Genetics
and
Plant Breeding

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Multiple alleles

Alleles : alternate forms of the same gene

Characters studied by Mendel : had two alternate forms

Ex : Plant height ___Tall , dwarf

Seed shape: round, wrinkled etc

Here one form is dominant over other. For Ex. Tall is dominant over dwarf

However, many genes have more than two alternate forms – govern the same trait

Ex : Coat colour in rabbit

Agouti : Dark grey

Chinchala: Mixed colour and white

Himalayan: White body and black tips

Albino : White

Agouti , Chinchala, Himalayan, Albino

k.
nce
c.

Crosses were made in different combinations

Crosses are

I. Agouti X Chinchilla

Agouti X Himalayan F_1 Agouti

Agouti X Albino

II. Chinchilla X Himalayan

Chinchilla X Albino F_1 Chinchilla,

III. Himalayan X Albino F_1 Himalayan

In F_2: 3 Dominant: 1 Recessive

For ex: First case: 3 Agouti: 1 Chinchalla
3 Agouti: 1 Himalayan
3 Agouti: 1 Albino

Second case : 3 Chinchalla : 1 Himalayan
3 Chinchalla : 1 Albino

Third case : 3 Himalayan : 1 Albino

Therefore Allelic relationship: $C > c^{ch} > c^{h} > c$

Another example is ABO blood group in Human

Antigen : It refers to a substance or agent when introduced into the system of vertebrate animal like cow , goat , man etc., induces the specific antibody , which binds specifically to this (antigen) substance

Antigens are present in red blood corpuscles (RBCs)

If a person has a specific antigen in his RBCs, his serum has usually the antibodies for the other antigen.

In human RBCs: two types of antigen: A and B

Depending on the presence of this in humans there are four blood groups : A, B, AB, O

Antibody: It is a type of protein which is commonly referred to as Immunoglobin(Ig).

It is usually found in the serum or plasma.

The presence of antibody can be demonstrated by its reaction with an antigen. Antigen antibody interaction leads to agglutination (clumping of particles)

Blood groups in human are controlled by a single gene with three alleles I^A, I^B and i

Allelic relationship: $I^A = I^B > I$

Blood groups in humans

BLOOD GROUP	ANTIGENS ON RBCs	ANTIBODIES IN SERUM	GENOTYPE S
A	A	Anti-B	$I^A I^A$, $I^A i$
B	B	Anti-A	$I^B I^B$, $I^B i$
AB	A & B	**NEITHER**	$I^A I^B$(universal acceptor)
O	**NEITHER**	Anti-A & Anti-B	ii(Universal donor)

Points to be noted:

1. I^A I^B >I
2. An individual will have only two alleles
3. At population level all alleles will be present

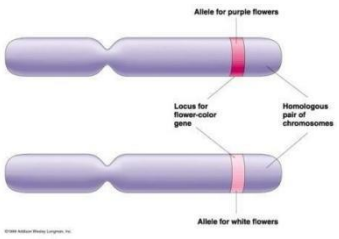
The number of possible genotypes in a series of multiple alleles is

== ½ n (n+1) **Where n** = number of alleles

- Di-allelic genes can generate 3 genotypes. (AA, Aa. Aa)
- Genes with 3 alleles can generate 6 genotypes.
- Genes with 4 alleles can generate 10 genotypes.
- Genes with 8 alleles can generate 36 genotypes

Characteristic features of multiple alleles

1. Multiltiple alleles always belong to the same locus and one allele is present ata locus at a time in a chromosome
2. Multiple alleles always control the same character of an individual



3. Wild type allele is dominant over other alleles
4. There is no crossing over in the multiple alleles
5. In a series of mutiple alleles wild type is always dominant
6. When two mutant types are crossed wild form cannot be recovered
7. The cross between two mutant alleles will always produce mutant

   phenotype.

   Examples of multiple alleles are 1) fur colour in a rabbit, 2) ABO blood group in man 3) Wing type in drosophila 4) Eye colour in drosophila etc.

   In plants self incompatibility in tobacco, *Brassica*

Linkage - types of linkage and estimation of linkage.

The number of genes in any organism exceeds the number of pairs of chromosomes. For instance in Drosophila, 10,000 or more of genes have been identified, yet there are only four pair of chromosomes. Since genes usually reside on the chromosomes, each chromosome must contain many genes. Genes on the same chromosome will not assort independently and hence Mendel's law of independent assortment is not universal but is limited to genes on different pairs of homologoues. The tendency of genes to go together in inheritance because of their residence on the same chromosome is called 'Linkage'.

The principle of linkage was discovered by Bateson and Punnet in 1906 in the sweat pea, plant, *Lathyrus odoratus*. However, linkage, as a concept was put forth by Thomas Hunt Morgan in 1910 based on his experiment on *Drosophila melanogaster*. The genes located on the same chromosome are called linked genes. All the genes located on a particular chromosome, form a linkage group. Since, the genes present on a particular chromosome have their alleles located on its homologous chromosome, genes on a pair of homologous chromosomes. Hence, the number of linkage groups corresponds to the number of haploid chromosomes found in a species.

Drosophila melanogaster has four linkage groups which can be distinguished into three large and one small linkage groups corresponding to the four pairs of chromosomes. Twenty-three linkage groups are present in humans corresponding to 23 pairs of chromosomes. Pea plant has seven linkage groups, corresponding to the seven pairs of chromosomes. In *Zea mays* there are 10 linkage groups**.**

Chromosome Theory of Linkage

Morgan, along with Castle formulated the chromosome theory of linkage. It has the following postulates;

1. Genes are found arranged in a linear manner in the chromosomes.
2. Genes that exhibit linkage are located on the same chromosome.
3. Genes generally tend to stay in parental combination, except in cases of crossing over.
4. The distance between linked genes in a chromosome determines the strength of linkage. Genes located close to each other show stronger linkage than that are located far from each other, since the former are less likely to enter into crossing over.

Ex 1: Genes in different pairs of homologous chromosomes assort independently giving 1:1:1:1 test cross ratio (Dihybrid).

AaBb x aabb

Gametes : AB, Ab, aB, ab ab

Test cross progeny ¼ AaBb : ¼ Aabb : ¼ aaBb : /aabb

Ex 2: Linked genes stay together in the same combination as they were in parents. Genes above the line are in one chromosome.

P : $\frac{A\ B}{a\ b}$ X $\frac{a\ b}{a\ b}$

Gametes AB, ab ab

Test cross progeny: $^1/_2$ AB/ab : $^1/_2$ ab/ab.

Large deviations from a 1:1:1:1 test cross ratio of a dihybrid could be used as an evidence for linkage. Linked genes do not always stay together, however, because homologous nonsister chromatids may exchange segments (crossing over) of varying length with one another during meiotic prophase-I. Thus crossing over is an exception to the linkage phenomenon.

Linkage in maize

'C' for coloured aleurone is dominant over 'C' colourless

Sh for Full endosperm is dominant over 'sh' shrunken.

Parents (Short 'S' , 's'	Col full	x	Colourless,	Shrunken
	CCSS			ccss

↓

	Ce	Ss	Colour full

↓

F2	Colour full	7300
	Colourfull shrunken	200
	Colour full	200
	Colouless shrunken	2300

F_2 did not show 9: 3: 3: 1 ratio. There were greater number of colour full, colour shrunken (parental types) than colourfull shrunkern , colour full, If two character considered separately,they segregate 3 : 1

i.e. Colour - 7500 Full - 7500, Colouless - 2500 Shrunken – 2500

Test cross

	Colour full	x	Colourless shrunken	
	CCSS		eess	
F1		CeSs	x	eess
F2	F2	Colour full	4800	No expected
		Col. Shrunken	200	ratio 1:1:1:1
		Col. Less full	200	
		Col less shrunken	4800	

The data shows that the two pairs of genes did not segregate independently

Segregation of two pairs of genes on two pairs of chromosomes

Let us suppose that, gene 'C' is located on chromosome number 9 and 'S' on chromosome number 10 of maize. The segregation of chromosome bearing C and c is entirely independent of segregation of chromosome bearing S and s. So four type of gametes Cs, Cs, eS, eS are formed in F_1 and F_2 normal dihybrid ratio 9:3:3:1 and test cross 1:1:1:1

Segregation for two pairs of genes on one pair of chromosomes

Let us suppose that, two genes C and S are located on chromosome No. 9 during meiosis only 2 gametes will be formed Cs and cs gametes. So, Genes C and S situated on same chromosomes are said to be linked. Linkage is the association of character in inheritance due to fact that genes determining them are physically located on the same chromosomes.

Detection of Linkage

Compare the number of individuals observed in each class with those expected on the basis of independent assortment and then to test the deviation between these two values by chi-square test

Symbol of linked genes

While representing linked gene, the two homologous chromosomes are indicated by two horizontal links.

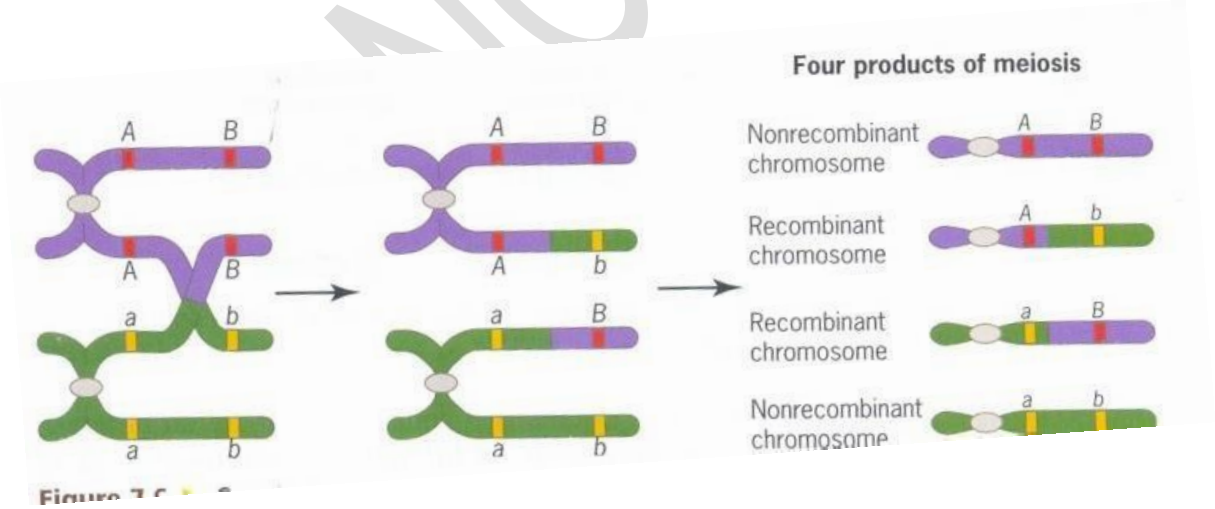
e.g. $\frac{CS}{cs}$ $\frac{CS}{cs}$ CS/cs

Coupling phase: Linkage of two the dominant or two recessive genes (AB/ab).

Repulsion phase: Linkage of dominant and recessive gene (aB/Ab).

Crossing over

Recombination of linked genes is due to the exchange of corresponding segments between the chromatids of homologous chromosomes and was first observed by Belgian cytologist Janssens.



Chiasma frequency: A pair of synopsed chromosomes (Bivalent) consists of four chromotids called tetrad. Every tetrad usually experiences at least one chiasma some where along its length.

Generally longer the chromosome, the greater the number of chiasmata. The frequency with which a chiasma occurs between any two loci is directly proportional to the distance between them. Thus, farther apart genes located on a chromosome, greater could be the opportunity for chiasma to occur between them. Similarly, closer the two genes are linked; smaller would be the chance of chiasma to occur between them. When a chiasma forms between two gene loci, only half of the meiotic products will be cross over type, therefore chiasma frequency is twice the frequency of crossover producer.

$$\text{Chiasma \%} = 2\ (\text{Crossover \%})$$

OR

$$\text{Crossover \%} = {}^{1}/_{2}\ (\text{Chiasmata \%})$$

Double crossover: It refers to the two crossovers occurring simultaneously in an adjacent area along the length of paired homologous chromosome.

Interference and *Coincidence*: In most of the higher organisms, formation of one chiasma actually reduces the probability of another chiasma forming in an immediately adjacent region of the chromosome. In another words the influence of one chiasma on the probable occurrence of another in its vicinity is known as 'Interference'. This reduction in chiasma formation may be of physical inability of the chromatids to bend back upon themselves within certain minimum distances. The net result of this interference varies in different segments of the chromosome and is usually expressed in terms of a coefficient of coincidence or the ratio between the observed and the expected double crossovers.

$$\text{Coefficient of Coincidence} = \frac{\text{\% Observed double crossovers}}{\text{\% expected double crossovers}}$$

Coincidence is the complement of interference

Coincidence + Interference: 1:0

When interference is complete (1.0), no double crossovers will be observed and coincidence becomes zero. When we observe all the double crossovers expected, coincidence is unity and interference becomes zero. When the interference is 30% operative coincidence becomes 70%.

Estimation of Linkage and Genetic mapping

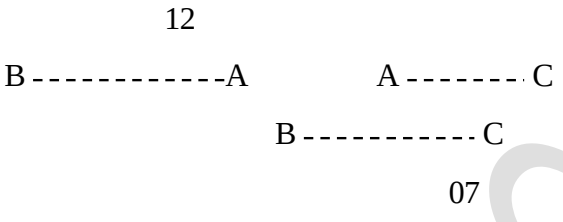
Genetic mapping: Two aspects of genetic mapping are:

(1) Determination of the relative gene order (2) Determination of the relative distance between the genes.

Gene Order: The additivity of map distance allows us to place genes in their proper linear orders. Three linked genes is in the middle. If double crossover do not occur, map distance may be treated as completely additive units. When we are given distances A-B: 12, B-C: 7 AC: 5.

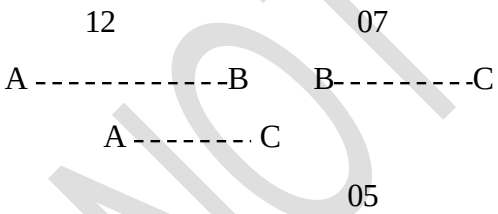
Determine the correct gene order.

Case I. Let us assume that A is in the middle



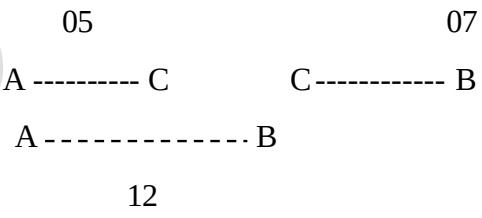
The distance B-C is not equitable. Therefore A cannot be in the middle.

Case –II. Let us assume that B is in the middle



The distance A-C are not equitable therefore B cannot be in the middle.

Case III. Let us assume that C is in the middle



In case where double cross over do occur in three point test cross, the alternative position of each of the three genes in the middle should be tried as in the previous case after establishing the linkage relationship (Whether it is in coupling or Repulsion). Produce single and double cross overs, then compare with the different phenotypic classes of segregating population (such as

C.O. region I,C.O region II, and double crossovers). If it agrees with the different phenotypic classes then our proposed gene order is correct.

Gene distance: The unit of distance is an expression of the probability that the crossing over will occur between the two genes under consideration. One unit of map distance (Centimorgan) is therefore equivalent to 1% crossing over.

Example 1: If the genotype Ab/aB produce 8% each of the cross over gametes (AB) and (ab) then the distance between A and B genes would be 16 map units.

Example 2: If the map distance between B and C gene is 20 units, 10% each of the crossover gametes (Bc and bC) would be produced.

Each chiasma produce 50% cross over products, 50% crossing over is equivalent 50 map units. If the average number of chiasma is known, length of the chromosome may be predicated by the following formula.

Total length : Mean number of chasmata x 50

Linkage relationship from a two point test cross:

To determine the mode (coupling or repulsion) and the intensity of linkage.

Example 1: Dihybrid parent x Test cross parent

Aa. Bb ab/ab

(Linkage ?)

F_1	42%	Aa Bb	Parental types	8%	Aa bb	Recombinant type
	42%	aa bb		8%	aaBb	
Total :	84%			16%		

Test cross parent contributes ab to each progeny. The remaining genes come from dihybrid parent. Thus A and B must be residing on one chromosome while a and b on the other homologous of the dihybrid parent, Genes are in coupling phase AB/ab. The cross over value is 16% strength or intensity of linkage is 84%. Two point test cross helps to know the distance between the two genes.

Linkage relationship from a three point test cross

To determine the gene order by manipulating the parental combinations into proper order for the production of double cross over types.

Ex : Trihybrid parent x Test cross parent

Aa, Bb, Cc abc/abc

36% AabbCc	9% aabbCc	4% AabbCc	1% AaBbCc
36% aaBbCc	9% AaBbcc	4% aaBbcc	1% aabbcc

The 72% group is composed of parental types because non-cross-over genes are always produced in the highest frequency. The test cross parent obviously contributes only abc to the progeny. Hence, one chromosome has A, b and c genes while its homologues has a, B and C. The next question is which one is in the center or middle. Since 50% of the double crossover group (2% group) has all the three dominant genes, the gene order must be BAC.

Linkage studies revealed the following

1. Genes that assort at random are non linked genes. Genes that do not segregate at random are linked genes.
2. Linked genes are arranged in a lines fashion on the chromosome. Each linked gene has a definite and constant order in its arrangement.
3. The distance between the linked genes determines the degree of strength of linkage. Closely located genes show stronger linkage that the widely located genes.
4. Linked genes do not always stay together, but are often exchanged reciprocally by cross over.

Complete Linkage : The genes closely located in the chromosome show complete linkage as they have no chance of separating by crossing over and are always transmitted together to the same gamete and the same offspring. Thus, the parental combination of traits is inherited as such by the young one.

Incomplete Linkage : The genes distantly located in the chromosome show incomplete linkage because they have a chance of separation by crossing over and of going into different gametes and offspring.

Importance of linkage in breeding

1. When there is a close linkage between desirable and undesirable characters these genes are inherited in blocks and not individually and recombination is practically nil. In such cases linkage has to be broken by ' irradiation'.
2. Also can know the distance between the two genes and can map the genes on the chromosome which are useful in plant breeding

Inheritance of Polygenic (Quantitative) characters

Characters studied by Mendel were controlled by single gene and which showed 3:1 phenotypic ratio in F_2. That means discrete phenotypic classes are clearly distinguishable in F_2. However majority of the biologically important characters show continuous variation in F_2. To study such characters they are subjected for measurements. For ex. height, weight, time value etc., Such characters are governed by many genes and each gene contribute very little to the character. Characters governed (controlled) by many genes are called **polygenic characters** or Quantitative **characters**.

Important features

1. Continuous variation

2. Marked influence of environment on the expression of the character

Therefore, it is very difficult to determine whether the expression of a given character in an individual is due to heredity or environment.

Inheritance of Quantitative characters was studied by several people. Important Findings was by Nelson Ehle (1908) . Proposed Multiple factor hypothesis based on his studies on inheritance of seed colour in wheat and oats.

He Crossed: Red seeded x White seeded

F_1: Red

In F_2: Different ratios: In some crosses, 3 Red: 1white, in some other crosses 15 Red : 1 white

And 63 Red:1 white.

However , on close examination 15 Red in the second cross he could further classify into different intensity of red colour as shown below

Dark red: 1

Medium dark red :4

Medium red :6

Light red :4

Total 15

F_2 ratio is - 1DR : 4 MDR : 6MR : 4LR : 1W

Nelson- Ehle gave explanation for this. He made following assumptions to explain his observation. Assumptions were

1. In crosses showing 15:1 ratio seed colour is governed by two genes
2. One of the allele of the each color gene produces seed colour – called positive alleles– R1, R2. Other alleles r1 and r2- does not produce colour called negative alleles
3. They do not show dominance, so heterozygotes show intermediate in colour between the two parents
4. Each positive allele has small and the equal effects :R1R1, R1 r1
5. Effect of positive allele of the different genes are additive R1, R2
6. Thus the intensity of colour depends on the number of positive alleles

Explanation:

Parents	Dark red		White
Genotypes	$R_1R_1R_2R_2$	×	$r_1r_1r_2r_2$
F_1		$R_1r_1R_1r_1$	Medium Red

In F_2

♀ \ ♂	*R1R2*	*R1r2*	*r1R2*	*r1r2*
R1R2	*R1R1R2R2* Dark red	*R1R1R2r2* Medium red	*R1r1R2R2* Medium red	*R1r1R2r2* Intermediate red
R1r2	*R1R1R2r2* Medium red	*R1R1r2r2* Intermediate red	*R1r1R2r2* Intermediate red	*R1r1r2r2* Light red
r1R2	*R1r1R2R2* Medium red	*R1r1R2r2* Intermediate red	*r1r1R2R2* Intermediate red	*r1r1R2r2* Light red
r1r2	*R1r1R2r2* Intermediate red	*R1r1r2r2* Light red	*r1r1R2r2* Light red	*r1r1r2r2* White

TABLE 12.1. Differences between polygenic and oligogenic traits

Polygenic Traits	*Oligogenic Traits*
1. Governed by several genes.	Governed by few genes.
2. Effect of each gene is not detectable.	Effect of each gene is detectable.
3. Usually governed by additive genes.	Governed by non-additive genes.
4. Variation is continuous.	Variation is discontinuous.
5. Separation into different classes is not possible.	Separation into different classes is possible.
6. Highly influenced by environmental factors.	Little influenced by environmental factors.
7. Statistical analysis is based on mean, variances and covariances.	Statistical analysis is based on frequencies or ratios.

Cytoplasmic Inheritance

The inheritance of most of the characters of an individual is governed by nuclear genes. But in some cases, the inheritance is governed by cytoplasmic factors or genes. When the transmission of characters from parents to offspring is governed by cytoplasmic genes; it is known as cytoplasmic inheritance or extra nuclear inheritance or extra chromosomal inheritance or non-mendelian inheritance or organellar inheritance.

The first case of cytoplasmic inheritance was reported by Correns in 1909 in four 'o' clock (*Mirabilis jalapa*) for leaf colour. Later on, cytoplasmic inheritance was reported by various workers in various organisms.

Characteristic Features of Cytoplasmic Inheritance: Cytoplasmic inheritance differs from Mendelian inheritance in several aspects and exhibits some characteristic features. The important characteristic features of cytoplasmic inheritance are briefly described below

S.No. Particulars	*Mendelian Inheritance*	*Cytoplasmic Inheritance*
1. Governed by	Nuclear genes	Plasma genes
2. Segregation pattern	Distinct	Not distinct
3. Reciprocal differences	Not observed	Observed
4. Maternal effects	Not observed	Observed
5. Genes mapping	Easy	Difficult
6. Location of genes	Chromosomes	Chloroplasts or mitochondria

1. Reciprocal Differences: Characters which are governed by cytoplasmic inheritance invariably exhibit marked differences in reciprocal crosses in F_1, whereas in case of nuclear inheritance such differences are not observed except in case of sex linked genes.

2. Maternal Effects: In case of cytoplasmic inheritance, distinct maternal effects are observed. This is mainly due to more contribution of cytoplasm to the zygote by female parent than male parent. Generally ovum contributes more cytoplasm to the zygote than sperm.

3. Mappability: Nuclear genes can be easily mapped on chromosomes, but it is very difficult to map cytoplasmic genes or prepare linkage map for such genes. Now chloroplast genes in Chlamydomonas and maize, and mitochondrial genes in human and yeast have been mapped.

4. Non-Mendelian Segregation: The mendelian inheritance exhibits typical segregation pattern. Such typical segregation is not observed in case of cytoplasmic inheritance. The segregation when occurs, is different from mendelian segregation.

5. Somatic Segregation: Characters which are governed by cytoplasmic genes usually exhibit segregation in somatic tissues such as leaf variegation. Such segregation is very rare for nuclear genes.

6. Infection-Like Transmission: Cytoplasmic traits in some organisms exhibit infections like transmission. They are associated with parasites, symbionts or viruses present in the cytoplasm. Such cases do not come under true cytoplasmic inheritance.

7. Governed by Plasma Genes:

The true cases of cytoplasmic inheritance are governed by chloroplast or mitochondrial DNA. In other words, plasma genes are made of cp-DNA or mt-DNA.

Classes of Cytoplasmic Inheritance:

There are three different classes of cytoplasmic inheritance or non mendelian inheritance, viz.,

1. Maternal effects
2. Inheritance due to infective particles, and
3. Cytoplasmic inheritance.

These are briefly described below with examples.

1. Maternal Effects:

When the expression of a character is influenced by the genotype of female parent, it is referred to as maternal effect. Such characters exhibit clear-cut differences in F_1 for reciprocal crosses. Maternal effects are known both in plants and animals. Some examples of maternal effects are briefly presented below.

(i) Coiling Pattern of Shell in Snail:

The effect of maternal genotype on the coiling behaviour in water snail was studied by Sturtevant. There are two types of coiling pattern of shell in snail (Limnaeaperegra), viz., right handed (dextral) and left handed (sinistral).

The coiling behaviour is controlled by a single gene. The dextral coiling behaviour is governed by dominant allele D and sinistral by recessive allele d. When a cross is made between dextral female and sinistral male, it produces dextral snails in F_1 as well as in F_2.

However, in F_3 a segregation ratio of 3 dextral and 1 sinistral is observed. Similarly, when a reciprocal cross is made, i.e., sinistral as female and dextral as male, all the snails are sinistral in F_1 and dextral in F_2. Again in F_3 a ratio of 3 dextral and 1 sinistral is observed (Fig. 11.1). This indicates that the inheritance of coiling direction in water snail depends on the genotype of female parent and not on its own genotype.

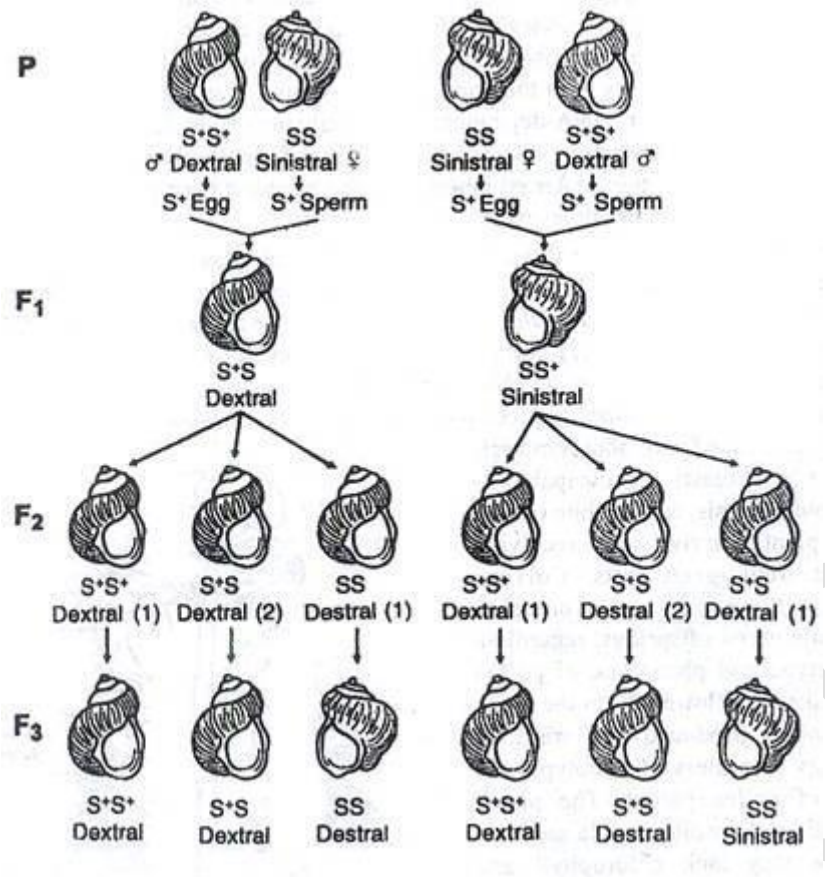


Fig. 1 Maternal effect in direction of coiling in Snail

The maternal genotype affects the organization of egg cytoplasm. In other words, it affects the orientation of first cleavage plain in the zygote. If it is tilted to the left, successive cleavages will produce a spiral to the left. If it is tilted to the right a dextral pattern will follow.

2. Inheritance Involving Infective Particles:

In some cases, cytoplasmic inheritance is associated with infective particles like parasite, symbiont or viruses which are present in the cytoplasm of an organism. However, such cases are not considered as true examples of cytoplasmic inheritance.

One example of this type is Kappa Particles in Paramecium:

There are two types of strains in Paramecium. One has kappa particles in its cytoplasm and other does not have such particles. The presence of kappa particles in the cytoplasm leads to production of a toxin known as paramecin. This toxin can kill the strain of Paramecium which lacks kappa particle. Thus, the strain with kappa particle is known as killer strain and that without kappa particle is called as sensitive strain.

Multiplication of kappa particles in the cytoplasm takes place by fission. However, their multiplication is governed by a dominant nuclear gene (K). They can multiply in the homozygous dominant (KK) or heterozygous (Kk) individuals.

Kappa particles cannot multiply in recessive (kk) individuals. Even if kappa particles are introduced into kk strains, they will gradually disappear due to their inability to multiply and the strain will become sensitive. Though the multiplication of kappa particles is dependent on nuclear genes, their action is independent of nuclear gene.

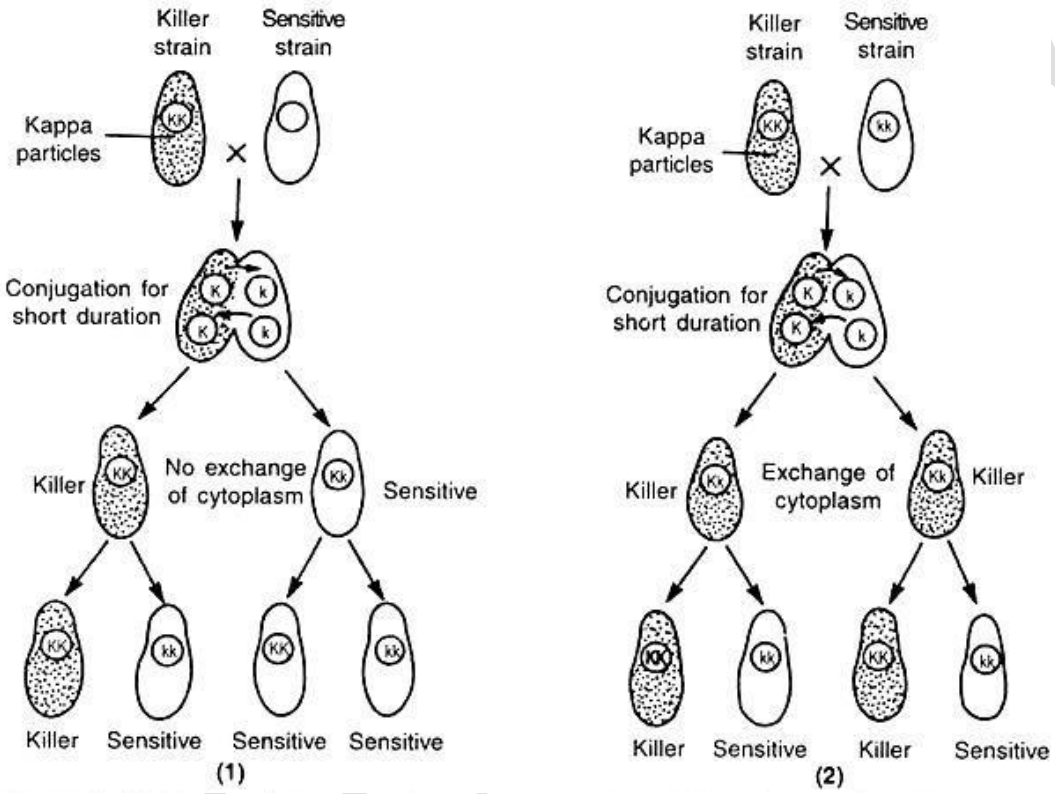


Fig. 2 Inheritance of kappa particles in paramecium 1. Exchange of nuclear genes 2. Exchange of both nuclear genes and cytoplasm.

3. Cytoplasmic inheritance : The true cytoplasmic inheritance is one which involves plastids (chloroplasts) and mitochondria. Thus, cytoplasmic inheritance is again of two types, viz., 1. plastid inheritance and 2. mitochondrial inheritance. The former is applicable to plants only because plastids are found only in plants. The mitochondrial inheritance is common for both plants and animals.

The cytoplasmic inheritance is governed by genes which are found in chloroplasts and mitochondria. The genes which govern cytoplasmic inheritance are called plasma genes or

cytoplasmic genes or cytogenes or extra nuclear genes. These genes are made of DNA found in chloroplasts (cp-DNA) and mitochondria (mt- DNA). The difference between the cytoplasmic DNA and Nuclear DNA

Cytoplasmic DNA	*Nuclear DNA*
1. Found in chloroplasts and mitochondria.	Found in chromosomes.
2. Usually circular except in ciliate protozoa where it is linear.	Linear in eukaryotes and circular in prokaryotes.
3. Synthesis continues throughout cell cycle.	Synthesis occurs only during interphase.
4. Replicates in both chloroplasts and mitochondria.	Replicates in chromosomes.

I. Plastid Inheritance:

Chloroplasts are the important plastids. Plastids have green pigments called chloroplasts. Plastids self-duplicate, have some amount of DNA and play an important role in cytoplasmic inheritance.

Important example of plastid inheritance is *Mirabilis jalapa*:

The first conclusive evidence of cytoplasmic inheritance was reported by Correns in 1909 for leaf colour in four 'o' clock plant (*Mirabilis jalapa*). This plant has three types of leaves, viz., green, white and variegated. Three types of results were obtained from crosses between these genotypes as given below.

1. When green was used as female and green, white or variegated as male, all individuals in F_1 were green.
2. When white was used as female and green, white or variegated as male, all individuals in F_1 were white.
3. When variegated was used as female and either green, white or variegated as male, various proportions of green, white and variegated individuals were obtained in F_1.

The inheritance is governed by chloroplasts which are originated from proplastids. If the proplastids are normal, they will develop into normal chloroplasts and when proplastids are mutants, they will produce white chloroplasts. This suggests that green leaf branches have normal chloroplasts; white branches have mutant chloroplasts and variegated have a mixture of both normal and mutant chloroplasts.

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ii. Mitochondrial Inheritance:

The inheritance of some characters is governed by mitochondrial DNA. The examples of mitochondrial inheritance include cytoplasmic male sterility in plants, pokyness in Neurospora, petite in yeast, etc.

One important example is Cytoplasmic Male Sterility: There are three types of male sterility in crop plants, viz., genetic (controlled by nuclear genes), cytoplasmic (controlled by plasma genes) and cytoplasmic genetic (controlled by both nuclear and plasma genes). The cytoplasmic male sterility is controlled by plasma genes associated with mtDNA or cpDNA.

The CMS lines are maintained by crossing them with a fertile line known as maintainer line. Three types of CMS lines, viz., CMS-T, CMS-C, and CMS-S have been studied in maize. It is believed that cytoplasmic male sterility is controlled by plasma genes which are part of mt-DNA. In other words, in maize cytoplasmic sterility is governed by mitochondrial DNA. Cytoplasmic sterility is found in several other crop plants, viz., pearl millet, Sorghum, cotton, etc.

Significance of Cytoplasmic Inheritance in Plant Breeding:

1. Cytoplasmic inheritance has been useful in explaining the role of various cytoplasmic organelles in the transmission of characters in different organisms.

2. Development of cytoplasmic male sterility. CMS lines have been developed in several crops like maize, pearl millet, Sorghum, cotton, etc. Availability of CMS lines has facilitated the production of hybrid seed in these crops at a cheaper cost than with hand emasculation and pollination method.

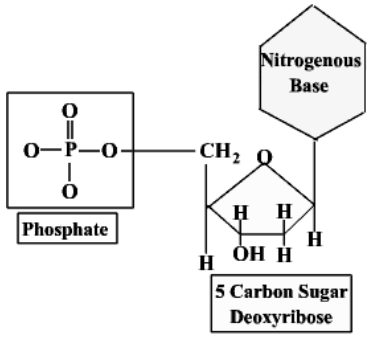
The CMS cytoplasm can be easily transferred to various agronomic bases for their use in the development of superior hybrids. Since CMS based hybrids have danger of uniformity, it is desirable to utilize various CMS sources.

Structure of DNA

Nucleic acids were first discovered by Miescher and he called it as nuclein, the term nucleic acid was given by Altman. Nucleic acids (DNA/RNA) are polymers (Poly nucleotides). The fundamental chemical building block of Nucliec acids are the nucleotides.

A nucleotide consists three parts:

1. Nitrogenous Base- (pyrimidine or purine)
2. Pentose sugar(deoxyribose/ ribose),
3. Phosphate group

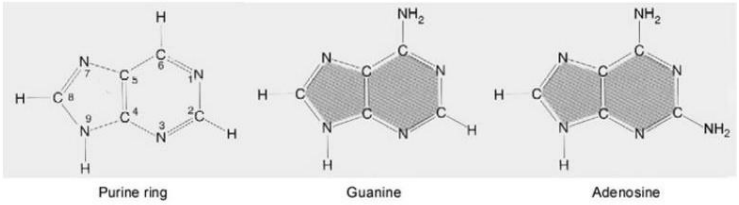


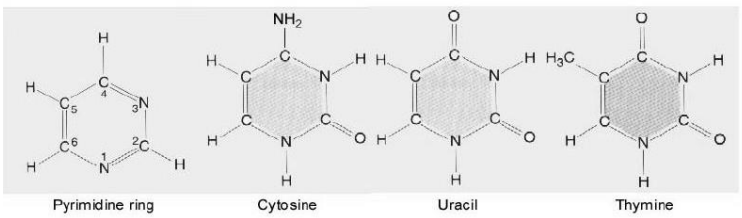
Deoxyribose Nucleotide

Nucleoside = Base + sugar (C-N, covalent bonds-Nitrogen glycoside linkage)

Nucleotide = Base + sugar + phosphate (2 sugar attached to phosphate by phospodiester bond)

1. **Nitrogenous Base**- There are two kinds of nitrogenous bases.
    a. Purines- Nine membered , double ringed structures and
    b. . Pyrimidines - Six membered , single ringed structure



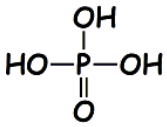


2. Pentose sugar- Each sugar unit contains five carbon atoms joined in a ring structure with an

oxygen atom. In RNA ribose sugar is present (at carbon position C-2 hydroxyl group is present) whereas in DNA 2'deoxy ribose sugar is present (contains a hydrogen atom at C-2 position). The first carbon atom C-1´ is covalently attached to one of four nitrogenous bases, phosphate groups are attached to the third (3´) and fifth (5´) carbon atoms by phospodiester bonds.(5´C-O-P-O-C3´)

3. Phosphate group- The phosphate group is got from Phosphoric acid H3PO4. It has three reactive

OH group and 2 are involved in forming the sugar phosphate backbone. Phosphate group is attached by phosphodiester bond. (An ester is an organic compound formed from an alcohol and acid. In the case of a nucleotide, the alcohol group is the 5 ' hydroxyl of the sugar and the acid is phosphoric acid.)



Watson and Crick (1953) proposed the double helical structure of DNA based on the information from two studies

1. **Base composition studies of Erwin Chargoff**

He analyzed DNA of different organisms and measured the levels of each four nitrogenous bases and observed that

- Double-stranded DNA consists of ~50% purines (A,G) and ~50% pyrimidines (T, C). The amount of purine is equal to amount of pyrimidines.
- The number of Adenine bases is equal to the number of Thymine bases, and number of

Cytosine bases are equal to Guanine bases. (A=T & G=C)

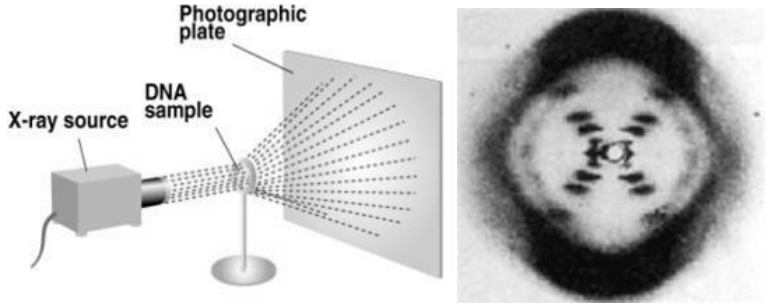
Chargaff's equivalence rule.

- DNA composition is species specific: amount and ratios of nitrogenous bases vary from one species to another. %GC content varies from organism to organism
- Ratio of A=T & C=G, Ratio of A + T +C +G = 100%

This molecular diversity supported DNA as hereditary material.

2. X-ray Diffraction studies of Maurice Wilkins and Rosalind Franklin

Wilkins and Franklin did X-ray crystallographic studies on DNA. And demonstrated that DNA was a helical structure with a diameter of about 20 Å and a pitch of about 34Å. Rosalind obtained a superior X-ray diffraction photograph of DNA, which was utilized by Watson and crick for construction of molecular model of DNA.



Photograph 51: X-ray diffraction photo of a DNA molecule (B type)

A native DNA is double stranded; each has many deoxyribonucleotides that are joined together by phospodiester bonds.

The DNA double helical structure - Watson and Crick (1953)

1. DNA has double strand i.e. two long polynucleotide chains which are coiled around a central axis forming a right handed double helical structure.
2. The two complementary chains/strands are antiparellal and form the backbone, one strand runs from C5´ to C3´ and other is from C3´ to C5´. This is essential for formation of hydrogen bonds between pairs of DNA bases.
3. DNA is a polymer of four nitrogenous bases ATGC, the nitrogenous bases of complimentary/opposite strand are paired as a result of hydrogen bonds i.e. A=T & G≡C.
4. The bases of both the chains are flat structures lying perpendicular to the axis; they are stacked on one another 3.4 Å (0.34nm) apart and are located inside of the structure.
5. Each complete turn of the helix is 34 Å (3.4nm) long thus 10 bases exist per turn in each chain.
6. The diameter is 20 Å
7. The turning of the DNA results in appearance of alternating larger major grooves and smaller minor grooves. These major grooves are site for protein binding.

Modes of Reproduction in Crop Plants

Reproduction: Development of new individuals(Progeny) from pre-existing ones(Parents)

Modes of reproduction: Manner in which new individuals originate

- It determines the genetic constitution of the crop plants, whether plants are homozygous/ heterozygous
- It determines the scheme of breeding programmes
- Knowledge of the modes of reproduction of crop plants is also important for hybridization which is the basis for almost all modern breeding programmes

Modes of reproduction are broadly classified into Asexual and Sexual reproduction

Asexual reproduction does not involve fusion of male and female gametes

In asexual reproduction new plants may arise from

1. Vegetative parts of the plants--- vegetative reproduction
2. May arise from the embryos that develop without fertilization—Apomixis– agamospermy – asexual reproduction through seed formation

In vegetative reproduce a new plant develops from the portion of the plant body of parent through natural vegetative propagation or through artificial vegetative propagation

Natural vegetative propagation

i. Underground stems
   a. Tuber-potato
   b. Bulb – onion, garlic
   c. Rhizome-zinger, turmeric
   d. Corm- colocasia

ii. Sub aerial stems
   a. Stolon, runner, suckers etc., Ex: Mentha sp, Date palm

iii. Bulbils: modified flowers that develop into plants directly without the formation of seeds- are vegetative bodies- their development does not involve fertilization, Ex. Agave, Lower flowers in the inflorescence of garlic generally develop into bulbils

2. Artificial vegetative propagation

i. Stem cuttings--- sugarcane , grapes, roses
ii. Layering
iii. Budding
iv. Grafting

Propagation of fruits and ornamental shrubs
v. Plant tissue culture-- micropropagation

In many of these species sexual reproduction occurs naturally but for certain reasons vegetative reproduction is more desirable

Significance of vegetative reproduction: offers unique possibilities in plant breeding

1. A desirable plant may be used as a variety directly regardless of whether it is homozygous/ heterozygous
2. Mutant buds/ branches or seedlings if desirable can be multiplied and directly used as a variety

Drawback : Does not allow transfer of desirable trait from one variety to another variety

Apomixis : Seeds are formed but embryo develops without fertilization. As a result the plants developing from seeds are identical in genotype with each other and with the parent plant

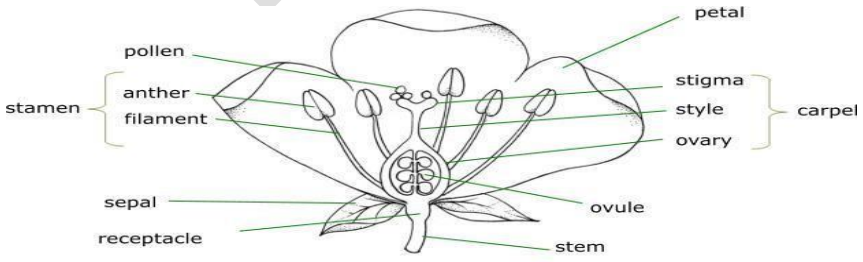
In apomictic species, sexual reproduction is either absent(obligate apomixis) Or sexual reproduction also occurs(facultative apomixes)

Many species generally show facultative apomixis

When embryos arise from the haploid cells, because progeny so obtained cannot be maintained further called **non- recurrent apomixes**. In **recurrent apomixes** embryos develop from the diploid cells and progenies can be perpetuated indefinitely

Sexual reproduction : It involves the fusion of male and female gametes to form a zygote which develops into an embryo

In plants male and female gametes are produced in specialized structures -- flowers



Types of flowers

Perfect flower : a flower containing both stamens and pistil– also called hermaphrodite flower

Staminate flower : it contains stamens but not pistil

Pistillate flower : it contains pistil but not stamens

Pistillate and staminate flowers occur on the same plant in a monoecious species Ex. Maize, colocasia, castor, coconut

In dioecious species: staminate and pistillate flower occur on different plants Ex. Papaya, Date palm,

How do plants produce male and female gametes

In plants meiotic division of specific cells in stamens and pistils yields male and female gametes respectively

Male gamete– microspores

Female gametes– megaspore

Production of microspores and megaspores is known as sporogenesis

Microspore– microsporogenesis– produced in anthers

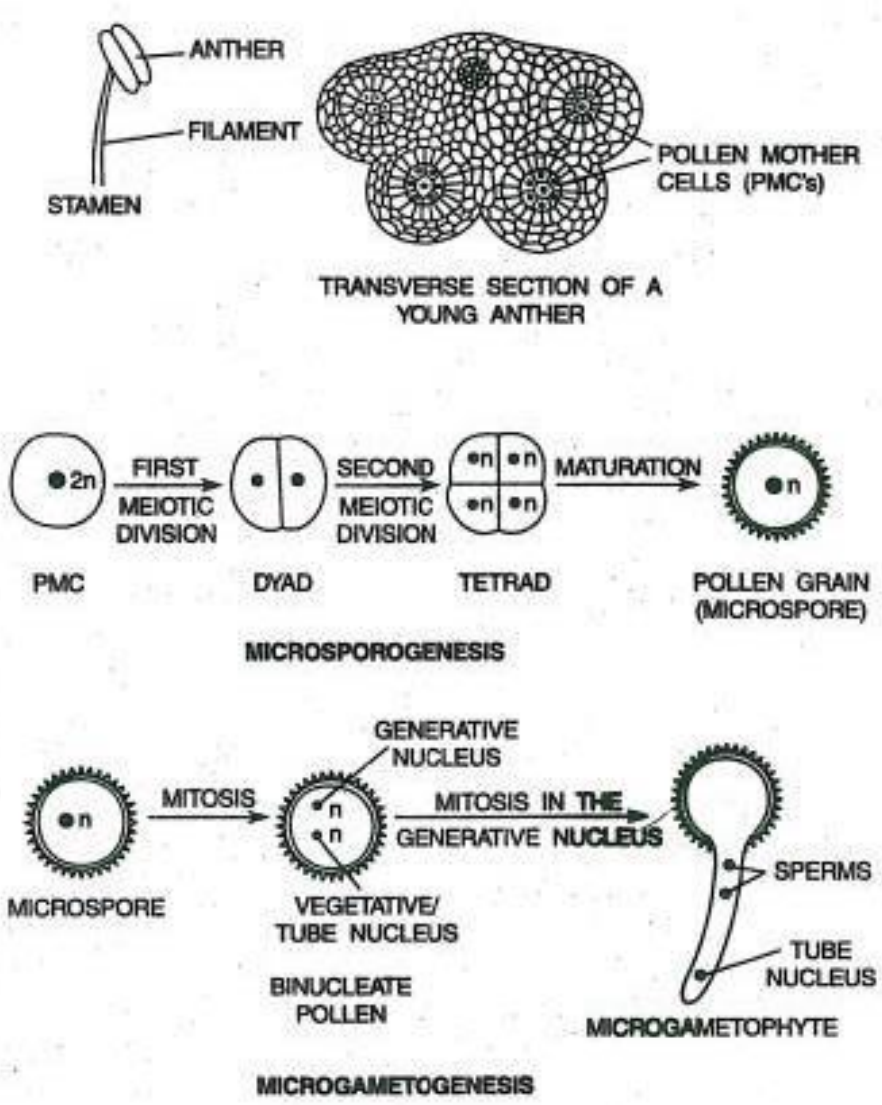
Megaspores – megasporogenesis– produced in ovules

Microsporangenesis

At an early stage of the anther, four vertical rows of cells one at each lobe, with dense protoplasmic content become apparent. Each cell divides into an inner large cell or archisporium and an outer smaller cell the parietal cell. The latter divides tangentially into 2 or 3 layers. These parietal cells again divide respectively by radial walls and extend the sporangeneous cell which also begins to divide forming a central group of cells. These (sporogenous) cells grow, separate from one another and become the pollen mother cells or microspore mother cells. The inner most layer of parietal cells abutting upon the sporogenuous cells and later the pollen mother cells, one more or called as tapetum. The cells of the tapetum less wedge shaped and contain one or more nuclei. It is a nutritive tissue supplying food to the pollen grains, as they develop. Ultimately the tapetum becomes disorganized.

The nucleus of each mother cell divide twice so 4 that four nuclei are formed in it. Of the two successive divisions the first one is meiosis and the second one is mitosis so nucleus has half (n) the usual (2n) number of chromosomes. The four nuclei so formed are arranged in a tetrahedral manner and cleavage of the cytoplasm occurs separating the nuclei into four distinct segments – the pollen cells. The walls of the mother cell disappear and each pollen cell secretes a thick outer

wall the exine and a thin inner wall the intine. The four mature cells separate from one another and form four pollen grains.



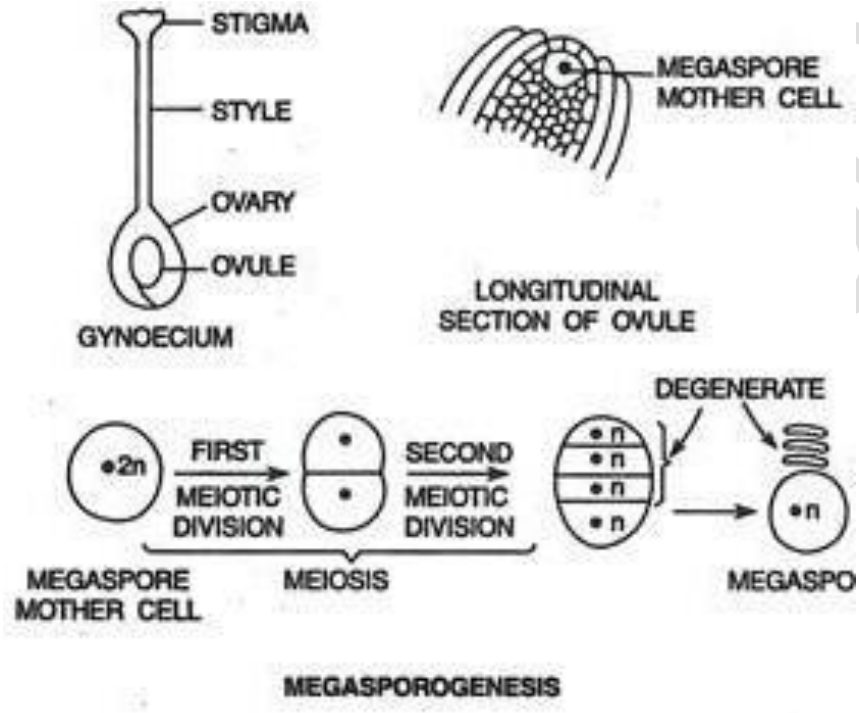
Microgametogenesis

When pollen grain fall on the stigma, it starts germinating, the intine grows out into a tube, called the pollen tube, through some definite thin and weak slits or pores, called germ pores, present in exine. Sometimes the pore is covered by a distinct lid which is pushed open by the growth of the intine. The nucleus of the pollen grain then divides into two nuclei, of which, the larger one is known as vegetative nucleus or tube nucleus and the smaller one the generative nucleus. As the pollen tube grows it carries with it at its apex, the tube nucleus and the generative

nucleus. The generative nucleus divides and two male reproductive units are formed which are known as the male gametes. The tube nucleus then gets disorganized.

Megasporogenesis

The ovule at first arises as a thin protruberance, from the placement in the cavity of the ovary. In it, even at a early stage a cell, i.e., the embroyasac mother cell becomes evident in the nucellus. This mother cell increase in size, divides meotically to give four cells with half (n) the number of chromosomes of the mother cell (2n). These four cells called megaspores are arranged in a row which is known as linear tetrad. Out of these, the three upper ones degenerate and appear as dark caps, while the lowest one functions as megaspore.

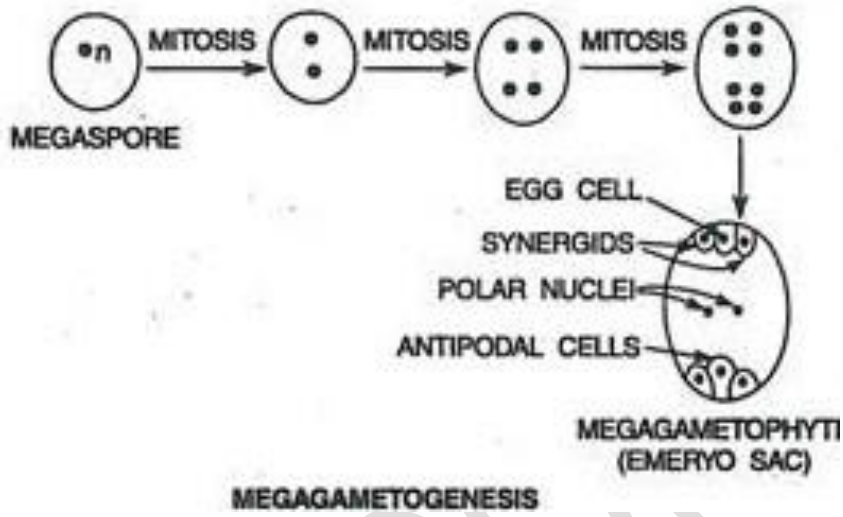


MEGASPOROGENESIS

Megagametogenesis

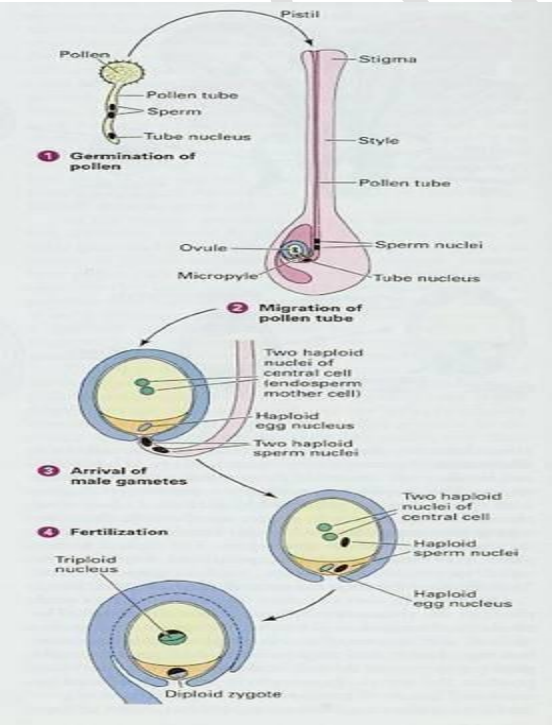
The nucleus of the functional megaspore divides by mitosis and the two daughter nuclei move to the two poles. These again divide mitotically so that the number is increased to four. Each of these four again divides mitotically resulting in an embryosac with eight nuclei, four at each end. The embryosac increase in size, then one nucleus from each end passes towards center and the two polar nuclei fuse together some where in the middle, forming the definitive nucleus. The remaining three nuclei at the micropylar end each surrounded by a thin wall, form the egg-apparatus, and the other three at the chalazal end form the antipodal cells. Of the three cells

constituting the egg apparatus, one is the female gamete known as egg cell (ovum or oospore) and the other two are known as synergids.



Syngamy or Fertilization:

After the pollen tube enters the embryosac, its tip dissolves and the male gametospores are set free. Of the two gametes one fuses with the egg cell while the other fuses with the definitive nucleus. Thus, fertilization (actually called double fertilization) is completed. The fusion of a male gamete with the definitive nucleus is called triple fusion. The fertilized egg cell gives rise to the embryo. The ovule corresponds to the seed and ovary as a whole fruit and the definitive nucleus forms the endosperm.



Anthesis : The first opening of flower is called anthesis. Generally it occurs in the morning. Exact time vary from one crop species to other crop species. It is greatly affected by the environmental conditions. Knowledge of anthesis of a crop species is desirable for making successful crosses. It determines the modes of reproduction

Modes of pollination:

Pollination refers to the transfer of pollen grains from anthers to the stigmas

Self pollination: Pollen from an anther may fall onto the stigmas of the same flower– autogamy

Cross pollination: pollen from flowers of one plant falls on the stigmas of the flowers of the another plant—also called allogamy

Geitonogamy results when pollen from a flower of one plants falls on the stigmas of another flower of the same plant. Genetic consequence is same as autogamy.

Self pollinated crops :

Cereals : Millets, Wheat, Rice , barley
Legumes : Pea, Groundnut, Gram, mung, Urd
Fibre : Jute
Vegetables : Tomato, Okra, Lettuce
Fruits: Apricot, Citrus, Peach

Cross pollinated

Cereals : Maize, Rye, Bajra, Niger
Legumes :Alfalfa, Red clover, White clover etc.,
Vegetables: Cabbage, Carrot, Cauliflower, Cucumber, Onion Pumpkin Radish, Turnip
Oilseeds : *Brassica campestris*, Sunflower,Castor
Forage crops :Rye grass,Tomothy grass,Smooth bromegrass,
Others sugarcane, some lines of potato
Fruits : Apple, Avacodo, Mango, Pear, Black berries, Raspberries

Often cross pollinated : Jowar, cotton, Broad bean,pigeonpea, Brassica juncea, Brassica campestris var yellow sarson, var toria, Safflower,Triticale

i) **Cleistogamy :** flowers do not open at all, ensures complete self pollination. Ex. Some varieties of Wheat, oats, barley, no.of other grasses

ii) Chasmogamy : flowers open, but only after pollination has taken place. Ex. Many cereals– wheat , barley, oats, rice, etc. Some cross pollination may occur

iii). In some crops like tomato, brinjal - **stigmas are surrounded by anthers**. Pollination generally occurs after flowers open, but position of the anthers in relation to stigmas ensures self pollination

iv) In several legumes: pea, mung etc., stamens and stigma are enclosed by two petals forming a keel

5. In few cases stigmas become receptive and elongate through the staminal coloumn

Genetic consequences of self pollination

1. Leads to rapid increase in homozygosity : AAx aa
2. Do not show inbreeding depression (loss in vigour due to inbreeding)
3. May exhibit considerable heterosis (superiority of the F_1 over the parents)

Aim of the breeding methods generally is to develop homozygous varieties. Inbreeding mechanisms are generally under precise genetic control

Cross pollination : Also called allogamy . Pollen grains from flowers of one plant pollinate the flowers of other plants. It may be b**rought out by**

Wind—anaemophily

Water- hydrophily

Insects – entomophily

Many of the crop plants are naturally cross pollinated. In many species a small amount –5-10% of selfing may occur

Mechanisms of cross pollination

1. Dicliny : unisexuality is a condition in which flowers are either staminate/ pistillate

i. Monoecy: a) staminate and pistillate flowers occur in the same plant ; in the same inflorescence –castor, banana, mango, coconut

b) In separate inflorescence– maize

ii. Dioecy– male and female flowers are on different plants– plants are either male, female

Ex. Papaya, Date palm, Hemp, Asparagus, Spinach

2. Dichogamy : stamens and pistils of hermaphrodite flowers may mature at different times

i. Protogyny : pistils mature before stamens, Ex: pearl millet

ii. Protandry : stamen mature before pistils, Ex maize, sugarbeet

iii. In Lucerne, stigma does not become receptive until the waxy film is broken by the visit of honeybees which also effects c.p

iv. Combination of two or more of the above .Ex. Maize has got monoecy and protandry

v. Self incomaptibilty : Failure of pollen from a flower to fertilize the same flower or other flowers on the same plant

Two types of self incompatibility: i)Sporophytic ii) Gametophytic self incompatibility. In both the cases flowers do no set seeds on selfing. Self incompatibility is common in several species. Ex. Brassica, Some species of Nicotiana ,Radish,Rye,Grasses

vi. Male sterility: Refers to the absence of functional pollen grain in otherwise hermaphrodite flowers. Not common in natural populations. Great value in experimental populations especially in hybrid seed production

Genetic consequences of cross pollination

- Cross pollination preserves and promotes heterozygosity in a population
- C.p. species are highly heterozygous and show severe inbreeding depression on selfing
- Show considerable amount of heterosis
- Breeding methods in such species aim at improving crop species without reducing heterozygosity
- Usually hybrids are the aim of the breeders

Often cross pollinated species: In many crop plants cross pollination often exceeds and may reach upto 30 percent. Such species are called often c.p species. Ex. Jowar, Cotton, Pigeonpea, Safflower.

Genetic constitution is intermediate between Cross pollinated and self pollinated crops

Breeding methods suitable for either of them may be used. Most often hybrids are more superior to others

Self-Pollination	Cross-Pollination
Transfer pollen grains from the anther to the stigma of the same flower.	Transfer pollen grains from the anther to the stigma of the different flower.
This process can take place either in the same	This process can take place between two flowers

flower or another flower of the same plant.	on different plants.
It occurs in the flowers which are genetically same.	It occurs between flowers which are genetically different.
Occurs only in perfect flowers.	Occurs both in perfect or imperfect flowers.
Causes homogenous conditions in progenies.	Progenies are heterogeneous
Self-pollination increases genetic uniformity and decreases genetic variation.	Cross-pollination decreases genetic uniformity and increases genetic variation.
Causes inbreeding.	Causes outbreeding.
Reduces the gene pool.	Maintains the gene pool.
In self-pollination, both the stigma and anther mature at the same time.	In cross-pollination, both the stigma and anther mature at the different time.
This process is carried out even when the flowers are closed.	For cross-pollination to happens flower should be open.
No need of pollinators to transfer pollen grains.	Require pollinators to transfer pollen grains.
Pollen grains are directly transferred onto the stigma of the flower.	Pollen grains are transferred through insects, wind, water, animals, etc.

Male sterility and its significance

Male sterility: Refers to the absence of functional pollen grain in otherwise hermaphrodite flowers. Not common in natural populations. Great value in experimental populations especially in hybrid seed production

There are different types of male sterility: Mainly classified into

1. Genetic male sterility(GMS)
    a. Temperature sensitive genetic male sterility
    b. Photoperiod sensitive genetic male sterility
    c. Transgenic genetic male sterility
2. Cytoplasmic male sterility(CMS)
3. Cytoplasmic genetic male sterility (CGMS)
4. Chemically induced male sterility

Genetic male sterility and cytoplasmic genetic male sterility are of great use in the production of hybrid seeds. It helps in avoiding manual emasculation during hybrid sed production which is labour consuming tedious and costly.

1. Genetic male sterility : (Nuclear male sterility) Generally governed by single recessive gene (nulclear gene) " ms". Dominant gene governing male sterility is also known– ex Safflower. GMS occurs widely in plants. There can be many ' ms' genes in a given species

Inheritance of male sterility

msms x MSMs

(Male sterile) (male fertile)

F_1 Msms (Male fertile)

In F_2 3 fertile : 1 sterile (1MsMs; 2Msms: 1msms)

Maintenance : msmsxMsms

Harvesting the seeds only from the male sterile plants

1male sterile (msms) : 1 male fertile(Msms)

Used for hybrid seed production in castor, pigeonpea tomato

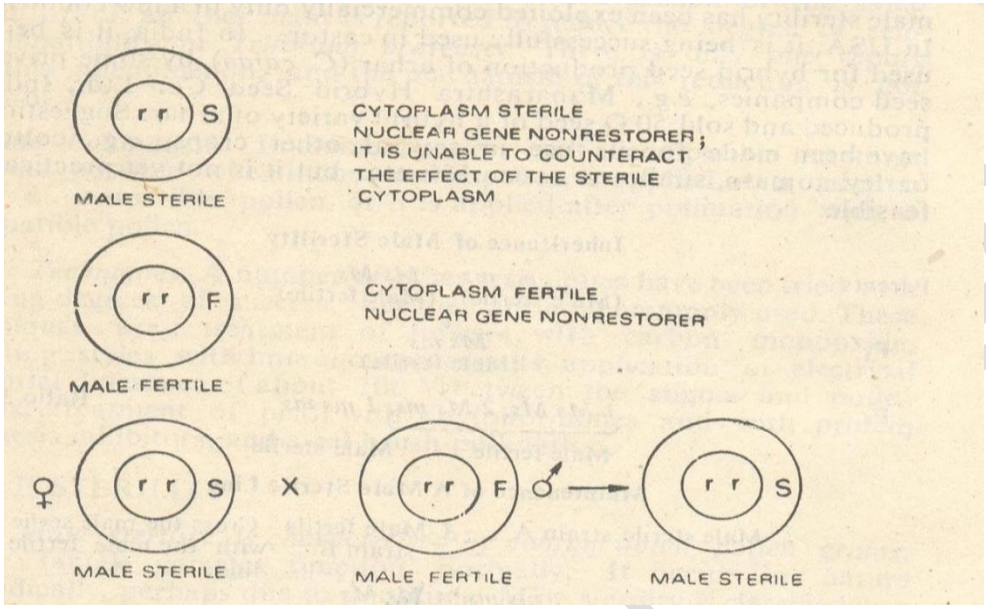
Drawback of this type

i) During maintenance only 50% male sterile plants are obtained
ii) During hybrid seed production male fertile plants need to be rouged out before flowering
iii) Cost is more

1 a. Photoperiod sensitive genetic male sterility : Expression of ms gene is drastically affected by the prevailing photoperiod provided the temperature is within the range (23^0-29^0 C for rice).Within this temperature sterility is obtained under long day conditions(day length more than 13hr 45 min. But under short day conditions almost normal fertility is obtained.This type of male sterility is being used to develop hybrid rice in china

1b Temperature sensitive Genetic male sterility (TGMS): Expression is mainly influenced by temperature. Temperature higher than a critical point allows the ms gene to express and male sterility is obtained. Temperature lower than the critical point male fertility .In rice, critical temperature is 23-29^0 C. For rice line pei-Ai 64S it is 23.3^0C. It is being used to produce hybrid rice in china

2. Cytoplasmic male sterility: This type of male sterility is determined by the cytoplasm.It is the result of mutation in the mitochondrial genome(mtDNA) which leads to an unfavorable nuclear-mitochondrial interaction. Ex.CMS-T of maize, Ogura CMS of brassicas show rearrangements inherited as a maternally transmitted trait. F_1 will be male sterile.



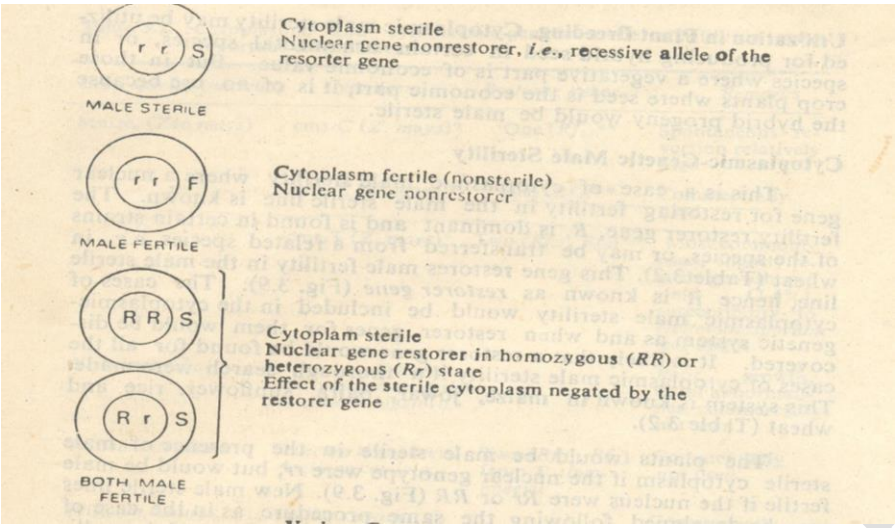
Utilization of CMS in Plant Breeding: since the F_1 produced are male sterile, can be utilized in producing hybrid seed in certain ornamental species or in species where vegetative part is of economic value. Not useful where seed is the economic part

Cytoplasmic Genetic Male Sterility(CGMS): Male sterility is determined by the cytoplasm, there is a nuclear gene which restore fertility in the F_1

Plasmagenes producing male sterility located on mtDNA .Nuclear gene – restorer gene restores male fertility, eliminates the effect of cytoplasm. Restorer is usually dominant

Any genotype(line) can be made male sterile by transferring male sterile line through repeated back cross breeding method.

In CGMS : A line is male sterile line, B line is maintainer line- maintains male sterility, R line is restorer of fertility.



CGMS– known in several crop species: Maize, Jowar, Bajra,Sunflower, Wheat

In many crop species– it is being commercially used– Jowar, Bajra, sunflower, Rice etc.,

Significance of male Sterility in Plant Breeding

- Male sterility a primary tool to avoid emasculation in hybridization.
- Hybrid production requires a female plant in which no viable pollens are borne. Inefficient emasculation may produce some self fertile progenies.
- GMS is being exploited (Eg.USA-Castor, India-Arhar).
- CMS/ CGMS are routinely used in Hybrid seed production in corn, sorghum, sunflower and sugarbeet, ornamental plants.
- Saves lot of time, money and labour.

Limitations in using Male Sterile line

- Existence and maintenance of A, B & R Lines is laborious and difficult.
- If exotic lines are not suitable to our conditions, the native/adaptive lines have to be converted into MS lines.
- Adequate cross pollination should be there between A and R lines for good seed set.
- Synchronization of flowering should be there between A & R lines.
- Fertility restoration should be complete otherwise the F1 seed will be sterile Isolation is needed for maintenance of parental lines and for producing hybrid seed.

Centre of Origin/ diversity of a crop species

Cultivated plants were not distributed uniformly throughout the world. Even now- certain areas show far greater diversity than others for certain cultivated crops and their wild relatives.

Centre of diversity: refers to the geographic region in which greater variability of a crop occurs

Biodiversity : refers to the geographic region in which greatest variability present within and among species of all living organisms and their habitats

Concept of Centres of Origin was given by N.I. Vavilov based on his studies of a vast collections of plants at the Institute of Plant Industry, Leningrad. He was a Russian scientist. He was a first plant explorer, eExplored in over 100 collection missions in 64 countries covering 5 continents during 1920-1930's. He collected corn, potato grains, beans, fodder, fruits and vegetable seeds. Established Vavilov 's Institutes in Russia- Institute of Plant Industry.He was the Director of the Institute from 1916-1936. In 1926, Vavilov proposed that crop plants evolved from wild species in the areas showing great diversity and termed them as **Primary Centres of Origin**. Later the crops moved to other regions primarily due to human activities. These regions generally lack the richness in variation found in the primary centre of origin. Some species show considerable diversity of forms although they did not originate there. It is called secondary centre of origin of these species.

Vavilov also postulated Law of homologous series in variation" Characters found in one species are also found in other related species" .Ex. Diploid , tetraploid and haxaploid wheats show series of identical contrasting characters. Similarly the genus Secale duplicates the variation found in genus Triticum. Thus a character not observed in a species but found in related species is likely to be found in the collections of that species made from the centre of its origin.

Vavilovian centres of diversity of crop plants (after Vavilov, 1951)

Name of centre	Main crops for which genetic diversity is found
A. Main Centres	
1. China	Naked oat (SC), Soybean, Adzuki bean, Common bean (SC), Small Bamboo, Leaf Mustard (SC), Apricot, Peach, Orange, Sesame (SC), China tea, etc.
2. Hindustan	Rice, ChickPea, Moth Bean, Rice bean, Horsegram, Brinjal, Cucumber, Tree Cotton, Jute, Pepper, African Millet, Indigo, etc.
3. Central Asia	Bread wheat, Club wheat, Shot wheat, Rye (SC), Pea, Lentil, Chickpea, Sesame, Flax, Safflower, Carrot, Radish, Apple, Pear and Walnut.
4. Asia Minor or Persia	Einkorn wheat, Durum wheat, Poulard wheat, Bread wheat, Two Rowed barley, Rye, Red oat, Chickpea (SC) lentil, Pea (SC), Flax, Almond, Pomegranate, Pistachio, Apricot and Grape.
5. Mediterranea	Durum wheat, Husked oats, Cabbage, Olive, Broad bean and Lettuce.
6. Abyssinia	Durum wheat, Poulard wheat. Emmer wheat, Barley, Chickpea, Lentil, Pea, Flax. Sesame, Castor bean, African Millet, and Coffee.
7. Central America or Mexico	Maize, Common bean, Upland cotton, Pumpkin, Gourd, Squash, Sisal hemp and Pepper.
8. South America	Potato, Sweet potato, Lima bean, Tomato, Papaya, Tobacco and Sea Island cotton.
B. Subsidiary Centres	
9. Indo-Malaysia	Banana, Coconut, Yam, and Pomelo
10. Chile	Potato.
11. Brazil and Paraguay	Peanut, Rubber Tree, Cocoa (SC), Pineapple, etc.

SC = Secondary centre.

Breeding methods in self pollinated crops

Different breeding methods used in self pollinated crops are listed below

1. Improvement of existing genetic variability
    a. Mass selection
    b. Pure line selction
2. Improvement by hybridization and selection in segregatingpopulations
    a. Pedigree selection
    b. Bulk method
    c. Back cross method
3. Other approaches in self pollinated crops
    a. Multiline varieties
    b. Population improvement approaches
    c. Rapid isolation of homozygous lines
    d. Hybrid varieties

1. Mass Selection:

Selection? isolation of desirable plant types from the population is known as selection.Mass selection the earliest method of selection. Man has always practiced mass selection consciously or unconciously from the time of domestication. In its most basic form mass selection consists of selecting individuals on the basis of phenotypic superiority and mixing the seeds for using as planting material for next season.

Procedure for evolving variety by mass selection

First year : Large number of phenotypically similar plants having desirable characters are selected. The number may vary from few hundred to few thousand. The seeds from the selected plants are composited to raise the next generation.

Second year : composited seed planted in a preliminary field trial along with standardchecks. The variety from which the selection was made should also be included as check. Phenotypic characterlistics of the variety are critically examined and evaluated.

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

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

Modification of mass selection

Mass selection is used for improving a local variety. Large number of plants is selected (I year) and individual plant progenies are raised (II year). Inferior, segregating progenies are reflected. Uniform, superior rows are selected and the seed is bulked. Preliminary yield trials are conducted in third year. Fourth to seventh year multilocation tests are conducted and seed is multiplied in eight year and distributed in ninth year. Many other modifications also are followed depending on the availability of time and purpose for which it is used.

Merits of Mass selection:

1. Can be practiced both in self and cross pollinated crops

2. The varieties developed through mass selection are more widely adopted than pure lines.

3. It retains considerable variability and hence further improvement is possible in future by selection

4. Helps in preservation of land races

5. Useful for purification of pureline varieties

6. Improvement of characters governed by few genes with high heritability is possible.

7. Less time consuming and less expensive.

Demerits of mass selection

1. Varieties are not uniform

2. Since no progeny test is done, the genotype of the selected plant is not known

3. Since selection is based on phenotype and no control over pollination the improvement brought about is not permanent. Hence, the process of mass selection has to be repeated not and then.

4. Characters which are governed by large number of genes with low heritability cannot be improved.

5. It cannot create any new genotype but utilizes existing genetic variability.

Application of mass selection: At present it has limited use in improvement of local varieties, purification and production of pure line varieties nuclear seed.

a. Improvement of Desi varieties: local varieties consist of mixtures of several pure lines differing in various traits. But these varieties have unique advantage of being well adapted to the local environment and stable performance. Hence mass selection can improve the local variety without adversely affecting its adaptability and stability.

b. Purification of the existing pure lines : Pure lines tend to develop variability over the time due to mechanical mixture, natural hybridization and mutation . Hence the purity of pure line varieties can be maintained through regular mass selection.

Achievements

Mass selection must have been used by pre historic man to develop present day cultivated cross from their wild parents. It was also used extensively before pureline selection came into existence.

2. Pureline selection

A pureline is a progeny of a single homozygous plant of a self-pollinated species. In this method of breeding a large number of plants are selected from a self pollinated crop and harvested individually. Individual plant progenies from selected plants are evaluated and the best progeny is released. Pure line variety is a obtained from a single homozygous plant of a self pollinated crop and is maintained by self pollination.

All the plants of a pure line have the same genotype. The phenotypic differences within a pureline are due to environment. Therefore variation within a pureline is not heritable. Hence **selection in a pureline is not effective.**

Pureline selection has been the most commonly used method of improvement of self pollinated crops. Almost all the present day varieties of self pollinated crops are purelines. Pureline selection has several applications in improvement of self pollinated crops. It is used to improve local varieties, old pureline varieties and introduced varieties

General procedure for evolving a variety by pureline selection

First year : A large number of plants (200-3000) which are superior than the rest are selected from a local variety or mixed population and harvested separately (in some cases individual heads or stems may be selected). The number of plants to be selected depends upon the breeder's discretion but should be as large as possible in view of the available time, land, funds, labour etc. It is advisable to select for easily observable characters such as flowering, maturity, disease resistance, plant height etc.

Second year: Progenies of individual plants selected in 1st year are grown separately with proper spacing (plant to row or head to row). The progenies are evaluated by taking elaborate date on visual characters such as plant height, duration, grain type, ear characters besides yield. The number of progenies should be reduced as much as possible. Disease epiphytotics may be created to test the progenies for disease resistance, poor, weak, diseased, insect attacked and segregating progenies are rejected. The superior progenies are harvested separately. If necessary the process may be repeated for one or more years.

Third year : The selected progenies, now called as cultures are grown in replicated trial for critical evaluation of yield etc. The best local variety is used as a check and should be grown at regular intervals, after every 15 or 20 cultures for comparison. This is known as preliminary yield trial. Superior cultures based on observable characters and yield are selected. The number is drastically reduced.

Fourth & Fifth years: The superior cultures are tested against the local checks in yield trials. Observations are recorded on many characters like diseases resistance, days to flower, days to

maturity, height of the plant ear characters, test weight and yield. The data is subjected to statistical analysis to identify really superior cultures. If necessary the trials may be extended for one more year or season. Inferior culture are rejected and a few (4-5) promising cultures are selected.

Sixth, Seventh and Eighth years: The promising cultures selected are evaluated at Several locations along with strains or cultures of other breeders and local checks. One or two promising cultures are selected.

Ninth year: The best progeny identified earlier is multiplied, named and released as a variety for official release of any variety (approval from the variety releasing committee of the state or central is necessary).

Application of pureline selection

- Popular and favourite method for the improvement o local varieties that have considerable variability
- Plant introduction materials are subjected for this method to develop suitable varieties
- Selection is done in old pureline variety to isolate new pureline from genetic variability produced over the time

Achievements : Several varieties developed by pureline selection were released in many crops. Some examples are given below

Rice : Mtu-1, Mtu-3, Mtu-7, Bcp-1, Adt-1, 3, 5, and 10
Wheat : NP4, NP6, NP12
Mungbean : T1 and B1

3. Pedigree Method

Pedigree Selection was initially developed by **Love** in 1927. In this method individual plants are selected from F_2 and subsequent generation, their progenies are grown and of all the parent-offspring relationship is maintained and selection is continued until progenies become homozygous and no segregation is observed. This method used for selection from segregating population of crosses in self pollinated crops. It is used for combination or transgressive breeding.

Procedure of pedigree method

First year : The selected parents are crossed to produce F_1 seed

Second year: F_1 seeds are space planted to each produces maximum number of F_2 seed. 15-30 F1 plants are sufficient to produce good F2 populations.

Third year: 200-10000 F_2 plants are space planted and 100-500 plants are selected and their seeds are harvested separately. As many F_2 plants as possible to handle efficiently should be selected. The selection depends on skill of the breeder and his ability to judge to select F_2 which produce good progeny.

Fourth year: Individual plant progeny are space planted. Individual F_3 plant with desirable characters from superior progenies is selected.

Fifth year: F_4 generation :Individual plants progenies are space planted desirable pants are selected undesirable progenies are rejected. Progenies are compared visually and more plants are selected from superior progenies. Selection of desirable plants from superior progenies selection is practiced within / between families.

Sixth year: F_5 Generation: Many families have reached homozygous and may be harvested in bulk. The breeder has to assess the yielding potential of progenies, 25-100 progenies are advanced and tested in preliminary yield trial.

Seventh year: F_6 Generation: Multi row plots and evaluated visually progenies harvested bulk and they have become homozygous.

Eights year: F_7 Generation: Preliminary yield trail with replication to identify the superior progenies. Progenies are evaluated for other component character 2-5 outstanding lines superior to check are advanced to multi location testing.

Ninth year. F_8 –F_{10} Generation: Replicated yield trial at several locations. They are tested for yield as well as for resistance.

Tenth year: F_{11} generation: Seed multiplication and release.

Merits of pedigree method

1. Maximum opportunity for the breeder to use his skill and judgment for the selection of plants in segregating generation.
2. It provides information about the inheritance of qualitative character from the pedigree record.
3. Chances of recovering transgressive segregants are more.
4. Weak and defective progenies are eliminated at an early stage.

Demerits of pedigree selection

1. Maintenance of accurate pedigree record is tedious and takes up valuable time
2. Selection of progenies in every generation laborious, time consuming. Difficult to handle many crosses.
3. No opportunity for natural selection.
4. Possibility of losing the valuable genotype is early segregating generation.

Applications of pedigree method

1. Commonly used method for selection from segregating population
2. Method is used in combination breeding and transgressive breeding

4. Bulk Method

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

Application: Cereals, small millets, grain legumes and oil seeds.

Procedure of Bulk method

First year : Hybridization*:* Parents are selected and crossed

Second year. F_1 generation*:* $F_1$is space planted more than 200 F_1 plants

Third – seventh year: F_2-F_6 generation*:* Planted at commercial seed rate, spacing and harvested as bulk, during this period. Frequency of population changes due to outbreak of disease or pest. Ar tificial selection is done, large population is raised, 30000-50000 plants in each generation.

Eighth year: F_7 generation*:* 50000 plants are space planted about 1000-5000 plants with phenotype is selected and the seeds are harvested separately.

Ninth year: F_8 generation*:* Individual plant progenies are single/multi row plants, since progenies are homogygous and harvested in bulk weak and inferior progenies are rejected and 100-300 individual plant progenies with desirable characters.

Tenth year: F_9 generation: Preliminary yield trial with standard check, yield and quality parameter is taken for selection.

Eleventh – thirteen year: F_{10}---F_{12} generation*:* Replicated yield trails are conducted. Yield and its component characters are evaluated along with the check. Superior progenies are released as variety

Fourteenth year: F_{13} generation*:* Seed multiplication of the newly released variety and distribution to farmers.

Application of bulk method

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

Merits of Bulk method

1. It is simple, convenient, inexpensive and particularly suited for small seeded crops.
2. Artificial or natural selection eliminate undesirable types and increase the frequency of desirable types.
3. Natural selection is likely to increase the frequency of superior genotypes in the population

4. Little work and attention is needed in F_2 and the subsequent generations, and no pedigree record is to be kept.
5. Due to large population, transgressive segregants are more likely to appear and increase in frequency under natural selection.
6. Individual plant selection is done at homozygous condition; it is more effective than the selection in F_2 and F_3 generations.
7. Natural selection improves characters like the adaptation to prevailing environment which are difficult to assess and select for while artificial selection leads to increase in the frequency of desirable types.
8. It is most suitable for studies on the survival of genes and genotypes in populations.

Demerits of bulk method

1. It takes much longer time taking in developing new variety.
2. Short-term bulk natural selection has little effect on the genetic composition of population.
3. Provide little opportunity for the breeders to exercise his skill or judgement in selection.
4. Large number of progenies has to be handled at the end of the bulking period.
5. Information on the inheritance of characters cannot be obtained.
6. In some cases, natural selection may act against the agronomically desirable types.
7. Due to markedly different environment condition, off-season crop and greenhouse cannot be used to advance the generations.

5. Backcross method

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

Objectives of this breeding method

1. To improve one or two specific defects of a high yielding variety and a well adapted variety with desirable character.
2. The characters lacking in this variety are transferred to it from a donor parent without changing the genotype of this variety except for the genes being transformed.

Recipient parent : Well adapted, high yielding variety, lacking one or two characters and hence receives these genes from other variety. Donor parent: The variety which donates one or two useful genes.

Recurrent parent: Since the recipient parent is repeatedly used in the backcross programme, it is also known as the recurrent parent. Non-recurrent parent : The donor parent, on the other hand,

is known as the non-recurrent parent because it is used only once in the breeding programme (for producing the F_1)

Procedure of Back cross method

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 rust, and that resistance to stem rust is dominant to susceptibility. A generalized scheme of the backcross programme for the transfer of rust resistance from variety B to variety A is given below.

1. Hybridization : Variety A is crossed to varie ty B. Generally, variety A should be used as the female parent. This would facilitate the identification of selfed plants, if any.
2. F_1 Generation : F_1 plants are backcrossed to variety A. Since all the F_1 plants will be heterozygous for rust resistance, selection for rust resistance is not necessary.

3. First Backcross Generation (BC_1): half of the plants would be resistant and the remaining half would be susceptible to stem rust. Rust resistant plants are selected and backcrossed to variety A. BC_1 plants resistant to rust may be selected for their resemblance to variety A as well.

4. BC_2-BC_5 Generations: In each backcross generation, segregation would occur for rust resistance. Rust resistant plants are selected and backcrossed to the recurrent parent A. Selection for the plant type of variety A may be practiced, particularly in BC_2 and BC_3.

5. BC_6 Generation : On an average, the plants will have 98.4 per cent genes from variety A. Rust resistant plants are selected and selfed; their seeds are harvested separately.

6. BC_6 F_2 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.

7. Yield Tests : The new variety is tested in a replicated yield trial along with the variety A as a check. Plant type, date of flowering, date of maturity, quality etc. are critically evaluated. Ordinarily, the new variety would be identical to the variety A in perfor mance. **Detailed yield tests are, therefore, generally not required and the variety may directly be released for cultivation**

Transfer of a Recessive Gene : When rust resistance is due to a recessive gene, all the backcrosses cannot be made one after the other. After the first backcross, and after every two backcrosses, F_2 must be grown to identify rust resistant plants. The F_1 and the backcross progenies are not inoculated with rust because they would be susceptible to rust. Only the F_2 is tested for rust resistance.

A generalized scheme for the transfer of a recessive gene for rust resistance is given below.

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

F_1 Generation: F_1 plants are backcrossed to the recurrent parent.

BC_1 Generation: Since rust resistance is recessive, all the plants will be rust susceptible. Therefore, there is no test for rust resistance. All the plants are self-pollinated.

BC_1F_2 Generation: 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.

BC_2 Generation: There is no rust resistance test. Plants are selected for their resemblance to the recurrent parent A, and backcrossed with the recurrent parent.

BC_3 Generation: There is no disease test. The plants are self-pollinated to raise F_2. Selection is usually done for the plant type of variety A.

BC_3F_2 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: There is no rust resistance test. Plants are back-crossed to variety A.

BC_5 Generation: There is no rust test. Plants are self-pollinated to raise F_2 generation.

BC_5F_2 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.

BC_5F_3 Generation: individual plant progenies are grown and subjected to rust epiphytotic. A rigid selection is done for resistance to stem rust and for the characteristics of variety A. Seeds from several similar rust resistant homogeneous progenies are mixed to constitute the new variety.

Yield Tests: It is the same as in the case of transfer of a dominant gene.

Merits of back cross method

1. Back cross method retains all desirable character of a popular adapted varieties and replaces undesirable allele at particular locus
2. Useful for the transfer of disease resistance and incorporation of quality traits into a variety
3. This is used for the development of isogenic lines,
4. Extensive tests are not required 2-3 generation can be raised in off season nurseries green houses, it would save time.
5. This is the only method for the inter specific gene transfer and transfer of cytoplasm.
6. Male sterility and fertility restoration genes can be transferred to various back ground.

Demerits of Back cross method

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

Application of backcross method

1. Inter varietal transfer of simply inherited traits. Characters governed by one or two genes like disease resistance are successful.
2. Inter varietal transfer of quantitative characters and highly heritable quantitative characters like earliness, plant height, seed size and seed shape is transferred.
3. Inter specific transfer of simply inherited characters: Disease resistance is transferred from related species to cultivated species. Inter specific transfer of genes are easy when the chromosome of the two species pair regularly.
4. Transferring of cytoplasm: wild species cytoplasmic are transferred to cultivated species transfer of male sterility. The variety or species from which the cytoplasm is to be

transferred is used as the female parent. The parent to which the cytoplasm is to be transferred is used as the male parent in the original cross and back cross. After 6-8 back crosses the progeny would have the nuclear genotype of the recurrent parent and the cytoplasm from the donor parent.

5. Production of isogenic lines : Isogenic lines are identical in their genotype except for one gene
6. Germplasm conversion: When valuable germplasm cannot be utilized in breeding programmesand may be used as recurrent parent in separate back cross programme these lines are called converted lines.

Breeding methods in cross pollinated crops

1. Mass selection

In the method, a number of plants are selected on the basis of their phenotype, and open-pollinated seeds from them is bulked together to rise the next generation. Its efficiency is dependent upon the number of genes controlling the characters, gene frequencies and more importantly heritability of the concerned trait. It is based on the maternal parents only and there is no control on the pollen parent. Plants are selected based on the phenotype and o progeny test is conducted. The selection cycle may be repeated one or more times in order to increase the frequency of favourable alleles: this selection scheme is called **phenotype recurrent selection.**

Modification in Mass Selection

The two drawbacks of mass selection, viz., lack of control of pollen source and confusing effect of the environment on phenotypes of individual plants is addressed by the following modifications in the mass selection:

1. Control on pollen source: Inferior plants present in the field are identified based on those characters, expressed before flowering and are detasselled. Then the selected plants are allowed to open-pollinate.

2. Controlled pollination: Pollen from all the selected plants is colle this bulk pollen is used to pollinate the selected plants thereby achieving control on the pollen source.

Stratified mass selection: It was suggested by Gardner in 1961 and is also known method of mass selection. The selection field is divided into several small plots each having 40-50 plants. Equal number of superior planets is selected from all the plots. Seeds from all the selected plants are composited to rise the next 67 penetration. The basic of this modification is the recognition that variation due to environment.

Minimizing the Environmental influence: Plants of a single genotype (hybrid) are planted as checks after every one, two or four plants of the variety under selection. The yields of plants under selection are expressed as per cent yield of nearest check plant. Principle of contiguous control is excised. Merits of Mass selection

1. Selection cycle is only one year

2. It is extremely simple, selection is based on the phenotype hence work of breeding is minimum

3. It is highly efficient in improving characters that are easily identified visually and have high heritability

4. With proper care, it is efficient in improving yield, because most of cross-pollinated have a high additive component of genetic variance, which responds well to selection

5. Improved population will be similar to original population hence range of adaptation extensive yield trails may not be required before its release as a new variety.

Demerits of Mass selection

1. Since the selection of plants is based on the phenotype, but most of the quantitative characters are considerably affected by environment, hence superior phenotype is often a poor basis for the identification of superior genotype.

2. Selected plants are pollinated by both superior and inferior plants present in the population as they are allowed to open-pollinate. This reduces the effectiveness of selection.

3. High intensities of selection reduce population size, as a result lead to some inbreeding and nullify the gain under selection.

2. **Progeny selection**

The most extensively used and simplest form of progeny selection is the ear-to-row method, used extensively in maize was developed by Hopkins in 1908.

Procedure of Progeny Selection Ear-lo-row method: Simplest form, selection cycle is of only one year. But it suffers from the defect that plants in the superior progenies are pollinated by those in both superior and inferior progenies thereby, reducing the effectiveness of selection.

1 Year	Superior phenotype plants are selected and are open pollinated. Seeds Superior phenotype individual plants are harvested separately.
2 Year	Single progeny row is grown from selected plants. Superior progenies are selected and allowed to open pollination and seeds are harvested separately
	Process of 2nd Year cycle is repeated (usually 4-5 cycle)

3. **Modified Ear-to-row method**

This method was specially designed to problems encountered in the above ear-to-row method. In this method, plants from superior progenies only are allowed to mate among themselves it is commonly used in maize bra in USA. But for each selection cycle, two years is required as compared with only one case of ear-lo-row method.

1 Year	Superior phenotype plants are selected and are open-pollinated. Seed from individual plants are harvested separately.
2 Year	50% of the seeds are sown in single progeny row, superior progenies are allowed to open pollinate. Remaining 50% of the parental seeds of the superior progenies are bulked to raise the next generation.
	1 and 2nd Year process is repeated (usually 4-5 cycles)

Hybrids, synthetics and Composites

Hybrids : The progeny of a cross between genetically different plants is called hybrid. In other word hybrid is F1 generation of mating between genetically dissimilar plants. Most of the hybrid varieties are F1 from two or more purelines (Tomato, *L esculentum*) or inbreds (Maize, *Zea mays*).
An inbred is a nearly homozygous line obtained through continuous inbreeding of cross – pollinated species. When F_1 generation from a cross between two or more purelines inbreds or other genetically dissimilar population is used for commercial cultivation is called as hybrid variety. Hybrid varieties are the most potent means for the exploitation of heterosis.

Heterosis: The superiority of F_1 hybrid over both its parents in terms of yield or some other characters or heterosis is increased vigours, growth, yield or function of a hybrid over the parents, resulting from crossing of genetically unlike organisms. The term heterosis was first coined by Shull in 1914. Generally heterosis manifested as an increase in vigour, size, growth, yield or some other characteristics. But in some cases, hybrid may be inferior to the weaker parent this is also regarded as heterosis.

The superiority of F_1 is estimated over average of the two parents (mid parent). This practise has found some acceptance particularly in the practical studies. However, in practical plant breeding the superiority of F_1 over mid parent is of no use since it does not offer the hybrid any advantage over the better parent. More generally, heterosis is estimated over the superior parent such heterosis is referred as heterosis. The term heteroecism is not commonly used since most breeders regard this to be only case of heterosis and referred to as such i.e Heterosis.

Steps in the development of hybrid varieties

1. Development of inbred lines: Single crosses are used as source population. uusually developed by close inbreeding(selfing). Other methods is through haploid production followed by chromosome doubling

2. Evaluation of inbreds:Identification of inbred which produce outstanding hybrids. It is most critical and expensive step in the development of hybrids. Has four steps

    a. Phenotypic evaluationof inbreds. Inbred showing inferior performance are discarded

    b. Top cross test: inbreds are crossed with open pollinated variety. Progeny performance is a reliable estimate of general combining ability(GCA) of inbreds.

    c. Single cross evaluation : all possible single crosses are made among the inbreds. Number of single crosses will be n(n-1)/2. Superior crosses are identifiedand released as hybrids. Limitation: Cost of F_1 seed is more because F_1 seed is produced on female which is inbred and is weak. F_1 seed produced will be less.

d. Prediction of double cross performance: double cross involves 4 inbred. (AXB) X (CXD). Advantage cost of seed is less

3. **Production of hybrid seeds**: It is governed by the floral structure and mode of pollination which decides the ease in emasculation of the female parent and effective pollen dispersal from the male parent to ensure a satisfactory seed set on the female parent. For ease in hybrid seed production one can exploit the male sterility and self incompatibility mechanisms described earlier. Also where ever feasible hand emasculation can be used(cotton, tomato) or or one can go for chemically induced male sterility (used for rice in China and Wheat in USA).

Merits of hybrid varieties

1. Yields are more

2. More uniform particularly the single cross hybrids

Demerits of hybrid varieties

1. Farmers have to purchase fresh hybrid seeds every year which is costly.

2. Hybrid seed production requires **technical skill, hence tedious and costly.**

Synthetic variety: In practical plant breeding, heterosis can be fully exploited in the form of hybrids in cross pollinated species, and also in some self pollinated crops. In cross- pollinated species, heterosis can also be exploited partially in the form of synthetic and composite varieties.

Definition of Synthetic Variety: A Variety which is produced by crossing in all combination a number of inbred lines that combine well with each other. Once synthesized, a synthetic is maintained by open-pollination in isolation and is referred as synthetic variety.

Hayas and Garber suggested the commercial utilization of synthetic varieties in Maize in 1919. Synthetic varieties have been of great value in the breeding for those cross – pollinated crop, where pollination control is difficult. E .g Alfalfa, cloves, forage crop species etc. Even in maize improvement synthetic varieties are becoming increasingly important.

A synthetic varieties can developed from inbreds, clones, and open pollinated varieties. The end products of recurrent selection, which are already tested for GCA are generally, used to constitute synthetic varieties. Generally 5-8 good general combining inbreds are used to constitute a synthetic variety. Synthetic variety consists of several heterozygous initially. Since subsequently the variety is maintained by open pollination, some degree of selfing occurs resulting in fixation of some genes. A result in later generation synthetic variety consists of several heterozygotes. Thus a synthetic variety has a heterogeneous population.

Merits of Synthetic variety

1. Less costly compared to hybrids.
2. Farmer can maintain his synthetic variety for more seasons which is not possible in hybrids.

3. Because of wider genetic base the synthetics are more stable over years and environments.
4. Seed production is more skilled operation in hybrids where as it is not so in synthetics.

Demerits of Synthetic variety

1. Performance is little bit lower compared to hybrids because synthetics exploit only GCA while hybrids exploit both GCA and SCA.
2. The performance may not be good when lines having low GCA are used.

Composite Variety : In cross pollinated crops, the mixture of genotype from several sources is maintained bulk from one generation to the next is referred as composite variety OR

Composite variety is a variety derived from advance generation of random mated out standing lines (Germplasm inbreds, varieties, hybrids, advance generation lines).

Mixing the seeds of several phenotypically outstanding lines produces a composite variety 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 like synthetic composite are commercial varieties and are maintained by open – pollination in isolation. Mixing the seeds of various genotypes, which are similar in maturity height, seed size, colour, etc. develops composite varieties. The variety is maintained by open pollination. Farmers can use their own seed for 3 to 4 years.

Differences between synthetics and composites

Sr.No	Synthetic Variety	Composite Variety
1	Crossing in all combination of number of lines that combine well with each other	Mixing the seeds of several phenotypically outstanding lines it and encouraging open pollination to produce crosses in all combination among the lines
2	4-10 numbers of parents are involved.	Many numbers of parents involved.
3	It is tested for GCA.	Not tested for GCA
4	Cost of seed is less than composite variety.	Cost of seed is less than hybrid.
5	It shows less heterosis than hybrid.	It shows more heterosis than synthetic.
6	Reconstituted is done	Reconstituted is never done.
7	Prediction of performance possible.	Prediction of performance is not possible.
8	Maintenance of variety easy.	Maintenance of variety is difficult but easy than hybrid.
9	Ex. ICMS- 7703, ICMS-7704	Ex. ICTP-8203, WCC-75.

Breeding methods in vegetatively propagated plants

Clone : A clone is a group of plants produced from a single plant through asexual reproduction. The crop plants can either be propogated by seeds or by vegetative parts. The vegetative propogation is resorted due to :

1. Lack of seed : Eg. Ginger, termiric
2. There is short viability of seed : Eg. Sugarcane
3. The seed production is very rare : Eg. Banana
4. Seeds are produced under special conditions only : Eg. Sugarcane, potato

Characteristics of Asexually propagated crops :

1. Majority of them are perennials : Eg . Sugarcane, fruit trees.

The annual crops are mostly tuber crops : Eg. Potato, cassava, Sweet potato

2. Many of them show reduced flowering and seed set
3. They are invariably cross pollinated
4. These crops are highly heterozygous and show severe inbreeding depression upon selfing.
5. Majority of asexually propagated crops are polyploids : Eg. Sugarcane, Potato, Sweet, Potato
6. Many species are interspecific hybrids. Eg. Banana, Sugarcane

Characteristics of a clones :

1. All the individual belonging to a single clone are identical in genotype
2. The phenotypic variation within a clone in due to environment only
3. The phenotype of a clone is due to the effects of genotype(g), the environment(e) and the genotype x environment interaction (GxE), over the population mean(M)
4. Theoratically clones are immortal. They deteriorate due to viral/bacterial infection and mutations.
5. Clones are highly heterozygous and stable
6. They can be propagated generation after generation without any change.

Importance of a clone

1. Owing to heterozygosity and sterility in many crops clones are the only means of propagation.
2. Clones are used to produce new varieties.

3. Clones are very useful tools to preserve the heterozygosity once obtained. In many crops the superior plants are maintained. (Mango, orange, apple, sugarcane)

Sources of clonal selection :

1. Local varieties
2. Introduced material
3. Hybrids and
4. Segregating populations

Clonal selection :

The various steps involved in clonal selection are briefly mentioned below.

First year : From a mixed variable population, few hundred to few thousand desirable plants are selected. Rigid selection can be done for simply inherited characters with high heritability. Plants with obvious weakness are eliminated.

Second year : Clones from the selected plants are grown separately, generally without replication. This is because of the limited supply of propagating material for each clone, and because of the large number of the clones involved.

Characteristics of the clones will be more clear now than in the previous generation.

Based on the observations the inferior clones are eliminated. The selection is based on visual observations and on judgement of the breeder on the value of clones. Fifty to one hundred clones are selected on the basis of clonal characteristics.

Third year : Replicated preliminary yield trial is conducted. A suitable check is included for comparison few superior performing clones with desirable characteristics are selected for multilocation trials.

At this stage, selection for quality in done. If necessary, separate disease nurseries may be planted to evaluate disease resistance of the clone s.

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

Ninth year : The superior clones are multiplied and released as varieties.

Advantages :

1. Varieties are stable and easy to maintain

2. Avoids inbreeding depression

3. Clonal selection, combined with hybridization generates necessary variability for several selections.

4. Only method to improve clonal crops

5. Hybrid vigour is easily utilized selection may be used in maintaining the purity of clones.

Disadvantages

1. Selection utilizes the natural variability already present in the population.

2. Sexual reproduction is necessary for creation of variability through hybridization.

3. Applicable only to the vegetatively propagative crops.

Problems in Breeding asexually propagated crops

1. Reduced flowering and fertility

2. Difficulties in genetic analysis

3. Perennial life cycle.

Clonal degeneration : The loss in vigour and productivity of clones with time is known as clonal degeneration and results due to :

1. Mutation

2. Viral diseases

3. Bacterial diseases

Achievements

I. Through clonal selection :

Potato : 1.Kufri Red from Darjeeling Red Round

2. Kufri Safed from phulwa

3. Bombay Green banana is a bud selection from dwarf Cavendish : pidi monthan from Monthan

II. Through hybridization : Potato