons, etc.
European-Siberian region	Peach, pear, plum, apricot, apple, almond, walnut, pistachionut, cherry, *cannabis*, black mustard, chicory, hops, lettuce
South American region	Potato, sweet potato, Lima bean, amaranth, *Chenopodium*, *Cucurbita*, tomato, tobacco, lupin, papaya, pineapple, groundnut, Egyptian cotton, cassava, cacao, rubber tree
Central American and Mexican region	Maize, French bean, potato, *Cucurbita*, pepper/chilli, amaranth, *Chenopodium*, tobacco, sisal hemp, upland cotton
North American region	Jerusalem artichoke, sunflower, plum, raspberry, strawberry

2.11. GERMPLASM CONSERVATION

The germplasm has to be maintained 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 prepared for planting with relative ease; this is called ***germplasm conservation***. Germplasm can be conserved either (1) *in situ* or (2) *ex situ*.

2.11.1. *In Situ* Germplasm Conservation

Conservation of germplasm in its natural habitat or in the area where it grows naturally is known as **in situ *germplasm conservation*.** This is achieved by protecting this area from human interference; such an area is often called ***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 microcentre within 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 *Mangifera*.

2.11.1.1. *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.

2.11.1.2. *Demerits*. Gene sanctuaries suffer from certain limitations as listed below.

1. They are easiest to demarcate, difficult to establish and very difficult to maintain. This is particularly so in a country like India, which has an ever increasing population pressure.
2. These can not conserve the variability found in crop plants, for which *ex situ* conservation is the only answer.

2.11.2. *Ex Situ* Germplasm Conservation

Conservation of germplasm away from its natural habitat is called **ex situ *germplasm conservation*.** It can be achieved in the following five ways: (1) seed gene banks, (2) plant or field gene banks, (3) shoot-tip gene banks, (4) cell and organ gene banks, and (5) DNA gene banks.

2.11.2.1. *Seed Gene Banks*. In ***seed gene banks*** germplasm is stored as seeds of various accessions. *Virtually all gene banks are essentially seed banks*. Seed conservation is quite easy, relatively safe and ordinarily needs minimum space. Under suitable conditions, seeds of many species can be stored for up to 50–100 years. Containers of glass, tin, plastic or a combination of these may be used for seed storage. Seeds are classified, mainly on the basis of their storability, into two major groups: (1) orthodox and (2) recalcitrant; this grouping of seeds was proposed by Roberts in 1973.

1. *Orthodox Seeds*. Seeds of this type can be dried to a moisture content of 5% or lower without lowering their viability. 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.

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 tropical crops like *Citrus*, cocoa, coffee, rubber, oil palm, mango, jackfruit, etc. belong to this group. Such seeds present considerable difficulties in storage. Therefore, germplasms of such plants are conserved by alternative approaches.

The conditions for seed storage depend mainly on the duration of storage. Generally, seed bank collections are classified into three groups: (1) base collections, (2) active collections and (3) working collections. This grouping increases the efficiency of use and the level of management of the collections.

1. *Base Collections.* These consist of all the accessions present in the germplasm of a crop, which are stored at about –20°C with 5% moisture content; they are disturbed only for regeneration. Germination tests are done every 5–10 years. 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 used for evaluation, multiplication and distribution of the accessions. Active collections 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. This is essential to prevent any appreciable shift in the genetic make up of the collections.

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.

2.11.2.2. Field Gene Banks. Essentially, a ***field*** or ***plant gene bank*** is an orchard or a field, in which accessions of fruit trees or vegetatively propagated crops are grown and maintained. Field banks suffer from the following serious limitations: they (1) require large areas, (2) are expensive to establish and maintain, and are prone to damage from (3) disease and insect attacks, (4) man-made or (5) natural disasters and (6) human errors in handling. Few good plant banks exist in India.

2.11.2.3. Shoot Tip Gene Banks. In such gene banks, germplasm is conserved as slowgrowth cultures of shoot-tips and nodal segments. Their regeneration consists of subculturing the cultures, which may be done every 6 months to 3 years. This approach offers the following chief merits for the conservation of germplasms 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.

2.11.2.4. Cell and Organ Gene Banks. A germplasm collection based on cryopreserv (at –196°C in liquid nitrogen) embryogenic cell cultures, shoot-tips and or somatic/zygo embryos may be called ***cell and organ bank.*** The techniques for cryopreservation of pla cells and tissues are being rapidly refined, and some such banks have been established, *e.g.* for potato in Germany.

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

2.12. GERMPLASM EVALUATION

Evaluation consists of assessment of the germplasm accessions for their various features traits of some known or potential use in breeding programmes. Germplasm evaluation is truly multi-disciplinary activity; generally, germplasm accessions are evaluated f morphological, physiological, biochemical, plant pathological (*i.e.*, disease resistance entomological (*i.e.*, insect resistance) and other features. The characters assessed must b related to the need of the breeders and other users, since they are the ones who are going utilize the germplasm. Obviously, evalution involves experts from different disciplines. It the most critical step determining the utilization of a collection. A poorly assessed germplas collection is unlikely to be of any use to the breeders. A reliable evaluation of germplasm extremely valuable for germplasm collections, but it is very difficult and time consuming. A a result, the true diversity present in many germplasm collections is yet to be assessed.

IPGRI, Rome has developed model lists of descriptors (= characters) for whic germplasm accessions of various crops should be evaluated. A ***descriptor*** is a character that considered important and/or useful in the description of a population/an accessio Descriptors differ according to species, and the value of a descriptor depends primarily on t user concerned. For example, plant breeders tend to choose descriptors of agronom importance that would be useful in crop improvement and are, usually, under polygen control. In contrast, botanists choose morphological descriptors irrespective of their genet control. Geneticists, on the other hand, favour qualitative traits with monogenic inheritanc The IPGRI model lists of descriptors represents a compromise and includes a minimu number of universally accepted descriptors that is expected to facilitate the exchange information and material. It should be kept in mind that even such accessions, which do n possess a trait of some value to the breeders should be retained in the collection. This because what seems to be of no value today, may become a highly valuable feature tomorro

2.13. GERMPLASM CATALOGUING, DATA STORAGE AND RETRIEVAL

Each germplasm accession is given an accession number. This number is prefixed, in Ind with either IC (*indigenous collection*), EC (*exotic collection*) or IW (*indigenous wil*

Information on the species and variety names, place of origin, adaptation and on its various features or descriptors is also recorded. The usefulness of an accession, in fact, the entire germplasm collection, becomes known to the plant breeders only when the information about the features of the accessions becomes available to them. Therefore, catalogues of the germplasm collections for various crops are published by the gene banks.

The amount of data recorded during evaluation is huge. Its compilation, storage and retrieval is now done using special computer programmes. At present, there are many genetic resources documentation systems used by different gene banks; sometimes a single gene bank may use different systems for different crops. It was once thought that gene banks worldwide should use one ideal and universally accepted documentation system. However, documentation systems soon become obsolete, and softwares permit a free exchange of information between gene banks using different documentation systems, provided they use the same descriptors.

2.14. GERMPLASM MULTIPLICATION AND DISTRIBUTION

The germplasm accessions requested by breeders/researchers are multiplied and supplied to them, usually without cost. Ordinarily, active collections are used for this purpose. This is a very important activity of gene banks since it is the very purpose for which they are established. Generally, only a limited quantity of seed is provided to each worker. It is expected that each breeder/research worker will report back to the concerned gene bank his assessment of the important characters of the accessions used by him.

2.15. GERMPLASM UTILISATION

The germplasm can be used in a breeding programme in the following three ways: (1) it may be directly release as a variety, (2) it may be subjected to selection for developing a variety and (3) it may be used a as parent in hybridization programmes. These aspects are considered in the next chapter dealing with plant introduction (Sections 3.7 and 3.8).

Utilization of germplasm collections having several thousand accessions is an extremely demanding task. In 1984, Frankel and Brown put forth the concept of core collection to facilitate germplasm utilization. A ***core collection*** consists of a set of the minimum number of accessions that together represent the genetic diversity of the concerned crop and its wild relatives. Thus a core correction is a subset of the total accessions of a crop; it provides the users most of the genetic variability of the concerned crop in a set of workable number of accessions. Therefore, each accession in a core collection is, to some extent, representative of a number of accessions in the gene bank. However, a core collection should not replace the original collection, and it should be regarded as a strategy of germplasm utilization that makes useful accessions more accessible. However, the present knowledge of plant diversity in any crop is insufficient to enable the development of core collections.

The land races usually have poor agronomic features and cannot be used directly in breeding programmes. Therefore, such accessions that have desirable traits are first crossed with modern varieties and breeding lines (= *elite gene pool*) to improve their agronomic features. The lines derived from these crosses are usually deficient in certain desirable traits,

but they can be used directly in the breeding programmes, whereas the original accessions could not be used directly. This phase is often called ***prebreeding, germplasm enhancement*** or ***development breeding,*** and is critical for the utilization of primitive, agronomically inferior germplasm. An example of pre-breeding is germplasm conversion described in Chapter 18 (Section 18.3.7).

2.16. INTERNATIONAL COOPERATION AND AGREEMENTS

Cooperation among countries and regions is important for effective germplasm conservation and, particularly, exchange. It would greatly facilitate collection, rejuvenation, characterization and evaluation of accessions, and would promote exchange of germplasm and technologies. Since 1950s, several agencies, particularly FAO and UNO have promoted and supported such cooperation. FAO hosted three International Technical Conferences during 1967, 1973 and 1981, each of which resulted in the publication of a book summarising the state of knowledge and technical advances in conservation and utilization of plant genetic resources (PGRs).

International Agricultural Research Centres have also promoted and facilitated international technical cooperation. IBPGR was established in FAO in 1974 with a specific mandate to promote international cooperation on the conservation of plant genetic resources. IBPGR has now been reorganised as IPGRI (International Plant Genetic Resources Institute), Rome, which is a fully independent institute that will work in close cooperation with FAO and other international research centres. The Commission on Plant Genetic Resources was established in FAO in 1983 as a forum that would negotiate, develop and monitor international agreements and regulations on genetic resources. Till 1993, 114 countries were members of this commission. Some important agreements on PGRs of agricultural interest as follows : (1) The International Undertaking on Plant Genetic Resources (1983) and (2) International Code of Conduct for Collection and transfer of PGRs; these are briefly described below.

2.16.1. The International Undertaking on Plant Genetic Resources (1983)

This international agreement was approved by FAO in 1983. It is a nonbinding formal agreement based on the principle that PGRs are a common heritage of mankind and should be available without restriction for plant breeding and scientific purposes. This agreement defines the responsibility of countries and provides a framework for international cooperation. Annexures to the undertaking recognize (1) the rights of both donors of germplasm and of technology to seek adequate compensation for their contributions, as well as (2) the farmer's rights. FAO and IBPGR are developing an international network of base collections in gene banks under the auspices of FAO that guarantee unrestricted access to the germplasm contained therein.

2.16.2. International Code of Conduct for Collecting and Transfer of PGRs

This code of conduct has been developed and negotiated through the Commission on PGRs. It aims to promote collection and safe transfer of germplasm; it also provides the

procedures to be followed by collectors for making requests for PGR collection missions (= exploration) and by governments for issuing licenses for the same.

2.16.3. Global System for the Conservation and Utilization of PGRs

This comprehensive system was developed by the Commission on PGR to promote and monitor systematic cooperation and coordination of PGR activities. By 1993, 132 countries has joined the system. FAO, in close collaboration with IPGRI, is developing global information and early working mechanisms, networks for *in situ* conservation areas and for *ex situ* collections, and periodical reports on the state of world's PGRs.

2.17. FUTURE ACTIVITIES :

The main tasks that need to be completed concern virtually all the aspects of germplasm conservation and utilization. Chang (1991) has summarised these tasks as follows :

1. Completing field explorations and consolidating germplasm collections.
2. Improving germplasm preservation technology.
3. Improving germplasm dissemination and ensuring duplicate storage.
4. Expanding systematic evaluation and standardized documentation.
5. Enhancing communication between conservationists, evaluators, breeders, researchers, biotechnologists and statisticians to promote utilization of unimproved germplasm and wild species. The use of these germplasms is rather meagre due to the following : lack of systematic evaluation, meagre research on novel sources of germplasm, insufficient ecogenetic studies on germplasm composition, inadequate documentation and information dissemination, and insufficient prebreeding efforts. A multidisciplinary collaboration, interdisciplinary interaction, and information dissemination are expected to promote their utilization.
6. Duplications within gene banks should be reduced.
7. Risk of accession loss should be reduced by maintaining germplasms at duplicate storage sites.
8. Slowgrowth storage/cryopreservation technology should be developed for species that produce recalcitrant seeds or are vegetatively propagated.
9. Nondestructive monitoring of seed viability needs to be developed.
10. *In situ* conservation should be strengthened to complement *ex situ* conservation.
11. Collection of more accessions of primitive landraces and wild relatives of most crops needs to be done.
12. Establishment of *ex situ* collections in areas having favourable environmental conditions, such as, natural caves in permafrost zones and high altitude deserts that have extremely low humidity coupled with cold temperatures. For example, Norway is establishing an international seed bank under permanent natural freezing conditions of Svalbard. This move will markedly reduce the cost of *ex situ* PGR conservation.
13. Nations rich in PGR should develop laws that protect PGR and deter genetic erosion.