TAMIL NADU AGRICULTURAL UNIVERSITY

AGB 301

PRINCIPLES AND METHODS OF PLANT BREEDING (1+1)

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CONTENTS

PLANT BREEDING

Plant breeding is a science based on principles of genetics and cytogenetics. It aims at improving the genetic make up of the crop plants. The following objectives of plant breeding are,

i. Higher yield
ii. Improved quality
iii. Diseases and insect resistance
iv. Change in maturity duration
v. Agronomic characteristics
vi. Photo insensitivity
vii. Synchronous maturity
viii. Non-shattering characteristics
ix. Determinate growth
x. Dormancy
xi. Moisture stress and salt tolerance
xii. Elimination of toxic substances
xiii. Winter hardiness

Some well-known achievements are development of semi-dwarf wheat and rice varieties, mobilization of Indian canes, and production of hybrid and composite varieties of maize, Jowar and bajra.

POLLINATION SYSTEMS

The mode of reproduction determines the genetic constitution of crop plants i.e whether the plants are normally homozygous of heterozygous. This is turn determines the goal of the breeding programme.

If the crop plants were naturally homozygous e.g. as in self-pollinated crops like wheat, a homozygous line would be desirable as a variety. But, if the plants are heterozygous naturally, as in cross-pollinated crops like maize, a heterozygous population has to be developed as a variety.

Consequently the breeding methods have to be vastly different for the two groups of crop plants. The knowledge of mode of reproduction of crop plants is also important of making artificial hybrids. Production of hybrids between diverse and desirable parents is the basis of almost all the modern plant breeding programmes.

MODES OF REPRODUCTION

Reproduction in crop plants maybe broadly grouped in to two categories.

1. Asexual - Vegetative reproduction and apomixis
2. Sexual

MODES OF POLLINATION

Pollination refers to the transfer of pollen grains from anthers to stigmas. Pollen from an anther may fall on the same flowers leading to " Self pollination " or " Outo gamy".

When pollen from flowers of one plant are transmitted to the stigmas of flowers of another plant, it is known as “cross pollination" or allogamy.

A third situation “Geitonogamy" results when pollen from a flower of one plant galls on the stigmas of other flower of the same plant e.g. maize. The genetic consequences of geitonogamy are the same as those of quitogamy.

SELF POLLINATION

Many cultivated plant species reproduce by self-pollination. These species as a rule must have hermaphrodite flowers. But in most of this sp., self-pollination is not complete and cross-pollination may occur upto 5%. Several factors like variety,

environmental conditions like temperature humidity and location affect the degree of cross-pollination. There are various mechanisms that promote self-pollination.

1. CLEISTOGAMY - In this case, flowers do not open at all. This ensures complete self-pollination. Since, foreign pollen cannot reach the stigma of closed flowers. It occurs in some varieties of wheat (*Triticm sp*.) Oats (*Avena* sp.), Barley (*Hordaum vulgare*) and in a number of other grasses.

2. CHASMOGAMY - In some sp. the flower open, only after pollination has taken place. This occur in many cereals, such as wheat, barley, rice and oats.

3. In crops like tomato (*Lycopersicum esculentum*) and brinjal (*Solanum melongena)*, the stigma are closely surrounded by anthers. Pollination generally occurs after the flowers open. But the position of anthers in relation to stigma ensures self-pollination.

4. In some species, flowers open but the stamens and the stigma are hidden by other floral organs. In several legumes e.g. pea, mung bean, urd bean, soybean, bengalgram. Two petals forming a keel enclose the stamens and the stigma.

5. In a few sp. stigmas become receptive and elongate through stamina columns. This ensures pre-dominant self-pollination.

GENETIC CONSEQUENCES OF SELF POLLINATION

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

CROSS POLLINATION

In cross-pollination species, the transfer of pollen from a flower the stigmas of the other may be brought about the wind (anemophilic) water (hydrophilic) or insects (entomophilic). Many of the crop plants are naturally cross-pollinated. In many sp. a small amount (upto 5-10 per cent) of selfing may occur. There are several mechanisms that facilitate cross-pollination.

1. DICLINY - or unisexuality is a condition in which flowers are either staminate (mala) or pistillate (female)

a. Monecy - Staminate and pistillate flowers occur in the same plant, either in the same inflorescence e.g. castor, mango, banana, coconut or in separate inflorescence e.g

maize. Other monoecious species cucurbits, walnut, chestnut, straw berry, rubber, grapes and cossava.

b. Dioecy- The male and female flowers are present on different plants. E.g. Papaya, date, hemp, asparagus and spinach.

2.DICHOGAMY - Stamens and pistils of hermaphrodite flowers may mature at different times facilitating cross pollination.

a. Protogzymy - In crop sp. like cumbu, gynoecium matures fruits.

b. Protandry - In maize and sugar beets androecium mature first.

3.In lucerene, stigma are covered with a waxy film. The stigma does not become receptive until the waxy film is broken. The waxy membrane is broken by the visit of honey bees which also effect cross pollination.

1. A combination of two or more of the above mechanisms may occur in some species. This improves the efficiency of the system in promoting cross pollination. E.g. Maize exhibits bothmonecy and protandry.
2. Self incompatibility - It refers to the failure of pollen from a flower to fertilize the some flowers or other flowers on the same plant. It is highly effective in preventing self pollination. e.g. self icompatibility in common in Brassica, Nicotiana, Radish, Rye and Many grasses.
3. Male sterility - It refers to the absence of functional pollen grains. But it is of great value for the production of hybrid seeds.

Genetic consequences of cross-pollination

Cross-pollination preserves and promotes heterozygosity in a population. Cross-pollinated sp. are highly heterozygous and show mild to severe inbreeding depression and a considerable amount of heterosis. The breeding methods in such species aim at improving the crop species with out reducing heterozygosity to an appreciable degree.

OFTEN CROSS-POLLINATED SPECIES

In many crop plants, cross pollination often exceeds 5 per cent and may reach 30 per cent. Such sp. are generally known as " often cross pollinated crops" e.g. Sorghu, cotton, redgram and safflower etc.,

The genetic architecture of such crops is intermediate between self-pollinated and cross-pollinated sp. Consequently in such species breeding methods suitable for both of them may be profitably applied. But often hybrid varieties are superior to others.

INCOMPATIBILITY

It is the inability of a plant producing functional female and male gametes to self-seed when self-pollinated. It is met with both in heteromorhphic species with differences in morphology of flowers of different plants and in homomorphic species with no differences in floral morphology. The term “Self incompatibility" was originally coined by Stout in 1917.

Incompatibility is due to some physiological hindrance to fertilization caused by the failure of pollen to germinate on the stigma or slow growth of the pollen tube along the style sometimes fertilization is effected, but the embryo degenerates at a very early stage.

The main features of self-incompatibility are;

i. It is an important out breeding mechanism, which prevents autogamy and promotes allogamy.
ii. Self-incompatible species do not produce seed on self-pollination but lead to normal seed set on cross-pollination.
iii. It maintains high degree of heterozygosity in a species due to out breeding and reduces homozygosity due to elimination of in breeding of selfing.
iv. Self-incompatibility results due to morphological genetic, physiological and biochemical causes. It is not under single genetic control.
v. Self-incompatibility reaction can operate at any stage between pollination and fertilization.
vi. Self-incompatibility has been reported in about 70 families of angiosperms including several crop species.

CLASSIFICATION

Self-incompatibility can be classified on the basis of

i. flower morphology
ii. genes involved
iii. site of expression of self-incompatibility reaction and
iv. pollen cytology

Basis of classification	Types of incompatibility	Brief description
Flower morphology	a. Heteromorhphic	Self incompatibility is associated with differences in flower morphology
	i. Distyly	Styles and stamens are of two types i.e. short and long.
	ii. Tristyly	Styles and stamens have three positions i.e. short medium and long.
	b. Homomorhphic	Flowers do not differ in morphology
	i. Saprophytic	Self-incompatibility is governed by genotype of pollen producing plant.
	ii. Gametophytic	Self-incompatibility is governed by genetic constitution of gametes.
Genes involved	a. Monoalble	Self-incompatibility is governed by single gene
	b. Diallelic	Self-incompatibility is governed by two genes
	c. Polyallelic	Self-incompatibility by several genes
Site of expression	a. Stigmatic	Self-incompatibility genes express on the stigma
	b. Stylar	Self-incompatibility express in the style
	c. Ovarian	Self-incompatibility express in the ovary
Pollen cytology	a. Binucleate	Pollen grains have two nuclei
	b. Trinuleate	Pollen grains have three nuclei.

SELF INCOMPATIBILITY

Band on flower morphology, self-incompatibility system is of two types.

i. Heteromorphic system.
ii. Homomorphic system a. Gametophytic control b. Sporophytic control

HETEROMORPHIC SYSTEM

When self-incompatibility is associated with differences in floral morphology. It is known heteromorphic system. In this system, self-incompatibility results due to differences in the length of style and stamen. This system is divided into two types viz., a. Distly and b. Tristly.

a. Distly: It refers to two types of styles (short and long) and stamens (low and high). This system operates in the family Primulaceae. In Primula, there are two types of

flowers. i.. Thrum type which has short style and high anthers. ii. Pin type with long style and high anthers. The crosses are compatible only between the style and stamen of matching length. In otherwords, crosses are compatible between Pin x Thrum or Thrum x pin but not between Pin x Pin and Thrum x Thrum flowers.

Lateron, it was discovered that, incompatibility barrier between Pin and Pin and Thrum x Thrum are govered by a single gene S which behaves in a heterozygous (Ss) and Pin is homzygous recessive (ss). Thus thrum is dominant over Pin. Cross between thrum and Pin produce thrum and Pin in 1:1 ratio in F1.

Distyly

MATING		PROGENY	
Phenotype	Genotype	Genotype	Phenotype
Pin x Pin	Ss x Ss	Incompatibility mating	-
Pin x Thrum	Ss x Ss	1 Ss x 1 Ss	1 Thrum : 1 Pin
Thrum x Pin	Ss x ss	1Ss x 1 ss	1 Thrum x 1 Pin
Thrum x Thrum	Ss x Ss	Incompatible	-

The incompatibility reaction of pollen is determined by the genotype of the plant producing them. The incompatibility system therefore in heteromorphic saprophytic.

Several variations were observed in other plants. For example in Linum grandiflorum, flowers have long and short styles, but pollengrains are of same size. The limonium vulgare stamens and styles are monomorphic, but stigmatic surface and pollen size are dimorhphic.

b. Tristly

When style has three positions (short, medium and long) and filaments are of three lengths corresponding to the length of style.

Any one plant has one style length and four stamens with two different lengths of filaments pollination are compatible only between stigmas and anthers at the same level. Thus each type of plant can effectively fertilize the other two types.

1. Homomorphic system

In this system, the plants do not have differences in the length of style stamens or other floral parts. This system is very much important in crop plants. It can operate in various ways as given below:

i. The pollen grains do not germinate on the stigma of the same flower. If they germinate the pollen tube fails to penetrate the stigma as in Rye, Cabbage and Radish.

ii. The pollen grains may germinate but there is retard action of pollen tube growth.

iii. In some cases, there is slow rate of pollen tube growth and it rarely reaches the ovary.

iv. In some cases, pollen tubes growth may be normal but it does not release the male gamete.

Homomorphic system is of two types viz., a. Gametophytic system and b. Sporophytic system.

Gametophytic system

MAIN FEATURES OF GAMETOPHYTIC SYSTEM

- Self-incompatibility in majority of species is governed by a single gene S, which has large number of multiple alleles.[In Rye self-incompatibility reaction is governed by two loci (Lundquist,1956)].
- In this system alleles have individual action in the style without interaction.
- Pollen grains are unable to germinate or function on a pistil having similar allele as that of pollen. The pollen tube growth is usually inhibited in the style or ovary.
- This system gives rise to three types of pollination's v.z, (1) Fully incompatible (S_1S_2 x S_1S_2) in which both alleles are common in the pollen and ovule (2) Half the pollen is compatible (S_1S_2 x S_1S_3), in which one allele is different, and 3) Fully fertile (S_1S_2 x S_3S_4) when both alleles differ in pollen and ovule.
- Gametophytic system permits recovery of male parent only in the partially fertile crosses which are obtained when one allele differs in the cross, viz., S_1S_2 x S_1S_3. This cross would give rise to S_1S_3 and S_2S_3 progeny.
- Plant sps. belonging to gametophytic self-incompatibility system have binucleate pollen.

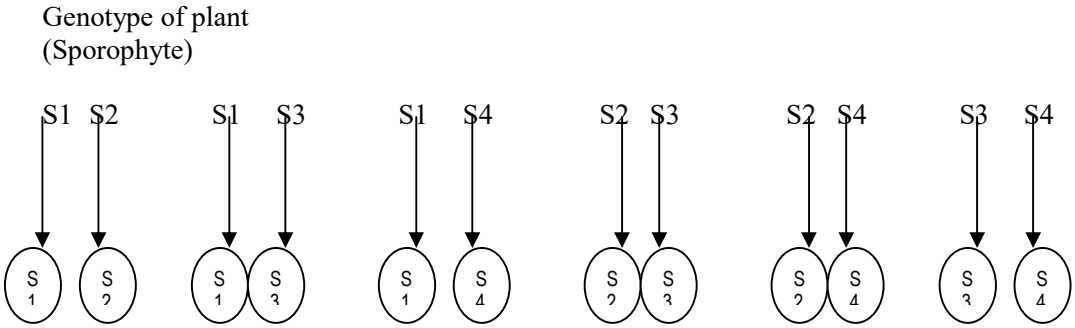
MAIN FEATURES OF SPOROPHYTIC SYSTEM

- Here the self-incompatibility is controlled by a single gene S that has multiple alleles.
- The alleles may show dominance, individual action or interaction in either pollen or style as per allelic combinations involved.
- This system exhibits inhibition of pollen germination or pollen tube growth on the stigma of same flower.
- The Sporophytic systems contains a form of dominance in which S_1 is dominant over all others, S_2 is dominant over all except S_1, and so on ($S_1 > S_2 > S_3 > S_4$). In this system, crosses between different genotypes are either fully fertile or completely sterile.
- Pollen grains from both heterozygous or homozygous plants react in a similar fashion due to dominance effect of male parent. For example, pollen grains from S_1S_1 or S_1S_2 plants would have S_1 phenotype and from S_2S_2 or S_2S_4 as S_2 phenotype.
- This system permits recovery of parental genotypes in some crosses. For example, a cross between S_1S_3 female and S_2S_3 male will produce S_1S_2 , S_1S_3 , S_2S_3 and S_3S_3 genotypes, which represent parental genotypes also.
- Plant species belonging to this system of self-incompatibility generally have trinucleate pollens.

Comparison of gametophytic and Sporophytic systems of self incompatibility

S. No.	Gametophytic system	Sporophytic system
1	Self incompatibility is controlled by the genetic constitution of pollen	Self incompatibility is controlled by the genotype of pollen producing plant (sporophyte)
2	Incompatibility is governed by a single S gene with multiple alleles	Self-incompatibility is also governed by a single S gene with in either alleles.
3	Alleles have individual action in the style without interaction	Alleles may show dominance, individual action or interaction in either pollen or style
4	The pollen tube growth is usually inhibited in the style or ovary	Pollen germination or pollen tube growth is inhibited on the stigma
5	Plant species belonging to this system have binucleate pollen grains	Plant species belonging to this system have trinucleate pollen grains
6	Recovery of only male parent is possible from crosses	Recovery of both male and female parents is possible from crosses
7	Does not permit production of homozygotes	Permits production of some homozygotes
8	Crosses may be sterile, partially fertile or fully fertile	Crosses would be either fully sterile or full fertile
9	Such incompatibility can be overcome by polyploidy	This cannot be overcome by polyploidy
10	Examples of this system include red clover, white clover, rye, potato, tomato etc.,	Examples of this system include radish, cabbage, cauliflower etc.,

HOMOMORPHIC SPROPHYTIC SYSTEM OF INCOMPATIBILITY



Genotype of gametes

Incompatibility reaction of pollen grains.	A11 S1	A11 S1	A11 S1	A11 S2	A11 S2	A11 S3
Incompatibility Reaction of style	S1	S1		S1	S2	S2	S3

S1 S2 x S1 x S2 ⟶ Complete incompatibility

S1 S2 x S1 x S3 ⟶ Complete incompatibility

S1 S2 x S1 x S4 ⟶ Complete incompatibility

S1 S2 x S2 x S3 ⟶ Complete incompatibility

Significance of self incompatibility

Self-incompatibility is of great significance to plant breeders. It is an important pollination control device, which prevents autogamy and promotes allogamy. In plant breeding it is useful in two main ways.

i. Production of hybrids

Self-incompatibility provides a way for hybrid seed production without emasculation and without resorting to genetic or cytoplasmic male sterility. IT has been utilized for production of commercial hybrids in Brassica and sunflower. Two self incompatible lines are planted in the alternate row for hybrid seed production. Harvest from both the lines as hybrid seed. In Japan it used for cruciferous crops.

ii. Combining desirable genes

Self-incompatibility system permits from 2 or more different sources through natural cross pollination that is not possible in self-compatible species. Moreover knowledge of self-incompatibility specially in fruit crops, helps fruit growers to increase the yield of fruits by providing suitable pollination.

Limitations

i. It is very difficult to produce homozygous inbred lines in a self-incompatible species. Bud pollination has to be made to maintain the parental lines.

ii. Self-incompatibility is affected by environmental factors like temperature and humidity self-incompatibility is reduced or broken down at high temperature humidity.

iii. Sometimes bees visit only one parental line in the seed production resulting in sibmating.

STERILITY

It is due to failure of any of the process concerned with normal alteration of generation viz., development of pollen, embryo sac, and embryo endosperm causing non-functional gametes. So failure to set seeds, may be due to sterility, caused by non - functional gametes.

Sterility may be caused by chromosomal aberrations, gene action or cytoplasmic influences.

Chromosomal sterility

Sterility in auto polyplids, interspecific hybrids eneuploids and individuals carrying chromosomal aberrations in very often due to chromosomes.

Sterility in autopolyploids.

Autopolyploids are usually highly sterile because the behaviour of chromosomes during meiosis in autopolyploids in peculiar due to the fact that they posses more than two homologous chromosomes.

We shall consider meiosis in an auto triploid as an example of autopolyploids. During zygonema stage, genetically homologous regions of the chromosomes pair in such a very that at any one place, chromosome pairing in between two chromosomes only. Two of the three homologous chromosomes may completely pair as bivalent, leaving one chromosome unpaired as an univalent. There are seven possible configurations at diakinesis of an auto triploid as follows:

1. Three univalents
2. A ring bivalent and an univalent
3. A rod bivalent and an univalent
4. A trivalent having the form of ring of two, with third chromosome attached to the ring at the one end.
5. A trivalent having the form of a ring of two, with the third chromosomes attached to the ring at each end.
6. A trivalent having the form of a 'Y'
7. A trivalent having the form of chain

Behaviour of univalent in Anaphase-I.

An univalent that reaches the spindle either remains without division on the equatorial plate and so is not included in the daughter nuclei or divides into two chromotids, one moving to each pole so slowly that it may not be included in the daughter nuclei. An univalent that does not reach the spindle in either lost in the cytoplasm or occasionally caught up by chance into one of the two daughter nuclei.

Behaviour of Trivalents

Two chromosomes may move to opposite poles leaving one on the equatorial plate (false movement). Triploids do not have a balanced complement of chromosome, only a few or viable.

Chromosome pairing in autotetraploid

One quadrivalent or two bivalents may be formed at the zygonema stage, if the pairing between the four homologous chromosomes is complete. If the pairing is incomplete, they may form one bivalent and two univalents or one trivalent and one univalent or very rarely four univalents.

In auto tetraploid, the sterility is not however usually as high as in triploids, because tetraploids have even number of homolgous chromosomes and regular segregation is more likely than in triploids.

Sterility in interspecific hybrids

The most characteristic feature of interspecific hybrids in sterility in a greater or lesser degree. The fact that amphidiploids derived from several hybrids become fertile once each chromosome has a fully homologous partner with which to pair shows that the sterility of the F1 is sometimes due sterility to chromosomes.

Sterility in Aneuploids

Aneuploids tend to be irregular at meiosis and as a result they are highly sterile. Monosomics and trisomics posses an uneven numbers of some particular chromosome and therefore form a high percentage of unbalanced gametes. In the meiosis of a monosomic, the old chromosome passes at random to either pole resulting in formation of two kinds of gametes (n and n-1). Frequently, the included in either daughter nucleus.

At meiosis, in a trisomic, all the three chromosomes may form a trivalent or bivalent and univalent. It gives rise to gametes with n +1 or n chromosomes. Gametes with n+1 chromosome, especially on the male side, do not offer function in fertilization.

Sterility due to chromosomal aberrations

Chromosomal aberrations very often cause sterility because they give rise to gametes that carry deficiencies or duplications for some genes. In most plants, embryosac with deficiencies or duplications may be functional but pollen grains with deficiencies or duplications are mostly inviable. Consequently plants carrying chromosomal aberrations may produce fewer seeds than normal plants.

MALE STERILITY

It is characterized by non-functional pollen grains while female gametes function normally. It occurs in nature sporadically perhaps due to mutation.

It is classified into three groups;

1. Genetic male sterility
2. Cytoplasmic male sterility
3. Cytoplasmic genetic.

Genetic male sterility

Genetic male sterility is governed by single recessive gene ms, but dominant genes governing male sterility are also known. (e.g. safflower)

A male sterile line may be maintained by crossing it with heterozygous male fertile plants such a mating produces 1:1 male sterile and male fertile plants.

Inheritance of genetic male sterility

ms ms x Ms Ms

(male stetile) (male fertile)

↓

F1 Ms ms - Male fertile

↓

F2 1 MsMs : 2 Ms ms : 1 ms ms

3:1

Male fertile Male sterile

Maintenance of male sterile lines

Male sterile " A" Male fertile " B"

Ms ms x Ms ms

↓

1 Ms ms : 1 ms ms

(male sterile) (Male sterile)

(seed harvested)

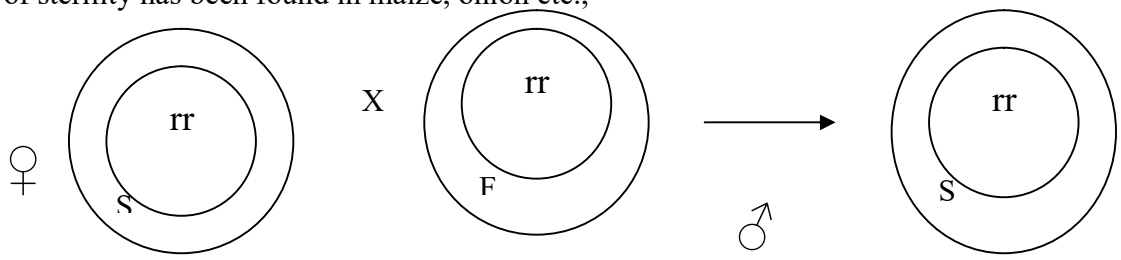
Maintained by sibmating seeds from male sterile plants one harvested

Genic male sterility utilization in plant breeding

Genetic male sterility may be used in hybrid seed production. The male sterile lines are inter planted with homozygous male fertile pollination. The genotypes of the ms ms and Ms ms lines are identical except for the ms locus i.e. they are isogenic and are known as male sterile (A0 and maintain (B) lines respectively. The female line would therefore, contain both male and sterile and male fertile plants. The male fertile plants must be identified and removed before pollen shedding. This is done by identifying the male fertile plants in seedling stage, either due to the pleiotropic effect of the ms gene or due to the phenotypic effect of a closely linked gene. Roguing of a male fertile plants from the female line is costly as a result of which the cost of hybrid seed is higher. Due to these difficulties, genetic male sterility has been exploited commercially only in a few countries. In USA it has been successfully used in castor. In India, it has been used in redgram by some private seed companies.

CYTOPLASMIC MALE STERILITY

Plants carrying particular types of cytoplasm are male sterile but will produce seed if pollinated by pollen from male fertile plants. These seeds produce only male sterile plants since their cytoplasm is derived entirely from the female gametes. This type of sterility has been found in maize, onion etc.,



Male sterile Male fertile Male sterile

The male sterile line is called " A" line and male fertile line is known as the maintainer line ♂ "B" line, as it is used to maintain the male sterile line. The genes conditioning cytoplasmic male sterility, particularly in maize residue in mitochondria, and may be located is a plasmid like element.

CMS may be transferred easily to a given strain by using that strain as a pollinator (Recurrent parent) in the successive generation of a backcross programme. After 6 to 7 backcrosses, the nuclear genotype of the male sterile line will be almost idendtical to that of the recurrent pollinator strain.

Utilization in plant Breeding

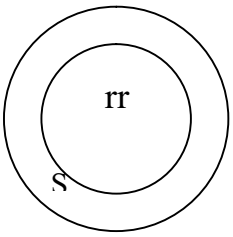
CMS may be utilized for producing hybrid send in certain ornamental species, or in species where, a vegetative part is economic value. But in these crop plants where seed is the economic part, it is of no use because the hybrid progeny would be male sterile.

CYTOPLASMIC GENETIC MALE STERILITY

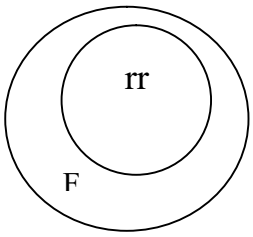
In this system, a nuclear gene for restoring fertility in the male sterility line is known. The fertility restorer gene 'R' is dominant and found in certain strains of the species or maybe transferred from a related species. e.g. wheat. This gene restores male fertility in the male sterile line, and hence it is known as restorer gene. This system is known in maize, cholam, pearl millet, sunflower, rice and wheat.

The plants would be male sterile in the presence of male sterile cytoplasm, if the nuclear genotype were rr, but would be male fertile, if the nucleus were Rr or RR. New male sterile lines can be developed by repeated back crossings as in the case of cytoplasmic system. But the nuclear genotype of the pollinator strain used in the transfer must be "rr" otherwise the fertility would be restored.

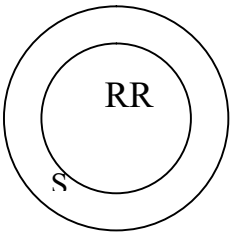
CYTOPLASMIC GENETIC MALE STERILITY - Various genotypes & phenotypes



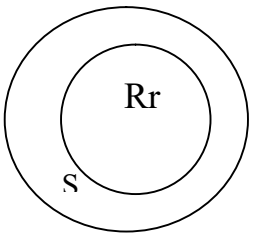
Male sterile
Cytoplasm sterile
Nuclear gene- non-restorer
Recessive allele



Male fertile
Cytoplasm fertile
Nuclear genes non-restorer



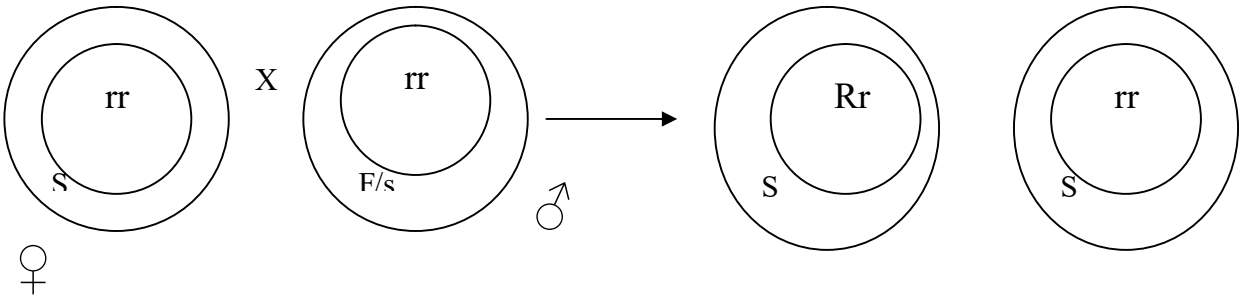
Cytoplasm sterile
Nuclear gene- non-restorer
in homozygous (RR) or heterozygous (Rr)



Male fertile

Effect of sterile cytoplasm
engaged by restorer gene.

Results of various matings:



♀
Male sterile

Male fertile

Male fertile

Male sterile

Utilization in plant breeding

The cytoplasmic genetic male sterility is used commercially to produce hybrid seeds in maize, pearl millet, cholam, Rice and wheat.

Origin of male sterile cytoplasm

Male sterile cytoplasm arises spontaneously in nature or maybe produced by the breeder. The various sources of the male sterile cytoplasm are as follows

i. Spontaneous mutation: arise in low frequencies isolated in maize, pearl millet and sunflower.

ii. Interspecific hybridization: Transfer of the full somatic chromosome complement of a crop species, through repeated back crossing, into the cytoplasm of a related wild species often leads to cytoplasmic male sterility. In cross-pollinated sp. the male sterile cytoplasms have generally originated through mutation, while in self-pollinated crops, they have been transferred from related species.

iii. Induction through Ethidium Bromoide: Male sterile cytoplasm may be induced by seed treatment with Ethidium bromide. E.g. Petunia.

Chemically induced male sterility

The chemical at a particular concentration is sprayed on the foliage prior to flowering and this inhibits production of viable pollen without injuring the gynoecium. The flower set seed on cross-pollination. The chemicals used for inducing male sterility are called male gametocides, pollen sterility are called male gametocides, pollen suppressants and chemical hybridizing agents.

Environmental influence on male sterility

Environment influences the expression of male sterility in certain crops. Temperature sensitive (TGMS) and photoperiod sensitive (PGMS) genic male sterility has been identified in certain crops like rice, sorghum, tomato, maize castor and sugar beet.

Use of environmental genetic male sterility (EGMS), either TGMS or PGMS is involving hybrids is known as " Two line breeding". In China two line hybrids based on TGMS system are popular in rice.

LIMITATIONS OF CYTOPLASMIC GENETIC MALE STERILITY FOR USE IN PLANT BREEDING

i. Undesirable effects of cytoplasm: Male sterile cytoplasm generally has undesirable side effects. For example - Texas cytoplasm in maize is the most successful cytoplasm commercially, but slightly retards growth, reduces yield, plant height and leaf number. It also makes the plants susceptible to helminthosproium leaf blight. The male sterile cytoplasm in tobacco could not be used due to its severe undesirable side effects.

ii. Unsatisfactory fertility restoration: In many cases, restoration of fertility is not satisfactory. As a result, these sources cannot be used in the production of hybrid seed.

iii. Unsatisfactory pollination: Natural pollination is often not satisfactory, except in wind pollinated crops line maize. This reduces the production of hybrid seed and thereby increases its cost. In some sp. the capsicum, this has prevented the use of male sterility in hybrid seed production.

iv. Modifier genes: This may reduces the effectiveness of cytoplasmic male sterility and lead to some pollen production by the male sterile lines.

v. Some times, cytoplasm may also be contributed by the sperm, which is the long run, may lead to a breakdown of the male sterility mechanism.

vi. Male sterility Mechanism may breakdown partially under certain environmental condition, resulting in some pollen production by the male sterile liens. This problem is encountered in maize, barja and sorghum.

vii. In crops like wheat, polyploid nature of the crop and undesirable linkage with the restorer gene make it very difficult to develop a suitable restorer (R) line.

APOMIXIS

Seeds are formed but the embryos develop without fertilization. The plants resulting from them are identical in genotype to the parent plant. In apomixis, sexual reproduction in either suppressed or absent. When sexual reproduction does occur, the apomixis is termed as " Facultative". But when sexual reproduction is absent it is referred to as obligate.

CLASSIFICATION

Adventive Embryony

Embryos develop directly from vegetative cells of the ovule, such as nucellus, integument and chalaza. Adventive embryony occurs in Mango (*Mangifera indica*) citrus etc.,

Apospory

Some vegetative cells of the ovule develop into unreduced embryosacs after meiosis. The embryo may develop from egg cell or some other cell of this embryo sac. It occurs in some species of Hieraceum, Malus, crepis, Ranum culus etc.,

Diplospory'

Embryo sac is produced from the megaspore, which may be haploid or more generally diploid. Generally the meiosis is no modified that the megaspore remains diploid. Diplospory leads to parthenogenesis or apogamy.

Parthenogenesis

The embryo develops from egg cell. Depending upon whether the embryosac is haploid or diploid, parthenogenesis is termed as haploid or diploid parthenogenesis. Haploid parthenogenesis occurs accidentally and has been reported in Solanum nigera, Nicotiana, Crepis and Maize. Diploid parthenogenesis occurs in many grasses e.g. Taraxacum.

Apogamy

Synnergids or antipodal cells develop into an embryo. Like parthenogenesis, apogamy may be haploid or diploid depending upon the haploid or diploid state of the embryosac. Diploid apogamy occurs in Anternna, Alchemilla, Allium and many other plant species.

Significance of Apomixis

Apomixis is a nuisance when the breeder desires to obtain sexual progeny. But it is of great help when the breeder desires to maintain varieties. Thus in breeding of apomicitc species, the breeder has to avoid apomictic progeny when he is making crosses or producing inbred lines. But once a desirable genotype has been selected, it can be multiplied and maintained through apomictic progeny. This would keep the genotype of a variety intact.

Classification based on stability

Based on the stability of apomixis in subsequent generations, they are classified as,

1. Recurrent (stable) apomixis
2. Non-recurrent (unstable) apomixis

Diploid apospory, diploid parthenogenesis and diploid apogamy are recurrent apomixis. Haploid apospory, haploid parthenogenesis and haploid apogamy are non-recurrent apomixis.

Androgamy

Refers to the development of embryo from one of the male gametes, inside or outside the embryo sac and it is haploid in nature.

Apomicts conserve the genetic constitution of the parent. Heliozygosity and consequent hybrid vigour can be permanently fixed through apomixis. Genetically uniform individuals can be rapidly multiplied, as it does not involve segregation. Breeding for apomicts is called " Single line breeding".

CENTRES OF ORIGIN

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. 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 the other areas primarily due to the activities of the man. These 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. Dominant genes characterize primary centres and secondary centres are characterized by a diversity of recessive character and are also devoid of wild relatives.

Law of homologous series in variation

Vavilov postulated this law of homologues series and this law states that characters found in one species also occur in other related species. In wheat diploid (2x), tetraploid (4x) and hexaploid (6x) wheats show a series of identical contrasting characters. Similarly, genes secale duplicates the variation found in 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 from the centre of its origin.

Main centres of origin proposed by Vavilov.

1. Chinese centre
2. Hindustan centre
3. Central Asiatic Centre
4. Near Eastern centre
5. Mediterranean centre
6. Abyssinian centre
7. South Mexican and Central American centre.
8. South American centre

1. Chinese centre

   This centre consists of the mountainous regions of the Central and Western China and the adjacent low lands. It is the largest and oldest independent centre of origin. A total of 136 endemic plants are listed, among which are a few important crops such as,

It is the primary centre of origin: Soybean, Radish. *Colocasia antiguorum, Panicum, Miliaceum* and some other species of millets, buckwheat, opium proppy. Several species of Brassica and Allium, Brinjal , some species of Cucurbita, pears, peaches, apnicotd, plums, orange, Chinese tea.

It is the Secondary centre of origin for maize, Rajsmash, Cowpea, turnip, sesame.

2. Hindustan centre: this centre includes Assam and Burma (now called Myanmar), Malaya Archipelago, Java and Sumatra one hundred and seventeen plants are considered to the endemic.

It is the primary centre if origin for Rice, Arhar, Chickpea, Mungbean, Brinjal, Turnip *Cucumis sativus*, Lettuce, certain species dioscorea, Raphanus indicus, Saccharum officinarum several species of cotton (particularly Gossypium arboreum), Hemp, Black pepper (Piper nigrum) indigo, mango, orange, sour lime and Some other citrus species, coconut, banana and turmeric.

3. Central Asiatic centre

This region includes north west India (Punjab, Northwest frontier province and Kashmir), Afghanistan, Tadjikistan and Uzbekistan (USSR) and Tian-Shan (China). Forty three plants are tested. It is also known as the Afghanistan centre of origin. The crops originated in this centre. The crops originated in this centre (Primary centre of origin) are, wheat (*Triticum aestivum*), club wheat (*Tritcum compactum*), Pea (*Pisum sativum*), Broad bean (*Vicia faba*). Linseed, Safflower cotton (G. *herbaceum*), Musk melon, carrot, pear, almond, Grapes, apple, Spinach, apricot. It is secondary centre of origin of rye.

4. Near Eastern centre

This is also known as the Asia Minor centre or Persian centre of origin. This region includes the interior of Asia Minor, all of Transcancasia, Iran and high lands of Turkmenistan (USSR). Eighty-three species are included in this region. The crop species that originated in this region (primary centre of origin) include nine species of Triticum, rye, alfalfa, Persian elover, carrot, cabbage, oats, lettuce, fig, pomegranate, apple several species of pyrus, prunus, grape, almonds, chestnut. It is the secondary centre of origin of rape, black mustard, turnip and apricot.

5. Mediterranean centre

This region includes the borders of the Mediterranean sea. Eighty four plants are known to have originated here including many valuable cereals, legumes and cultivated vegetables. The species that originated in this centre (primary centre of origin) are: Durum wheat (T. durum),, emmer wheat (T. dicoccum) and other Triticum species, several species of Avena, Barley, Lentil, several species of Lathyrus, pea, broad bean, Lupeens, Chickpea, clovers, several species of Brassica, Onion garlic, Lettuce, Antichoke, Asparagus, Lavender and Peppermint.

6. Abyssinian Centre

It comprises Abyssinia (now Ethiopia) Eritrea and parts of Somalia. Thirty eight species are native to this region. It is the primary centre of origin for *Hordeum vulgare* (Barley), *Triticum durum, T. turgidum T. dicoccum*, *Sorghum bicolor*, Bajra, gram lentil, *Dolichos lab lab*, Linseed, Safflower, sesame, castor, coffee, onion, okra. It is the secondary centre of origin for broad bean. (*Vicia jaba*).

7. South Mexican and Central American centre

This includes the region of southern parts of Mexico, Guatmela, Honduras and costa rica. The plants originated as primary centre here maize, Rajmash (*Phaseolus vulgaris*), Lima bean (*P. lunatus*), melons, pumpkin, sweet potato, Arrow root, chillies, cotton, (*G. hirsutum and G. purpureascens*), papaya (*carica papaya*), guava and avacado.

8. South American centre

This centre includes the high mountainous region of Peru, Bolivia, Ecuador, Colambia, Parts of Chile and Brazil and whole of Paraguay. This centre is the primary centre of origin for many species like potato, maize, lima bean, pea nut, pine apple (*Ananas comora*), pumpkin (C*ubbita maxima*), Egyptian cotton (*G. barbadense*), tomatoes, guava, tobacco, quinine tree, cassava (M*anihot utilissima*) and rubber.

Centres of diversity

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 are may exhibit much greater diversity

than the centre as a whole. These areas are known as "Micro centres". The crop evolution appears to proceed at a more rapid rate in such micro centres.

Vavilov called this small areas varietal richness within the basic centre of diversity as " agro-ecological groups". This idea was extended by Harlan (1951) who used the term " Miccro centre" a region, which may contain an astonishing variation of one or more crops. For wheat Harlan identified three such micro centres in Turkey. These gene micro centre present another breakdown in the geo-botanical pattern of variation and in these places evolution is still producing rapidly. Harlan advocates an intensive survey of micro centre populations.

Vavilov began with five centres in 1926, but raised them to eight with three sub centres in 1935 and 1951. Later authors, such as Darlington and Janaki Ammal (1945) have increased the number of centres to 12; In 1956, Darlington brought it to 15 and subsequently in 1973 to 16, Zhukovsky (1965) one of the Vavilov's Collegues, proposed a series of twelve " Macro centre" on " Megagene" centres covering almost the whole world. The mega gene centres are :

1. China
2. Indo-China - Indonesia
3. Australia- Newzealand
4. Indian sub continent
5. Central Asia.
6. West Asia
7. Mediterranean Coastal and adjacent region
8. Africa
9. Europe - Siberia
10. Central America
11. Bolivia - Peru - Chile
12. North America.

In 1971, Harlan developed the idea of centres and non-centres. In fact he was prompted in his thinking by evidence that seems to demonstrate that plant domestication occurred almost every where. Such a vast region could hardly be termed a " centre" without distorting the very meaning of the world. So he called it a non-centre.

DOMESTICATION

It is the process of bringing wile species under human management.

The present day cultivated plants have been derived from wild weedy species. The great wild relative was brought about by selection by man as well as nature. Domestication of wild species is still being done and is likely to continue for a long time in the future. This is because, the human needs are likely to change with time. Consequently,. The wild species of little importance today may assume great significance tomorrow.

A notable case of recent development is that of several members of *Eupharbicea* producing latex. The latex of these plants may be commercially used for the extraction of petroleum products. Seeds of jobjobu contain oil, is highly suitable as an industrial lubricant. The plants producing latex are gophor plant (*Hevea sp.)* milk weed (*Euphorbia lathyrus*) etc., As a result the field of these plant are called " Living oil fields".

Natural and Artificial selection under domestication

Selection

May be described as a phenomenon of some genotypes from population leaving behind more progeny than others. The genotypes that produce more progeny are selected for and others are selected against. In nature, there is a continuous selection by natural forces e.g. Temperature, soil, weather, pest and diseases etc., as a result the genotypes more suited to a given environment have behind more progeny than the less adapted ones. This process is known as " **Natural selection**".

The selection by man or "**artificial selection**" often permits only the selected plants to reproduce the progeny from the remaining plants are generally de carded. Thus the natural selection retain considerable variability in the species, while artificial selection progressively reduces this variability.

Artificial and natural selection have led to several distinct changes in the characteristics of domesticated species.

GERMPLASM

The sum total of hereditary material or genes present in a species is known as the germplasm of that species. A germplasm collection is the collection of a large number of genotypes of a crop species and its wild relatives. Germplasm collections are also known as gene banks or world collections, when they are sufficiently large to include genotypes from all over the world.

Germplasm collections are maintained to preserve the genetic variability in crop species and their wild relatives. They furnish the richest source of variability, crop improvement would ultimately depend upon the availability of this variability, to be utilized in breeding programme.

Genetic Erosion

In modern agriculture, large tracts of land are put under pure line varieties of self-pollinated crops and under hybrids of cross-pollinated crops. This has led to a gradual disappearance of local varieties and open pollinated varieties, which are reservoirs of considerable variability. Cultivation and grazing are destroying many wild species and their breeding grounds. Wild relatives of crop may be eliminated by introduced species of weedy nature or even by cultivated forms derived from them. The gradual loss of variability in the cultivated forms and in their wild relatives is referred to as " genetic erosion". This variability arose in nature over a long period of time and if lost would not be produced in a short period.

PLANT GENETIC RESOURCES AND CONSERVATIN

The total genetic diversity of cultivated species and their wild relatives in collectively termed as " genetic resources". Most of the countries are greatly concerned about loss of species richness i.e Biodiversity. The establishment of International Board for plant genetic resources (IBPGR) to coordinate germplasm conservation activities throughout the world reflects this concern. Germplasm collections are being made and maintained to conserve as many as genotypes as possible. The germplasm collections contain land varieties, various wild forms, primitive races exotic collections and highly evolved varieties. Some of the important germplasm collections are listed below:

i. Institute of Plant Industry, Leningrad, has 1,60,000 entries of crop plant.

ii. Royal Botanic Gardens, Kew. England has over 45, 000 entries.

iii. World collections of some of the crops are maintained at the following places.

a. Sugarcane- Canal point, Florida, USA and Sugarcane Breeding Institute, Coimbatore.
b. Groundut - Mumbai, Senegal (Africa)
c. Potato - Cambridge, U.K and Wisconsin, U.S.
d. Annual New world cotton - Near Tashkent, U.S.S.R.
e. Coffee -Ethiopia (Africa)
f. Sweet Potato - Newzealand.

iv. The National Bureau of plant resources (NBPGR) at New Delhi is maintaining large collections of sorghum, pennisetum, wheat, barley, oats, rice, maize and other crops.

v. International Rice Research Institute (IRRI), Los Banos, Philipines is maintaining 42, 000 rice strains and varieties. More than 15,000 entries are maintained in Central Rice Research Institute, (CRRI) Cuttack.

Evaluation and utilization of germplasm

The germplasm accessions are sown in the field adopting usually an augmented design and checks are sown at regular intervals for comparison. Observations are recorded on all plant characters including quality aspects. In addition they are also scored for drought resistance etc., Usually a multidisciplinary approach is followed to observe, score record the characters under study. Then the data can be easily documented with computer facilities.

The best genotypes can be evaluated under further yield trials and released as a variety. Based on the trait under selection, donors can be identified and utilized in the breeding programme. The donors can be used as parents and involved in development of hybrids.

PRESERVATION OF GERMPLASM

Most of the seeds lose viability quickly. Consequently germplasm collection have to be grown every few years. The difficulties generally experienced are:

i. Growing, harvesting and storing large collections is a costly affair requiring much time, labour land money.

ii. There is also risk of errors is labelling.

iii. The genotypic constitution of entries may also change, particularly when the y are grown in environments considerably different from that to which they are adapted. This is particularly true in cross-pollinated species and for local varieties of the self-pollinated species.

The difficulties may be considerably reduced by cold storage of seeds. Seeds of most of the plant species can be stored for 10 years or more at low temperature and low humidity. Thus the entries can be grown every 10 years instead of every year. NBPGR has developed cold storage facilities for germplasm maintenance and this is known as National Germplasm Repository.

GENE SANCTUARY

It is defined as an area of diversity protected from human interference. A gene sanctuary conserves the germplasm insitu, within the environment where it naturally grows. This not only conserves the germplasm with very expensive, but also permits evolution to proceed on its natural course. This allows the appearance of new gene combinations and new alleles not present in the pre existing population. NBPGR has established gene sanctuaries in Meghalaya for citrus and in the North Eastern region for Musa, Citrus, Oryza, Saccharum and Mangifera.

Exploration: are trips for the purpose of collection of various forms of crop plants and their related species. Exploration generally cover those areas that are likely to show the greatest diversity of forms. The centres of origin are such areas and are often visited by various exploration teams. In addition to wild flowers, lend and open pollinated varieties are also collected. Exploration is the primary source of all the germplasm maintained in germplasm collections.

An expedition has to be meticulously planned. It must be based on a sound knowledge of the biosystematics of the genera and species to be collected. The ecology of vegetation types and the climatology of the region to be explored should also be considered. More emphasis should be placed on ecological aspects. A preliminary survey may be conducted before the collections are actually made. The job of an exploration is a difficult one. The job of an exploration is a difficult one as many diverse types as possible should be collected and as far as possible, duplication in the collections should be avoided.

Generally, it is extremely difficult to avoid duplication, this in turn, leads to overcrowding of germplasm collections. This becomes more difficult because the value of various types, either directly as varieties or as parents in hybridization, cannot be accurately predicted from their appearance i.e. phenotype.

PLANT INTRODUCTION

Plant introduction consists of taking a genotype or a group of genotypes of plants into new environments where they were not being grown before. This introduction may involve new varieties of a crop already grown in the area, wild relatives of the crop species or a totally new crop species for the area. Often the materials are introduced from other countries or continents. But movement of crop varieties from one environment into another within a country is also introduction. Some examples of within the country introduction are popularization of grape cultivation in Haryana, of wheat in West Bengal and of rice in Punjab. Introduction may be classified into two categories, primary and secondary.

Primary introduction

When the introduced variety is well suited to the new environment. It is released for commercial cultivation without any alteration in the original genotype, this constitutes primary introduction. It is less common particularly in countries having well organized crop improvement programme.

Example. Introduction of semi-dwarf wheat (*Triticum aestivum*) varieties, Sonora 64, Lerma Roja (pronounced as "Lerma Roho') and of semi dwarf Rice (O. sativa) varieties Taichung native 1, IR 8, IR 28, IR 36, IR 64,. IR 66, IR 72 are some examples of primary introduction in this country.

Secondary introduction

The introduced variety maybe subjected to selection to isolate a superior variety. Alternatively, it may be hybridized with local varieties to transfer one or few characters from this variety to the local ones. These processes are known as secondary introduction. It is much more common than primary introduction.

Example: Kalyansoa and Sonalika wheat varieties selected from materials introduced from CIMMYT, Mexico.

Semi dwarf wheat and rice varieties developed through hybridization with introduced varieties etc.,

TKM 9, ADT 36, ADT 39, ADT 43, TRY 1, TRY (R) 2, ASD 18 rice varieties.

Purpose of plant introduction

The main purpose of plant introduction is to improve the plant wealth of the country.

Main objective of plant introduction

i. To obtain an entirely new crop plant e.g Maize, potato, tomato

ii. To serve as new varieties. E.g. IRRI varieties.

iii. To be used in crop improvement

iv. To save the crop from diseases and pests. Eg. Coffee from leaf rust. Hevea Rubber from leaf diseases.

v. For scientific studies

vi. Aesthetic value.

Procedure for plant introduction

The chief function of plant introduction is to make available variation to be utilized in breeding programme. Introduction of the following steps:

1. Procurement
2. Quarantine
3. Cataloguing
4. Evaluation
5. Multiplication
6. Distribution.

Plant introduction agencies in India

1. NBPGR, New Delhi (Routed only through NBPGR)

2. Forest Research Institute, Dehra Dun

3. Botanical Survey of India.

4. Central Research Institute for various crops.

Adaptation

It is the process by which organisms become more suited to survive and function in a given environment. It also refers to the results of this process.

Adaptability

It is ability of a genotype to produce a relatively narrow range of phenotypes in different environments. It is the result of genetic homeostasin, which refers to the

buffering capacity of a genotype to environmental fluctuations. The performance of a genotype mainly depends on the environmental interaction.

Acclimatization

Generally, the introduced varieties perform poorly because they are often not adapted to the new environment. Sometimes, the performance of a variety in the new environment improves with the number of generations grown there. The process that leads to the adaptation of a variety to a new environment is known as " Acclimatization". Acclimatization is brought about by a faster multiplication of those genotypes, that are better adapted to the new environment. Thus acclimatization is essentially natural selection.

The extent of acclimatization is determined by

i. the mode of pollination
ii. the range of genetic variability present in the original population and
iii. the duration of life cycle of the crop.

As a result, cross-pollination is much more helpful in acclimatization than self-pollination.

Merits of plant introduction

i. It provides entirely new crop plants
ii. Provide superior varieties either directly, after selection or hybridization.
iii. Introduction and exploration are the only feasible means of collection germplasm and to protect variability from genetic erosion.
iv. It is very quick and economical method of crop improvement, particularly when the introduction are released as varieties either directly or after a simple selection.
v. Plants may be introduced in new disease free areas to protect them from damage e.g. Coffee and Rubber.

Demerits of plant introduction

The disadvantages of plant introduction are associated with the introduction of weeds, diseases and pests.

Weeds:

i. Aregemme mexicana
ii. Eichhornia crassipes

iii. Phylaris minor

Are the some of the noxious weeds introduced in India.

Diseases

Late blight of potato was introduced from Europe flag smut of wheat was introduced from Australia, Bunchy top Coffee rust came from Ceylon of Banana.

Insect pests

Potato tuber moth came from Italy in 1900 Wooly aphids of apple and fluted scale of citrus were also introduced in India along with plant introductions.

Ornamentals turned weeds

Water hyacinth, *Lantana camara* were both introduced as ornamental plants, but they are now noxious weeds.

Threat to ecological balance

Some introduced species may disturb the ecological balance in their new home, and may cause serious damage to the ecosystem. e.g. Eucalyptus sp. introduced from Australia cause a rapid depletion of the sub soil water reserves.

However, most of the cases of introduction of weeds, diseases and insect pests occurred during a period when quarantine was almost non existent. At present, plant introductions have to satisfy rigid quarantine laws. They are thoroughly examined for weeds disease and pest before their entry is permitted.

BREEDING METHODS IN SELF POLLINATED CROPS

Various procedures like introduction, selection, hybridization, mutations are used for genetic improvement of crop plants. The choice of breeding method mainly depends upon four main factors.

1. Mode of pollination
2. Mode of Reproduction
3. Gene action
4. Breeding objectives in a crop species.

SELECTION

In self-pollinated crop, selection permits reproduction only in those plants that have the desirable characteristics. This is achieved by raising the next generation from seeds produced by the selected plants only. Seeds from the remaining plants are rejected. Selection is essentially based on the phenotype of plants.

The two requirements of selection are;

1. Variation must be present in the population
2. Variation must be heritable.

The purpose of selection in to isolate desirable plant type from a population. Selection is one of the two fundamental steps of any breeding programme. The two basic steps are:

PROGENY SELECTION

Evaluation of the worth of plants on the basis of the performance of their progenies is known as progeny test. Louis De Vilmorin developed the progeny test. Therefore it is also known as " Vilmorin Isolation principal" or Vimorin Principle.

Vilmorin observed that sugar beet plants with high sugar content could be grouped into three classes based on the sugar content of their progenies. The first group of plants produced progenies high in sugar content, the progenies from the second group had some plants with high and some with low sugar content, while the third group produced progenies low in sugar content. Thus plants similar in phenotype (high sugar content) produced considerably different progenies. From three observations, Vilmorin

concluded that the real value of a plant can be known only by studying the progeny produced by it.

The progeny test in the basic step in every breeding method. The progeny test serves two valuable functions.

i. To determine the breeding behaviour of a plant i.e. whether it is homozygous or heterozygous.

ii. To find out, whether the character for which the plant was selected, is heritable i.e due to genotype.

Selections have to be based on phenotype. The relative contributions of genotype and environment to the phenotype of the selected plants can be determined through progeny test. If the phenotypic differences are due to differences in genotype, they will be present in the progeny as well. Otherwise they will be absent in the progeny.

PURE LINE CONCEPT

A pure line is the progeny of a single homozygous plant of a self-pollinated species. All the plants in a pure line have the same genotype. The phenotypic differences within a pure line are due to the environment and have no genetic basis. Therefore, variation within a pureline is not heritable.

The concept of pureline was proposed by Johnnsen in 1903, on the basis of the studies with Beans (*Phaselous vulgaris*). Beans are strictly self-pollinated species. Johannsen obtained commercial seeds of the 'princess variety' of beans. The commercial seed lot showed variation for seed size. He selected the seeds of different sizes and grow them separately. The progenies thus obtained differed in seed size. Progenies from larger seeds generally produced larger seeds than those obtained from smaller seeds. This clearly showed that, the variation in seed size in the commercial seed lot princes had a genetic basis. As a result, selection for seed size was effective.

Johannsen further studied 19 lines; each line was progeny of a single seed from the original seed lot. He discovered that each line showed a characteristic mean seed weight, ranging from 640 mg in Line No.1 to 350 mg in Line No. 19. The seed size with in a line showed some variation, which was much smaller than that in the original commercial seed lot. Johannsen postulated that the original seed lot was a mixture of pure

lines. Thus each of the 19 lines represented pureline, and the variation in seed size within each of the purelines had no genetic basis and was entirely due to environment.

The observations revealed that, the variation for seed size in the original seed lot of princess had a genetic basis and was heritable. The two main conclusions from the Johannsen experiment are:-

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

GENETIC MAKEUP OF SELF-POLLINATED CROPS

Self-pollination increases homozygosity with a corresponding decrease in heterozygosity. Self-pollination is the most intense form of in breeding, since this case, the same individual functions as the male as well as the female parent.

The effect of self-pollination on homozygosity and heterozygosity may be illustrated by an example. Suppose an individual heterozygous for a single gene (Aa), in self pollinated in successive generations. Every generations of self-pollination will reduce the frequency of heterozygote Aa to 50 per cent of that in the previous generation. There is a corresponding increase in the frequency of the homozygotes, AA and aa. As a result, after 10 generations of selfing, virtually all the plants in the populations would be homozygous, ie. AA and aa. On the other hand the frequency of heterozygote Aa would be one only 0.095 per cent, which is negligible.

When a number of genes are segregating together, each gene would become homozygous at the same rate as Aa. Thus the number of genes segregating does not affect the percentage of homozygosity. The term homozygosity denotes the frequency of genes in homozygous condition in the population. Similarly, linkage between genes does not affect the percentage of homozygosity in the population.

No. of generations of selfing	Frequency (%)			Frequency %	
	AA	Aa	aa	Homozygotes	Heterozygotes
O	O	100	O	O	100
1	25	50	25	50	50
2	25 + 12.5	25	25 12.5	75	25
3	37.5+ 6.25	12.5	37.5+6.25	87.5	12.50
4	43.75+3.125	6.25	43.75+3.125	93.73	6.25
5	46.875+1.562	3.125	46.875+1.562	96.874	3.125
10	49.948	0.097	49.948	99.896	0.097
n	2n-1/ 2n+1	2/2n+1	2n-1/ 2n+1	2n-1/2n	1/2n

Population of completely homozygous plants = $[\ 2m\text{-}1\ /\ 2m\ ]^{n}$

Where, ' m' is the number of generations of selfing.

'n' is the number of genes segregating.

Thus, self-pollination has two main effects on the populations; first all the plants in the population become completely homozygous and second the population is a mixture of several homozygous genotypes.

PURE LINE SELECTION

A pure line is the progeny of a single, homozygous, self-pollinated plant. In pure line selection, a large number of plants are selected from a self-pollinated crop and are harvested individually; individual plant progenies from than are evaluated, and the best progeny is released as pureline variety. Therefore, pureline selection is also known as individual plant selection. A pureline variety is a variety obtained from a single homozygous plant of a self-pollinated crop.

CHARACTERISTIC OF PURE LINES

1. All the plants within a pureline have the same genotype as the plant from which the pureline was derived.
2. The variation within a pureline is environment and non-heritable.

3. Purelines become genetically variable with time. The genetic variation is produced by mechanical mixtures, natural hybridization or mutation.

Merits of pureline selection

1. Pureline selection achieves the maximum possible improvement over the original variety. This is because the variety is the best pureline present in the population.
2. Pureline varieties are extremely uniform since all the plants in the variety have the same genotype. Such a uniform variety is more liked by the farmers and the consumers than a less uniform variety developed through mass selection.
3. Due to its extreme uniformity the variety is easily identified in seed certification programmes.

Demerits of pure line selection

1. The varieties developed through pureline selection generally do not have wide adaptation and stability in production possessed by the local varieties from which they are developed.
2. The procedure of pureline selection requires more line space and more expensive yield trials than mass selection.
3. The upper limit on improvement is set by the genetic variation present in the original population.
4. The breeder has to devote more time to pureline selection than o mass selection. This leaves less time for other breeding programmes.

MASS SELECTION

A large number of plants of similar phenotype are selected and their seeds are mixed together to constitute the new variety. The plants are selected on the basis of their appearance or phenotype. Therefore selection is done for easily observable characters like plant height, ear type, grain colour, grains size, disease resistance, tillering ability, lodging resistance, shattering resistance etc., Sometimes yield of the plant may be used a criterion of selection. If the population has variation for grain characteristics like seed colour and seed size, selection may be done for them before the seeds of selected plants are mixed together.

Generally, the plants selected in mass selection are not subjected to progeny test. Incase of self-pollinated crop, mass selection has two major applications.

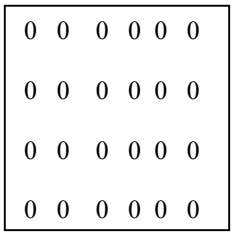
1. Improvement of desi or local varieties.
2. Purification of the existing pureline varieties.

Mass selection has only a limited application for the improvement of self-pollinated crops. It is generally not used for the handling of segregating populations derived from hybridization.

In cross-pollinated crops, mass selection leads to avoid inbreeding depression, loss in vigour and yield. Further because of the heterozygous nature of the population, several cycles of mass selection may effectively be practiced.

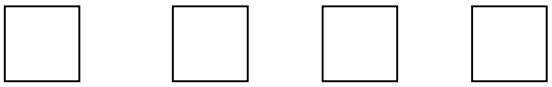
Mass selection procedure

I - Year



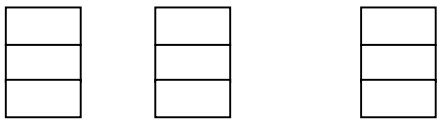
1. From a variable population, 200-2000 plants with similar but desirable traits are selected.
2. The seeds from selected plants are composited.

II - year



1. The composited seeds were planted in a preliminary yield trial along with standard check.
2. Phenotype of the selected population is critically evaluated.

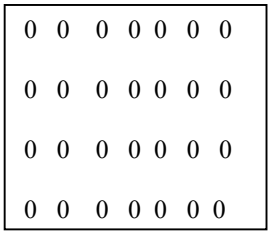
III -VIth Year



1. Promising selections are evaluated in co-ordinated trials at several locations.
2. If outstanding, released as a new variety.

VIIth - Year

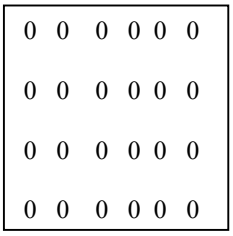
Seed multiplication for distribution.



Mass selection p in self-pollinated crops coupled with progeny testing

This method is more useful than the mass selection without progeny testing. It is commonly used for maintaining the purity of pureline varieties.

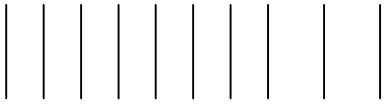
I - Year



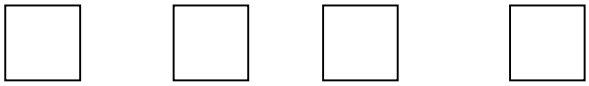
1. Select 200-2000 plants of similar but superior phenotype.
2. Harvest seeds separately from each selected plant.

II - year

1. Grow individual plant progenies
2. Reject inferior or segregating progenies.
3. Bulk the seeds from remaining progenies.



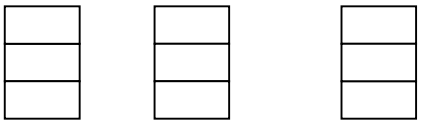
III Year



3. Preliminary yield trials from the bulked seed, standard checks are included.
4. If superior the variety is included in multilocation trials.

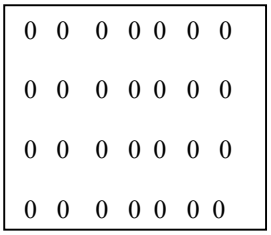
V- VIIth - Year

1. Multilocation coordinated yield trials
2. If superior released as a new variety.



VIIIth Year

Seed multiplication for distribution.



Merits

1. The varieties developed through mass selection are likely to be more widely adapted than purelines. It is generally accepted that a mixture of closely related purelines is more stable in performance over different environments than a single pureline.
2. Extensive and prolonged yield trials are not necessary. This reduces the time and cost needed for developing a new variety.
3. Mass selection retains considerable genetic variability.
4. It is a less demanding method. The breeder can devote more time to other breeding programmes.

Demerits

1. The varieties developed through mass selection show the variation and are not as uniform as pureline varieties. Therefore such varieties are generally less liked than pure line varieties.
2. The improvement through mass selection is generally less than that through pureline selection. It is because at least some of the plant progenies which make up the new variety would be poorer than the best pureline that may be selected from among them.
3. In the absence of progeny test, it is not possible to determine the genotype of the selected plants. As suggested by Allard, progeny test may be included in mass selection programmes to overcome this defect.
4. Varieties developed by mass selection are more difficult to identify the purelines in seed certification programmes.
5. Mass selection utilizes the variability already present in a variety or population. Therefore only those varieties that show genetic variation can be improved through mass selection. Thus mass selection is limited by the fact that it cannot generate variability.

GENETIC STRUCTURE OF A CROSS POLLINATED CROPS

Cross-pollinated crops are highly heterosis due to free intermating among their plants. They are often referred as " Random mating" populations because each individual of the population has equal opportunity of mating with any other individuals of that population. Such a population is also known as "Mendalian population" or "Ponmictic population". A Mendalian population may be thought of having a gene pool consisting of all the gametes produced by the population. Thus the gene fool may be defined as the sum total of all the genes present in a population.

HARDY WEINBERG LAW

It is the fundamental law of population genetics and provides the basis for studying Mendalian population. This law was independently developed by hardy (1908) in England and Weinberg (1909) in Germany. The Hardy-Weinberg law states that, the gene and genotype frequencies in a Mendalian population remain constant generation after generation if there is no selection, mutation, migration or random drift.

The frequencies of the three genotypes for a locus wilt two alleles, say 'A' and 'a' would be p^2 (AA) 2 pq (Aa), q^2 (aa)

where, 'p' represents the frequency 'A'

'q' represents the frequency 'a'.

The sum of p and q is one.

P + q =1

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

Let us consider a single gene with two allels, A and a in a random making population.

There would be 4 genotypes, AA, Aa, aa suppose the population has 'N' individuals of which,

'D' individuals are AA

'H' individuals are Aa

'R' individuals are aa So that D + H + R = N

The total number of allels at this locus in the population would be 2N, since each individual has two allels at a single locus.

The total number of 'A' allels = 2 D + H

(A A) (A a)

The ratio (2D +H) 2 N is therefore the frequency of ' A ' allele in the population and is represented by 'p'. Similarly the ratio (2R +H) 2 N in the frequency of allele 'a' and is written as 'q' therefore

P= (2 D+H) / 2 N = q = (2R +H) / 2 N

= (D + 1/2 H) / N = (R + 1/2 H)/N

Therefore. $p + q = \frac{D+H+R}{N} = \frac{N}{N} = 1$

P=1-q or q = q-p.

The values of p and q are known as gene frequency.

Gene frequency in the proportion of an allel 'A' or 'a' in the population.

Genotype frequency (Zygotic frequency) in the proportion of a genotype AA or Aa or aa.

FACTORS AFFECTING EQUILIBRIUM IN POPULATIONS

The equilibrium in random mating populations is disturbed by migration, mutation, selection and random drift.

Migration

It is the movement of individuals into a population from a different population. Migration may introduce new allels into the populations or may change the frequencies of existing allels.

Mutation

It is a sudden heritable change in an organism and is generally due to a structural change in a gene. Mutations may produce a new allele not present in populations or may change the frequencies of existing allels.

Random drift

It is also called, as genetic drift is a random change in gene frequency due to sampling error.

Inbreeding

Mating between individuals sharing a common parent in their ancestry is known as inbreeding. It reduces the proportion of heterozygotes and increases the frequency of homozygotes.

Selection

A differential reproduction rate of various genotypes is known as selection. Selection allows the selected genotypes to reproduce, while the undesirable genotypes are eliminated. Thus the breeder is able to improve the various characteristics by selecting for desirable types.

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

Most of the characters of economic importance are quantitative characters and are governed by many genes. Such characters show a continuous distribution. Selection of the extreme phenotype increases the frequency of desirable allels in the population.

The breeder has two basic tools to change the genetic composition of population.

1. Selection and 2. Mating system.

Mating systems

i. Random mating
ii. Genetic assortative mating
iii. Genetic disassortative mating
iv. Phenotypic assortative mating
v. Phenotypic disassortative mating.

Random mating

Each female gamete is equally likely to write with any male gamete and the rate of reproduction of each genotype is equal i.e. there is no selection. In such situations,

a. Gene frequencies remain constant
b. Variance for the character is constant and
c. The correlation between relatives or prepotency does not change.

2.Genetic assortative mating

The mating in between individuals that are more closely related by ancestry in random mating. This mating system is more commonly known as ' inbreeding'. It increases homzygosity and reduces heterozygosity. It is useful in development of inbreds, both partial and complete.

3. Genetic disassortative mating

Such individuals are mated which are less closely related by ancestry then would be under random mating. Thus in this system, totally unrelated individuals are mated. Examples of such a mating are inter varietal and interspecific crosses. This system would reduce homozygosity and increases heterozygosity.

4. Phenotypic assortative mating

Mating between individuals which are phenotypically more similar than would be expected under random mating is called phenotypic assortative mating. This is useful in the isolation of extreme population.

5. Phenotypic disassortative mating

Mating between phenotypically dissimilar individuals is referred to as phenotypic disassortative mating. It is very useful in making a population ' stable' i.e. maintaining variability. Suitable parents may be selected to remove their weakness. The progeny from such a mating would be more desirable than the parents. It is also useful when the desirable type is an intermediate one and the available parents have the extreme phenotypes. But the most notable use of this mating system is in maintaining variability in relatively smaller populations as it reduces inbreeding.

BREEDING METHODS IN CROSS-POLLIANTED CROPS

Populations of cross-pollinated crop species are highly heterozygous as well as heterogeneous. Their genetic makeup is such that they show variable inbreeding depression. Consequently, breeding methods for cross-pollinated crop aim at preventing in breeding. The breeding methods commonly used in cross-pollinated crops may be grouped into two broad categories;

i. Population improvement

ii. Hybrid and synthetic varieties.

In the case of population improvement, mass selection or its modifications are used to increase the frequency of desirable allels, thus improving the characteristics of populations.

In case of hybrid and synthetic varieties, a variable number of strains are crossed to produce a hybrid population, the strains that are crossed are selected on the basis of their combining ability.

The population improvement methods may be grouped into two general classes'

i. Without progeny testing

ii. With progeny testing

Without progeny testing

Plants are selected on the basis of their phenotype and number of progeny test is carried out. E.g. Mass selection.

With progeny testing

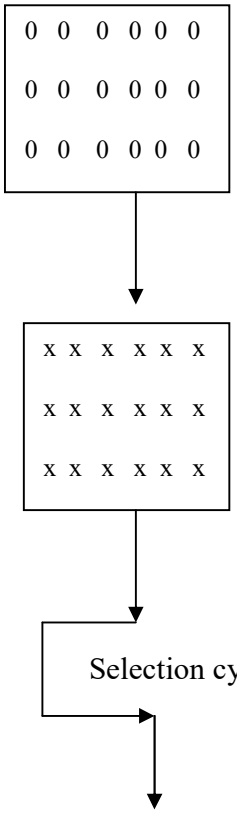
The plants are initially selected on the basis of their phenotype, but the final selection of plants that contribute to the next generation is based on progeny test. This class of population improvement includes;

Progeny selection or Ear -to row method and Recurrent selection.

Mass selection

It is the oldest breeding scheme available for cross-pollinated crops. In mass selection a number of plants are selected on the basis of their phenotype, and the open pollinated seed from them is bulked together to raise the next generation.

The selected plants are allowed to open pollinate i.e. to mate at random selection of plants is based on their phenotype and no progeny test in conducted. The selection cycle may be repeated one or more times to increase the frequency of favourable alleles. Such a selection scheme in generally known as phenotypic recurrent selection. Care should be taken to select a sufficiently large number of plants in order to keep inbreeding to a minimum. The efficiency of mass selection primarily depends upon the number of genes controlling the character, gene frequencies and more importantly heritability.



i. Several plants selected on the basis of phenotype

ii. Open pollinated seed from the selected plants grown

i. Bulk seed from the selected plants grown

ii. Mass selection may be repeated.

Selection cycle may be repeated one or more lines

Yield trial

Merits of mass selection

i. Work of the breeder is Kept to a minimum, since the selection are based on the phenotype of plants.

ii. The selection cycle is very short, i.e. only one generation

iii. It is highly efficient in improving characters that are easily identified visually and have high heritability. E.g. plant height, size of ear, date of maturity etc.,

Demerits

i. Selection of plants is based on the phenotype of individual plants. Superior phenotype is often a poor basis for the identification of superior genotype. The environment affects quantitative character.

ii. The selected plants are allowed to open pollinate so, the selected plants are pollinated by both superior and inferior plants present in the population. This reduces the effectiveness of selection.

Modifications of mass selection

Two defects of mass selection are;

i. Lack of control on the pollen source and

ii. Confusing effect of environment on the phenotype of individual plants.

The defects may be corrected as follows

1. Inferior plants in the field are destasselled and the remaining plants are allowed to open pollinate. This modification exercise some control on the pollen source, but the identification of inferior plants of necessity is based on only those characters which are expressed before flowering.
2. Pollen from all the selected plants is collected and bulked; this pollen is used to pollinate the selected plants. This ensures full control on the pollen source.
3. Stratified mass selection: This modification suggested by Gardner in 1961. It is also known as the 'grid method of mass selection'.

The field from which selection is to be done is divided into several small plots. E.g. having 40-50 plants each.

Equal numbers of superior plants are selected within in the plots, not among the plots. The seed from all the selected plants is composited to raise next generation that variation due to environment, including variation in soil fertility, will be much reduced with in the small plots than the whole field. Thus selection within the plots is expected to be more effective than that without any stratification. It has been able to increase the yielding ability of an open pollinated variety of maize, hays golden, by about 3% per cycle, for15 generations.

Effectiveness of mass selection

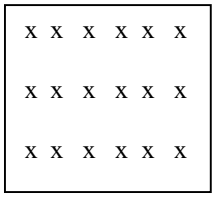
It has effectively improved characters with high heritability in maize e.g. ear height, lodging resistance, ear type, adaptiveness, oil and protein content, resistance to leaf blight and days to flowering.

SELECTION WITH PROGENY TEST

The simplest form of progeny selection is the ear to row method, which has been extensively used in maize.

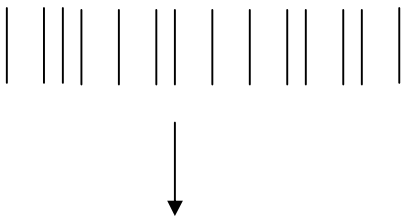
Ear - to -row method (By Hopkins in 1908)

1st Year



i. Plants selected on the basis of phenotype.
ii. Open pollinated seed from each plant harvested separately. (' I' selection cycle).

2nd Year



i. Small progeny rows grown from the selected plants.
ii. Superior progenies identified
iii. Phenotypically superior plants selected from superior plants
iv. Plants allowed to open pollinate seed harvested separately. ('II' selection cycle).

3rd Year

i. As in item 1 to 4 in the second year
ii. ('III' selection cycle).

Repeated one ore more times

Yield Trials

MERITS OF PROGENY SELECTION

i. Progeny selection is far more efficient than mass selection in the identification of superior genotypes. It is a far more accurate reflection of the genotype than the phenotype. This is a powerful tool for increasing the yielding ability of open pollinated varieties of maize. The yielding ability increased at the rate of 3-8 percent per selection cycle.

ii. Inbreeding may be avoided if care is taken to select a sufficiently large number of plant progenies and if the selected progenies are not closely related.

DEMERITS OF PROGENY SELECTION

i. There is no control on pollination and plants are allowed to open pollinate. This reduces the efficiency of selection.

ii. Many of the progeny selection schemes are complicated and involve considerable work.

iii. The selection cycle is usually of two years. Thus the time requirement for selection is twice as much as that in the case of mass selection.

RECURRENT SELECTION

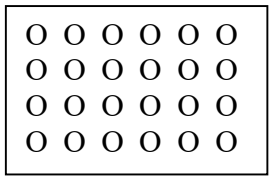
The idea of recurrent selection was first suggested by Hayes and Garber in 1919 and independently by East and Jones in 1920. After 1945, Hull suggested that recurrent selection might be useful in improving specific combining ability. The recurrent selection schemes were devised in relation to heterosis breeding. The idea was to ensure the isolation of superior inbreds from the populations subjected to recurrent selection for their ultimate utilization in the production of hybrid and synthetic varieties.

Recurrent selection schemes are of four different types;

1. Simple recurrent selection
2. Recurrent selection for general combining ability (R.S.-GCA)
3. Recurrent selection for specific combining ability (R.S.-SCA)
4. Reciprocal recurrent selection (R.R.S)

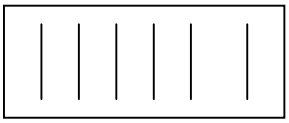
Simple recurrent selection

Original population

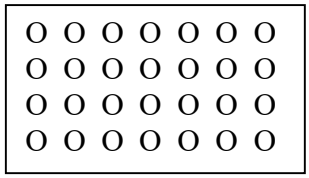


i. Phenotypically superior plants selected.
ii. Selected plants self pollinated
iii. Seeds harvested separately.
iv. Seeds evaluated, superior seeds retained.
(Original selection cycle)

Intercross block

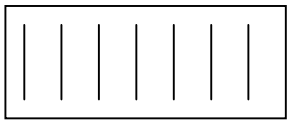


i. Individual plant progenies planted
ii. All possible inter-crosses made
iii. Equal amounts of seed from all intercross composited.
(First recurrent selection cycle)



i. Composited intercross seed planted
ii. As in I to iv. In the first year

Composite intercrosses



i. Individual plant progenies planted
ii. As in ii to iii in the second year.

Intercross block

May be repeated (as in the first recurrent selection cycle)

In simple recurrent selection a number of plants with desirable phenotype are selected and self-pollinated. Separate progeny rows are grown from the selected plants in the next generation. The progenies are intercrossed in all possible combination by hand. Equal amount of seed from each cross is composited to produce next generation. This completes the original selection cycle. For recurrent selection, several desirable plants are selected from the composited population obtained from the original selection cycle. They are selected on the basis of phenotype and are self-pollinated. Progeny rows are grown and all possible intercrosses are made by hand. Equal seeds from all the intercrosses are

composited to produce the next generation. This constitutes the first recurrent selection cycle. The population may be subjected to one or more recurrent selection cycles.

Recurrent selection is effective in increasing the frequency of desirable genes in the population. It is the most suited for character with high heritability. The mean of selected population shifts in the direction of selection.

Recurrent selection of general combining ability (RSGCA)

In RS GCA, the progeny for progeny testing are obtained by crossing the selected plants to a tester strain with broad genetic base. A tester strain is the common parent mated to a number of lines, strains or plants. A tester with a broad genetic base implies a population that has a large genetic variation. E.g., Synthetic variety or an open pollinated variety.

The differences between plant x tester, progenies would be primarily due to the general combining ability (GCA) of the plants. It is therefore assumed that the plants selected on the basis of superior performance of their plant x tester progenies would have superior GCA.

Recurrent selection of Specific combining ability (RS SCA)

Hull first proposed it in 1945. The objective of RS SCA is to isolate, from a population such lines that will combine well with a given inbred. It is assumed that a large part of heterosis in the result of non-additive gene action i.e. dominance and epistasis. This part of heterosis will therefore depend on specific gene combinations and is designated as Specific Combining Ability (SCA). If plants are selected on the basis of performance of this progeny derived from test cross with an inbred, they would be selected for their combining ability with the inbred used as tester. It may be expected that these plants would have genes or gene combinations that specifically combine well with the genes present in the tester inbred. The procedure for RS SCA is identified with that for GCA, except that in this case an inbred is used as a tester in the place of an open pollinated variety. The tester must be an outstanding inbred because it would be one of the parents of the hybrid that would be produced using the inbred lines isolated from the improved population.

Reciprocal Recurrent Selection (RRS)

Comstock, Robinson and Harvey proposed it in 1949. The objective is to improve two different populations A and B, serve as testers for the plants selected from the other populations.

For example a random sample of plants from populations 'A' serve as the tester for the plants selected from 'B'. Similarly a random sample of plants from populations 'B' serves as the tester for those selected from population 'A'. It may be seen that, this selection method allows for the selection of both GCA and SCA. It selects for GCA because the two testers (populations A and B) have broad genetic base since they are genetically heterogeneous. Selection of SCA is accomplished because the two populations would be crossed with each other to produce the commercial variety and the plants in each of the two source populations are selected for their abilities to combine well with the gene combinations present in other population, that is for SCA with each other.

Brief description of the various selection schemes for populations improvement
(Description based on maize)

Selection scheme	Brief description
Intra population improvement	For improvement within a population
A. Mass selection	Selection based on the phenotype of individual plants; open pollination. Inferior plants detasseled; Open pollination among the remaining plants.
B. Family selection	Selection based on means of individual plant progenies or families.
i. Half sib	Plants within each family (individual plant progeny) are half sibs, i.e. have one parent in common usually female parent.
a. Ear to Row	Families produced by open pollination; selection within superior families, number of replicated trial, unrestricted open pollination among all the families.

b. Modified Ear to Row	Superior progenies identify by replicated yield trial; a random bulk of all the families.
c. Half sib selection	Only superior progenies planted in the crossing block and allowed to open pollinate
d. Modified half sib	Half sibs are used for yield trial. S1 families from plants producing superior half sibs inter-mated through open pollination.
e. Broad base test cross	Half sib families produced by crossing the selected plants to a tester with a broad genetic base used for yield trial; S1 progenies from plants producing superior half sib families inter-mated (syn. Recurrent selection for GCA).
f. Narrow base test cross	As in the broad base test cross but the tester has a narrow genetic base (Syn. Recurrent selection for SCA)
2. Full Sib	Plants within each family are full sibs; produced by mating the selected plants in pairs
3. Inbred or selfed	Families produced by selfing S1- families produced by one generation of selfing used for evaluation superior families inter-mated (Syn.)

HETEROSIS AND INBREEDING DEPRESSION

Cross-pollinated species and species reproducing asexually are highly are heterozygous. These species usually show a severe reduction in fertility and vigour due to inbreeding. Conversely hybridization between unrelated strains generally leads to an increased vigour and fertility.

Inbreeding

It is mating between individuals related by descent or ancestry. When the individuals are closely related. E.g. in brother sister mating or sib mating; the degree of inbreeding is high. The highest degree in breeding is achieved by selfing.

Selfing reduces heterozygosity by a factor of 1/2 in each generation. The degree of inbreeding increases in the same proportion.

Inbreeding depression

It may be defined as the reduction or loss in vigour and fertility as a result of inbreeding.

Effects of inbreeding

1. Appearance of Lethal and sub lethal allels: Chlorophyll deficiency, rootless seedlings, defects in flower structure. These plants cannot be maintained and are lost from the population.
2. Reduction in vigour: Plants become shorter and weaker, reduction in size of various plant parts.
3. Reduction in Reproductive ability: Poor reproduction.
4. Separation of the population into distinct lines: The population rapidly separates into phenotypically distinct lines.
5. Increase in homozygosity: Variation within a line decreases rapidly. The lines, which are almost homozygous due to continued inbreeding and are maintained through close inbreeding, are known as inbred lines.
6. Reduction in yield: Inbreeding generally leads to a loss in yield. In maize the best inbred lines yield about half as much as the open pollinated varieties from which they were produced.

Degrees of inbreeding depression

The various species differ considerably in their response to inbreeding. They may be grouped into four broad categories.

1. High inbreeding depression: e.g. Alfalfa, carrot - do not survive resulting in lethality.
2. Moderate inbreeding depression: Maize, sorghum, cumbu. Reproduction in fertility and yield upto 50% production and maintenance of inbred lines are relatively easier in these species.
3. Low inbreeding depression: e.g. Onion, cucurbits, rye, and sunflower. Loss invigour and fertility is small. Reduction in yield is small or absent.
4. No inbreeding depression: Self-pollinated species do not show inbreeding depression, although they do show heterosis.

Homozygous and heterozygous balance

This concept was advanced by Mather, to explain the varied response of different species to inbreeding. The species carry a large number of lethal, sub vital and other unfavourable recessive genes. Which are of little immediate value to the species. The sum total of these unfavourable genes is known as "Genetic Load".

The harmful effects of such recessive allels are masked by their dominant allels as a result of which they are retained in the population. The population therefore develops a genetic organization, which favours heterozygosity. This type of genetic organization is known as heterozygous balance, because it promotes heterozygosity.

The self-fertilized species are naturally homozygous. They have no genetic load, because unfavourable recessive genes become homozygous and are eliminated from the population. These species therefore, develop a genetic organization, which is adapted to homozygosity i.e., which does not produce undesirable effects in the homozygous state. This type of genetic organization is known as homozygous balance.

OVER DOMINANCE HYPOTHESIS

This hypothesis was independently proposed by East and Shull in 1908. According to this, heterozygotes at atleast some of loci are superior to both the relevant homozygotes. Thus heterozygote 'Aa' consequently heterozygosity resulting from inbreeding produces inbreeding depression. It would therefore, be impossible to isolate inbreds as vigorous as F_1 hybrids.

In 1936, East proposed that at each locus there are several allels e.g., 91, 92, 93, 94….. etc with increasingly different functions. Heterozygotes for more divergent allels would be more heterotic than those involving less divergent ones.

For example 91 94 would be superior to be 91 92, 92 93, and 93 94.

It is assumed that, the different allels some where different functions. The hybrid is therefore able to perform the functions of both the allels, which is not possible in the case of two homozygotes.

HETEROSIS

The term heterosis was first used by Shull in1914.

Heterosis may be defined as the superiority of an F1 hybrid over both its parents in terms of yield or some other character. Generally heterosis is manifested as an increase in vigour, size, growth rate, yield or some other characteristics. But in some cases, the hybrid may be inferior to the weaker parent. This is also regarded as heterosis.

Hybrid vigour describes only the superiority of hybrids over their parents.

LUXURIANCE

It is the increased vigour and size of interspecific hybrids. The principle difference between heterosis and luxuriance lies in the reproductive ability of the hybrids. Heterosis is accompanied with an increased fertility, while luxuriance is expressed by interspecific hybrids that are generally sterile.

Different heterosis

1. Relative heterosis (or) Average heterosis

   The superiority of F1 is estimated over the average of two parents or the mid parent (But it is not useful in practical plant breeding).

2. Heterobeltiosin

   Superiority of F1 over better parents.

3. Standard heterosis

   Superiority of F1 over standard variety.

Manifestation of heterosis

Heterosis is the superiority of a hybrid over its parents. This superiority may be in yield, quality, diseases and insect resistance, adaptability, general size or the size of the specific parts, growth rate, enzyme activity etc.,

1. Increased yield

It is the most important objective of plant breeding. The yield may be measured in terms of grain, fruit, seed, leaf, tubers or the whole plant.

2. Increased reproductive ability

It is expressed in higher yield of seeds or fruits.

3. Increase in size and general vigour

The hybrids are generally more vigorous. E.g. Fruit size in tomato, head size in cabbage, cob size in maize, head size in Jowar etc.,

4. Better quality

In onion, many hybrids show better keeping quality, but not yield.

5. Earlier flowering and maturity

Hybrids are earlier in flowering and maturity than the parents. Many tomato hybrids are earlier than their parents.

6. Greater resistance to disease and pests
7. Greater adaptability

Hybrids are generally more adapted to environmental changes than inbreds.

GENETIC BASES OF HETEROSIS AND INBREEDING DEPRESSION

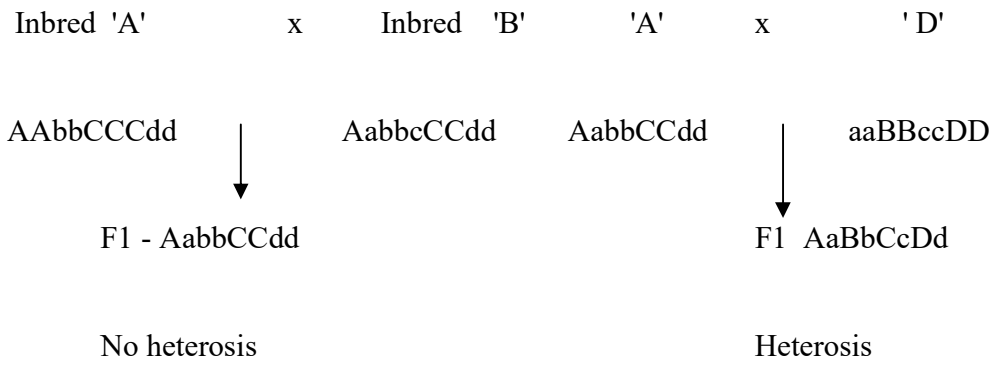
Heterosis and inbreeding depression are closely related phenomena. In fact they may be regarded as two opposite sides of the same coin. There are two main theories to explain heterosis and consequently inbreeding depression.

Dominance hypothesis

It was first proposed by Davenport in 1908. At each locus the dominant allele has a favourable effect, while the recessive allele has an unfavourable effect. In heterozygous state, the deleterious effects of recessive allels are masked by their dominant alleles. Thus

heterosis results from the masking of harmful effects of recessive allels by their dominant allels. The harmful effects of recessive allels, which become homozygous due to inbreeding, on the other hand, produce inbreeding depression.

Heterosis in an F1 hybrid is a result of the masking of harmful effects of recessive allels present in one parent by the dominant alleles present in the other plant and vice versa. Hybrids from parents with similar recessive and dominant allels would show little or no heterosis, while those with different allels would show heterosis. Generally parents of diverse origin are more likely to produce heterotic progeny than those of similar origin.



Harmful effects of 'b' and 'd' genes are not masked

Mechanisms involved in hybrid seed production

1. Hand emasculation and pollination enabling production of large quantity of hybrid seeds in each pollination. E.g. Cotton, Bhendi, Tomato, Brinjal, Chillies, Tobacco, Maize, coconut, onion, papaya.
2. Cytoplasmic - genic male sterility. E.g. Rice, Sorghum, Wheat, Tobacco, Cotton.
3. Genic, male sterility - Redgram, castor.
4. Self incompatibility - E.g. Potato, Tomato, Brasssica, Tobacco, Forage legume.
5. Apomixis - Guinea grass, Buffalo grass
6. Vegetative propagation after crossing- Sugarcane, potato, cumbu, Napier hybrid grass.
7. Graft hybrids- Mango, sapota, jack, apple, guava, orange.

Steps in heterosis breeding

1. Collection and evaluation of germplasm: Genetically divergent genotypes will be the basic source materials in heterosis breeding. The application of D_2 statistics helps to

group the varieties into cluster, varieties within a cluster having little divergence and those between clusters registering low to high divergence based on D_2 values.

2. Development of inbred lines: By repeated selfing of the parental varieties followed by progeny testing and selection among progenies a large number of inbred lines may be developed.

In cross-pollinated species, selfing will lead to inbreeding depression in the early generations of selfing, which becomes progressively less in each succeeding generation. A condition is finally reached when there is no further loss of vigour and the plants breed true. Each inbred may have a combination of genes different from another inbred and may be used for developing a homozygous inbred. The undesirable lines are discarded and the desirable ones are maintained. Vigorous inbred lines, uniform in appearance can thus be developed from open pollinated varieties after five to seven generations of self pollination followed by rigorous selection.

3. Testing inbred lines for general combining ability

The value of an inbred line ultimately depends upon its ability to produce a superior hybrid in combination with another inbred line. The combining ability in therefore defined as the ability of an inbred to transmit desirable performance to its hybrid progenies.

The inbred variety cross, more popularly called the topcross in therefore made for the preliminary testing of a large particular inbred in a series of hybrid combinations is known as its general combining ability, and the top cross test measures the GCA of the inbred to be tested are crossed with a standard variety.

Inbred line	x	Standard variety	Progeny
A	x	"	High yielding
B	x	"	High yielding
C	x	"	High yielding
D	x	"	High yielding
E	x	"	Poor yielding

A, B, C and D are said to be high GCA.

4. Testing inbreds for specific combining ability (SCA)

Those inbred lines with good G.C.A are then crossed in all possible combinations and the specific ability of a line to combine well with another line is determined from the yield of the progenies.

Inbred lines	Yield progeny
A x B	High
A x C	Average
A x D	Average
B x C	Average
B x D	Average
C x D	High

The produce usually employed for estimating GCA and SCA are di allele analysis, Line x tester analysis, by adopting any one of the above techniques to test the GCA and SCA of inbreds the best inbreds with good SCA are selected for production of hybrids.

5. Combining inbreds into single cross

A single cross is a cross between two inbreds (A x B). In the commercial production of single cross seed two inbreds to be crossed are planted in an isolated field in such a way that two rows of the inbred to be used as the female parent, alternate with one row of the inbred line in maize used as the female parent in detasseled and allowed to be open pollinated by pollen from the line used as the male parent.

Single cross seed is usually small in size yields are low as the inbred plants on which the seed is produced are relatively unproductive .

6. Combining inbreds into double crosses

The double cross in a cross of two single cross hybrids (A x B) x (C x D). Each single cross hybrid in the F1 of a cross between two inbred lines and in heterozygous, but productive and gives seeds in abundance. It is these seeds that are distributed to the farmers for growing plants in the next season.

Use of Cytoplasmic male sterility in production of hybrids

Hybrid seeds may be produced without emasculation by the utilization of cytoplasmic male sterility. A Cytoplasmic male sterile plant will produce fertile progeny if it is pollinated by pollen from a male fertile plant ('R' line) containing restorer genes. As three lines viz., the male sterile line ('A' line), the isogeneic maintainer line ('B' line) and the restorer line ('R' line) are involved in heterosis breeding employing Cytoplasmic genic male sterility, it is called ' three line breeding'.

Chemically induced male sterility

Male sterility can be induced by chemicals and such chemicals are called male gametocytes, pollen suppressants and chemical hybridizing agents (CHA). The chemical at a particular concentration is sprayed on the foliage prior to flowering and this inhibits production of viable pollen without injuring the gynoecium.

Self incompatibility

Two self-incompatible but cross compatible lines are planted in alternate rows, the seeds produced by both lines would be hybrid seed. Alternatively, a self-compatible line may be inter planted with a self-incompatible line only is used as the hybrid variety. This system is being commercially used for hybrid seed produced in some Brassica crops in Europe and Japan e.g. *Brassical oleracea* (Cabbage)

Merits of hybrid varieties

1. In many self pollinated crops, yields about 25-30% more than pure line varieties.
2. Exploit the heterosis to the greatest possible extent.

Demerits of hybrid varieties

1. Farmers have to use new hybrids seed every year. They cannot produce their own seed.
2. Hybrid seed production needs more technical skill.

HYBRIDIZATION

Crossing of two plants or lines of dissimilar genotypes is known as hybridization. The seeds as well as the progeny resulting from the hybridization are known as hybrid or F1. The progeny of F1 obtained by selfing or intermating of F1 plants, and the subsequent generations are termed as segregating generations. The term ' Cross' is often used to denote the products of hybridization i.e. the F1 as well as the segregating generations.

Objectives

The chief objective of hybridization is to create genetic variation. When two genotypically different plants are crossed, the genes from both the parents are brought together is F1. Segregation and recombination produce many new gene combinations in F2 and later generation i.e. segregating generations. The aim of hybridization may be the transfer of one or few qualitative characters or use the F1 as hybrid variety.

Combination breeding

The main aim of combination breeding is the transfer of one or more characters into a single variety, from other varieties. A familiar example of combination breeding is that of disease resistance. In combination breeding one of the parents must have in a sufficient intensity, the character under transfer while the other parent is generally a popular variety.

Transgressive breeding

Aims at improving yield or its contributing characters through transgressive segregation. Transgressive segregation is the production of plants in an F2 generation that are superior to both the parents for one or more characters such plants are produced by an accumulation of plus or favourable genes from both the parents as a consequence of recombination.

The parents involved in hybridization must combine well with each other, and should preferably be genetically diverse i.e. quite different. Each parent is expected to contribute different plus genes which when brought together by recombination give rise to transgressive segregant.

Types of hybridization

The plants or lines involved in hybridization may belong to the same variety, different varieties of the same species, different species of the same genus or species from different genera. Based on the taxonomic relationships of the two parents, hybridization may be classified into two broad groups.

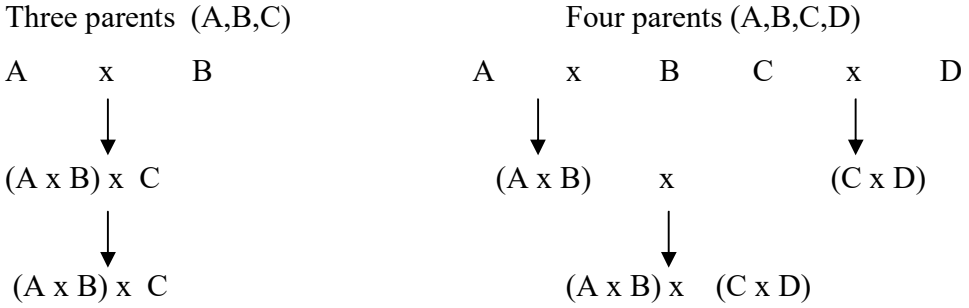
1. Inter-varietal
2. Distant hybridization.

Inter-varietal hybridization

The parents involved in hybridization belong to the same species. They may be two strains, varieties or races of the same species. It is also known as intra-specific hybridization. In crop improvement programmes, inter varietal hybridization is the most commonly used. The inter varietal crosses may be simple or complex depending upon the number of parents involved.

Simple cross: Two parents are crossed to produce the F1. The F1 is selfed t produce F2.

Complex cross: More than two parents are crossed to produced the hybrid, which is then used to produced F2 such a cross is also known as convergent cross, because this crossing programme aims at converging i.e. bringing together genes from several parents into a single hybrid.



Complex hybrid

In breeding of highly improved self-pollinated crops like wheat and rice, complex crosses are common practices today. As crop improvement progresses the crop varieties would accumulate more and more favourable genes.

Distant hybridization

It includes cross between different species of the same genus or different genera. When two species of the same genus are crossed it is known as interspecific

hybridization. But when they belong to two different genera, it is termed as inter generic hybridization. Generally the objective of such crosses is to transfer one or few simply inherited characters like disease resistance to a crop species. For e.g.

i. C O 31. Rice variety was developed from the cross, *Oryza sativa* var indica x O. perennis.
ii. All the present day sugarcane varieties have been developed from complex crosses between *Saccharum officinarum* (Noble cane), *S.barberi* (Indian cane) and *Saccharum* sp. like *S. spontaneous*.
iii. The improvement in length of Indian cotton (*Gossypium arboreum*) has been brought about by crossing it with American cultivated cotton (G. hirsutum).
iv. Intergenric cross line (wheat) Triticum sp. x Secale cereale (Rye) - Triticale

Useful for developing new crop species like Triticale.

Procedure of hybridization

There are seven steps involved in hybridization

1. Choice of parents
2. Evaluation of parents
3. Emasculation
4. Bagging
5. Tagging
6. Pollination
7. Harvesting and storage of F1 seed.

1. Choice of parents

The choice of parents mainly depends upon the objectives of breeding programme. In addition to other objectives, increased yields are always an objective of the breeder. Therefore, at least one of the parents involved in a cross should be a well adapted and proven variety in the area, for which the new variety in being developed. The other variety should be having characters that are absent in this variety. Some parents produce superior F1s and F2s, while other do not. This property of the parent is known as "combining ability". The combining ability of the parents may serve as a useful guide in selection of parents for hybridization programme. Thus the choice of parents is the basic step in a hybridization programme and often more than anything else, determines its success or failure.

2. Evaluation of parents

If the performance of parents in the area, where breeding is to be done is not known, it should be determined, particularly for the characters they are expected to contribute and for disease resistance. New strains should also be checked for mechanical mixture and for heterozygosity. If it is suspected to be heterozygosity, it may be necessary to self-pollinate a parent for one or more generations.

3. Emasculation

The removal of stamens or anthers or the killing of pollen grains of a flower without affecting in any way the female reproductive organ is known as emasculation. The purpose of emasculation is to prevent self-fertilization in the flowers of the female parent. In dioecious plants, male plants are removed, while in monoecious species the male flowers are removed to prevent self-pollination. But emasculation is essential in bisexual flowers. The various techniques of emasculation are, hand emasculation, suction method, hot weather emasculation, alcohol treatment, cold treatment, genetic emasculation and use of gametocides.

4. Bagging

Immediately after emasculation, the flowers or the inflorescence are enclosed in suitable bags of appropriate size to prevent random cross-pollination. In cross-pollinated crops, like maize, the male flowers are also bagged to maintain the purity of pollen used for pollination. Butter paper bags are the most commonly used.

5. Tagging

The emasculated flowers are tagged just after bagging. The tags are attached to the flower or the inflorescence with the help of thread. The following information is recorded on the tags with the carbon pencil.

a. Date of emasculation b. Date of pollination c. Name of the female and male parent.

6. Pollination

The two important operations that determine the amount of seed set in hybridization are emasculation and pollination. In case of pollination, mature fertile and viable pollen should be placed on a receptive stigma to bring about fertilization. It is advisable that fresh pollen from mature anthers should be used for pollination.

7. Harvesting and storing the F1 seeds

The crossed head or pods should be harvested and threshed. The seeds should be dried and properly stored to protect them from storage pests. The seeds from each cross should be kept separately and preferably kept with labels.

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

PEDIGREE METHOD

The methods generally used for handling segregating generations may be grouped into three categories.

i. Pedigree method

ii. Bulk method

iii. Back cross method

Pedigree method

Individual plants are selected from F2 and the subsequent generations and their progenies are tested. During the entire operation a record of all the parent off spring relationship is kept. This is known as " pedigree record". Individual plant selection is continued till the progenies show no segregation. At this stage, selection is done among the progenies because there would no genetic variation within the progenies.

The pedigree may be defined as a description of the ancestors of an individual and it generally goes back to some distant ancestors in the past.

Maintenance of pedigree record

Generally each cross is given a number the first two digits of this number refer to the year in which the cross was made, and the remaining digits denote the serial number of the cross in that year.

E.g. First system

Generation	Number	Description
F3	9911-7	Progeny in the 7^{th} row in the F3 plot year'99
F4	9911-7-4	Progeny in the 4^{th} row in the F4 plot selected from the progeny in the 7^{th} row of F3 plot.
F5	9911-4-14	Progeny in the 14^{th} row in the F5 plot selected from the progeny in the 4^{th} row in the F4 plot

Second system

In each generation the selected plants are assigned serial number with in individual progenies. E.g.

F3	9911-7	Progeny obtained from plant No7 selected in F2.
F4	9911-7-4	Progeny from plant No.4, selected from the F4 progeny derived from the plant No.7 selected in F2.
F5	9911-7-4-2	Progeny from plant No.2 selected from F4 progeny.

In this system, pedigree of a progeny is immediately known and does not have to refer to the previous year's records. But there is a greater chance of error in this system, Since more numbers are to be recorded.

Application of pedigree method

It is most commonly used method for selection from segregating generations of crosses in self-pollinated crops. It is suitable for improving specific characteristics such as disease resistance, plant height and maturity time etc., as well as yield and quality characteristics.

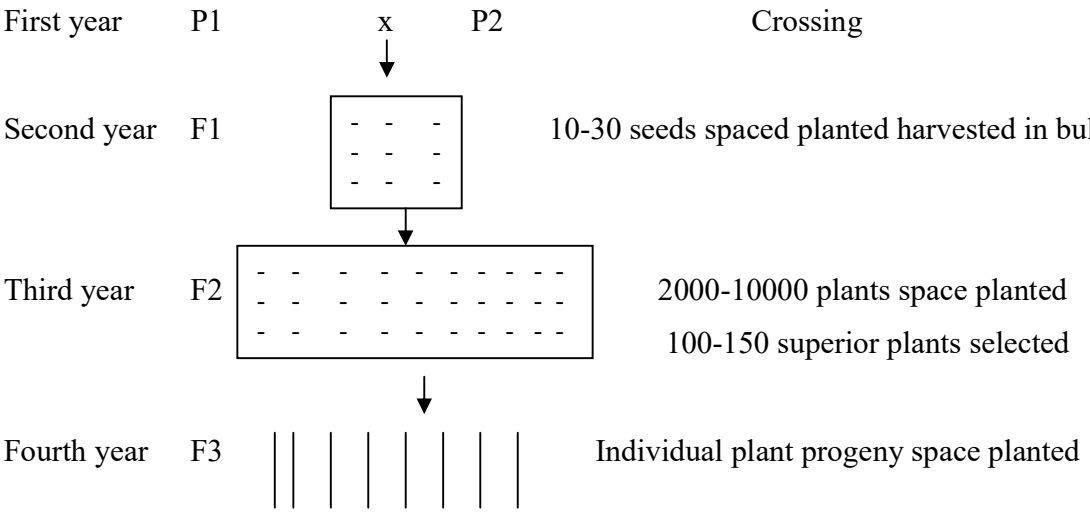
Pedigree method procedure

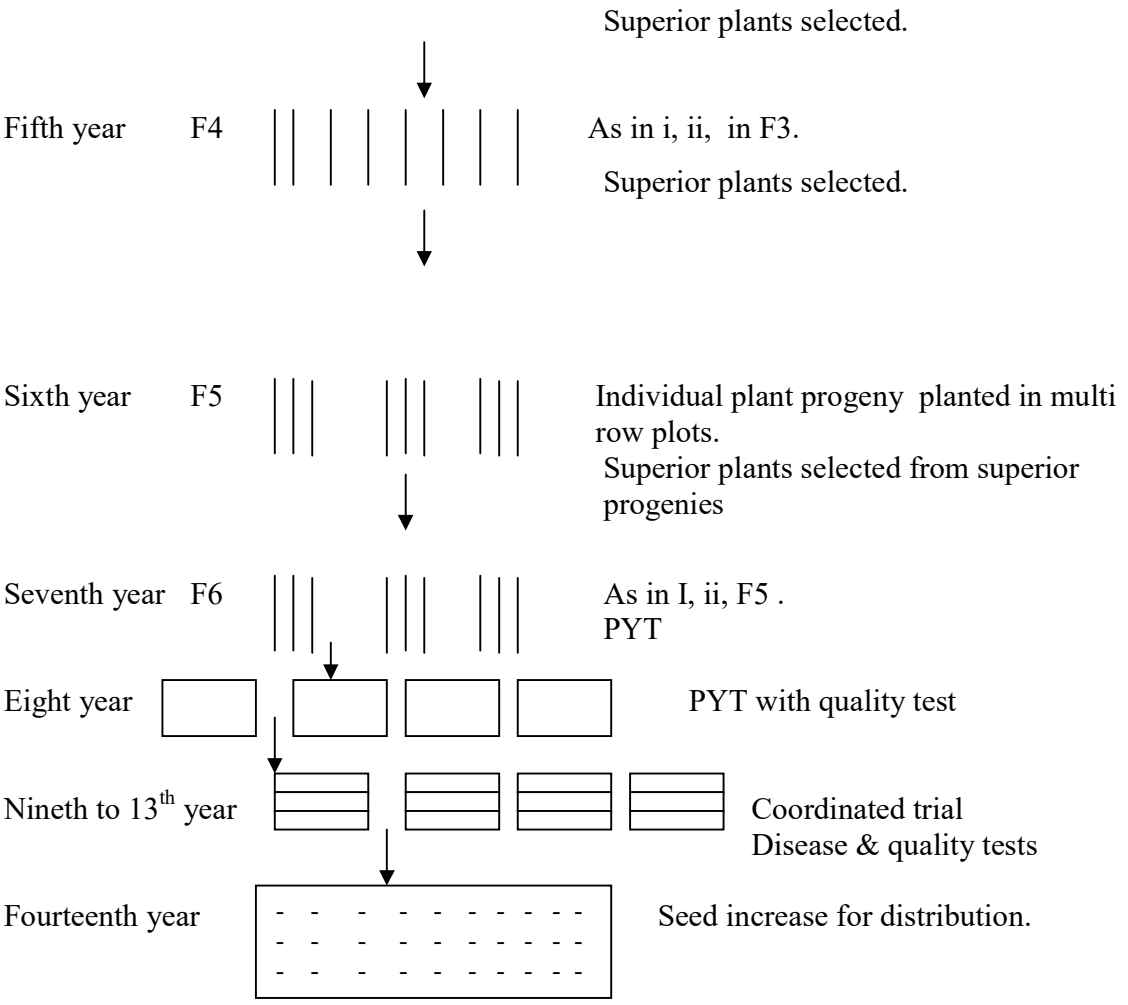
Hybridization : The selected parents are crossed to produce a cross as the F1 seed.

F1 Generation: F1 seeds are space-planted so that eachF1 plant produces the maximum F2 seed ordinarily, 15-30 F1 plants should produce enough seed for a good F2 population size.

F2 generation: In F2 2000-10,000 plants are space planted to facilitate selection. About 100-500 plants are selected and their seeds are harvested separately.

Schematic representation





The selection in F2 is based on the characteristics that are simply inherited e.g. plant height, head type, seed colour, disease resistance, presence of awns, etc., It may be emphasized that the breeder must not select too many F2 plants. He should select only as many F2 plants as he can handle efficiently in the subsequent generations with the facilities at his disposal. The value of selection will largely depend upon the skill of breeder. This because he has to judge which F2 plant would produce superior progeny for characters like yield. The breeder develops through a close and deep study of the concerned crop species.

F3 generation

Individual plant progenies are space planted. Each progeny should have about 30 or more plant. Individual plants with desirable characteristics are selected, particularly from superior progenies. Out standing plants from inferior progenies may also be

selected. The number of plants selected in F3 should be preferably less than that of the F3 progenies. If the number of superior progenies is small, the whole cross may be rejected.

F4 generation

Individual plant progenies are space planted. The emphasis is on selection of desirable plants from superior progenies. The number of plants selected in F4 is generally much lower than that of F4 progenies. Progenies with defects and undesirable characteristics are rejected.

F5 generation

Individual plant progenies are generally planted according to the recommended commercial seed rate. Often there or more rows are grown for each progeny to facilitate comparison among progenies.

Many families may have become reasonably homozygous and maybe harvested in bulk. The breeder has to visually assess the yielding potential of progenies and reject the inferior ones. The number of progenies must be reduced to a size manageable in preliminary yield trials, which is usually 25-100 progenies.

F6 generation

Individual plant progenies are planted in multi row plots and evaluated visually. Progenies are harvested in bulk since they would have become homozygous. Progenies showing segregation may be eliminated unless they are outstanding preliminary yield trial may be planted for those progenies which are reasonably homozygous and have enough seed.

F7 generation

Preliminary yield trials with 3 or more replications are conducted to identify few superior lines. The progenies are evaluated for lodging, disease resistance, maturity and quality tests for selection. Standard commercial varieties must be included as checks for comparison two to five outstanding lines, if superior to checks would be advanced to the coordinated trials.

F8 to F11 generation

The superior lines are tested in replicated yield trials at several locations. The lines are evaluated for yield resistance, maturity and quality. Superior line would be released as a new variety.

F12 generation

The seed of the new variety will be multiplied for distribution.

MERITS OF PEDIGREE METHOD

1. This method gives the maximum opportunity for the breeder to use his skill and judgement for the selection of plants, particularly in the early segregating.
2. It is well suited for the improvement of characters, which can be easily identified and are simply inherited.
3. Transgressive segregation for yield and other quantitative characters may be recovered.
4. It takes less time than the bulk method to develop a new variety.
5. The breeder may often able to obtain information about the inheritance of qualitative characters from the pedigree record.
6. Plants and progenies with visible defects and weakness are eliminated at on early stage in the breeding programme.

MERITS OF PEDIGREE METHOD

1. Maintenance of accurate pedigree records takes up valuable time.
2. Selection among and within a large number of progenies in every generation is laborious and time consuming.
3. The success of this method largely depends upon the skill of the breeder.
4. Selection of yield in F2 and F3 is ineffective. If care is not taken to retain a sufficient number of progenies valuable genotypes may be lost in the early segregating generations.

Mass pedigree method

Breeding method in which the population is maintained as a bulk for certain number of generations till such time when conditions suitable for selection occur; at this stage pedigree method of breeding is applied.

Bulk method (Nilsson-Ehle)

It is also known as ' Mass method' or ' Population method of breeding'. In this method, F2 and subsequent generations are harvested in mass or as bulks to raise the next generation. At the end of bulking period, individual plants are selected and evaluated in a

similar manner as in the pedigree method of breeding. The duration of bulking may vary from 6-7 to 30 or more generations. During the bulking period, artificial selection may or may not be practiced.

Applications

It may be used for three different purposes

1. Isolation of homozygous lines
2. Waiting for the opportunity for selection
3. To provide opportunity for natural selection.

Isolation of homozygous lines

Bulk method is used for the isolation of homozygous lines with minimum of effort and expense. Therefore, a preliminary yield trial maybe conducted in the second year after selection of the individual plants.

Waiting for the opportunity for selection

Selection for resistance to disease, lodging, cold etc., depends upon the presence of suitable environmental conditions favouring disease epidemic, severe lodging, cold killing, etc., such environments do not occur every year. The segregating generations may be carried in bulk until such environments occur. Individual plants are then selected and handled as in the pedigree method. In duration of bulking in the case would depend upon the occurrence of the particular environment. It may end in F2 itself or may continue upto F6 or beyond. This method is generally known as " Mass -pedigree method of Harlan".

Opportunity for natural selection

Maintenance of bulks in inexpensive and without much effort. Some bulk population may be carried upto F2o are F 30 to provide an opportunity for natural selection to act. It is assumed that, natural selection would favour higher yielding genotypes and eliminate the poorer genotypes.

BULK METHOD PROCEDURE

Hybridization

Selected parents are crossed according to the objective of the breeding programme.

F1 generation

F1 is space planted and harvested in bulk. The number of F1 plants should be as large as possible. Usually more than 20 plants should be grown.

F2 to F6 generation

F2 to F6 generations are planted at commercial seed rates and spacing. These generations are harvested in bulk. During the period. Artificial selection is generally not done. The population size should be as large as possible, preferably 30,000 -50,000 plants in each generation.

F7 generation

About 30-50 thousand plants are space planted. 1000 to 5000 plants with superior phenotypes are selected and their seeds harvested separately. Selection is based on the phenotype of plants, grain characteristics, disease reaction etc.,

F8 generation

Individual plant progenies are grown in single or multi row plots. Most of the progenies would be reasonably homozygous and are harvested in bulk. Weak and inferior progenies are rejected. Only 100-300 plant progenies wit desirable characters are saved. Some progenies would show segregation. Such progenies are generally rejected.

F9 generation

Preliminary yield trial is conducted with standard checks. The yield is used as a basis for the selection of superior progenies. The progenies are evaluated for height, resistance, maturity and quality aspects.

F10-F13 generation

Replicated yield trials are conducted over several locations using standard commercial varieties as checks. A superior line is released as a new variety.

F14 generation

Seed of the released variety is increased for distribution to the cultivators.

Merits of bulk method

1. The bulk method is simple, convenient and inexpensive.
2. No pedigree record is to be kept, which saves time and labour
3. Little work and attention is needed in F2 and the subsequent generations. The breeder is free to concentrate more on other breeding projects.

4. Natural selection increases the frequency of superior types in the population, progenies selected from long term bulks are likely to the far superior to those selected from F2 or short term bulks.
5. There is a greater chance isolation of transgressive segregants is more likely to appear and increase due to natural selection.
6. Artificial selection may be practiced to increase the frequency of desirable types.

Demerits of bulk method

1. Bulk method takes a much longer time to develop a new variety.
2. In short term bulks, the natural selection has little effect or the genetic composition of populations.
3. It provides little opportunity for the breeder to exercise his skill in selection.
4. A large number of progenies have to be selected at the end of the bulking period.
5. Information on the inheritance of characters cannot be obtained.

MODIFIED BULK METHOD

A modification of bulk method based on artificial selection in F2 and the subsequent generations is outlined below:

F2 and F3 generation

F2 and F3 generations are space planted and a large number (1000-5000) of desirable plants are selected. Seeds from the selected plants are bulked.

F4 generation

F4 is space planted and 1000to 500 desirable plants are selected. Seeds from the selected plants are harvested separately.

F5 generation

Individual plant progenies are grown. Selection among progenies is based on plant height, disease resistance, lodging resistance, maturity date and other agronomic characteristics. Undesirable and inferior progenies are eliminated. Often only 10-30% of the progenies may be saved. Seeds from each of the selected progenies are harvested in bulk.

F6 generation

A preliminary yield trial is planted using the bulk seeds from the selected individual plant progenies observation are recorded on agronomic characteristics and yield. Quality tests may be done on superior progenies.

F7 generation

Superior progenies selected on the basis of yield trial are space planted for further purification. Individual plants are selected from the superior progenies and their seed is harvested separately.

F8 generation

Individual plant progenies are grown inferior progenies and progenies showing segregation are ordinarily rejected. Each selected progeny is harvested in bulk.

F9 generation

Preliminary yield trial is conducted to identify few superior progenies for detailed yield tests. Quality test is done to eliminate undesirable progenies.

F10-F13 generations

Replicated yield trials are conducted at several locations with standard varieties as checks. The lines that are superior to the standard checks would be released as new varieties.

F14 generation

Seed of the newly released variety is multiplied for distribution among the farmers.

This modified bulk method provides an opportunity for the breeder to exercise his skill and judgement in selection of superior plant types in the early generations (F2 to F4). At the same time it does not involve laborious record keeping as in the case of the pedigree method.

POLY PLOIDY IN PLANT BREEDING

The somatic chromosomes number of any species, whether diploid or polyploid is designated as ' 2n' and the chromosomes number of gametes in denoted as 'n'. An individual carrying the gametic chromosome number 'n' is known as 'haploid'. A monoploid on the other hand, has the basic chromosome number X. In diploid species n=X. One 'X' constitutes a genome or chromosome complement.

Individuals carrying chromosome number other than diploid number are known as heteroploids.

The change in chromosome number may involve once or few chromosomes of the genome. This is known as aneuploidy.

Aneuploidy - One or a few for chromosome extra of missing from 2n - 2n I few

Nullisonic - One chromosome pair missing - 2n-2

Monosonic - One chromosome missing - 2n-1

Double monosomic-One chrosome from each of two different pairs missing- 2n-1-1

Trisonic - 2n+1 Double Trisonic 2n+1+1 Tetrasonic 2n+2 (extra one pair)

Application in crop improvement

1. Aneuploids are useful in studies on the effects of loss or gains of an entire chromosome or a chromosome are on the phenotype of an individual.
2. Aneuploids are useful in locating a linkage group and a gene to a particulars chromosome.
3. Study of Aneuploids has shown the homeology between A, B and D genomes of wheat.
4. Aneuploids are useful in identifying the chromosomes involved in translocations.
5. They are useful in the production of substitution lines. It is useful for transfer of genes carried by specific chromosomes of a variety into another one.

Autopolyploid

Euploidy is more commonly known as ploypoidy. When all the genomes present in a polyploid species are identical, it is known as 'autopolyploid'. In case of allopolyploids, two or more distinct genomes.

In autopolyploidy are included monoploidy, triploidy tetraploidy and higher levels of ploidy. Autoploidy are directly or indirectly through chromose doubling.

Origin and production of doubled chromosome numbers

1. Due to treatment with physical agents
2. Regeneration invitro
3. Colchicine treatment
4. Chemical agents

Application of autoploidy in crop improvement

Monoploids and haploids

Monoploids are weaker than diploids and are little agricultural value directly.

1. They are used for developing homozygous diploid lines, following chromosome doubling is two years. This greatly reduces the time and labour required for the isolation of inbred and pure lines.
2. They may be useful in the isolation of mutants.
3. Haploid derived diploids may be expected to be more efficient than that based on zygote derived diploid.

Haploids occur spontaneously in low frequencies may be induced from pollen grains through callus formation or embryo production and by chromosome elimination in certain interspecific crosses.

Triploids

These are by hybridization between tertraploid and diploid strains. They are generally highly sterile. This feature is useful in the production of seedless watermelons. In certain species they may be more vigorous than the normal diploids.

Seedless watermelons are grown commercially in Japan. They are produced by crossing tetraploid (4x used as female) and diploid (2X, used as male) lines, since the reciprocal cross (2X x 4X) is not successful. Triploid plants do not produce true seeds almost all the seeds are small. For good fruit setting, pollination is essential. For this purpose diploid lines are planted in the ratio 1 diploid: 5 triploid plants.

Triploid sugarbeet (*Beta vulgaris*)

Produce large roots and more sugar per unit area than diploids, while tetraploids produce smaller roots and lower yield than diploids. Apparently, 3X is the optimum level

of ploidy in sugar beets. Triploid seeds maybe produced is one of the following two ways.

1. Using 4 x plants as female and 2X as male
2. Using 2x as female and 4x as male

Commercial triploid sugarbeet seed is produced by inter planting 4 x and 2x lines in the ratio of 3:1 and the seeds from both 4x and 2x plants is harvested. This seed consists of about 75% triploid (3x) seeds. Triploid sugarbeet may give 10-15% higher yields than diploids.

Triploid tea

Produces larger shoots and more biomass yield, more cured leaf per unit area and more drought tolerant to drought than diploid.

Tetraploid

Autoploids have been produced in large number of crops species. They may be useful in one of the following ways; in breeding, improving quality, overcoming self-incompatibility, making distant crosses and used directly as varieties.

Some autotetraploids may be superior in some quality characters to their respective diploids. E.g. Tetraploid maize has 43% more carotenoid pigment and vitamin A activity than the diploid.

Some tetraploids may be hardier than diploids.

Auto tetraploidy in able to overcome self-incompatibility in certain cases like tobacco. Certain distant crosses are not successful at the diploid level, but are relatively successful at the autotetraploid level e.g. Brassica.

Autotetraploids are larger in size and are more vigorous than diploids. Autotetraploid varieties of forage crops have been considerably successful. Many ornamentals are autotetraploids with increased flower size with long flowering duration.

Autotetraploids have been explored in several crop species but the most successful case in that rye, barley and jowar, where larger grains increased protein content and higher yields are the objective.

Allopolyploidy

Allopolyploids have genomes from two or more species. Several of our crop plants are allopolyploids.

Origin

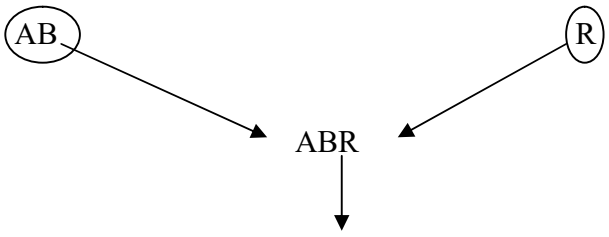
The present day allopolyploids were most likely produced by chromosome doubling in F1 hybrids between two distinct species belonging to same genus or to different genera. Experimental production of allopolyplids in achieved by doubling the chromosome number of distant hybrids with the help of Colchicine or some other agent. The productions of allopolyploids involve two steps.

1. Production of F1 distant hybrid
2. Chromosome doubling

Experimental production of an allopolyploid

Triticum turgidum Scale cerale

AABB x RR



Tritical - AABBRR - Allohexaploid

Raddish Cabbage

Raphanus sativa x Brassica oleraceae

Raphenobrassica fertile - (But leaves like radish root like cabbage)

The aim of producing Raphanobrassica was to synthetic a crop species that would combine the root or radish (R. Sativus) and the leaves of the cabbage. Raheno Brassica did combine the characteristic root and shoot systems of the two parental species, but in

opposite direction, that is it had leaves like radish and roots like cabbage. On the other hand, Tritical has combined the favourable features of the two parental species i.e the hardiness of rye and yielding ability of wheat.

In general allopolyploids are more vigorous than diploids, but this also is not true in all the cases. Another feature of allopoloyploids is that many of them are Apomictic.

Applications of Allopolyploids in crop improvement

Allopoloyploids have been more successful as crop species than autoploids. Many of our present day crop species are allopoloyploids. It is estimated that, about one third of the angiosperms are polyploids and by far the vast majority of them are allopolyploids.

i. Utilization a bridging species: Amphidiploids serve as a bridge in the transfer of character from one species to related species generally from a wild species to a cultivated species. e.g. Nicotiana, Gossypium

ii. Creation of new crop species: Triticale in the most successful synthetic allopolyploids produced by crossing wheat with Rye.

iii. Widening the genetic base of existing allopolyploids

The genetic base of some natural allopoloids may be narrow and it can be eividenced by introduced more vairability. E.g *Brassica napus*.

Limitations of allopolyploidy

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

BREEDING FOR STRESS RESISTANCE

Stress

It is a system of forces that affects the normal growth, development and productivity of crops.

Cultivated crops are exposed to different kinds of stresses caused by biotic and abiotic factors.

Biotic stress

1. Fungi or bacteria and viruses that causes diseases and damage to the plants.
2. Insect and nematode cause damage by cutting or boring into the plant parts or sucking of the cell sap.
3. Parasites such as curcuta, loranthus etc., that live on the host, and draw nutrients from the host.
4. Monocot and dicot weeds.

Abiotic stress

Climate, ecological and edaphic factors that affect the crop. They include problem soil with salinity and sodicity (Alkalinity and acidity), extremes of temperature and water stresses causing cold, drought and deep water conditions, deficiency or excess of certain minerals causing zinc deficiency, Phosphorus deficiency iron toxicity etc.,

Disease

A physiological deviation from the normal functioning of the organism (i.e. the crop plant) caused by pathogenic organisms is a disease and may be caused by fungi, bacteria or viruses.

Resistance

The inherent ability of an oraganism to resist or with stand the pathogen is called ' Resistance"

Pathogenicity

It is ability of a pathogen to attack a host. It includes virulence and aggressiveness. Virulent strains of pathogen cause much severe symptoms of the disease and they carry the virulence gene that enables it to attack a particular host genotype. Virulence is due to the action of one or a few genes.

An aggressive strain of a pathogen causes severe disease on all the host genotypes which they are able to attack and aggressiveness is polygenically inherited.

Host-Pathogen relationship

A disease in the result of an interaction of genes governing resistance in the host with those governing pathogen city in the pathogen depends not only the genotype of the host resistance, but also upon the genotype of the virulence or aggressiveness.

Flor (1942) proposed the " Gene for gene hypothesis" according to which for every gene for resistance in the host there is corresponding gene for pathogenecity in the pathogen.

\+ Pathogen can infect the host susceptible

\- Pathogen cannot infeet the host is resistant

Pathogen

	V1	V1
R1	-	+
R1	+	+

Host

There are atleast two allels at a locus controlling resistance / susceptibility in the host (R-r) and two allels at a corresponding locus in the pathogen (V-v) controlling / aggressiveness.

Out of the four possible interactions between these allels only one combination leads to the expression of resistance. The demonstration of gene-for gene relationship requires genetic studies of both the host and the pathogen. While breeding for resistance, it is necessary to make a survey of all physiological races found in the locality and to breed for resistance to all prevalent races. This is essential because a variety may be resistant to one race but susceptible to another.

Concept of resistance

Vertical resistance: Vander Plank (1960) usually immunity, towards a virulent race/pathotype. The specific virulent race produces susceptible response. Generally controlled by olizogenes

Horizontal resistance: Resistance governed by polygenes and in pathotype-non specific. It is controlled by polygenes.

SINGLE SEED DESCENT METHOD

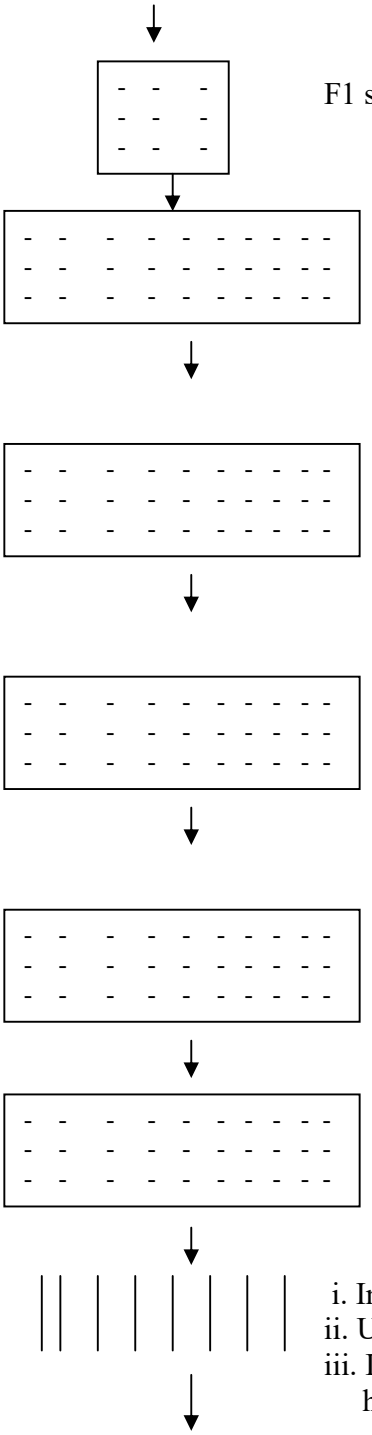
It is the modification of bulk method in which, a single seed from each of the one to two thousand F2 plants is bulked to raise the F3 generation. Similarly in F3 and the subsequent generations one random seed is selected from every plant present in the population and planted in bulk to raise the next generation. This procedure is followed till F5 or F6 when the plants would have become nearly homozygous. Selection is done mainly among the progenies and the number of progenies is sufficiently reduced to permit replicated trial in the next generation. Individual plants may be selected only from standing families showing segregation. Thus preliminary yield trials and quality tests begin in F7 to F8 and coordinated yield trials in F8 or F9.

The objective of single seed descent method in the rapidly advance the generations of crosses; at the end of the scheme, a random sample of homozygous genotype obtained. The important features of this scheme are:

1. Lack of selection till F5 or F6 when the population in reasonable homozygous.
2. Raising of F3 and later generations from a bulk of one seed from each F2 and the subsequent generation plant in order to ensure that each F2 plant is represented equally in the end of population.

Schematic representation of single descent method

P1 x P2 Selected plants hybridized.



F1 F1 space planted harvested in bulk.

F2 F2 densely planted

From each plant one random seed selected and bulked.

F3 As in F2

F4 As in F2

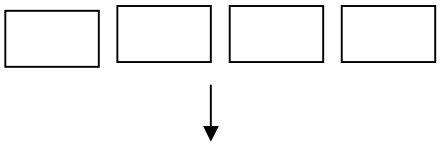
F5 As in F2

F6 i. F6 space planted

ii. 100-500 plants with desirable traits harvested separately

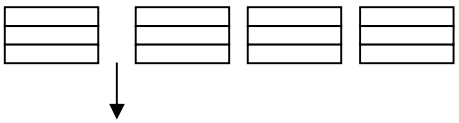
F7 i. Individual plant progenies grown
ii. Undesirable progenies eliminated
iii. Desirable homozygous progenies harvested in bulk.

F8



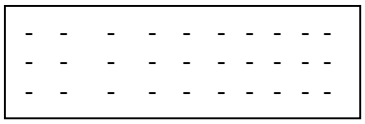
iv. Individual plants may be selected in outstanding progenies showing segregation

F9-F10



PYT with suitable check.
Quality test
Coordianted trials diseases and quality tests.

F11-F14



Seed increase for distribution.

BACKCROSS METHOD

A cross between a hybrid (F1 or segregating generation) and one of its parents is known back cross. In the back method, the hybrid and the progenies in the subsequent generations are repeatedly backcrossed to one of their parents As a result, the genotype of backcross progeny becomes increasingly similar to that of the parent to which it is backcrossed. The objective of the backcross method in to improve one or two specific defects of a high yielding variety.

For example a wheat variety Malviya 12, susceptible to leaf rust, but is a highly desirable variety. This variety in known as recipient parent, is crossed with a leaf rust resistant variety, sparrow this resistant variety is called as donor parent. The F1 hybrid and the progeny in the subsequent generations are backcrossed to recipient parent i.e Malviya 12. Since the recipient parent is repeatedly used in the backcross programme. It is also known as the "Recurrent parent". The donor parent is known as " Non Recurrent parent" because it is used only once in the breeding programme (for producing F1 hybrid).

Prerequisites of a backcross programme

For successful development of a new variety through the backcross method, the following requirements must be fulfilled.

1. A suitable recurrent parent must be available which lacks in one or two characteristics
2. A suitable donor parent must be available. The donor parent should have the character to the transferred in a highly intense form.
3. The character to the transferred must have high heritability. Preferably it should be determined by one or few genes.
4. A sufficient number of backcross should be made so that the genotype of the recurrent parent is recovered in full. Ordinarily 6-7 backcross are sufficient for the purpose.

Applications of the backcross method

It is applied to both self and cross-pollinated crops for transfer of resistance from one variety to another.

1. Intervarietal transfer of simply inherited characters

Characters governed by one or two major genes e.g. disease resistance, seed colour, plant height etc., are the most suited for transfer.

2. Intervarietal transfer of quantitative characters

The quantitative characters like earliness, plant height, seed size seed shape may also be transferred from one variety to another, if they have high heritability.

3. Interspecific transfer of simply inherited characters

Disease resistance from related species to the cultivated species. e.g. leaf and stem rot resistance from *Triticum tinopheevii, T. monococcum, Aegilops speltodides* and rye *to T. aestivam*.

Black arm resistance from several gossypium spp to G. hirsutum.

4. Transfer of cytoplasm

Transfer of cytoplasm is particularly desirable in cases of cytoplasmic male sterility. The variety or species from which the cytoplasm is to be transferred is used as the female parent. The recurrent plant, the parent to which the cytoplasm is to be transferred, is used as the male parent. After 6-8 backcrosses, the progeny would have the nuclear genotype of the recurrent parent and the cytoplasm from the donor plant.

5. Transgressive segregation

Backcross method may be modified to produce transgressive segregants. Firstly, the F1 may be backcrossed only 1-2 times to the recurrent parent leaving much heterozygosity for transgressive segregants to appear. In the second modification, two or more recurrent parents may be used in the backcross programme to accumulate genes from them into the backcross progeny. Such modification of the backcross would produce a new variety that would not be like any one of the recurrent parents.

6. Production of isogenic lines

Isogenic lines are identical in their genotype, except for one gene. Such lines are useful in studying the effects of individual genes on yield and other characteristics. Isogenic lines are easily produced by the backcross method.

7. Germplasm conversion

In some crops, valuable germplasms cannot be utilized in breeding programme. Since these lines are photosensitive. Such lines may be used as recurrent parent in

separate back cross programmes with a photo insensitive non-recurrent parent for the transfer of photo insensitivity. The lines derived from these programmes would be photo insensitive forms of their recurrent parents. These new lines are called converted lines and the process is commonly known as germplasm conversion.

PROCEDURE OF BACKCROSS METHOD

The plan of backcross method would depend upon whether the gene being transferred in recessive or dominant.

Transfer of a dominant gene

Let us suppose that, a high yielding and widely adapted variety "A" is susceptible to stem rust. Another variety "B" is resistant to stem rest, and that resistant to stem rust is dominant to susceptibility.

Hybridization

Variety "A" is crossed with "B". Generally variety "B" should be used as female parent. This would facilitate the identification of selfed plants if any.

F1 generation

F1 plants are back crossed to variety A" all the F1 plants will be heterozygous for rust resistance, selection for rust resistance is not necessary.

First back cross generation (BC1)

Half of the plants would be resistant and the remaining half would be susceptible to stem rust. Rust resistant plants are selected and back crossed to variety A. BC1 plants resistant to rust may be selected for their resemblance to variety "A" as well.

BC2-BC5 generations

In each backcross generations, segregation's would occur for rust resistance. Rust resistant plants are selected and back crossed to the recurrent parent.

BC6 generation

On an average, the plants will have 98.4 genes from variety "A". Rust resistant plants are selected and selfed. Their seeds are harvested separately.

BC6 F2 generation

Individual plant progenies from the selfed seeds of the selected plants are grown. Rust resistant plants similar to the plant type of variety 'A' are selected. The selected plants are harvested separately.

BC6 F3 generation

Individual plant progenies are grown. Progenies homozygous for rust resistance and similar to the plant type of variety 'A' are harvested in bulk. Several similar progenies are mixed to constitute the new variety.

Yield tests

The new variety is tested in a replicated yield trial along with the variety 'A' as a check. The new variety would be identical to the variety A in performance.

Transfer of a recessive gene

When rust resistance is to a recessive gene, all the back crosses cannot be made one after the other. After the first backcross, and after every two back crosses, F2 must be grown to identity rust resistant plants. The F1 and the backcross progenies are not inoculated with rust because they would be susceptible to rust. Only the F2 is tested for rust resistance.

Hybridization

The recurrent parent is crossed with rust resistant donor parent. The recurrent parent is generally used as the female parent.

F1 generation

F1 plants are back crossed to the recurrent parent.

B C1 generation - Since rust resistance is recessive all the plants will be rust susceptible. Therefore, there is not test for rust resistance. All the plants are self-pollinated.

BC1 F2

Plants are inoculated with rust spores. Rust resistant plants are selected and backcrossed with the recurrent parent. Selection is done for the plant type and other characteristics of the variety 'A'.

BC2 generation

There is no rust resistant test. Plants are selected for their resemblance to the recurrent parent. A and back crossed with the recurrent parent.

BC3 generation

There is no disease test. The plants are self-pollinated to raise F2.

BC3 F2 generation

Plants are inoculated with stem rust. Rust resistant plants resembling variety A are selected and backcrossed to variety 'A'. Selection for plant type of 'A' is generally effective.

BC 4 generation

No resistance test. Plants are backcrossed to variety 'A'.

BC 5 generation

No resistance test. Selfing for raising F2.

BC5 F2 generation

Plants are subjected to rust epidemic. A rigid selection is done for rust resistance and for the characteristics of variety 'A'. Selfed seeds from the selected plants are harvested separately.

BC5 F3 generation

Individual plant progenies are grown and subjected to rust epiphytic. A rigid selection is done for resistance to stem rust and for characteristics of variety A seeds from several similar rust resistant homogenous progenies are mixed to constitute the new variety.

Yield tests

It is some as the case of transfer of a dominant gene.

Merits of backcross

1. The genotypes of new variety is nearly identifical with that of the recurrent parent, except for the genes transferred. Thus the outcome of a back cross programme is known and it can be reproduced any time in the future.
2. It is not necessary to test the variety developed by the backcross method in extensive yield tests because the performance of the recurrent parent is already known. This may save upto 5 years time and a considerable expense.
3. The back cross programme is not dependent upon environment, except for that needed for the selection of the character under transfer. Therefore off-season nurseries and greenhouse can be used to grow 2-3 generations each year. This would reduce the time required for developing the new variety.

4. Much smaller populations are needed in the backcross method than in the case of pedigree method.
5. Defects, such as susceptibility to disease of a well-adapted variety can be removed with out affecting its performance and adaptability. The farmers prefer such a variety, because they know the recurrent variety well.
6. This is the only method for inter-specific gene transfer, for the transfer of cytoplasm.
7. It may be modified so that transgressive segregation may occur for quantitative characters.

Demerits of backcross

1. The new variety generally cannot be superior to the recurrent parent, except for the character that is transferred.
2. Undesirable genes closely linked with the gene being transferred may also be transmitted to the new variety.
3. Hybridization has to be done for each backcross. This is difficult, time taking and costly.
4. By the time the backcross programme improves it, the recurrent parent may have been replaced by other superior varieties.

Recessive gene transfer

Other approaches to breeding self-pollinated crops

The common methods of breeding in self-pollinated crops, either use the variability already present in the population (mass selection, pure line selection) or the variability created through hybridization. The effect of either of these approaches in a rapid increase in homozygosity. So a number of other breeding approaches have been suggested for the improvement of self-pollinated crops. The important new approaches are,

1. Multi-line varieties
2. Population approach.
3. Rapid isolation of homozygous lines
4. Hybrid varieties.

Multi-line varieties

These are mixture of several purelines of similar height, flowering and maturity dates, seed colour and agronomic characteristics, but having different genes for disease resistance.

The purelines constituting a multiline variety must be compatible i.e they should not reduce the yielding ability of each other, when grown in mixture. The idea of multi line varieties was put forward by Jenson in 1952 for use in cereals. In 18954, Borlaug suggested that several purelines with different resistant genes should be developed backcross programmes using one recurrent parent. Multiline variety appear to be a useful approach to control diseases like rust, where new races are continuously produced.

Population breeding approach

In population breeding outstanding F2 plants are mated among themselves in pairs or in some other fashion. The intermating of selected F2 plants restorers heterozygosity in the progeny which provides for grater opportunity for recombination. This also brings together the desirable genes from different F2 plants and would help in accumulation of favoruable genes in the intermated population. Thus the chances of the recovery of transgressive segregants would increase considerably. This process may be repeated one ore more time. The idea of population approach was first suggested by Palmer in 1953.

Rapid isolation of homozygous lines

In self-pollinated crops, the breeders aim at developing superior homozygous liens. In crossing programmes, the segregating materials have to be carried to at least F45 of often, F6 for reaching homozygosity, to permit preliminary evaluation. Technique are now available, at least in some crop species for the isolation of completely homozygous lines from the F1 generation itself. This technique consists of ;

1. Extraction of haploid plants often F1 plants using anther culture or distant hybridization.
2. Chromosome completely homozygous diploid plants and subsequently, progenies.

HYBRID VARIETIES AND SYNTHETIC VARIETIES

Self-pollinated crops show little or no loss in vigour or yield due to inbreeding. But F1 hybrids are generally more vigorous and higher yielding than either of their parents. They are also more stable phenotypically than the parental lines. The superiority of an F1 over its parents is known as heterosis or hybrid vigour.

SYNTHETIC VARIETIES

A synthetic variety is produced by crossing in all combinations a number of lines that combine well with each other. Once synthesized a synthetic is maintained by open pollination in isolation.

COMPOSITE

A composite variety is produced by mixing the seeds of several phenotypically outstanding lines and encouraging open pollination to produce crosses in all combinations, among the mixed lines. The lines used to produce a composite variety are rarely tested for combining ability with each other. Consequently, the yields of composite varieties cannot be predicted in advance. The composites are commercial varieties and are maintained by open pollination in isolation.

Operations in producing a synthetic variety

The lines that make up a synthetic variety may be inbred lines, clones, open-pollinated varieties, short term inbred lines or other populations tested for GCA or for combining ability with each other.

Evaluation of lines for GCA

The GCA is generally estimated by topcross or polycross test. The lines are evaluated for GCA because synthetic varieties exploit that portion of heterosis which is produced by GCA.

Polycross refers to the progeny of a line produced by natural pollination, with a random sample of pollen from a number of selected lines. It is commonly used forage crops. Poly crops progeny are generally produced by open pollination in isolation among the selected lines. The lines that have high GCA are selected as parents of a synthetic variety.

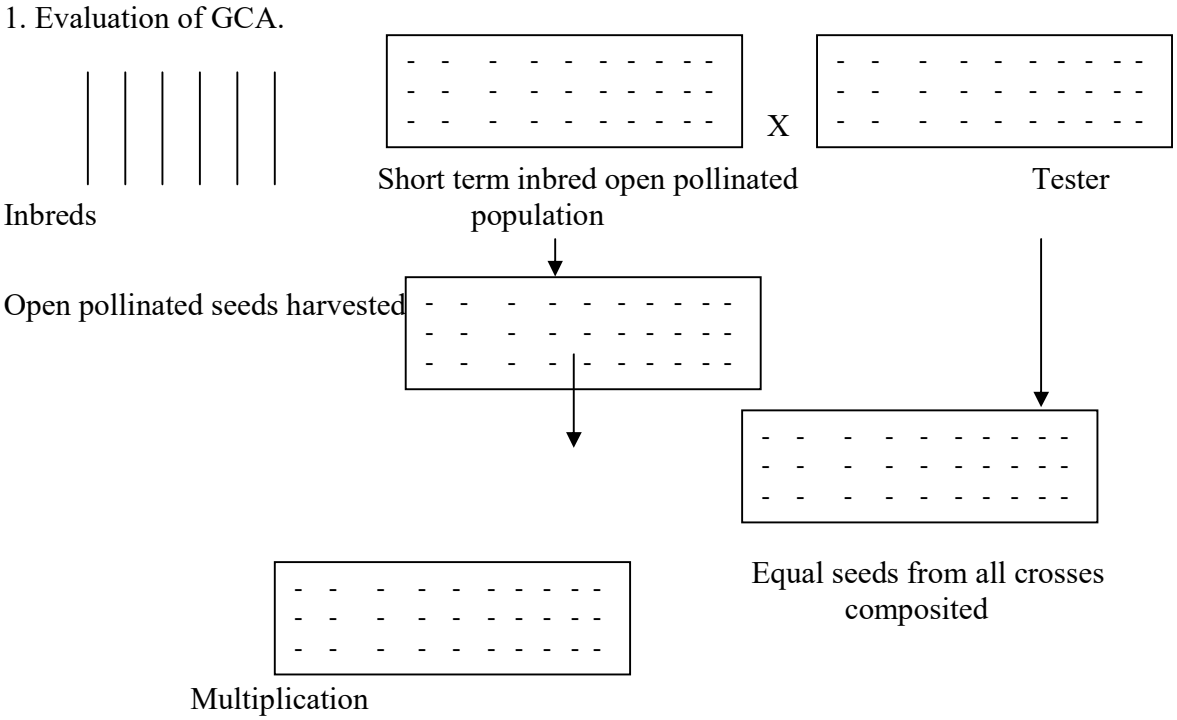
Production of a synthetic variety

A synthetic variety may be produced in one of the following two ways.

1. Equal amounts of seeds from the parental line (Syn 0) are mixed and planted in isolation. Open pollination is allowed and expected to produce crosses in all combinations. The seed from this population is harvested in bulk; the population raised from this seed is the Syn1 generation.
2. All possible crosses among the selected lines are made in isolation. (The parental constitute syn 0 generation). Equal amounts of seed from each cross is composited to produce the synthetic variety. The population derived from through composited seed is known as the syn.1 generation.

Multiplication of synthetic varieties

After a synthetic variety has been synthesized, it is generally multiplied in isolation for one or more generation before its distribution for cultivation.



The open pollinated progeny from the Syn 1 generation is termed as Syn 2 tht from Syn 2 as Syn 3 etc. The performance of Syn 2 is expected to the lower than that of Syn1. Due to the production of new genotypes and a decrease in heterozygosity as a

consequence of random mating. However there would not be a noticeable decline in the subsequent generations produced by open pollination (Syn 3, Syn4, Syn 5 et.c,). Since zygotic equilibrium for any gene is reached after one generation of random mating. The synthetic varieties are usually maintained by open pollinated seed and may be further improved through population improvement schemes, particularly through recurrent selection.

Merits

1. The farmer does not have to purchase new seed every year, unlike hybrid varieties. The synthetics can be maintained for several years from open-pollinated seed.
2. The cost of seed is relatively lower than that of hybrid varieties.
3. In variable environments, synthesis are likely to do better than hybrid varieties because, synthetics are having wider genetic base than hybrids.
4. Seed production of hybrid varieties is a more skilled operation than that of synthetic varieties.
5. Synthetic varieties are good reservoirs of genetic variability.

Demerits

1. The performance of synthetic varieties is usually lower that of single or double cross hybrids. This is because synthetics exploit only GCA, while the hybrid varieties exploit both GCA and SCA.
2. The performance of synthesis is adversely affected by lines with relatively poorer GCA.
3. Synthesis can be produced and maintained only is cross-pollinated crop species, while hybrid varieties can be produced both in self-pollinated and cross-pollinated crops.

CLONAL SELECTION

Some agricultural crops and a large number of horticultural crops are asexually propagated. Some common asexually propagated crops are sugarcane, potato, sweet potato colocasia, Discorea (gams), Mentha, Ginger, turmeric, banana etc., almost all the fruit trees.

Segregation and recombination produce new gene combinations due to which the progeny differ from their parents in genotype and phenotype. A sexual reproduction, on the other hand, produces progeny exactly identical to their parents in genotype because the progeny are derived from vegetative cells through mitosis. It preserves the genotype of an individual indefinitely. Any genotype is preserved and maintained through asexual reproduction.

Characteristics of Asexually propagated crops

1. A great majority of them are perennials e.g. sugarcane, fruit trees etc.,
2. Many of them show reduced flowering and seed set.
3. They are invariably cross pollinated
4. These crops are highly heterozygous ands show severe inbreeding depression
5. A vast majority of asexually propagated crops are either polyploids eg., sugarcane, potato.
6. Many species are interspecific hybrids eg. Banana and sugarcane.
7. This crop consists of a large number of clones that is progeny derived from a single plant through asexual reproduction.

CLONE

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

Characteristics of a clone

1. All the individuals belonging to a single clone are identical in genotype.

2. The phenotype variation with in a clone is due to the environment only
3. The phenotype of a clone is due to the effects of genotype (G) the environment (E) and the G x E interaction over the population mean (r)

   Phenotype (P) = M+G+E+ GE
4. Theoretically clones are immortal i.e. a clone can be maintained indefinitely through asexual reproduction. But clones usually degenerate due to viral or bacterial infections.
5. Clones are generally, highly heterozygous and show severe loss in vigour due to inbreeding.

Genetic variation within clones

It may arise due to somatic mutation, mechanical mixture and occasional sexual reproduction.

Clonal degeneration

Theoretically, clones are immortal. The loss in vigour and productivity of clones with time is known as clonal degeneration. The clonal degeneration may result from (1) mutation (2) viral diseases and (3) bacterial diseases.

Mutation

It is a recurrent process, it may become a problem over a long period of time

Viral diseases

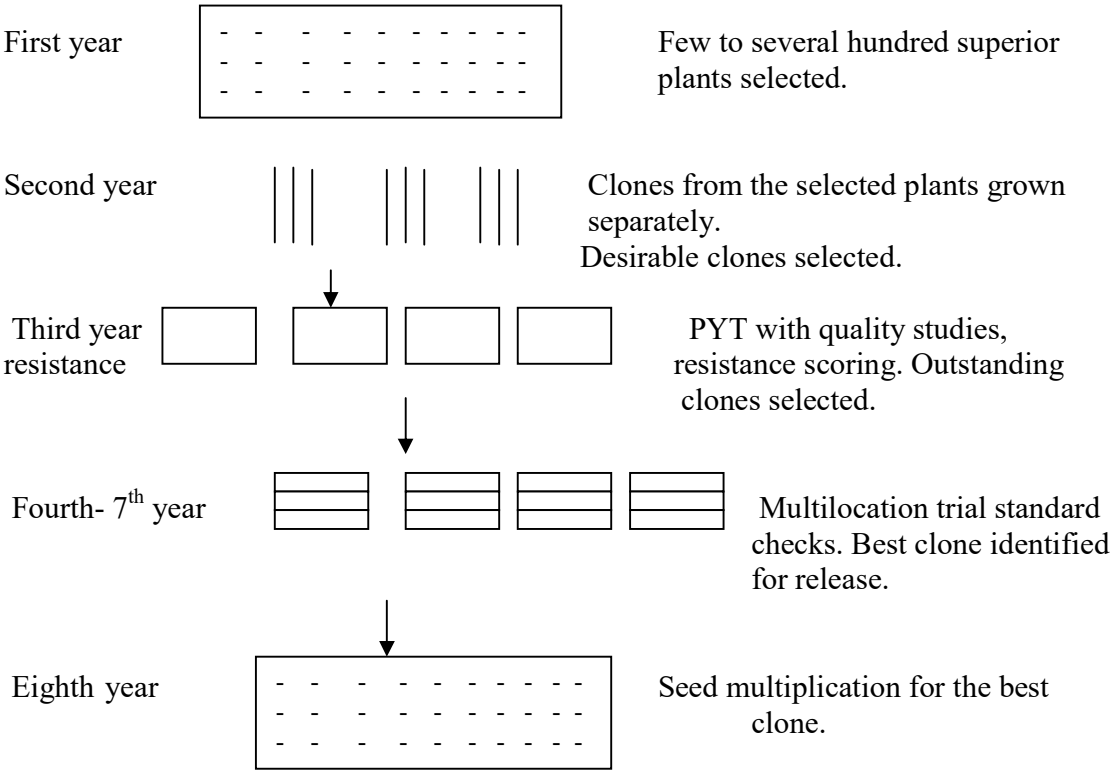
They are easily transmitted through vegetative propagules. Viruses are perhaps responsible for more cases of clonal degeneration than any other single cause.

Bacterial diseases

By the result of bacterial infections making clonal degeneration.

Methods of improvement of Asexually propagated crops

A single outstanding plant selected form a population forms the basis of a new variety. The breeding behaviour or genotypes of the plant is not important, Since there would be no further sexual reproduction. The outstanding plant may be selected from an old unimproved variety, an improved variety that has become variable or from a population produced by crossing two or more clones. The procedure of selection used for such crops is known as "clonal selection". Since the selected plants are used to produce new clones.



In the earlier stages of clonal selection, when selection is based on single plants or single plots, the emphasis is on the elimination of weak and undesirable plants or clones. The breeder cannot be reasonably hope to identify superior genotype at this stage. In the later stages when replicated trials are the basis of selection, the emphasis is to identify and select the superior clones.

Merits of clonal selection

1. It is the only method of selection applicable to clonal crops. It avoids inbreeding depression and preserves the gene combination present in clones.
2. Clonal selection can be combined with hybridization to generation necessary variability for selection.
3. The selection scheme is useful in maintaining the purity of clones.

Demerits of clonal selection

1. This method utilizes the natural variability already present in the population. It is not devised to generate variability.
2. Sexual reproduction is necessary for the creation of variability through hybridization.

HYBRIDIZATION IN CLONAL CROPS

Clonal crops generally improved by crossing two or more desirable by crossing two or more desirable clones, followed by selection in the F1 progeny and in the subsequent clonal generation once the F1 has produced, the breeding procedure is essentially the same as clonal selection. The improvement through hybridization involves three steps.

1. Selection of parents
2. Production of F1 progeny
3. Selection of superior clones.

Selection of parents

The value of F1 progeny would depend upon the parents used. Parents are generally selected on the basis of their known performance both as varieties and as parents in hybridization programmes. The performance of a strain in hybridization programmes depends on its prepotency and general combining ability. It would be highly desirable to known the relative values of GCA and SCA is like crop to be improved.

Production of F1 progeny

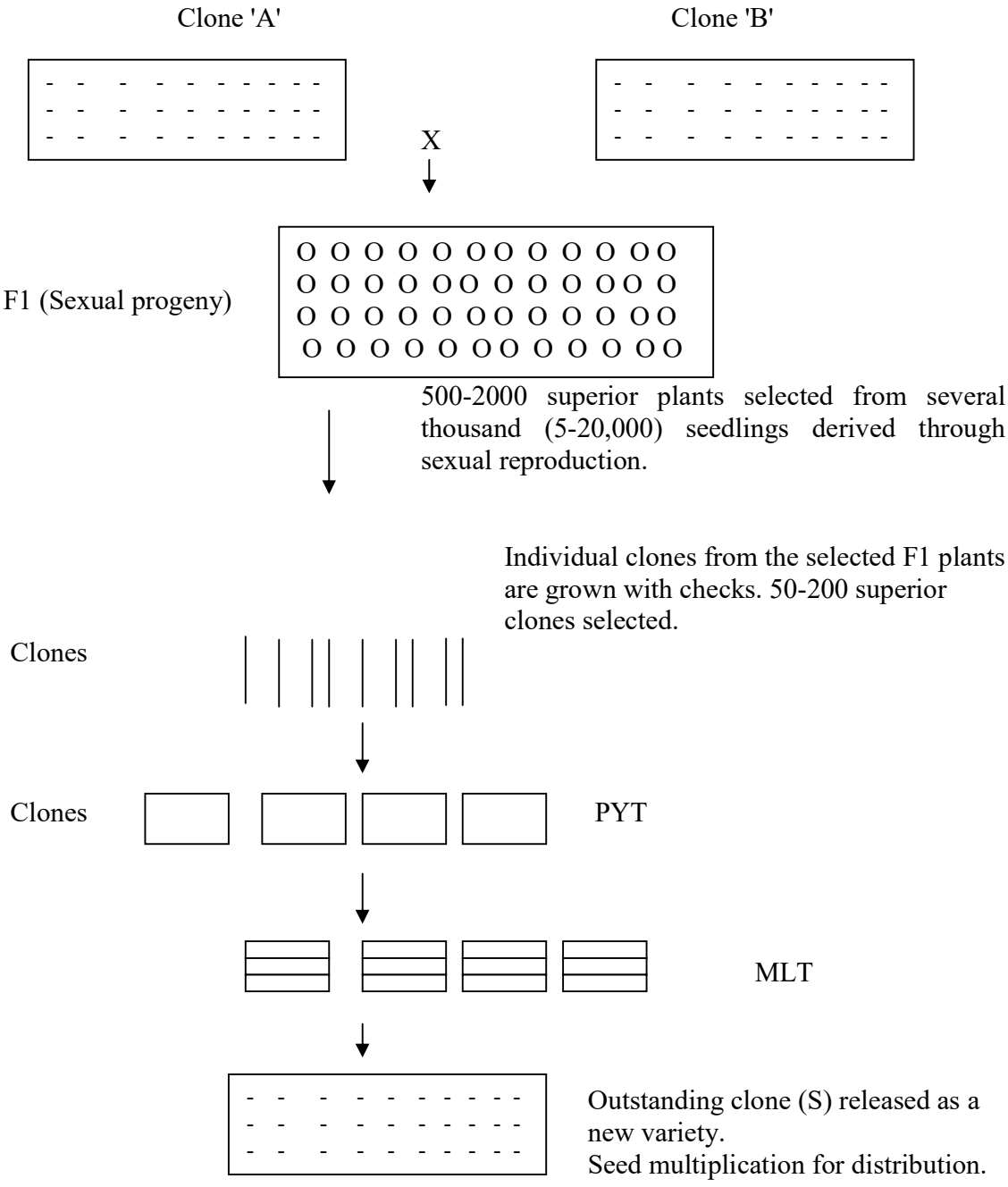
Generally clonal crops are cross-pollinated and they may show self-incompatibility. The selected parents may be used to produce single crosses involving two parents or an equivalent of a poly cross involving more than two parents.

Selection among F1 families

When the breeding value of parents is not known and the relative contribution of GCA and SCA is not available, a large number of crosses have to be made inorder to ensure that atleast some of the crosses would produce outstanding progeny in F1. In such cases, it would be difficult to evaluate large number of F1 progeny in detail. To avoid this generally small samples of several F1 populations are grown. The general worth of individual F1 families or population is estimated visually. Inferior families are eliminated. Promising families with outstanding individuals are then grown at a much larger scale for selection.

Scale for selection

The selection procedure within in F1 families is essentially the same as that in the case of clonal selection.



INTERSPECIFIC HYBRIDIZATION IN THE IMPROVEMENT OF CLONAL CROPS

Interspecific hybridization has been successfully used in the improvement of clonal crops like, potato, sugarcane, strawberries etc., potato variety "Kufri Kuber' was developed from a complex cross (*Solanum curtilobum x S. tubersoum) x Solanum andigena.* This vareity shows much less clonal degeneration in the plains than the vareity up to date. Generally interspecific crosses are made to transfer specific characters such as disease resistance from the wild species to the cultivated potato. For example *S. demissum* has been extensively used as a source of late blight resistance.

All sugarcane varieties now in cultivation have developed from complex crosses between sugarcane varieties have been developed from complex crosses between *Saccharum officinarum* (Noble cane), *S.barberi* (Indian cane) and *Saccharum* sp. like *S. spontaneous* has been used to combine its and high yielding ability of S. officinarum.

The principle reason for such a great success is then asexual reproduction this completely avoids segregation and recombination. Another reason in that most of them are not seed crops, hence flowering and fertility are not essential for their success as varieties.

Problems in the breeding asexually propagated crops

There are several problems peculiar to clonal crops, which are difficult to resolve. There are three major problems in their breeding

1. Reduced flowering and fertility
2. Difficulties in genetic analysis and
3. Perennial life cycle.

Reduced flowering and fertility

Clonal crops grown for vegetative parts generally show reduced flowering; some varieties do not flower at all e.g., sugarcane, potato, sweet potato, colocassia etc., They also show interspecific hybridity and cytoplasmic male sterility. In fruit crops, flowering does occur, but seed set is generally much reduced. Because of reduced flowering and seed set, many desired clones cannot be used in hybridization programmes of many clonal crops.

Difficulty in genetic analysis

The reasons for difficulties are i. Reduced flowering ii. Sterility and iii. Perennial life cycle.

Perennial life cycle

Drastically increases the time required for obtaining sexual progeny for the genetic analysis of clones. Genetic analysis is most of the fruit trees in generally not attempted for this reason. Replicated yield trials are not possible in the case of perennials.

Achievements

Clonal selection

1. Kufri red potato vareity is a clonal selection from Darjeeling Red Round; It was developed from a single disease free plant.
2. Bombay green banana from Dwarf Cavendish by bud selection.

Hybridization

1. Potato varieties - Kufri Alankar, Kufri Kuber, Kufri Jyothi, (late Blight resistant).
2. Sugarcane: CO 541, CO 1148, CO 1158, COS 510 and CO 975

Polycross test

It is based on the seed obtained by random mating of a selected clone with all the other selected clones. To facilitate random mating among the clones, each clone is planted at several locations, each clone is planted on different dates. Poly crosses are generally not perfect i.e. mating in non random, and in many cases the mating may be highly non-random.

The polycross test is the most commonly used for estimating GCA in such crop species. The available evidence indicates that it is a more reliable test for GCA than open pollinated progeny test or top crosses test.

WIDE HYBRIDIZATION

Hybridization between individuals from different species, belonging to the same genus or two different genera, is termed as distant or wide hybridization

When individuals being crossed belong to species from two different genera, it is referred as intergeneric hybridization. When individuals from two distinct species of the same genes are crossed it is known as interspecific hybridization.

BARRIERS FOR CROSSSING

Several wild species are not crossable with the commerical cultivars due to various isolation barriers. The isolation barrier may be pre-zygotic that prevents fertilization and zygote formation or postzygotic in which fertilization takes place, hybrid zygotes are formed but they are inviable or give rise to weak or sterile hybrids.

Pre zygotic barriers

1. Failure of pollen germination
2. Slow growth of the pollen tube
3. Inability of the pollen tube to reach the ovary
4. Arrest of pollen tube in the style, ovary and ovule.

These are due to genic differences or differences in ploidy between species.

Post –Zygotic barriers

1. Hybrid inviability and weakness leading to chromosome elimination, lethality and embryo abortion.
2. Hybrid sterility
3. Hybrid breakdown with weak or sterile individuals in F2 owing to recombination of the gene complements of the parental species.

Techniques to overcome isolation barriers

Pre zygotic barriers can be overcome by the following techniques.

i. Mechanical removal of style followed by pollination of the exposed stylar end
ii. Bud pollination.
iii. Use of growth hormones such as GA3, IAA, NAA etc.,
iv. Invitro fertilization
v. Protoplast fusion
vi. Chromosome doubling before hybridization.
vii. Adopting bridging species technique

Post zygotic barriers can be overcome by

i. Chromosome doubling (Amphidiploidy)
ii. Back crossing
iii. Embryo rescue
iv. Tissue culture techniques.

Breeding procedure for wide hybridization

1. Backcross breeding

When interspecific crosses between two species of varying ploidy level are made invariably the hybrids are sterile. By chromosome doubling with application of Colchicine, amphidiploids can be produced. Such amphidiploids are fertile.

Cultivated tobacco, Nicotiana tabacum (2n=24) which crossed to N. glutinosa (2n=12) produced sterile F1 and by chromosome doubling an amphidiploid N. digluta (2n=36) was produced. This was reasonably fertilize with N. tabacum. By repeated backcrossing, a mosaic resistant line with 2n=24 was developed.

2. Amphidiploidy

The manmade cereal Triticale is an intergenic allopolyploid combining Triticum aestivum (Wheat 2n=42) and Secale cereale (rye –2n-14).

Rapanobrassica was synthesised by crossing Raphanus sativus, radish (2n-18) and Brassica olereaceae cabbage (2n-20).

3.Bridging species Technique

When direct crosses between two species are difficult, a third species is used in such crosses. Hexaploid wheat, Triticum aestivum (2n-42) does not cross with diploid species. When T. dicoccoides (2n=28) is crossed to Aegilops umbellulata (2n=14) and an amphidiploid was produced it crossed with T. aestivum (2n=42). Nicotiana sylvestrin (2n=24) is the bridging species to transfer nematode resitance from N. repanda (2n-48) to N. tacbaccum (2n=48).

3. Alien-addition and Alien substitution lines

By crossing two unrelated species of different ploidy level and doubling the chromosome number of the sterile F1, fertile amphidiploids are obtained. The amphidiploid in backcrossed to the cultivated species repeatedly twice or thrice and them selfed. In the selfed progeny, plants with one chromozome pair from the donor species in addition to the normal diploid chromosome of the parent species may be present and the y are called alien –addition lines. In certain other plants, one chromosome pair of the donor species may substitute one chromosome pair of the parent species when they are called alien substitution lines. By adopting the above methods, mosaic resistance from Nicotiana glutinosa (2n=24) was transferred to N. tabaccum (2n-48) by alien addition (2n=48+2) and alien substitution (2n=48-2+2).

MUTATION BREEDING

Mutation is a sudden heritable change in a characteristic of an organism. Mutations produced by changes in the base sequences of genes are known as gene or point mutations. The term mutations was introduced by Hugo de Vries in 1900

Spontaneous mutation

Mutations occur in natural populations (without any treatment by man) at a low rate. These are known as spontaneous mutations. The frequency of natural mutations is generally one in ten lakhs

Induced mutation

Mutations may be artificially induced by a treatment with certain physical or chemical agents. Such mutations are known as induced mutations, and the agents used for producing them are termed as mutagen. The utilization of induced mutations for crop improvement in known as mutation breeding. Induced mutations have a great advantage over the spontaneous ones, they occur at a relatively higher frequency so that it is practical to work with them.

Characteristics of mutations

1. Mutations are generally recessive, but dominant mutations also occur.
2. Mutations are generally harmful to the organism, but a small proportion (0.1 percent) of them are beneficial.
3. Mutations are random i.e., they may occur in any gene. However some genes show higher mutations rate than others.
4. Mutations are recurrent, that is the same mutations may occur again and again.
5. Induced mutations commonly show pleiotropy, often due to mutations in closely linked genes.

Mutagen

Agents used for induction of mutations are known as mutagens. The mutagens are classified into two groups, physical and chemical mutagens.

Physical mutagen

The mutations inducing radiation's are of two kinds.

i. Ionizing radiation ii. Non ionizing radiation.

Non-ionizing radiation

When compounds absorb energy from non-ionizing radiations, their electrons are raised to higher energy levels (excitation). It results in increased reactivity of the affected molecules leading to mutations.

The only one non-ionizing radiation capable of inducing mutations in ultra violet light. U-V radiation can be obtained from a mercury vapour lamp. U V rays have much longer wave lengths (about 2500 Angstroms)

Chemical mutagens

1. Alkylating agents – eg., EMS (Ethyl Methane Sulphonate) MMS (Methyl Methane Sulphonate)
2. Acridine dyes eg., Ethidium Bromide, acriflavine proflavine
3. Base analogue – eg. 5 Bromouracil, 5 – Chlorouracil
4. Others - eg., Nitrous acid, hydoxyl amine , sodium azide.

Ionizing radiation

Alpha, Beta and gamma rays of radio active substances, Neutrons and X rays are examples of ionizing radiation. When ionizing radiations passes through matter, atoms, absorb energy from them and lose electrons. When an atom becomes ionized, molelcule of which it is a part undergoes chemical change. If the molelcule is a gene and if this changed gene duplicate its new pattern, the result of the change is a mutation.

Gamma garden

The gamma garden of the Indian Agricultural Research Institute, New Delhi is a three-acre plot. In the centre of this field, there is a large source of radioactive cobalt (CO^{60}) and plants in pots are kept at varying distances from the source, irradiated and studied. It is used for irradiating whole plants during different stages and for varying durations.

Gamma rays are of shorter wavelength than X-rays and hence are penetrating. Gamma rays are commonly measured in terms of Roentgen units (r).

Mutagenesis

Treating a biological material with a mutagen in order to induce mutations is known as mutagenesis. Exposure of a biological material to radiation (x-rays, gamma rays etc.,) is known as irradiation.

Part of the plant to the treated

Seeds, pollen grains, or vegetative propagules (buds and cuttings) may be used for mutagenesis. Chemical mutagens are best used with seeds.

Dose of the mutagen

Mutagen treatments reduce germination, growth rate, vigour and fertility (pollen as well as ovule). An optimum dose in the on which produces the maximum frequency of mutations and causes the minimum killing. LD 50 in that dose of a mutagen which would kill 50 percent of the treated individuals. LD 50 value varies with the crop species and with the mutagen used. A preliminary experiment is generally conducted to determine the suitable mutagen dose. Dose of the mutagen may be varied by varying the intensity or the treatment time. Intensity in the case of chemical mutagens may be varied by changing the concentration of mutagens.

Mutagen treatment

The selected plant part is exposed to the desired mutagen dose. The case of chemical mutagens, seeds are usually presoaked for a few hours, to initiate metabolic activities, exposed to the desired mutagen and then washed in running tap water to

remove the mutagen present in them. The treated seeds are immediately planted in the field to raise the M1 generation. M2, M3, M4 etc are the subsequent generations derived from M1, M2, M3 etc., plants through selfing.

DOSIMETRY

The dose of X ray and gamma rays is measured roentgen (r) units which is defined as the quantity of radiation whose associated corpuscular emission per 0.001293 gm of air produces in air, ions carrying one esu of electricity per cc of air at NTP. The roentgen is expressed in mt. (0.001 r) and Kr (1000 r).

Radiation Absorbed Dose (RAD)

One rad corresponds to the absorption of energy of 100 ergs / gm of tissue.

Radiation equivalent physical (REP)

It has been introduced to measure the ionization by X, B and r particles. It corresponds to the amount of any kind of radiation producing the same number of ion pairs of energy in tissue of water as are produced by one r of x or gamma radiation.

Curie (C)

It is defined as the activity of a radioactive isotope in which 3.7×10^{10} disintegration takes place per second.

Molar (M)

One molar solution is the one molecular weight of the chemical in one litre of water.