BOT(N)- 220 & BOT(N)-220L

B.Sc. III Semester

GENETICS AND PLANT BREEDING

DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY, HALDWANI

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DEPARTMENT OF BOTANY
SCHOOL OF SCIENCES
UTTARAKHAND OPEN UNIVERSITY

Phone No. 05946-261122, 261123
Toll free No. 18001804025
Fax No. 05946-264232, E. mail info@uou.ac.in
htpp://uou.ac.in

Expert Committee

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Karnprayag

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Augustmuni

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Assistant Professor
Department of Botany
Uttarakhand Open University, Haldwani

Dr. Pooja Juyal
Assistant Professor (AC)
Department of Botany
Uttarakhand Open University, Haldwani

Dr. Kirtika Padalia
Assistant Professor (AC)
Department of Botany
Uttarakhand Open University, Haldwani

Dr. Prabha Dhondiyal
Assistant Professor (AC)
Department of Botany
Uttarakhand Open University, Haldwani

Dr. Pushpesh Joshi
Assistant Professor (AC)
Department of Botany
Uttarakhand Open University, Haldwani

Programme Coordinator

Dr. S.N.Ojha
Assistant Professor
Department of Botany, School of Sciences
Uttarakhand Open University, Haldwani, Nainital

Unit Written By

GENETICS AND PLANT BREEDING: BOT(N)-220	
BLOCK-1 GENETICS	
Unit-1	Adopted from unit 5 of BSCBO 302 (978-93-90845-77-4) of UOU
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Unit-5	Adopted from unit 8 of BSCBO 302 (978-93-90845-77-4) of UOU
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Unit-7	Adopted from unit 10 of BSCBO 302 (978-93-90845-77-4) of UOU
Unit-8	Adopted from unit 11 of BSCBO 302 (978-93-90845-77-4) of UOU
LABORATORY COURSE: BOT(N)- 220L	
Unit-1(L)	Adopted from unit 6 of BSCBO 304 (978-93-90845-79-8) of UOU
Unit-2(L)	Dr.Priyanka Sharma Assistant Professor (AC) Department of Botany, School of Sciences Uttarakhand Open University, Haldwani
Unit-3(L)	Adopted from unit 7of BSCBO 304 (978-93-90845-79-8) of UOU
Unit-4(L)	Adopted from unit 8 of BSCBO 304 (978-93-90845-79-8) of UOU

Edited and Compiled By:

Dr. Prabha Dhondiyal
Assistant Professor (AC)
Department of Botany, School of Sciences
Uttarakhand Open University, Haldwani

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BLOCK-1 GENETICS

UNIT-1 GENETIC INHERITANCE

Contents:

1.1 OBJECTIVES

After reading this unit students will be able-

- To understand the genetic inheritance
- To understand about Mendel's experiment and laws of inheritance, and an insight into Mendelian or Classical Genetics.

1.2 INTRODUCTION

All living organism reproduce and reproduction results in the formation of offspring of their same kind. However, the resulting offspring need not always resemble to the parent. Several characteristics may differ among individual belonging to the same species. These differences are known as *variations.* The mechanism of transmission of characters from parents to offspring, resemblance as well as differences, is termed as *heredity.* The scientific study of heredity, variation and the environmental factor accountable for these variations is known as *genetics.*

The father of genetics is Gregor Mendel (1822-1844), a late 19th-century scientist and Austrian monk and a teacher in Augustinian Monastery at Brunn (in Czeckoslovakia, now called Brno). Mendel studied 'trait inheritance', patterns in the way traits (character) were handed down from parents to offspring. He discovered that individual traits are inherited as discrete *factors* which retain their physical identity in a hybrid. Later on these factors were called *genes*. The term 'gene' was given by Danish botanist Wilhelm Johannsen in 1990. Traits studied by Mendel were clear and discrete. Such discrete traits are known as *Mendelian characters.*

Every chromosome in a cell contains many genes and each gene is located at a particular site or *locus* in the chromosome. Chromosomes that carry same set of genes in the same sequence are called *homologous* for example human body cell contains 23 pairs of homologous chromosome.

Alleles are the alternative forms of a gene, which code for different versions of a particular inherited character. We can also define it as genes occupying corresponding positions on homologous chromosomes and controlling the same characteristic (e.g. height of plant) but producing different effects (tall or short). A dominant allele hides the expression of a recessive allele and it is represented by the uppercase letter. A recessive allele is the allele that expresses its effect only in homozygous state and in heterozygous condition its expression is masked by dominant allele. It is represented by lowercase letter.

Homozygous and Heterozygous

Each diploid parent has two allels for a trait- they may be:

1. Homozygous, when they possess two identical alleles for a trait.

Homozygous dominant (TT)

Homozygous recessive (tt)

2. Heterozygous, when they possess one of each allele for a particular trait (Tt).

Genotype and Phenotype

These terms are used in genetics to distinguish the physical appearance from the genetic constitution. Genotype is defined as the genetic constitution of an individual for any particular character or trait, usually expressed by symbol e.g. tt, Tt or TT etc. The physical appearance of an individual for any particular trait is defined as the phenotype. Phenotype of an individual is dependent on its genetic constitution.

1.3 MENDEL'S EXPERIMENT AND LAWS OF INHERITANCE

The laws of inheritance were derived by Gregor Mendel, a nineteenth-century Austrian monk conducting hybridization experiments in garden peas (*Pisum sativum*). Between 1856 and 1863, he cultivated and tested some 5,000 pea plants. He published the results of his experiment in 'Annual Proceedings of Natural History Society of Brunn'.From these experiments, he induced two generalizations which later known as *Mendel's Principles of Heredity* or *Mendelian inheritance*.

Mendel work remained hidden for about three decades (34 years) but in 1900 three workers rediscovered Mendel's work independently. These were *Hugo de Vries* (Holland) worked on evening primrose (*Oenothera), Karl Correns* (Germany) worked on maize (*Zea mays*) and *Tschermak* (Austria) worked on different flowering plants. All these workers after performing their experiment separately reached to the same conclusion and republished the original work of Mendel in 'Flora' (1901).

Regardless, the "re-discovery" made Mendelism an important but controversial theory. Its most vigorous promoter in Europe was William Bateson, who coined the terms "genetics" and "allele" to describe many of its view. The model of heredity was highly contested by other biologists because it implied that heredity was discontinuous, in opposition to the apparently continuous variation observable for many traits. Many biologists also dismissed the theory because they were not sure it would apply to all species. However, later work by biologists and statisticians such as R.A. Fisher showed that if multiple Mendelian factors were involved in the expression of an individual trait, they could produce the diverse results observed. Thomas Hunt Morgan and his assistants later integrated the theoretical model of Mendel with the chromosome theory of inheritance, in which the chromosomes of cells were thought to hold the actual hereditary material, and created what is now known as classical genetics, which was extremely successful and cemented Mendel's place in history.

Mendel's findings allowed other scientists to predict the expression of traits on the basis of mathematical probabilities. A large contribution to Mendel's success can be traced to his decision to start his crosses only with plants he demonstrated were true-breeding. He also only measured absolute (binary) characteristics, such as colour, shape, and position of the offspring, rather than quantitative characteristics. He expressed his results numerically and subjected them to statistical analysis. His method of data analysis and his large sample size gave credibility to his data. He also had the foresight to follow several successive generations

(F2, F3) of pea plants and record their variations. Finally, he performed "test crosses" (back-crossing descendants of the initial hybridization to the initial true-breeding lines) to reveal the presence and proportion of recessive characters.

Mendel's Laws

Mendel discovered that, when he crossed purebred white flower and purple flower pea plants (the parental or P generation), the result was not a blend. Rather than being a mix of the two, the offspring (known as the F_1 generation) was purple-flowered. When Mendel self-fertilized the F_1 generation pea plants, he obtained a purple flower to white flower ratio in the F_2 generation of 3 to 1. The results of this cross are tabulated in the Punnett square below.

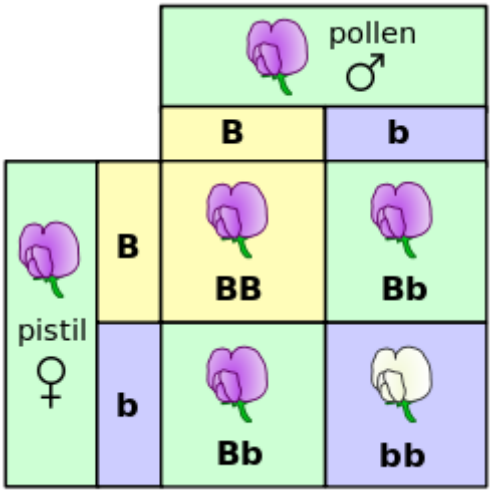


Fig.1.1 A Punnett square for one of Mendel's pea plant experiments

He then conceived the idea of heredity units, which he called "factors". Mendel found that there are alternative forms of factors - now called genes - that account for variations in inherited characteristics. For example, the gene for flower colour in pea plants exists in two forms, one for purple and the other for white. The alternative forms are now called alleles.

Mendel also hypothesized that allele pairs separate randomly, or segregate, from each other during the production of gametes: egg and sperm. Because allele pairs separate during gamete production, a sperm or egg carries only one allele for each inherited trait. When sperm and egg unite at fertilization, each contributes its allele, restoring the paired condition in the offspring. This is called the **Law of Segregation**. Mendel also found that each pair of alleles segregates independently of the other pairs of alleles during gamete formation. This is known as the **Law of Independent Assortment**.

The genotype of an individual is made up of the many alleles it possesses. An individual's physical appearance, or phenotype, is determined by its alleles as well as by its environment. The presence of an allele does not mean that the trait will be expressed in the individual that possesses it. If the two alleles of an inherited pair differ (the heterozygous condition), then one determines the organism’s appearance and is called the dominant allele; the other has no

noticeable effect on the organism's appearance and is called the recessive allele. Thus, in the example above dominant purple flower allele will hide the phenotypic effects of the recessive white flower allele. This is known as the **Law of Dominance** but it is not a transmission law, dominance has to do with the expression of the genotype and not its transmission.
In the pea plant example above, the capital "P" represents the dominant allele for purple flowers and lowercase "p" represents the recessive allele for white flowers. Both parental plants were true-breeding, and one parental variety had two alleles for purple flowers (*PP*) while the other had two alleles for white flowers (*pp*). As a result of fertilization, the F_1 hybrids each inherited one allele for purple flowers and one for white. All the F_1 hybrids (*Pp*) had purple flowers, because the dominant *P* allele has its full effect in the heterozygote, while the recessive *p* allele has no effect on flower colour. For the F_2 plants, the ratio of plants with purple flowers to those with white flowers (3:1) is called the phenotypic ratio. The genotypic ratio, as seen in the Punnett square, is 1 *PP*: 2 *Pp* : 1 *pp*.

1.3.1-Principle of Segregation

Mendel followed the inheritance of 7 pea traits. Dominant traits, like round peas, appeared in the first-generation hybrids (F1), whereas recessive traits, like wrinkled peas, were masked. However, recessive traits reappeared in the second generation (F2). Each individual carries a pair of factors for each trait, and they separate from each other during fertilization. This is the basis of Mendel's principle of segregation.

On the basis of monohybrid cross (a cross involving only one trait), Mendel formulated the law of Segregation, this law states that every individual contains a pair of alleles for each particular trait which segregate or separate during cell division (assuming diploidy) for any particular trait and that each parent passes a randomly selected copy (allele) to its offspring. The offspring then receives its own pair of alleles of the gene for that trait by inheriting sets of homologous chromosomes from the parent organisms. Interactions between alleles at a single locus are termed dominance and these influence how the offspring expresses that trait (e.g. the colour and height of a plant, or the color of an animal's fur). At the time of formation of gametes each member of the pair of genes separate from each other so that each gamete carries only one factor (gene) i.e. gametes are always pure (law of purity of gametes).

Definition: The Law of Segregation states that the two alleles for a heritable character segregate (separate from each other) during gamete formation and end up in different gametes.

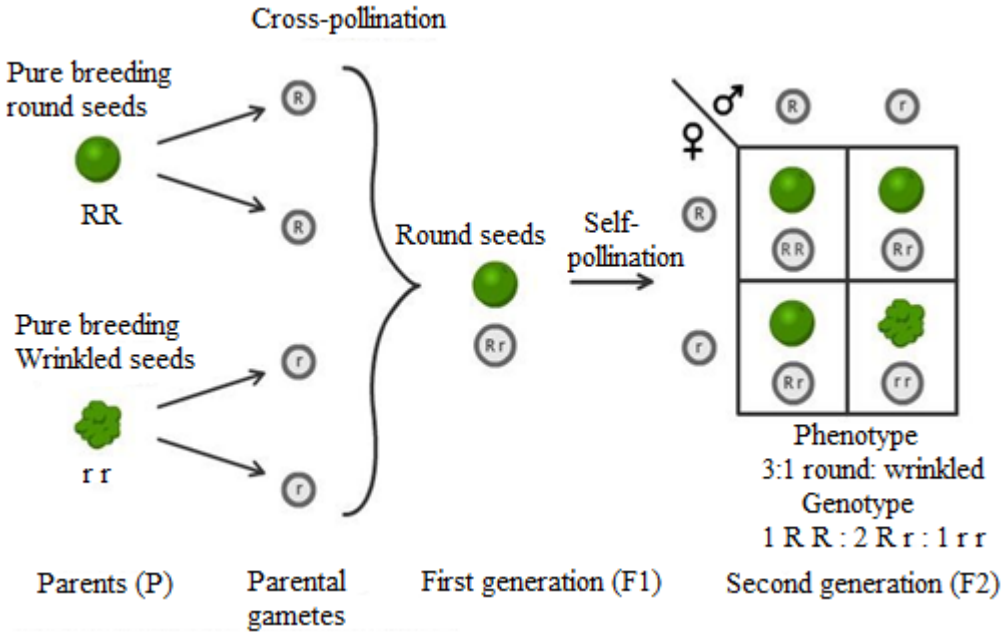


Fig. 1.2 Dominant and recessive phenotypes

1.3.2-Principle of Independent Assortment

The law in short stated that: In the inheritance of more than one pair of traits in a cross simultaneously, the factor responsible for each pair of traits are distributed to the gametes.

The Law of Independent Assortment, also known as "Inheritance Law", states that separate genes for separate traits are passed independently of one another from parents to offspring. That is, the biological selection of a particular gene in the gene pair for one trait to be passed to the offspring has nothing to do with the selection of the gene for any other trait. More precisely, the law states that alleles of different genes assort independently of one another during gamete formation. While Mendel's experiments with mixing one trait always resulted in a 3:1 ratio (Fig. 1) between dominant and recessive phenotypes, his experiments with mixing two traits (dihybrid cross) showed 9:3:3:1 ratios (Fig. 5.3). But the 9:3:3:1 table shows that each of the two genes is independently inherited with a 3:1 phenotypic ratio. Mendel concluded that different traits are inherited independently of each other, so that there is no relation, for example, between a pea seed shape (round or wrinkled) and seed colour (yellow or green). This is actually only true for genes that are not linked to each other.

A dihybrid cross shows Mendel's Law of Independent Assortment

In a dihybrid cross we are looking at the inheritance of two traits at the same time. Instead of looking at flower colour, we are going to look at two traits that affect the pea. Peas can either be round or wrinkled, and they can either be yellow or green. Round is dominant to wrinkled, so use **R** to represent round. Wrinkled is recessive and is represented by **r**. Always use the same letter so that you know you are specifying the same character. The dominant colour in peas is yellow, so we will use **Y** for yellow and **y** for green. Before Mendel could perform a dihybrid cross, he had to create a line that was true-breeding for both traits, so in this case the

line with peas that always had round shape and were always yellow were genotype **RRYY**, and the line with peas that were always wrinkled and green were **rryy**. What do you expect in the F1 generation when you cross these two true-breeding lines? That is straight forward because the only gametes that the round yellow plants can make will have the **RY** genotype, and the only gametes that the wrinkled green plants can make will have the **ry** genotype. Therefore, all of their offspring will be heterozygous. The phenotype of the F1 will be all round and yellow because those are the dominant traits.

Then, Mendel allowed these F1 plants to self-fertilize. This is where things got a bit tricky. These heterozygotes can make four different types of gametes. Do you know what they are? Write them down before you look at Figure 2 below. The law of segregation applies to each character. In addition, the two characters are independent when gametes are formed. So, the heterozygous plants can make four types of gametes, with all of the possible allelic combinations. There are gametes that are parental, **RY** and **ry**. They are called *parental* because they were also made by the parents in the P1 generation. However, you also find unique combinations of gametes, **Ry** and **rY**. These are *recombinant* gametes. Because each heterozygous individual can make four types of gametes, this results in a Punnett square with sixteen possible combinations.

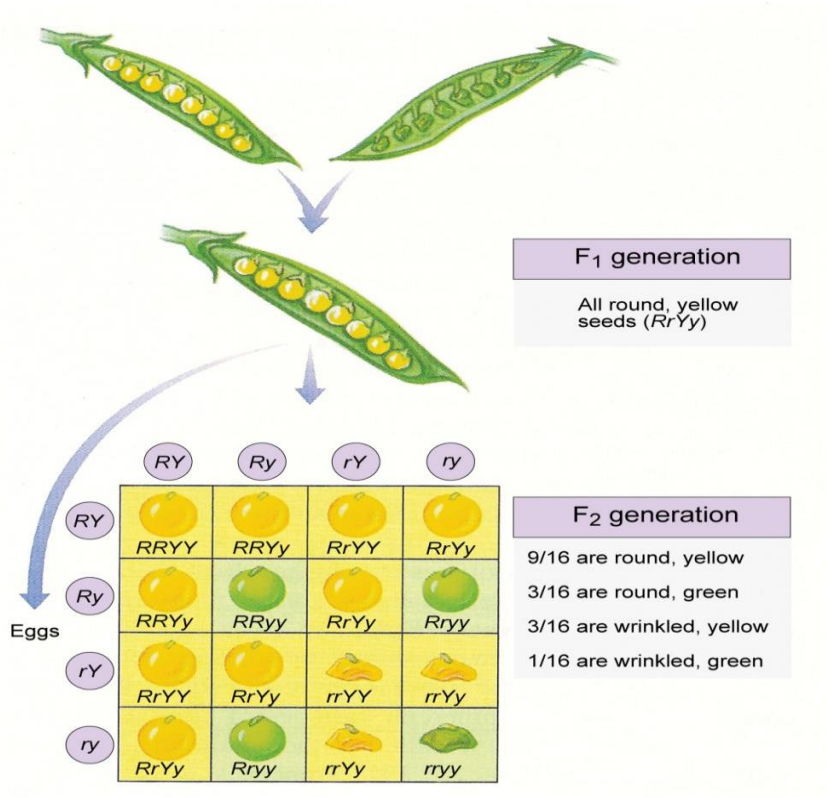


Fig.1.3: The results of a dihybrid Cross

Independent assortment occurs in eukaryotic organisms during meiotic metaphase I, and produces a gamete with a mixture of the organism's chromosomes. The physical basis of the independent assortment of chromosomes is the random orientation of each bivalent chromosome along the metaphase plate with respect to the other bivalent chromosomes.

Along with crossing over, independent assortment increases genetic diversity by producing novel genetic combinations.

Of the 46 chromosomes in a normal diploid human cell, half are maternally derived (from the mother's egg) and half are paternally derived (from the father's sperm). This occurs as sexual reproduction involves the fusion of two haploid gametes (the egg and sperm) to produce a new organism having the full complement of chromosomes. During gametogenesis the production of new gametes by an adult-the normal complement of 46 chromosomes needs to be halved to 23 to ensure that the resulting haploid gamete can join with another gamete to produce a diploid organism. An error in the number of chromosomes, such as those caused by a diploid gamete joining with a haploid gamete, is termed aneuploidy.

In independent assortment, the chromosomes that result are randomly sorted from all possible combinations of maternal and paternal chromosomes. Because gametes end up with a random mix instead of a pre-defined "set" from either parent, gametes are therefore considered assorted independently. As such, the gamete can end up with any combination of paternal or maternal chromosomes. Any of the possible combinations of gametes formed from maternal and paternal chromosomes will occur with equal frequency. For human gametes, with 23 pairs of chromosomes, the number of possibilities is 2^{23} or 8,388,608 possible combinations. The gametes will normally end up with 23 chromosomes, but the origin of any particular one will be randomly selected from paternal or maternal chromosomes. This contributes to the genetic variability of progeny.

1.3.3-Incomplete Dominance

Mendel's Law of Dominance states that recessive alleles will always be masked by dominant alleles. Therefore, a cross between a homozygous dominant and a homozygous recessive will always express the dominant phenotype, while still having a heterozygous genotype. Law of Dominance can be explained easily with the help of a mono hybrid cross experiment:- In a cross between two organisms pure for any pair (or pairs) of contrasting traits (characters), the character that appears in the F1 generation is called "dominant" and the one which is suppressed (not expressed) is called "recessive." Each character is controlled by a pair of dissimilar factors. Only one of the characters expresses. The one which expresses in the F1 generation is called Dominant. It is important to note however, that the law of dominance is significant and true but is not universally applicable.

According to the latest revisions, only two of these rules are considered to be laws. The third one is considered as a basic principle but not a genetic law of Mendel. Mendel explained inheritance in terms of discrete factors ‘genes’, that are passed along from generation to generation according to the rules of probability. Mendel's laws are valid for all sexually reproducing organisms, including garden peas and human beings. However, Mendel's laws stop short of explaining some patterns of genetic inheritance. For most sexually reproducing organisms, cases where Mendel's laws can strictly account for the patterns of inheritance are relatively rare. Often, the inheritance patterns are more complex.

Non-Mendelian Inheritance

The F_1 offspring of Mendel's pea crosses always looked like one of the two parental varieties. In this situation of "complete dominance," the dominant allele had the same phenotypic effect whether present in one or two copies. But for some characteristics, the F_1 hybrids have an appearance *in between* the phenotypes of the two parental varieties. A cross between two four o'clock (*Mirabilis jalapa*) plants shows this common exception to Mendel's principles. Some alleles are neither dominant nor recessive. The F_1 generation produced by a cross between red-flowered (RR) and white flowered (WW) *Mirabilis jalapa* plants consists of pink-colored flowers (RW). Which allele is dominant in this case? Neither one. This third phenotype results from flowers of the heterozygous having less red pigment than the red homozygous. Such conditions in which one allele is not completely dominant or semidominant or partial dominant over another are called **incomplete dominance**. In incomplete dominance, the heterozygous phenotype lies somewhere between the two homozygous phenotypes.

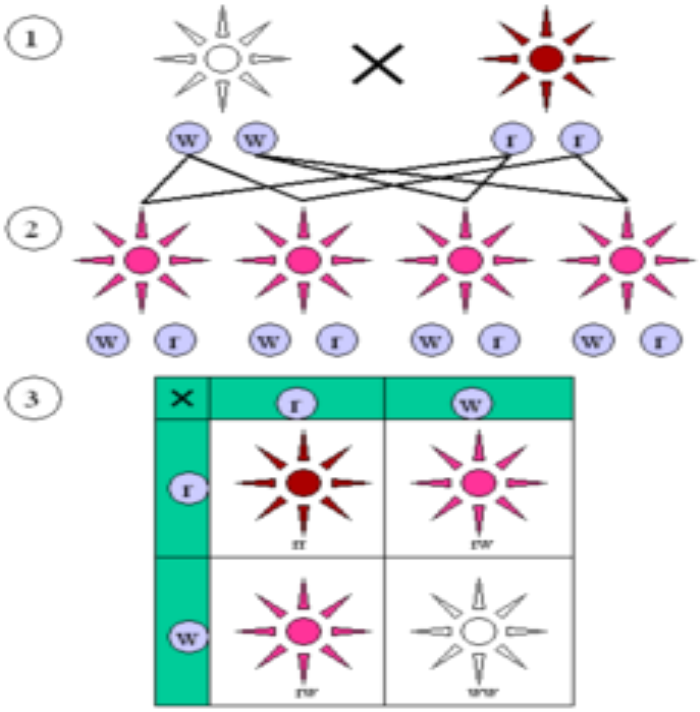


Fig.1.4. In four o'clock plants, the alleles for red and white flowers show incomplete dominance. As seen in the F_1 generation, heterozygous (wr) plants have "pink" flowers—a mix of "red" (rr) and "white" (ww) coloring. The F_2 generation shows a 1:2:1 ratio of red: pink:white

A similar situation arises from **codominance**, in which alleles that lack dominant and recessive relationships, and are both observed phenotypically to same degree. For example, in certain varieties of chicken, the allele for black feathers is codominant with the allele for white feathers. Heterozygous chickens have a color described as "erminette," speckled with black and white feathers. Unlike the blending of red and white colours in heterozygous four o'clocks, black and white colours appear separately in chickens. Many human genes, including one for a protein that controls cholesterol levels in the blood, show codominance,

too. People with the heterozygous form of this gene produce two different forms of the protein, each with a different effect on cholesterol levels.

In Mendelian inheritance, genes have only two alleles, such as *A* and *a*. In nature, such genes exist in several different forms and are therefore said to have **multiple alleles**. A gene with more than two alleles is said to have multiple alleles. An individual, of course, usually has only two copies of each gene, but many different alleles are often found within a population. One of the best-known examples is coat color in rabbits. A rabbit's coat color is determined by a single gene that has at least four different alleles. The four known alleles display a pattern of simple dominance that can produce four coat colors. Many other genes have multiple alleles, including the human genes for ABO blood type.

Furthermore, many traits are produced by the interaction of several genes. Traits controlled by two or more genes are said to be **polygenic traits**. *Polygenic* means "many genes." For example, at least three genes are involved in making the reddish-brown pigment in the eyes of fruit flies. Polygenic traits often show a wide range of phenotypes. The variety of skin color in humans comes about partly because more than four different genes probably control this trait.

1.4 SUMMARY

Inheritance is the process by which genetic informations are passed from parent to child. This is why members of the same family tend to have similar characteristics. Most of our cells contain two sets of 23 chromosomes (they are diploid). An exception to this rule are the sex cells (egg and sperm), also known as gametes, which only have one set of chromosomes each (they are haploid). However, in sexual reproduction the sperm cell combines with the egg cell to form the first cell of the new organism in a process called fertilization. This cell (the fertilized egg) has two sets of 23 chromosomes (diploid) and the complete set of instructions needed to make more cells, and eventually a whole person. Each of the cells in the new person contains genetic material from the two parents. This passing down of genetic material is evident if you examine the characteristics of members of the same family, from average height to hair and eye colour to nose and ear shape, as they are usually similar. If there is a mutation in the genetic material, this can also be passed on from parent to child. This is why diseases run in families.

Mendelian inheritance is inheritance of biological features that follows the laws proposed by Gregor Johann Mendel in 1865 and 1866 and re-discovered in 1900. It was initially very controversial. When Mendel's theories were integrated with the Boveri-Sutton chromosome theory of inheritance by Thomas Hunt Morgan in 1915, they became the core of classical genetics.

1.5 GLOSSARY

Gene: A unit of heredity composed of DNA occupying a fixed position on a chromosome (some viral genes are composed of RNA). A gene may determine a characteristic of an individual by specifying a polypeptide chain that forms a protein or part of a protein (**structural gene**); or encode an RNA molecule; or regulate the operation of other genes or repress such operation.

Allele: An **allele** is one of a pair of genes that appear at a particular location on a particular chromosome and control the same characteristic, such as blood type or colorblindness. **Alleles** are also called alleleomorphs. Your blood type is determined by the **alleles** you inherited from your parents.

Genetic inheritance: Inheritance is the process by which genetic information is passed on from parent to child. This is why members of the same family tend to have similar characteristics. Each cell in the body contains 23 pairs of chromosomes. One chromosome from each pair is **inherited** from your mother and one is **inherited** from your father. The chromosomes contain the **genes inherit** from parents. There may be different forms of the same **gene** – called alleles.

Heredity: Heredity is the passing of traits from parents to their offspring, either through asexual reproduction or sexual reproduction. This is the process by which an offspring cell or organism acquires or becomes predisposed to the characteristics of its parent cell or organism.

Mendel's Law of Segregation: The characteristics of the offspring are derived from both maternal and paternal factors. Every individual has a pair of genes governing a particular characteristic (e.g. the color of the eyes). During the formation of sex cells each pair is separated (segregated) so that each sex cell (egg or sperm) carries only one form of each gene. The offspring thus receives one from each parent and this pair of genes determines how the caracteristic is expressed (e.g. whether the child's eyes are blue or brown).

Mendel's Law of Independent Assortment: When considering more than one gene, Mendel noted that two characteristics do not always appear together. For instance a mother with blonde hair and blue eyes may have a blonde-haired child with brown eyes. Thus different characteristics can be independently inherited.

Mendel's Law of Dominance: A principle in genetics proved subsequently to be subject to many limitations: because one of each pair of hereditary units dominates the other in expression, characters are inherited alternatively on an all-or-nothing basis also called law of dominance.

1.6 SELF ASSESSMENT QUESTIONS

1.6.1 Multiple choice questions:

1- Gregor Mendel was:

(a) An English scientist who carried out research with Charles Darwin

(b) An early 20th century Dutch biologist who carried out genetics research

(c) An Austrian monk

(d) An American geneticist

2- An allele is-

(a) One of four possible forms of a gene (b) A heterozygous genotype

(c) A homozygous genotype. (d) One of several possible forms of a gene

3- In a two allele, one locus diploid system, True Breeding individuals are-

(a) Homozygous at one locus (b) Heterozygous at one locus

(c) Always dominant (d) Always recessive

4- Phenotype of an individual refers to the-

(a) Actual allele signal (b) Actual physical appearance

(c) Genetic makeup (d) Recessive allele

5- The idea that different pairs of alleles are passed to offspring independently is Mendel's principle of:

(a) Segregation (b) Unit inheritance

(c) Independent assortment (d) Blended inheritance

6- The idea that for any particular trait, the pair of alleles of each parent separate and only one allele from each parent passes to an offspring is Mendel's principle of:

(a) Independent assortment (b) Blended inheritance

(c) Unit inheritance (d) Segregation

7- Which of the following statements is true about Gregor Mendel?

(a) His ideas about genetics apply equally to plants and animals

(b) His ideas about genetics were useful to Darwin in his development of his theory of evolution

(c) His ideas about genetics do not apply equally to plants and animals.

(d) His discoveries concerning genetic inheritance were generally accepted by the scientific community when he published them during the mid 19th century.

8- Mendel believed that the characteristics of pea plants are determined by the:

(a) Inheritance of units or factors from both parents

(b) Inheritance of units or factors from one parent

(c) Relative health of the parent plants at the time of pollination

(d) None of the above

9- Genes are part of chromosome. Chromosomes are found in:

(a) Only in egg cells (b) In every cell of an organism

(c) Only in sperm cells (d) All of above

10- Chromosomes determine a person’s:

(a) Sex (b) Height

(c) Age (d) Marital status

1.6.1- Answer Keys: 1-(c), 2-(d), 3-(a), 4-(b), 5-(c), 6-(d), 7-(a), 8-(a), 9-(b), 10-(a)

1.7 REFERENCES

- Grafen, Alan; Ridley, Mark (2006). Richard Dawkins: How A Scientist Changed the Way We Think. New York, New York: Oxford University Press. p. 69. ISBN 0-19-929116-0.
- E. B. Ford (1960). Mendelism and Evolution (seventh ed.). Methuen & Co (London), and John Wiley & Sons (New York).
- Henig, Robin Marantz (2009). The Monk in the Garden : The Lost and Found Genius of Gregor Mendel, the Father of Modern Genetics. Houghton Mifflin. ISBN 0-395-97765-7. The article, written by an Austrian monk named Gregor Johann Mendel.
- Mendel's paper in English: Gregor Mendel (1865). "Experiments in Plant Hybridization".

1.8 SUGGESTED READINGS

- Peter J. Bowler (1989). The Mendelian Revolution: The Emergence of Hereditarian Concepts in Modern Science and Society. Johns Hopkins University Press.
- Atics, Jean. Genetics: The life of DNA. ANDRNA press.
- Reece, Jane B., and Neil A. Campbell. "Mendel and the Gene Idea." Campbell Biology. 9th ed. Boston: Benjamin Cummings / Pearson Education, 2011. 265.

1.9 TERMINAL QUESTIONS

1.9.1 Short answer type Questions:

1. Why do children look like their parents?
2. Why do some children look more like their mother and others look more like their father?
3. How is the similarity between children and parents controlled?
4. What controls the development of an organism?
5. What is a gene and where is it located?
6. Do all organisms have the same number of genes?
7. Is the number of genes proportional to size of the organism?
8. Do all genes get expressed?
9. How are genes regulated?
10. What do genes do in an organism’s development?

1.9.2 Long answer type Questions:

1. What two experimental innovations did Mendel use that allowed him to discover the laws of genetics?
2. What did Mendel conclude from his experiments?
3. Why Mendel’s First Law of Genetics is called the “Law of Segregation”?
4. Why Mendel’s Second Law of Genetics is called the “Law of Independent Assortment”?

5. Why a red 4 o'clock plant was crossed with a white 4 o'clock plant, they produced pink 4 o'clock plants. Explain why?
6. How can you account for the fact that in some cases organisms of the same phenotype are not of the same genotype? How can you account for cases of organisms with the same genotype but different phenotypes?
7. What causes biologists to suspect that chromosomes are involved in the transmission of the hereditary material?
8. What are genes?
9. What is the relationship between the gene and the appearance of an organism (Genotype vs. Phenotype)?
10. How does a cell divide into two cells?

UNIT-2 GENE INTERACTIONS AND EXTRA-CHROMOSOMAL ABERRATIONS

Contents:

2.1 OBJECTIVES

1. To study gene interactions.
2. To study extra chromosomal inheritance.
3. To study extra nuclear inheritance by cellular organalles.

2.2 INTRODUCTION

The Genotype is genetic constitution of an organism *i.e.,* full hereditary information. Phenotype is an organism's actual observed properties means external appearance *i.e.,* morphology, development, or behavior. An organism's genotype is a major influencing factor in the development of its phenotype (morphology), but it is not the only one. Even two organisms with identical genotypes normally differ in their phenotypes. The phenotype is the product of genotype and environmental influence. The concept of phenotypic plasticity defines the degree to which an organism's phenotype is determined by its genotype. A high level of plasticity means that environmental factors have a strong influence on the particular phenotype development.

Back Cross, Out cross and test cross: When F_1 individuals are crossed with one of the two parents from which they have been derived, then such a cross is called back cross. Back cross are of two types:- out cross and test cross. When Tt (F_1) is crossed with TT (Homozygous dominant parental), it is called out cross. When Tt (F_1) is crossed with tt (Homozygous recessive parental), it is called test cross. A test cross is a way to explore the genotpye of F_1 individuals. Early use of the test cross was as an experimental mating test used to determine what alleles are present in the genotype. Consequently, a test cross can help to determine whether a dominant phenotype is homozygous or heterozygous for a specific allele.

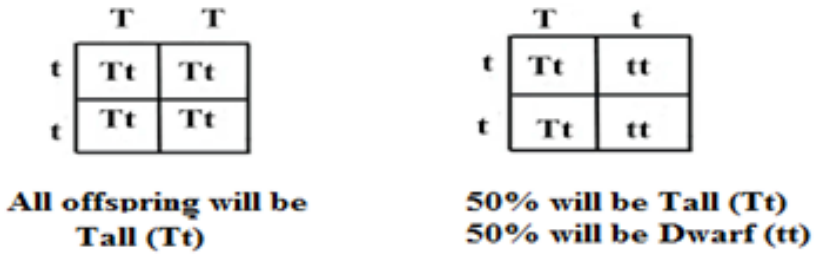


Fig.2.1: Test cross outcomes

2.3 EPISTASIS

Epistasis (Greek: standing upon) is the masking genetic phenomenon when the phenotypic effect of alleles at one gene masks or inhibits the expression of alleles of another gene. The term “epistatis” was first of all used by Bateson (1909). It is the interaction between non allelic genes in which one gene suppresses the expression of other gene. A gene is said to be epistatic when its presence suppresses the effect of a gene at another locus. But when two different genes which are not alleles, both affect the same character in such a way that the expression of one masks, inhibits or suppresses the expression of the other gene, it is

called epistasis. The gene that suppresses is said to be epistatic, and the gene which remains obscure is hypostatic.

In this section you will study genetic problem in the form of gene interaction as non-Mendelian genetics. When expression of one gene depends on the presence or absence of another gene in an individual, it is known as gene interaction. The interaction of genes at different loci that affect the same character is called epistasis. The term epistasis was first used by Bateson in 1909 to describe two different genes which affect the same character, one of which masks the expression of other gene. The gene that masks another gene is called epistatic gene, and the gene whose expression is masked is termed as hypostatic gene. Epistasis is also referred to as inter-genic or inter-allelic gene interaction.

The gene interactions have several characteristics as follows:

i. This is an essential feature of gene interaction which always involves two or more genes.

ii. The epistatic genes always affect the expression of one and the same character of an individual.

iii. The phenotype of a gene usually depends upon the presence or absence of epistatic gene. The gene which has masking effect is called epistatic gene and the gene whose effect is masked is known as hypostatic gene.

iv. Epistasis leads to the modification of Mendelian di-hybrid (9:3:3:1) or tri-hybrid ratio (27:9:9:9:3:3:3:1) in F_2 generation.

v. Epistasis is generally governed by dominant genes, but cases of recessive epistasis are also shown.

Mendelian genetics does not explain all kinds of inheritance for which the phenotypic ratios in some cases are different from Mendelian ratios (3:1 for monohybrid, 9:3:3:1 for di-hybrid, 27:9:9:9:3:3:3:1for tri-hybrid in F_2). This is because sometimes a particular allele may be partially or equally dominant to the other or due to existence of more than two alleles or due to lethal alleles. These kinds of genetic interactions between the alleles of a single gene are referred to as allelic or intra- allelic interactions.

Non-allelic or inter-allelic interactions also occur where the development of single character is due to two or more genes affecting the expression of each other in various ways. Thus, the expression of gene is not independent of each other and dependent on the presence or absence of other gene or genes; These kinds of deviations from Mendelian one gene-one trait concept is known as factor hypothesis or gene-interaction. Now epistasis term is used synonymously with almost any type of gene interaction that involves the masking of one gene by another gene. When epistasis is operative (gene interacts) the phenotypic ratio deviates from Mendelian ratio (3:1 for monohybrid, 9:3:3:1 for di-hybrid and 27:9:9:9:3:3:3:1for tri-hybrid) in F_2 generation. The phenomenon of two or more gene affecting expression of each other in various ways in the development of single character of an organism known as gene interaction/epistasis.

2.3.1 Types of gene interactions/epistasis: The two or more genes interact in several manners some common interactions are as follows:

(1) Dominant epistasis (12:3:1)
(2) Recessive epistasis or supplementary gene interaction (9:3:4)
(3) Double recessive/complementary gene interaction (9:7)
(4) Inhibitory gene interaction/dominant recessive epistasis (13:3)
(5) Polymorphic gene interaction (9:6:1)
(6) Duplicate gene interaction/double dominant epistasis (15:1)
(7) Collaborative supplementary/modified gene interaction (9:3:3:1)
(8) Polymeric gene interaction (9:6:1)

1. Dominant epistasis (12:3:1): A genetic phenomenon of non allelic gene interaction in which a dominant gene or a dominant gene pair inhibits or masks the expression of another dominant gene or gene pair.

For example: Fruit colour in summer squash

Three types of fruit colours are present in summer squash (*Cucurbita pepo*), *viz.*, white, yellow and green. White colour is controlled by dominant gene W and yellow colour by dominant gene Y. This white colour gene is dominant over both yellow and green.

The green fruits are produced in recessive condition (wwyy). A cross between plants having white and yellow fruits produced F_1 with white fruits. Inter-mating of F_1 plants produces plants with white, yellow and green coloured fruits in F_2 in 12 : 3 : 1 ratio (Fig. 10) instead of typical Mendelian dihybrid ratio (9:3:3:1).

W = white non allelic epistatic dominant gene.
Y = yellow hypostatic dominant gene.
y = green recessive gene.

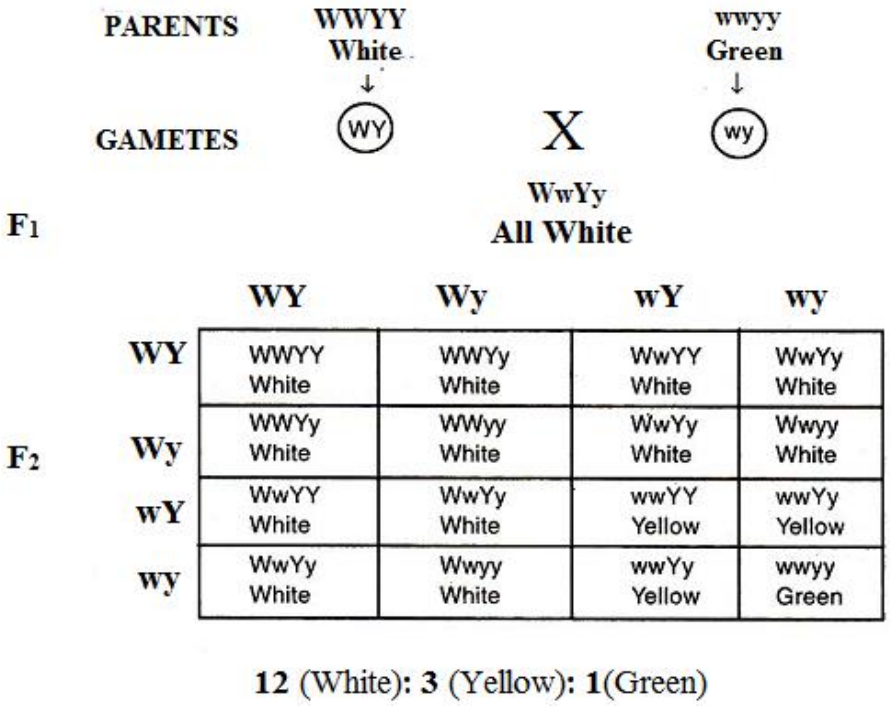
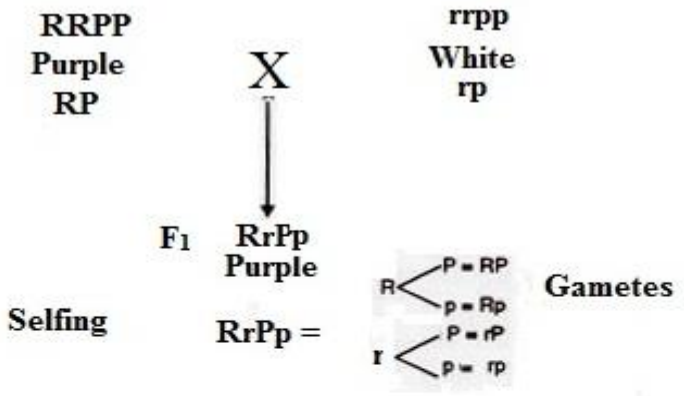


Fig.2.2: Dominant epistasis in summer squash (Cucurbita pepo)

2. Recessive epistasis or supplementary gene interaction (9:3:4): A genetic phenomenon of non allelic gene interaction in which a gene in its homozygous recessive state masks the expression of non allelic gene or gene pair.

In supplementary gene action, the dominant allele of one gene is essential for the development of the concerned phenotype, while the other gene modifies the expression of the first gene. For example, the development of grain colour in maize is governed by 2 dominant genes R and P. The dominant allele R is essential for red colour production; homozygous state of the recessive allele (rr) checks the production of red colour. The gene P is unable to produce any colour on its own but it modifies the colour produced by the gene R from red to purple. The recessive allele p has no effect on grain colour.



F2	RP	Rp	rP	rp
RP	RRPP Purple	RRPp Purple	RrPP Purple	RrPp Purple
Rp	RRPp Purple	RRpp Red	RrPp Purple	Rrpp red
rP	RrPP Purple	RrPp Purple	rrPP White	rrPp White
rp	RrPp Purple	Rrpp Red	rrPp White	rrpp White

9 (Purple) : 3 (Red) : 4 (White)

Fig.2.3: Recessive Epistasis or supplementary gene interaction in Maize Grain

3. Double recessive/complementary gene interaction (9:7): A genetic phenomenon of non allelic gene interaction in which homozygous recessive gene inhibits the expression of other gene and *vice versa*.

Or

A genetic phenomenon of non allelic gene interaction in which a gene or gene pair requires the help of dominant non allelic gene interaction. Complete dominance at both gene pairs, but either recessive homozygote is epistatic to the effect of the other gene.

For example: Flower colour in sweet pea (*Lathyrus odoratus*):

For the production of the purple flower colour both dominant C and P (complementary) genes are necessary. Otherwise in the absence of either dominant genes (C or P) the flower colour become white. Thus, C and P genes interact and both are essential for the purple colour expression of flower together. Complementation between two non-allelic genes (C and P) are essential for production of a particular or special phenotype *i.e.,* complementary factor.

P= Purple flower colour
C= Colourless
PPCC= Purple Colour flower
PPcc= Colourless
ppCC= Colourless

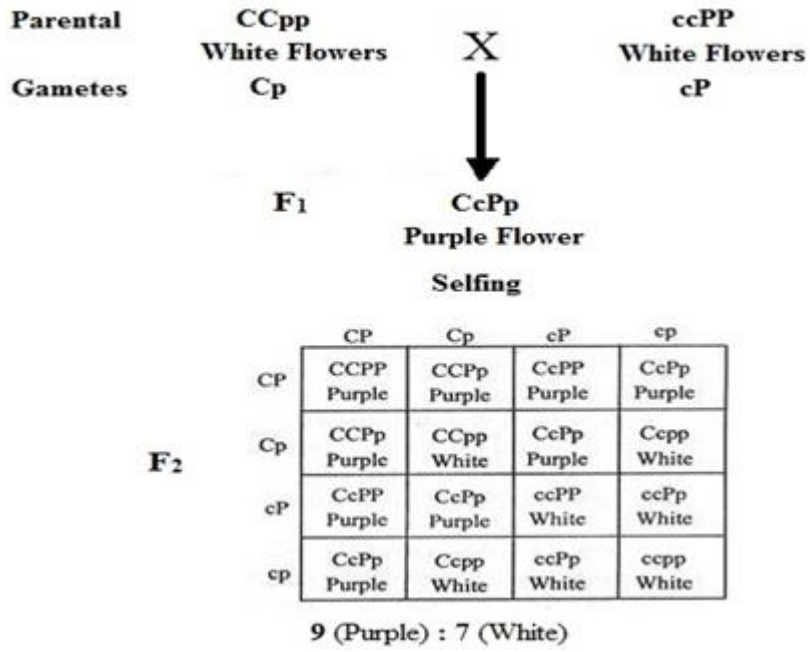


Fig. 2.4: Double recessive/Complementary gene interaction in Sweat Pea (Lathyrus odoratus)

4. Inhibitory gene interaction (13:3): In **Inhibitory gene interaction** the non-allelic dominant gene inhibits the expression of the other non-allelic dominant gene. A genetical phenomenon in which a gene is recessive for its own but dominant with regard to epistasis. The gene which inhibits the expression of an allele situated at different locus is called as inhibitory gene.

For example: Pigmentation in paddy leaves.

In paddy plants P gene is responsible for deep purple colour. But if I gene is present along with P then expression of purple colour is inhibited and becomes green. Thus in a cross, between green (IIpp) and purple (iiPP), gives all F_1 offspring green but in F_2 progeny, green and purple are obtained in ratio of 13:3 instead of typical 9:3:3:1 Mendelian F_2 ratio.

PPii= Purple

PPII= Green
P= purple but when interacts with I gene than inhibited by it and becomes green.
I= Green but when interacts with P gene than inhibits P gene Make it green.

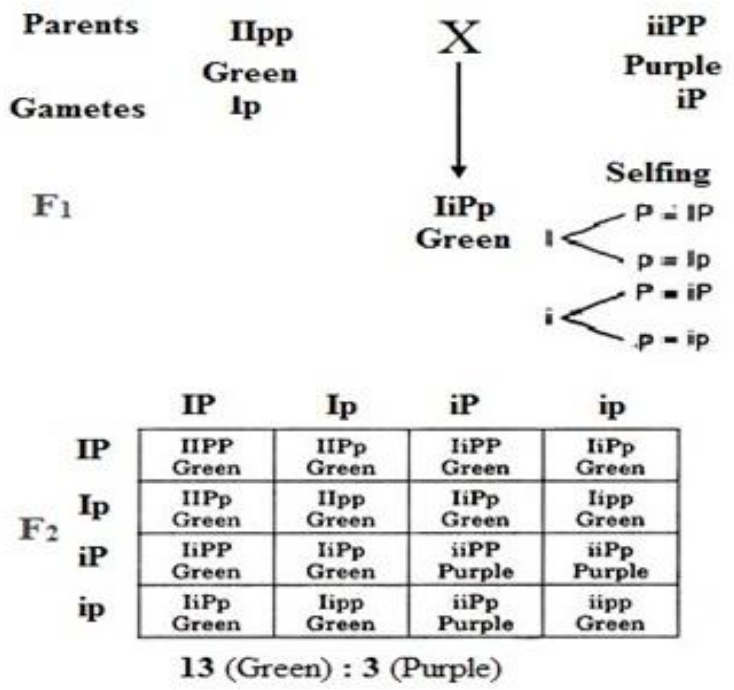


Fig.2.5: Inhibitory gene interaction paddy leaves pigmentation

6. Polymorphic gene interaction (9:6:1): When two or more genes (Allelic and non-allelic) govern any character separately, their effect is equal but when both or all genes are present together, there phenotypic effect is increased or raised as if the effects of the two or more genes were additive or cumulative. In this case both or all genes shows complete dominance. "Additive or cummulative effect of genes present at different loci is called polymerism." Thus, polymeric gene interaction modifies the typical 9:3:3:1 Mendelian ratio in to 9:6:1 ratio.

For example: pericarp colour in Wheat.

$C_1C_1C_2C_2$ = Deep Red
$C_1C_1c_2C_2$ = Light Red
$c_1c_1c_2c_2$ = Brown Colour

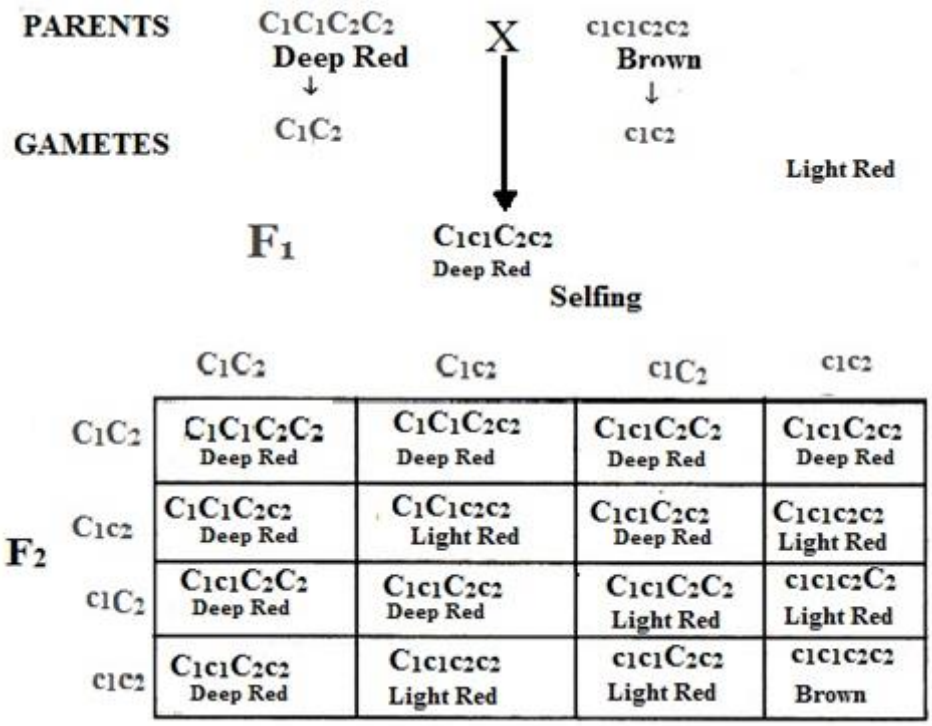


Fig.2.6: Polymorphic Gene interaction in wheat pericarp

7. Collaborative supplementary/modified gene interaction (9:3:3:1): A genetic phenomenon in which two non allelic dominant gene produces the different and independent effect but when they comes together they produces different/new effect.

They are two nonallelic genes which not only are able to produce their own effects independently when present in the dominant state but can also interact to form a new trait.

For example: Comb types in poultry are an example of collaborative supplementary genes, P and R. When homozygous pea combed and homozygous rose combed birds are crossed, all the offspring of F_1 generation have walnut comb. On selfing the walnut combed, F_2 generation comes to have all the four types of combs in the ratio of 9 (walnut): 3 (pea): 3 (rose): 1 (single) (Fig.6.15). This type of gene interaction produces the typical di-hybrid ratio of 9:3:3:1 in F_2 for a single character. Evidently the concerned character is governed by two genes showing complete dominance.

As worked out by Bateson and Punnett (1908), when both dominant alleles are present 'walnut' phenotype appears and when both recessive alleles are present 'single' comb appears. 'Rose' and 'Pea' phenotypes appear due to the presence of different single dominant alleles. If pea (rrPP) and rose (RRpp) are crossed, F_1 birds showed 'walnut' comb as it has the dominant alleles of both the genes P and R.

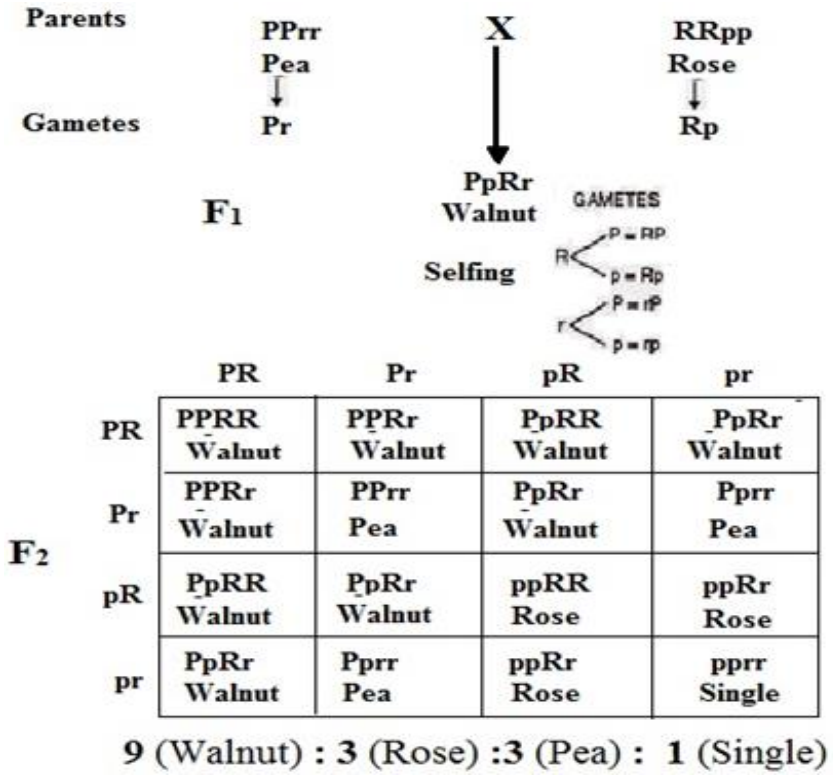


Fig. 2.7: Collaborative supplementary/Modified gene interaction in comb types in poultry

Allele: An **allele** is an alternative form of a given gene (Fig.6.7). An allele that produces the same phenotype whether its paired allele is identical or different called dominant allele and represented by uppercase letter (T), an allele that produces its characteristic phenotype only when its paired allele is identical called recessive allele and represented by lowercase letter (t).

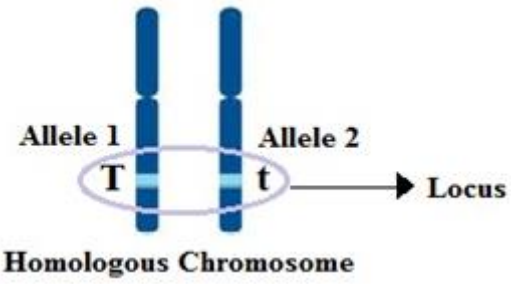


Fig.2.8: Allele on homologous chromosome

Multiple allelism: Three or more kinds of genes which occupy the same locus are referred to as multiple alleles and character governed by more than two alleles called multiple allelism.

Example 1: The ABO system in humans is controlled by three alleles, usually referred to as I^A, I^B, and I^O (I = isohaemagglutinin). I^A and I^B are codominant and produce type A and type B antigens, respectively, which migrate to the surface of red blood cells, while I^O is the

recessive allele and produces no antigen. So, the blood groups arising from the different possible genotypes are as follows:

Genotype	Blood Group
$I^A I^A$	*A*
$I^A I^0$	*A*
$I^B I^B$	*B*
$I^B I^0$	*B*
$I^A I^B$	*AB*
$I^0 I^0$	*O*

Self-Sterility in Plants: Kolreuter (1764) described self-sterility in tobacco (*Nicotiana longiflora).* East and Yarnell described that self-sterility is due to series of alleles designated as S_1, S_2, S_3 and S_4 etc. The hybrids S_1/S_2 or S_1/S_3 or S_3/S_4 are self-sterile because pollen grains from these varieties did not develop, but pollens of S_1/S_2 were effective and capable of fertilization with S_3/S_4.

2.4 EXTRACHROMOSOMAL INHERITANCE

All genetic loci are located on the chromosomes in the cell nucleus. The genes of nuclear chromosomes have a significant and key role in the inheritance of almost all traits from generations to generations. Nuclear chromosomes altogether cannot be considered as the sole vehicles of inheritance because certain experimental evidences suggest the occurrence of certain extra nuclear genes or DNA molecules in the cytoplasm of many prokaryotic and eukaryotic cells. These genes are found inside the organelles, such as mitochondria and chloroplasts in the cytoplasm. These organelles have a circular DNA molecule similar to that of a eukaryotic system. Extra nuclear inheritance or cytoplasmic inheritance is the transmission of genes that occur outside the nucleus. The characteristics inherited by them are known as extra chromosomal inheritance or cytoplasmic inheritance.

2.4.1 Characteristics and Detection of Cytoplasmic Inheritance:

Cytoplasmic inheritance does not show Mendelian inheritance. Here, a trait is transmitted from the parent to offspring through nonchromosomal, cytoplasmic means. Additional pattern of inheritance that deviate from a Mendelian pattern include certain special features.

I. Lack of Mendelian segregation and typical Mendelian ratios: Hereditary traits which are transmitted by cytoplasm do not show Mendelian segregation in crosses and in reciprocal crosses with respect to a particular set of characteristics controlled by a set of cytoplasmic genes producing dissimilar hybrids.

II. Maternal inheritance: Maternal inheritance is characterized by an extra-chromosomal inheritance that persists for many generations. The extra-chromosomal material may be from either the mitochondria or the chloroplast. The patterns of inheritance are not associated with meiosis or mitosis because the organelles are in the cytoplasm not in the nucleus. Organelles have circular chromosomes. Maternal (uniparental) effects are strictly defined as changes that occur only in the first generation of progeny.

Maternal inheritance is characterized by an extra chromosomal inheritance i.e., cytoplasmic factors that are transmitted to the succeeding generation through the egg of female organism. The female phenotype in a cross is always expressed in its offspring. In higher plants and animals, ovum or egg cell is comparatively large and contains large amount of cytoplasm. But male gametes or sperms have very little amount of cytoplasm. So, under this situation, most of cytoplasmic factors are transmitted to the progeny through the ovum of mother. It is known as maternal inheritance or trans-ovarian transmission. In this mode of transmission, all the offspring's of the parents have maternal condition and only female progeny can transmit the cytoplasmic characteristics to the succeeding generations.

In certain cases, it has been observed that certain characteristic phenotypic traits of F_1, F_2 and F_3 progeny are not the expression of their own genes, but rather those of the maternal parents. Such phenotypic expressions of maternal genes (genotype) may be short-lived or may persist throughout the life-span of the individual. The substances which produce the maternal effects in the progeny are found to be transcriptional products (i.e., mRNA, rRNA and tRNA) of maternal genes which have been manufactured during oogenesis and, which exist in the ooplasm of unfertilized eggs in the form of inactive protein coated and late translating mRNA molecules (informosomes) or inactivated rRNA and tRNA. These transcriptional products of maternal genes produce their phenotypic effects during early cleavage and blastulation when there occur little or no transcription since; maternal and paternal genes of zygote remain engaged in mitotic replication or duplication of DNA.

2.5 STUDY OF EXTRA-NUCLEAR INHERITANCE BY CELLULAR ORGANELLES

The eukaryotic cells possess a complement of chromosomes in the nucleus and extra DNA molecules or chromosomes in their mitochondria and chloroplasts. Mitochondria, chloroplasts, endosymbionts and cellular surfaces contain naked circular DNA and protein synthesizing apparatus which does not resemble with that of genes of nuclear chromosomes and is known by different terms such as extra-chromosomal, cytoplasmic or extra-nuclear inheritance.

These extra nuclear genetic materials present in the organelles are autonomous and code only for limited number of enzymes and polypeptides. Certain enzymes required for cellular respiration are synthesised in the mitochondria.

Similarly, chlorophyll and other pigments are synthesised in the plastid. Besides the involvement of such biosynthetic activities, these organelles DNAs are directly associated with the inheritance of some phenotypes which are not controlled by the nuclear genes.

The genetic material of chloroplasts and mitochondria are transmitted via the egg. During fertilization only the nucleus of the male gamete enters the egg, leaving the cytoplasm outside. Thus, the cytoplasm or the cytoplasmic genes of the zygote are contributed only by the egg and not by the male gamete. Therefore, the extra chromosomal inheritance is also known as maternal inheritance.

2.5.1 Endosymbiotic origin of Chloroplasts and mitochondria

Free living prokaryotes ancestors of chloroplasts and mitochondria invaded plant and animal cells but provide useful function and so a symbiotic relationship developed over time. Chloroplasts and mitochondria are organelles that contain their own DNA and protein-synthesizing apparatus. A widely held theory concerning their origin proposes that they were once infectious endosymbiotic prokaryotes that evolved such a dependence on the gene products of the host that they are no longer able to function autonomously (Fig 8.1).

This theory has been supported by the fact that the genetic components of these organelles are often similar to those found in prokaryotes. For example, the chloroplasts of certain algae and *Euglena* contain 70S type small ribosomes and "naked" chromosomes or DNA which is circular. Their protein synthesis begins with the amino acid N-formyl methionine, as does prokaryotic protein synthesis, and their DNA-dependent RNA polymerase is sensitive to the inhibitor rifampicin. The genetic materials of chloroplasts and mitochondria will be transmitted to offspring almost exclusively through the egg.

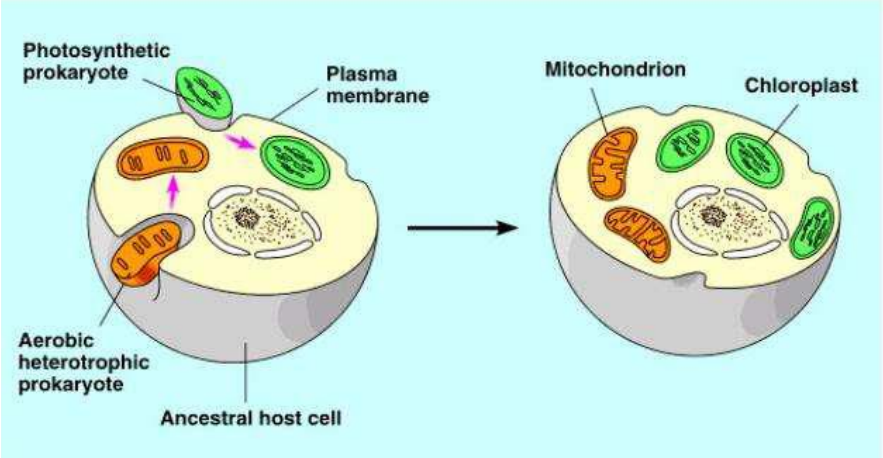


Fig 2.9: Endosymbiotic origin of Mitochondria and Chloroplast

2.5.1.1 Inheritance of chloroplasts:

The cytoplasm of plants bears minute pigments called chloroplast. Chloroplast genomes are 130-150 kb in size. Most genes are involved in photosynthesis. Corn has 20-40 chloroplasts per cell; with each chloroplast having 20-40 chromosomes (can make up 15% of DNA). Chloroplast arises from smaller DNA particles of the ovum and multiplies by division. During the formation of gamete a chloroplast enters the egg and the pollen receives none. Thus chloroplast is entirely a maternal contribution.

1. Chloroplast inheritance in Four O'clock plant (*Mirabilis jalapa*)

Chloroplast inheritance means the inheritance of chloroplast characteristics due to plasma genes located in chloroplast. Cytoplasmic inheritance or maternal inheritance or extra-

chromosomal inheritance of chloroplast has been studied in Four-o'clock plant, *Mirabilis jalapa* by Corens (1908). Albomaculatus race of this plant have variegated leaves with white and green patches. Sometimes a branch is formed which bears leaves which are either green or white or variegated. In contrast to other higher plants, mirabilis contains three types of leaves and parts: (1) full green leaves or branches having chloroplast, (2) white (pale) leaves or branches having no chloroplast, (3) variegated branches having leucoplast in white (pale) areas and chloroplast in green patches (Fig 2). Thus it forms the mosaic pattern of coloration on a leaf. Due to certain inheritable defects chloroplast of all cells or some cells of leaf often are unable to synthesize the chlorophyll pigments. Such cells remain non- green and form white or yellow coloured leaf, or white or yellow patches, interspersed with areas containing normal green cells with healthy chloroplasts.

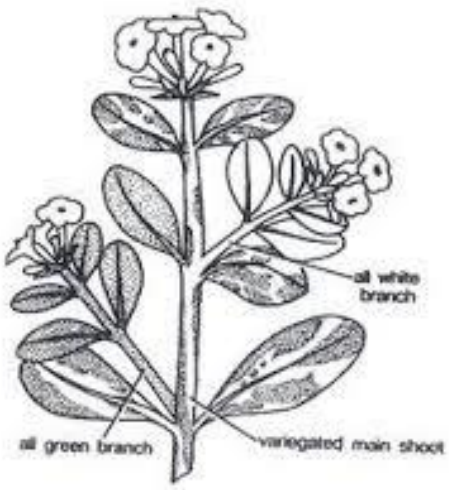


Fig 2.10: Leaf variegation in four O' clock plant (Mirabils jalapa)

Because, the chlorophyll pigment of chloroplast is related with photosynthesis of food and leucoplasts are incapable to perform photosynthesis, so the white or pale parts of plant survive by receiving nourishment from green parts. Correns reported that flowers on green branches produced only green offspring, regardless of the genotype and phenotype of pollen parent and likewise, flowers from the white or pale branches produced only white or pale seedlings regardless of genotype and phenotype of pollen parent. The plants developing from the white or pale seedlings die because they lack chlorophyll and cannot carry on photosynthesis. Crosses were made among the flowers associated with each leaf colour (Table 1). Corens (1908) further reported that flowers from the variegated branches yielded mixed progeny of green, white (pale) and variegated plants in widely varying ratios. These results are summarized in Table 1.

TABLE 1. Chloroplast inheritance in variegated four o'clock plants

S.No.	Branch of origin of the male parent	Branch of origin of the female parent	Progeny
1.	Green	Green, Pale or white Variegated	Green , Pale or white Green, pale or white Variegated
2.	Pale or white	Green Pale or white	Green, Pale or white Green, pale or white,

		Variegated	Variegated
3.	Variegated	Green, Pale or white Variegated	Green, Pale or white Green, pale or white Variegated

The irregularity of transmission from variegated branches could be understood by considering cytoplasmic genes (plasmagenes) of plastids. A study of the egg during oogenesis in *Mirabilis* reveals that the ooplasm contains plastids like cytoplasm of other plant cells. If the egg cell is derived from green plant tissues, its ooplasm will contain coloured plastids; if derived from white plant tissues, its ooplasm will contain white plastids; if derived from variegated tissues, its cytoplasm may contain coloured plastids only, white plastids only or a mixture of coloured and white plastids. A study of the pollenogenesis, however, reveals that pollen contains very little cytoplasm which in most cases is devoid of plastids. Without the plastids, the pollen cannot affect this aspect of the offspring's phenotype.

The pollen is devoid of plastid and cannot influence the inheritance of plastid. Thus the colour depends entirely upon the egg and what the egg produces is dependent upon the plastid of the cytoplasm. Thus it is an evidence of cytoplasmic inheritance.

In comparison to traits controlled by maternal effects, those traits controlled by maternal inheritance, the female phenotypes are always expressed in offspring. From this, it was suggested that the organelle DNA in the embryos of the four o'clock plant were inherited from the mother.

Mitotic segregation:- Variegated branches of *Mirabilis jalapa* produce three kinds of eggs. Some contain only white chloroplasts, some contain only green chloroplasts and some contain both types of chloroplasts. This process of sorting might be described as "mitotic segregation" In mitotic segregation since both segregation and recombination of organelle genotype takes place, it is called cytoplasmic segregation and recombination (its acronym is CSAR).

The results obtained from various crosses of leaf phenotypes *of Mirabilis jalapa*, as shown in Table 1 clearly indicates that leaf phenotype of the progeny is the same as that of the female parent. The phenotype of male parent did not contribute anything to the progeny.

All of the organelle DNA that is found in an embryo is from the female. The egg cell is many times larger than the pollen cells and contains both mitochondria and chloroplasts. Pollen is small and is essentially devoid of organelles, and thus organelle DNA. So any trait that is encoded by the organelle DNA will be contributed by the female.

In the case of the four o'clock plant, the different colours of the leaves are a result of the presence or absence of chlorophyll in the chloroplast, a trait that can be controlled by the chloroplast DNA. Thus, green shoots contain chloroplasts that have chlorophyll, the chloroplasts in the white shoots contain no chlorophyll and the variegated shoots contain some chloroplasts with chlorophyll and some without chlorophyll. Thus, depending on the

location in the plant where the flower comes from, the egg can have chloroplast with chlorophyll, without chlorophyll, or a mixture of the two types of chloroplasts.

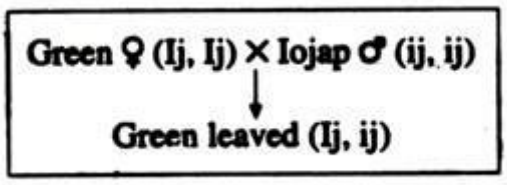
I. Inheritance of Pyrenoids in Chloroplasts of *Spirogyra triformus*

Spirogyra contains two chloroplasts in each cell. In 1920, Van Wisselingh found a cell in which one chloroplast had pyrenoids and the other chloroplast did not have pyrenoids. When this cell divided, both daughter cells were like the mother cell. Genes in the nucleus could not have caused this because both chloroplasts would have been the same. Genes in the cytoplasm outside of the chloroplast couldn't have caused this because both chloroplasts are in the same cytoplasm and would be the same. This could only be caused by genes in the chloroplast itself. This work proved that genes are present in the chloroplasts themselves, which control the phenotype of chloroplasts. Genes in the nucleus also control the phenotype of chloroplasts. There are hundreds of known genes located on chromosomes that control the phenotype of chloroplasts for instance albino gene in maize.

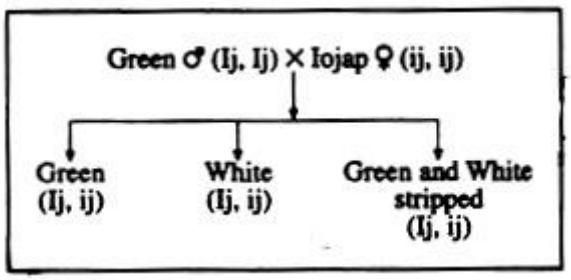
II. Maternal inheritance by *iojap* gene of maize:-

Higher plants suggest the existence of plastid genes controlling plastid integrity. A gene in corn plant called iojap (ij) has been mapped by M. Rhoades (1946) to nuclear chromosomes 7. In maize plant, iojap produces green and white stripped leaves. Plants homozygous for ij are either inviable white seedlings or variegated with a characteristic white striping, the phenotype being known as striped. The name iojap was derived from 'Iowa' state (USA), the source of maize strain and japonica, the name of a stripped variety.

When the variegated plants serve as females in a cross, they give rise to green, white, and striped progeny, regardless of the nuclear genotype of the paternal parent. Thus, if the pollen derives from a normal green Ij/Ij plant, the resulting progeny will be Ij/ij heterozygotes, but many will exhibit abnormal plastid pigmentation. The presence of the "normal" Ij gene has no curative effect. When a normal plant with green leaves used as a female parent is crossed with iojap parent, the offspring will be green leaved. In the reciprocal Ij/Ij female and X ij/ij male cross produced the Ij/ij progeny which are all normally pigmented.



Again, when a reciprocal cross is made between a normal green plant (used as male) and iojap plant (used as female). The offspring will be of three different types:



In iojap plants, green and white stripped trait of leaf is inherited from the female parent due to maternal inheritance. It seems that iojap plants contain two types of plastids- normal green, and abnormal iojap plastids. During the formation of egg cells plastids are randomly distributed in the egg cells. If the egg cell receives normal green plastids it will produce green leaved plants irrespective of which plant acted as pollen parent. If the egg cell receives abnormal colourless plastids, it will give rise to white leaved plants. If the egg cell receives both green and abnormal plastids it will give rise to plants with green and white stripped leaves.

The iojap trait, thus, exhibits classical maternal inheritance once it has become established in an ij/ij plant. Moreover, once established, it becomes independent of the ij gene, as can be demonstrated by crossing F_1 Ij/ij variegated females to Ij/Ij normal males. As shown in Fig 3 a mixture of green, striped and white progeny again results, even though some of the striped and white plants now have an Ij/Ij genotype. Thus, the iojap trait, once established, is permanent.

If stripped leaved F_x iojap (I_j,i_j) as female parent is crossed with normal green leaved (Ij Ij) as male parent the following types of offspring are obtained:

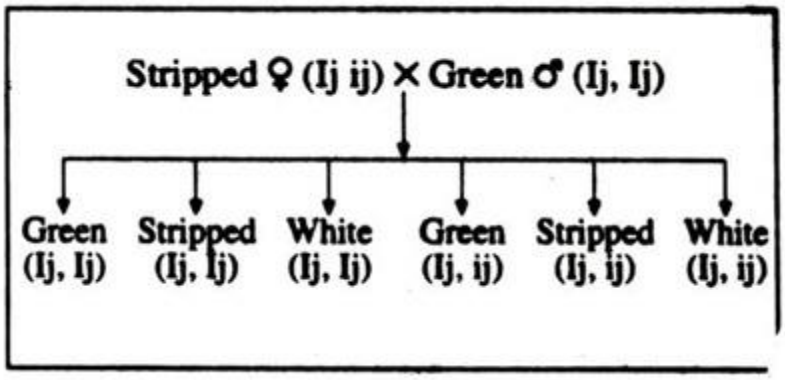


Fig 2.11: Stripped leaved F_x iojap (I_j,i_j) as female parent is crossed with normal green leaved (Ij Ij)

This backcross experiment shows that green males have no effect upon progeny. The iojap phenomenon has been explained by two hypotheses. One hypothesis holds that the ij/ij genetic constitution could bring about or permit, frequent mutations in the chloroplast genome that result the production of abnormal plastids. Another hypothesis suggests that certain cytoplasmic elements other than chloroplast mutations come into being or residence in ij/ij cells, are later inherited in the absence of this "susceptible" or "permissive" genotype, and bring about the bleaching of chloroplasts. It is also suggested that a nuclear gene controls

the development of abnormal plastids in the cytoplasm. So this type of inheritance is a case of inaction between nuclear and cytoplasmic inheritance.

2.5.1.2 Extra-nuclear inheritance by mitochondria:

The most important work on the genetics of mitochondria done in yeast was initiated by the discovery of petite mutants by B. Ephrussi (1953); subsequently mt DNA was studied in several organisms including plants and animals.

(i) Petite in yeast: Yeast (*Saccharomyces cerevisiae*) is single-celled Ascomycetes fungi. In the life cycle, diploid and haploid adult alternates, the former reproducing by asexual meiospores called ascospores, the latter by isogametes. The petite mutants in yeast fail to grow on carbon source such as glucose and produce smaller colonies (the "littles") when grown on sugars such as glucose. Since this difference can be observed only when such yeast cultures are kept in an oxygen- containing environment; it is concluded that petite mutants have a defective aerobic respiratory mechanism. In other words, slow growth of petite can be attributed to yeast cells utilization of less efficient fermentation process. These petites differ from wild type, called grande and arew characterized by (i) their insensitivity to inhibitors of aerobic pathways (such as cyanide), (ii) absence of cytochromes a, a_3, b and a number of other changes in mitochondrial respiratory enzymes, (iii) incomplete development of mitochondria and, (iv) lack of stainability of petite mitochondria.

The petite mutants can be segregational, i.e., they follow mendelian segregation and, therefore, presumably controlled by chromosomal genes. They may also be vegetative, i.e., non-segregational or extra-chromosomal. The genetic basis of petite character is a cytoplasmic factor ρ-factor $^{+}$ (rho) which may be absent or defective in petites. Thus, a vegetative petite can be neutral (ρ^{0}) which completely lack ρ^{+} or it may be suppressive (ρ^{-}) having a defective ρ^{+}. The neutral petites are not transmitted while suppressive petites are transmitted to a fraction of vegetative diploid progeny. In various strains of yeast, the suppressiveness varies from 1-99 per cent petites. The following two lines of evidences have suggested the association of ρ^{+} with mitochondrial DNA (mt DNA); (1) Ethidium bromide which induces petite mutations with 100 per cent efficiency, causes degradation of mt DNA after prolonged exposure of cells. In fact, neutral petites have been found lacking in mt DNA. (2) Suppressive petites base composition with respect to wild mt DNA.

2.6 SUMMARY

1. Heredity and variations are controlled by genes.
2. An allele is an alternative form of a given gene.
3. Three or more kinds of genes which occupy the same locus are referred to as multiple alleles and character governed by more than two allele called multiple allelism.
4. Epistasis (Greek=standing upon) is the masking genetic phenomenon when the phenotypic effect of alleles at one gene masks or inhibits the expression of alleles of another gene.
5. The term "epistatis" was first of all used by Bateson (1909).

6. When F_1 individuals are crossed with one of the two parents from which they have been derived, then such a cross is called back cross.
7. Back cross can be of two types: **Out cross and test cross;**
   When Tt (F_1) is crossed with TT (Homozygous dominant parental), it is called **out cross**.
   When Tt (F_1) is crossed with tt (Homozygous recessive parental), it is called **test cross**.
   A test cross is a way to explore the genotpye of F_1 individuals.
8. Non-allelic or inter-allelic interactions also occur where the development of single character is due to two or more genes affecting the expression of each other in various ways called gene interaction.
9. The two or more genes interact in several manners some common interactions are as follows:
   (1) Dominant epistasis (12:3:1)
   (2) Recessive epistasis or supplementary gene interaction (9:3:4)
   (3) Double recessive/complementary gene interaction (9:7)
   (4) Inhibitory gene interaction/dominant recessive epistasis (13:3)
   (5) Polymorphic gene interaction (9:6:1)
   (6) Duplicate gene interaction/double dominant epistasis (15:1)
   (7) Collaborative supplementary/modified gene interaction (9:3:3:1)
   (8) Polymeric gene interaction (9:6:1)

10. Extra-chromosomal inheritance, extra-nuclear inheritance, somal inheritance and maternal inheritance are all synonyms. All these terms can be defined as the inheritance of characteristics of only one of the two parents, usually the female parent to the progeny.

11. The reciprocal crosses show consistent differences as well as there is a lack of segregation in F_2 and subsequent generations. The inheritance of characters is governed by genes present in the cell cytoplasm rather than by genes on the chromosomes in the cell nucleus.
12. The genes controlling cytoplasmic inheritance are present outside the nucleus and in the cytoplasm, they are known as plasma genes, cytoplasmic genes, cytogenes, extra nuclear genes or extra chromosomal genes. These variations suggest that the genes for the inheritance of certain characters do not occur within the nucleus, but they are present in cytoplasm and play an important role in transmission of certain specific traits, which are not controlled by nuclear genes. Therefore, it builds up the concept of cytoplasmic inheritance.
13. The genes for cytoplasmic inheritance are independent, self-replicating nucleic acids.

2.7 GLOSSARY

Allele: Alternative form of a gene is called allele.

Back Cross: Backcross is a cross of F_1 hybrid with one of its parents.

Dihybrid cross: A **dihybrid cross** describes a mating experiment between two organisms that are identically hybrid for two traits.

Dominance: An allele or a gene that is expressed in an organism's phenotype, masking the effect of the recessive allele or gene when present.

Epistasis: Epistasis is the interaction between non allelic genes that influences a phenotype.
F_1= The first filial generation of offspring.
F_2= The second filial generation of offspring.
Gene: A unit of heredity which is transferred from a parent to offspring.
Genotype: Genetic constitution of an organism.
Hemizygous: A condition individual having only one of a given pair of genes.
Heredity: The phenomenon of passing of traits genetically from one generation to another.
Homologous: Having the same or allelic genes with genetic loci usually arranged in the same order homologous chromosomes.
Hybrid: The offspring resulting from the cross between parents of different species.
Monohybrid: A monohybrid cross is a breeding experiment conducted between parents, which differ in one specific trait only.
Offspring: Young born of organisms, produced through reproduction.

Out cross: A backcross of F1 offspring with dominant parent.

Phenotype: The physical or external appearance of an organism as a result of the interaction of its genotype and the environment.
Progeny: A genetic descendant or offspring, Collective offspring progeny.
Pureline: A population having a particular feature that has unchanged through many generations. The organisms are homozygous and are said to **Pureline** or true-breed.
Selfing (Syn= Inbreeding): The union of male and female gametes from same haploid, diploid, or polyploid organism.

2.8 SELF ASSESSMENT QUESTION

2.8.1 Multiple Choice Questions:

1. ABO blood group type in humans is an example of:
(a) Dominance (b) Codominance
(c) Incomplete dominance (d) Overdominance

2. Alternative form of gene is called:
(a) Phenotype (b) Phenocopy
(c) Allele (d) Genocopy

3. When F_1 individuals are crossed with one of the two parents from which they have been derived, then such a cross is called.
(a) Back cross (b) Test Cross
(c) Out cross (d) All of the above

4. An organism having two copies of the same allele for a gene is called:
(a) Homozygous (b) Heterozygous
(c) Hemizygous (d) Hybrid

5. When F_1 individuals are crossed with recessive parents then such a cross is called.:

(a) Out cross (b) Reciprocal Cross
(c) Dihybrid cross (d) Test Cross

6. The polymeric gene interaction modifies the typical 9:3:3:1 Mendelian F_2 ratio into:
(a) 9:6:1 (b) 9:3:4
(c) 15:1 (d) 12:3:1

7. A genetic phenomenon of non allelic gene interaction in which a dominant gene or a dominant gene pair inhibits or masks the expression of another dominant gene or gene pair is called
(a) Dominant epistasis (b) Recessive epistasis
(c) Dominance (d) Overdominance

8. The term "epistatis" was first of all used by:
(a) Mendal (b) Bateson
(c) Punnet (d) Kolreuter

9. Self sterility in tobacco is the example of genetic phenomenon.
(a) Epistasis (b) Multiple allelism
(c) Dominance (d) All

10. In case of Double recessive/complementary gene interaction the F_2 ratio becomes:
(a) 12:3:1 (b) 9:6:1
(c) 9:7 (d) 15:1

11. Transmission of genes that occur outside nucleus is called
(a) Extranuclear inheritance (b) Cytoplasmic inheritance
(c) Both A and B (d) None of above

12. Cytoplasmic inheritance can be studied by:
(a) Test cross (b) Back cross
(c) Reciprocal cross (d) None

13. In four o'clock plant normal leaves A and variegated leaves B occur in different plants, if B male is crossed with A female the hybrid has normal leaves but when B female is crossed with A male the hybrid has veriegated leaves , it is a case of
(a) Mutation (b) Cytoplasmic inheritance
(c) Complementary genes (d) Supplementary genes

2.8.2 Fill in the blanks:

(1) The term epistasis was given by _____.
(2) _____is the genetic phenomenon in which both of the alleles of a gene express themselves in heterozygous condition.
(3) The interaction of genes at different loci that affect the same character is called _____.
(4) _____ condition means that an organism has two different alleles of a gene.

(5) Thipolymeric gene interaction modifies the typical 9:3:3:1 Mendelian ratio in to _____.
(6) In _____gene interaction the non-allelic dominant gene inhibits the expression of the other non-allelic dominant gene.
(7) When the phenotype of F_1 heterozygous genotype lies between the phenotypes of parental homozygous genotypes, is called _____dominance.
(8) When F_1 individuals are crossed with one of the two parents from which they have been derived, such a cross is called _____cross.
(9) Alternative form of a gene is called_____.
(10) When F_1 individual is crossed with recessive parent, then such a cross is called _____cross.

2.8.3 True or False:

(1) When F_1 individuals are crossed with one of the two parents from which they have been derived, then such a cross is called test cross.
(2) Mendal coined the term epistasis.
(3) In Epistasis one allele inhibits the expression of another allele of same gene.
(4) Dominance is allelic while epistasis is non allelic genetic phenomenon.
(5) Self sterility gene is an example of multiple allelism.
(6) A backcross of F_1 offspring with dominant parent is called test cross.

2.8.4 Very short answer questions:

(1) Who coined the term epistasis?
(2) Define allele.
(3) Define dominance.
(4) What is recessive epistasis?
(5) What is the F_2 ratio in case of supplementary gene interaction?
(6) Define test cross.
(7) Define Petite in yeast
(8) Define Plasmagenes

2.8.1 Answer key: 1-(b), 2-(c), 3-(a), 4-(a), 5-(d), 6-(a), 7-(a), 8-(b), 9-(b), 10-(c). 11-(c), 12-(c), 13-(b).
2.8.2 Answer key: 1-Bateson (1909), 2- Codominance, 3- Epistasis, 4- Heterozygous 5-9:6:1, 6- Inhibitory, 7-Incomplete, 8- Back, 9- Allele, 10- Test.
2.8.3 Answer key: 1-False, 2-False, 3-False, 4-True, 5-True, 6-False,

2.9 REFERENCES

- Bateson, W. 1909. Heredity and variation in modern lights. In Darwin and modern science (eds. A. C. Seward), 85-101. Cambridge University Press, Cambridge.
- Bateson, W. and Punnett, R.C. 1908. Experimental studics in the physiology of heredity. Reports to the Evol. Comm. Roy. Soc. Rpt. 4, Poultry, pp. 18-35.

- **East**, **E.M.** and **Yarnell**, **S.H. 1929**. **Studies** on **self-sterility**. **VIII**. **Self-sterility allelomorphs**. **Genetics** 14:455-487.
- Kölreuter, J.G. (1761-1766), Vorläufige Nachricht von inigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen, nebst Fortsetzungen 1, 2 und 3, Leipzig: in der Gleditschischen Handlung.
- Mendel, G. 1866. Versuche über Plflanzenhybriden. Verhand-lungen des naturforschenden Vereines in Brünn, Bd. IV für das Jahr 1865, Abhandlungen, 3–47. (http://www.esp.org/foundations/genetics/classical/gm-65.pdf).
- Punnett, R. C. 1923 Heredity in poultry. London: Macmillan and Co.
- *Cytology, Genetics and Molecular Biology* by, Rastogi Publications, Meerut.
- *Genetics* by M.W. Strickbergar. McMillan Publication, New York.
- *Principle of Genetics* by Robert H. Tamarin, Tata-McGraw Hill, Seventh Edition (2002).

2.10 SUGGESTED READINGS

- Brooker, R. 2015. Genetics: Analysis and Principles (5th Eds.). McGraw-Hill Publishing Company.
- Gardner, E.J., Simmons, M.J. and Snustad, D.P. 2006. Principles of Genetics (8th Ed.). Wiley.
- Klug, W.S., Cummings, M.R., Spencer C. A., Palladino, M.A., Killian, D.2019. Concepts of Genetics (12th Ed.). Pearson.
- Klug, W.S., Cummings, M.R., Spencer C. A., Palladino.2019. Concepts of Genetics (10th Ed.). Pearson.
- Pierce, B. A. 2017.Genetics: A Conceptual Approach (6th Ed.). W.H. Freeman.
- Singh, B.D. 2014. Fundamentals of Genetics. Kalyani Publshers, India.
- Singh, B.D. 2016. Genetics (2nd Ed.). Kalyani Publishers, India.
- Anderson, E. G. (1923). Maternal inheritance of chlorophyll in maize. *Bot. Gaz.* **76**, 411-18.
- Rhoades, marcus M. (1931). Cytoplasmic inheritance of male sterility in *Zea mays*. *Science*, **73**, 340-41.
- C. W. Birky, Jr. (1995). Uniparental inheritance of mitochondrial and chloroplast genes: mechanisms and evolution. *Proceedings of the National Academy of Sciences USA*. **92**(25): 11331–11338.
- Mitchell MB, Mitchell HK (May 1952). A Case of Maternal" Inheritance in *Neurospora Crassa*. *Proc. Natl. Acad. Sci. U.S.A.* **38** (5): 442–449.

2.11 TERMINAL QUESTIONS

2.11.1 Short answer type questions:

1. What do you understand by Epistasis?
2. Define dominant epistais with suitable example(s).

3. Differentiate between epistasis and dominance.
4. What is the recessive epistasis, define with example?
5. Describe collaborative gene interaction with suitable examples.
6. Define backcross, testcross and out cross.
7. Define co-dominance with suitable examples.
8. What do you understand by gene interaction describe in brief.
9. Describe complementary gene interaction with example.

2.11.2 Long answer type questions:

1. Distinguish between cytoplasmic inheritances and nuclear inheritance.
2. What are the specific properties of chromosomal genes?
3. Discuss the role of chloroplasts and mitochondria in the cytoplasmic inheritance.
4. Which parent contributes more in cytoplasmic inheritance?
5. Why are most organelle genomes transmitted maternally?
6. A four o'clock plant with three kinds of branches (green, variegated and white) is used in a breeding experiment. What kinds of progeny are to be expected from each of these crosses? (a) Green female X white male (b) white female X green male? (c) Variegated female X green male?

UNIT-3 LINKAGE AND CROSSING OVER

Contents:

3.1 OBJECTIVES

After reading this unit students will be able-

- to define linkage and crossing over
- to understand the Insight into linkage mapping critical for identifying the location of genes of interest.

3.2 INTRODUCTION

Mendel's Second Law, or the law of the independent assortment, is valid for genes located in different chromosomes. These genes segregate independently during meiosis. However, Mendel's Second Law is not valid for phenotypical features conditioned by genes located in the same chromosome (genes under linkage), since these genes, known as linked genes, do not separate during meiosis (except for the phenomenon of crossing over). The fruit fly, or drosophila, has been suitable for studying genetics because it presents many distinct traits but only has four chromosomes (one sex chromosome and three autosomes).

3.3 LINKAGE

Genetic linkage is the tendency of alleles that are located close together on a chromosome to be inherited together during meiosis. Genes whose loci are nearer to each other are less likely to be separated onto different chromatids during chromosomal crossover, and are therefore said to be genetically linked. In other words, the nearer two genes are on a chromosome, the lower is the chance of a swap occurring between them, and the more likely they are to be inherited together.

Significance of linkage

(i) Linkage plays an important role in determining the nature and scope of hybridization and selection programmes.

(ii) Linkage reduces the chances of recombination of genes and thus helps to hold parental characteristics together. It thus helps organism to maintain its parental, racial and other characters. For this reason plant and animal breeders find it difficult to combine various characters.

3.3.1-Complete Linkage

The genes located on the same chromosome do not separate and are inherited together over the generations due to the absence of crossing over. Complete linkage allows the combination of parental traits to be inherited as such. It is rare but has been reported in male Drosophila and some other heterogametic organisms.

Example 1:

A red eyed normal winged (wild type) pure breeding female Drosophila is crossed to homozygous recessive purple eyed and vestigial winged male. The progeny or F_1 generation individuals are heterozygous red eyed and normal winged. When F_1 males are test crossed to homozygous recessive female (purple eyed and vestigial winged), only two types of individuals are produced— red eyed normal winged and purple eye vestigial winged in the ratio of 1 : 1 (parental phenotypes only). Similarly during inbreeding of F_1 individuals, recombinant types are absent. In practice, this 1: 1 test ratio is never achieved because total linkage is rare.

Example 2:
In Drosophila, genes of grey body and long wings are dominant over black body and vestigial (short) wings. If pure breeding grey bodied long winged Drosophila (GL/ GL) flies are crossed with black bodied vestigial winged flies (gl/gl), the F_2 shows a 3 : 1 ratio of parental phenotypes (3 grey body long winged and one black body vestigial winged).

This is explained by assuming that genes of body colour and wing length are found on the same chromosome and are completely linked.

3.3.2-Incomplete Linkage

Genes present in the same chromosome have a tendency to separate due to crossing over and hence produce recombinant progeny besides the parental type. The number of recombinant individuals is usually less than the number expected in independent assortment. In independent assortment all the four types (two parental types and two recombinant types) are each 25%. In case of linkage, each of the two parental types is more than 25% while each of the recombinant types is less than 25%.

Example 1:
A red eyed normal winged or wild type dominant homozygous female Drosophila is crossed to homozygous recessive purple eyed and vestigial winged male. The progeny or F_1 individuals are heterozygous red eyed and normal winged. F_1 female flies are test crossed with homozygous recessive males. It does not yield the ratio of 1: 1: 1: 1. Instead the ratio comes out to be 9: 1: 1: 8. This shows that the two genes did not segregate independently of each other. The data obtained and reported is as follows:

Phenotype	**Progeny**	**Observed**	**Expected if Complete Linkage**	**Expected if Independent Assortment**
Parental Types				
(a) Red eyed, normal winged		1339	1420	710
(b) Purple eyed vestigial winged		1195	1420	710
Recombinant Types				
(a) Red eyed, vestigial winged		152	Zero	710
(b) Purple eyed, normal winged		152	Zero	710

Only 9.3% recombinant types were observed which is quite different from 50% recombinants in case of independent assortment. This shows that in the oocytes of the F_1 generation only some of the chromatids undergo cross-over while the majority is preserved intact. This produces 90.7% parental types in the progeny.

Example 2:
In Sweet Pea (*Lathyrus odoratus*) blue flower colour (B) is dominant over red flower colour (b) while the trait of long pollen (L) is dominant over round pollen (l). A Sweet Pea plant heterozygous for both blue flower colour and long pollen (BbLl) was crossed with double recessive red flowered plant with round pollen (bbll). It is similar to test cross. In case the genes of the two traits are unlinked, the progeny should have four phenotypes (Blue Long, Blue Round, Red Long, and Red Round) in the ratio of 1: 1: 1: 1 (25% each). In case the two genes are completely linked the progeny should have both the parental types (Blue Long and Red Round) in the ratio of 1: 1(50% each). Recombinants should not appear. However, in the above cross Bateson and Punnett (1906) found both parental and recombinant types but with different frequencies in the ratio of 7: 1: 1: 7. (7 + 7 Parental and 1 + 1 recombinant types).

Phenotype	**Progeny**	**Observed frequency**	**Expected frequency if complete linkage**	**Expected frequency if Independent assortment**
Parental Types	(i) Blue Long	43.7%	50%	25%
Recombinant Types	(ii) Red Round	43.7%	50%	25%
	(a) Blue Round	6.3%	0%	25%
	(b) Red Long	6.3%	0%	25%

Only 12.6% recombinant types were observed against the expected percentage of 50% in case of independent assortment. Therefore, the genes are linked but undergo recombination due to crossing over in some of the cases.

Example 3: Morgan and his students have found that linked genes show varied recombinations, some being more tightly linked than others, (i) In Drosophila, crossing of yellow bodied (Y) and white eyed (W) female with brown bodied (Y^+) red eyed (W^+) male produced F_1 to be brown bodied red eyed. On intercrossing of F_1 progeny, Morgan observed that the two genes did not segregate independently of each other and, therefore, the F_2 ratio deviated significantly from expected 9: 3: 3: 1 ratio. He found 98.7% to be parental and only 1.3% recombinants. (ii) In a second cross in Drosophila between white eyed and miniature winged (wwmm) female with wild type or red eyed normal winged males, all the F_1 were found to be of wild type, i.e., red eyed and normal winged. An F_1 female fly was then test crossed with white eyed and miniature winged male. 62.8% of the progeny was of parental types while 37.2% were recombinants.

3.3.3-Linkage Group

A linkage group is a linearly arranged group of linked genes which are normally inherited together except for crossing over.

It corresponds to a chromosome which bears a linear sequence of genes linked and inherited together. Because the two homologous chromosomes possess either similar or allelic genes on the same loci, they constitute the same linkage group. Therefore, the number of linkage groups present in an individual corresponds to number of chromosomes in its one genome (all the chromosomes if haploid or homologous pairs if diploid). It is known as principle of limitation of linkage groups.

Fruit-fly *Drosophila melanogaster* has four linkage groups (4 pairs of chromosomes), human beings 23 linkage groups (23 pairs of chromosomes), Pea seven linkage groups (7 pairs of chromosomes), *Neurospora* 7 linkage groups (7 chromosomes), Mucor 2 linkage groups (2 chromosomes), *Escherichia coli* one linkage group (one pro-chromosome or nucleoid) while Maize has 10 linkage groups (10 pairs of chromosomes).

The size of the linkage group depends upon the size of chromosome. The smaller chromosome will naturally have smaller linkage group while a longer one has longer linkage group. This is subject to the amount of heterochromatin present in the chromosome. Thus Y-chromosome of man possesses 231 genes while human chromosome 1 has 2969 genes.

3.4 CROSSING OVER

Ever know a large family with many children, all of whom are indistinguishable from each other? Unless they are all identical twins, you have not encountered such a family. Non-twin siblings typically have a range of physical differences, from subtle distinctions in features to looking unrelated. Even though they inherited equal chromosomes from the same two parents, the combination of genes is diversified due to crossing over.

Crossing over is the exchange of genes between two chromosomes, resulting in non-identical chromatids that comprise the genetic material of gametes (sperm and eggs). This process results in the millions of sperm or eggs that are produced by an organism, each being different from one another. In other words, every single sperm or egg cell in your body is completely unique.

Think of it like two traders meeting to exchange their goods, resulting in both leaving with a more diverse collection of wares than they had before. Thanks to this process, living things have high diversity within populations, allowing for better chances of adaptation to changing conditions and survival of the species.

Crossing over occurs during meiosis I and is the process where homologous chromosomes pair up with each other and exchange different segments of their genetic material to form recombinant chromosomes. It can also happen during mitotic division, which may result in loss of heterozygosity. Crossing over is essential for the normal segregation of chromosomes during meiosis. Crossing over also accounts for genetic variation, because due to the swapping of genetic material during crossing over, the chromatids held together by the centromere are no longer identical. So, when the chromosomes go on to meiosis II and separate, some of the daughter cells receive daughter chromosomes with recombined alleles. Due to this genetic recombination, the offspring have a different set of alleles and genes than their parents do.

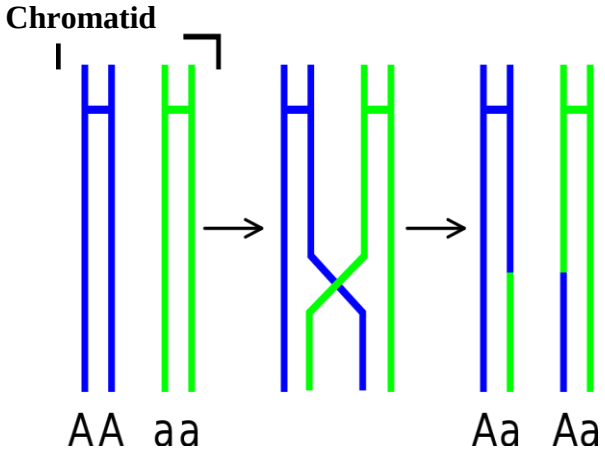


Fig. 3.1 Crossing over scheme

Chromosomal crossover (or **crossing over**) is the exchange of genetic material between homologous chromosomes that results in recombinant chromosomes during sexual reproduction. It is one of the final phases of genetic recombination, which occurs in the *pachytene* stage of prophase I of meiosis during a process called synapsis. Synapsis begins before the synaptonemal complex develops and is not completed until near the end of prophase I. Crossover usually occurs when matching regions on matching chromosomes break and then reconnect to the other chromosome.

Crossing over was described, in theory, by Thomas Hunt Morgan. He relied on the discovery of the Belgian Professor Frans Alfons Janssens of the University of Leuven who described the phenomenon in 1909 and had called it "chiasmatype". The term *chiasma* is linked if not identical to chromosomal crossover. Morgan immediately saw the great importance of Janssens' cytological interpretation of chiasmata to the experimental results of his research on the heredity of *Drosophila*. The physical basis of crossing over was first demonstrated by Harriet Creighton and Barbara McClintock in 1931.

Theories of Crossing Over

(i) Contact first theory (by Serebrovsky)

According to this theory the inner two chromatids of the homologous chromosomes undergoing crossing over first touch each other and then cross over. At the point of contact breakage occurs. The broken segments again unite to form new combinations.

(ii) The breakage-first theory (By Muller)
According to this theory the chromatids undergoing crossing over first of all break into two without any crossing-over and after that the broken segments reunite to form the new combinations.

(iii) Strain theory (by Darlington)
According to this theory the breakage in chromosomes or chromatids is due to strain caused by pairing and later the breakage parts again reunite.

Types of Crossing Over

(i) Single crossing over
In this type of crossing over only one chiasma is formed all along the length of a chromosome pair. Gametes formed by this type of crossing over are called single cross over gametes.

(ii) Double crossing over
In this type two chiasmata are formed along the entire length of the chromosome leading to breakage and rejoin of chromatids at two points. The gametes produced are called double cross over gametes.

(iii) Multiple crossing over
In this type more than two chiasmata are formed and thus crossing over occurs at more than two points on the same chromosome pair. It is a rare phenomenon.

Factors Influencing Crossing Over

1. Sex
In Drosophila, crossing over is completely suppressed in male but very high in female. Also there is a tendency of reduction of crossing over in male mammals.

2. Mutation
Gowen first discovered that mutation reduces crossing over in all the chromosomes of Drosophila.

3. Inversion
Inversion is an intersegmental change in the chromosome. In a given segment of chromosome crossing over is suppressed due to inversions.

4. Temperature

Plough has experimentally shown that when Drosophila is subjected to high and low temperature variations, the percentage of crossing over in certain parts of the chromosome is increased.

5. X-ray effect
Muller demonstrated that X-ray irradiations increase crossing over near centromere. Similarly Hanson has shown that radium increases crossing over.

6. Age
Bridges has demonstrated that the age also influences the rate of crossing over in Drosophila. When the female becomes older the rate of crossing over increases.

7. Nutrition
High calcium diet in young Drosophila decreases crossing over rate where as diet deficient of metallic ions increases crossing over.

8. The frequency of crossing over is less at the ends of the chromosome and also near the centromere in comparison to other parts.

Cytological Proof of Crossing Over

The first cytological evidence in support of genetic crossing over was provided by Curt Stern in 1931 on the basis of his experiments conducted with Drosophila. He used cytological markers in his studies. He selected a female fly in which one X-chromosome was broken into two segments.
Out of these two segments, one behaved as X-chromosome. The other X-chromosome had small portion of Y-chromosome attached to its one end. Thus, both the X-chromosomes in the female had distinct morphology and could be easily identified under microscope. In female fly, the broken X-chromosome had one mutant allele (carnation) for eye colour and another dominant allele (B) for bar eye shape.

The other X-chromosome with attached portion of Y chromosome had alleles for normal eye colour (red eye) and normal eye shape (oval eye). Thus, phenotype of female was barred. A cross of such females was made with carnation male (car+).

As a result of crossing over female flies produce four types of gametes, viz., two parental types or non-crossover types (car B and ++) and two recombinant types or crossover types (car+ and B+).

The male flies produce only two types of gametes (car + and Y), because crossing over does not take place in Drosophila male. A random union of two types of male gametes with four types of female gametes will produce males and females in equal number, means there will be four females and four males.

Stern examined the chromosomes of recombinant types, viz., red bar and carnation normal under microscope. He observed that in carnation normal females both the X-chromosomes were of equal length. In red bar flies, one X-chromosome was normal and other was fragmented.

The fragmented X-chromosome also had attached part of Y-chromosome. Such chromosome combination in red bar is possible only through exchange of segments between non-sister chromatids of homologous chromosomes. This has proved that genetic crossing over is the result of cytological crossing over. Similar proof of cytological crossing over was provided by Creighton and McClintock in maize.

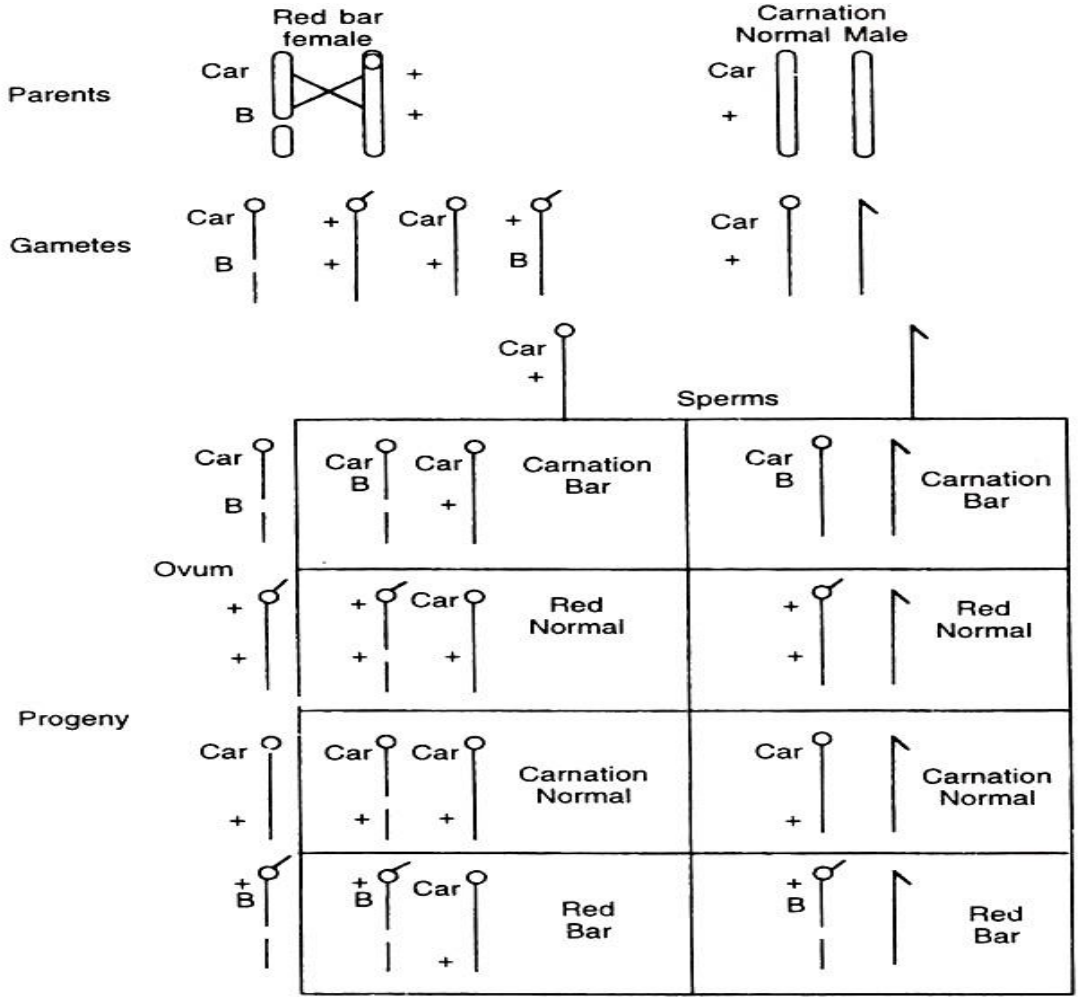


Fig.3.2, Cytological proof of crossing over in Drosophila

Significance of Crossing Over

1. Crossing over provides direct proof for the linear arrangement of genes,
2. Through crossing over segments of homologous chromosomes are interchanged and hence provide origin of new characters and genetic variations.
3. Crossing over has led to the construction of linkage map or genetic maps of chromosomes.

4. Linkage group and linear order of the genes help to reveal the mechanism of nature of genes.
5. Crossing over plays a very important role in the field of breeding to improve the varieties of plants and animals.

3.5 SUMMARY

Two genes are said to be under linkage, or linked, when they are located on the same chromosome. For example, research on the human genome discovered that the gene for factor III of clotting gene and the gene for factor V of clotting are located on the same chromosome (the human chromosome 1). However, the factor VII gene is not linked to those genes, since it is located on chromosome 13.
Linked alleles, for example, A-b and a-B, form the gametes A-b and a-B, which maintain the linkage of the alleles. This type of linkage is called complete linkage. However, in the first division of meiosis (meiosis I), the crossing over phenomenon may occur. Chromosomes from a pair of homologous chromosomes may exchange ends and certain once-linked alleles, for example, A-b and a-B, recombine to form different gametes, in this case, A-B and a-b. Crossing over a-B may happen when the arms of the chromatids of each homologous chromosomes are paired during meiosis. Matching portions of the ends of two non-sister chromatids (one from one homologous chromosome of the pair) break off and the pieces are exchanged, each of them becoming part of the arm of the other chromatid. For example, if the allele A is situated to one side of the arm relating to the point of breaking and the allele b is located on the other side, they will be separated and gametes A-B and a-b will be formed, instead of A-b and a-b. The percentage of recombinant gametes compared to normal gametes depends on the crossing over rate, which in turn depends on how far apart the given alleles are in the chromosome.

3.6 GLOSSARY

Crossing over: The exchange of segments between non-sister chromatids of homologous chromosomes during meiosis is called crossing over.
Recombination frequency: The proportion of recombinant types between two gene pairs as compared to the sum of all combinations is called cross over or recombination frequency.
Gene map: The recombination frequency is directly proportional to the distance between the linked gene loci. Genes can be mapped on a chromosome on the basis of their recombination frequencies. I% of recombination frequency is equal to I unit map distance.
Linkage map: A linkage map is a chromosome map of a species that shows the position of its known genes or markers relative to each other, rather than as specific physical points on each chromosome.
Centimorgan: A centimorgan, or recombination unit, by convention is the distance between two linked genes that corresponds to 1% of the recombination frequency of these genes.

3.7 SELF ASSESSMENT QUESTIONS

2.7.1 Multiple choice questions:

1- Who coined the term linkage-

(a) Mendel (b) Correns

(c) De Vries (d) Morgan

2- Mendel did not observe linkage due to-

(a) Crossing over (b) Synapsis

(c) Mutation (d) Independent assortment

3- The phenomenon of linkage was first observed in the plan-

(a) *Datura* (b) *Mirabilis jalapa*

(c) *Lathyrus odoratus* (d) *Pisum sativum*

4- How many linkage groups of chromosomes will be present in case of maize, if all its genes are mapped?

(a) 5 (b) 10

(c) 15 (d) 100

5- Crossing over is more frequent in-

(a) Males (b) Females

(c) Both (d) None of the above

6- Crossing over in diploid organism is responsible for-

(a) Dominance of genes (b) Segregation of alleles

(c) Recombination of linked genes (d) Linkage between genes

7- Complete linkage have been reported in-

(a) Maize (b) Human female

(c) Male Drosophila (d) Female Drosophila

8- Crossing over occurs during-

(a) Pachytene (b) Diplotene

(c) Diakinesis (d) Zygotene

9- Linkage prevents-

(a) Homozygous condition (b) Heterozygous condition

(c) Segregation of alleles (d) Hybrid formation

10- Coupling and repulsion phenomenon is concerned with

(a) Crossing over (b) Linkage

(c) Mutation (d) All of these

3.7.1 Answer Keys: 1-(d), 2(d), 3(c), 4-(b), 5-(b), 6-(c), 7-(c), 8-(a), 9-(c), 10-(b)

3.8 REFERENCES

- BRIMGES, C. B. 1916. Non-disjunction as proof of the chromosome theory of heredity. Genetics 1: 1-52; 107-163.
- William Bateson, E. R. Saunders, R. C. Punnett (1904) "Report II. Experimental studies in the physiology of heredity" Reports to the Evolution Committee of the Royal Society. http://archive.org/details/RoyalSociety. ReportsToTheEvolution Committee. Report Ii. Experimental
- Morton NE (1955). "Sequential tests for the detection of linkage". American Journal of Human Genetics **7** (3): 277–318. PMC 1716611. PMID 13258560.
- R. A. Fisher, and Balmukand, B. 1928. The estimation of linkage from the offspring of selfed heterozygotes. Journal of Genetics 20:79-92.
- Derivation of mapping function, from Introduction to Genetic Analysis. Griffiths, A. J. F.; Miller, J. H.; Suzuki, D. T.; Lewontin, R. C.; Gelbart, W. M. New York: W. H. Freeman & Co.; 1999.
- Mader, Sylvia (2007). Biology Ninth Edition. New York: McGraw-Hill. p. 209. ISBN 978-0-07-325839-3.
- Creighton H, McClintock B (1931). "A Correlation of Cytological and Genetical Crossing-Over in Zea Mays". Proc Natl Acad Sci USA **17** (8): 492–7. doi:10.1073/pnas.17.8.492. PMC 1076098. PMID 16587654.(Original paper)
- Harris Bernstein, Carol Bernstein and Richard E. Michod (2011). Meiosis as an Evolutionary Adaptation for DNA Repair. Chapter 19 in DNA Repair. Inna Kruman, editor. InTech Open Publisher. DOI: 10.5772/25117 http://www.intechopen.com/books/dna-repair/meiosis-as-an-evolutionary-adaptation-for-dna-repair
- Bernstein, H; Bernstein, C (2010). "Evolutionary origin of recombination during meiosis". BioSciene **60** (7): 498–505. doi:10.1525/bio.2010.60.7.5.
- Esposito, M (September 1978). "Evidence that Spontaneous Mitotic Recombination Occurs at the Two-Strand Stage". Proceedings of the National Academy of Sciences of the USA **75** (9): 4436–4440. doi:10.1073/pnas.75.9.4436.
- Kumar, A; Bassi, F; Paux, E (2012). "DNA repair and crossing over favor similar chromosome regions as discovered in radiation hybrid of Triticum". BMC Genomics **13** (339). doi:10.1186/1471-2164-13-339. Retrieved 14 March 2015.
- Smith, George P. (1976-01-01). "Evolution of Repeated DNA Sequences by Unequal Crossover". Science **191** (4227): 528–535.
- Metzenberg, Ab; et al. (May 1991). "Homology Requirements for Unequal Crossing Over in Humans". Genetics.

3.9 SUGGESTED READINGS

- Griffiths AJF; Miller JH; Suzuki DT; Lewontin RC; et al. (1993). "Chapter 5". An Introduction to Genetic Analysis (5th ed.). New York: W.H. Freeman and Company. ISBN 0-7167-2285-2.
- Poehlman JM; Sleper DA (1995). "Chapter 3". Breeding Field Crops (4th ed.). Iowa: Iowa State Press. ISBN 0-8138-2427-3.

3.10 TERMINAL QUESTIONS

3.10.1 Short answer type Questions:

1. Define crossing over. Give its significance.
2. What are linked genes? How can linked gene be separated?
3. Two genes A and B are linked. The other homologous chromosome contains their a and b allele. Give combination of alleles in gametes with and without crossing over.
4. Differentiate between parental and non-parental combinations.
5. Define recombination frequency.
6. What is gene map? How is it formed?
7. What is the importance of crossing over?
8. Define linkage map.
9. What is genetic map unit (m.u.), or a centimorgan?
10. What is Robust method of detection of linkage?

3.10.2 Long answer type Questions:

1. What is gene linkage? Demonstrate it with examples.
2. Write note on linkage groups.
3. What is crossing over? How is meiosis related to this phenomenon?
4. What is linkage map? How are they constructed? Explain.
5. Give different methods for detection of linkage map.
6. Why is Mendel’s Second Law not always valid for two or more phenotypical traits of an individual?
7. Why is drosophila a convenient animal for studying linked genes?
8. In genetic recombination by crossing over, what is the difference between parental gametes and recombinant gametes?
9. Why does the recombination frequency of genes vary depending on the distance between them in the chromosome?
10. How can the concept of recombination frequency be used in genetic mapping?
11. Is crossing over important for the diversity of biological evolution?

UNIT-4 POLYPLOIDY AND MUTATION

Contents:

4.1 OBJECTIVES

After reading this unit students will be able-

- To understand the ploidy systems, mechanism of polyploidy, and its advantages and disadvantages.
- To discuss about various types of mutations.

4.2 INTRODUCTION

Ploidy is the number of sets of chromosomes in a cell. Usually a gamete (sperm or egg, which fuse into a single cell during the fertilization phase of sexual reproduction) carries a full set of chromosomes that includes a single copy of each chromosome, as aneuploidy generally leads to severe genetic disease in the offspring. The gametic or haploid number (*n*) is the number of chromosomes in a gamete. Two gametes form a diploid zygote with twice this number (2*n*, the zygotic or diploid number) i.e. two copies of autosomal chromosomes. For humans, a diploid species, $x = n = 23$. A typical human somatic cell contains 46 chromosomes: 2 complete haploid sets, which make up 23 homologous chromosome pairs.

Because chromosome number is generally reduced only by the specialized process of meiosis, the somatic cells of the body inherit and maintain the chromosome number of the zygote. However, in many situations somatic cells double their copy number by means of endoreduplication as an aspect of cellular differentiation. For example, the hearts of two-year-old children contain 85% diploid and 15% tetraploid nuclei, but by 12 years of age the proportions become approximately equal, and adults examined contained 27% diploid, 71% tetraploid and 2% octaploid nuclei. Cells are described according to the number of sets present (the ploidy level). The generic term polyploid is frequently used to describe cells with three or more sets of chromosomes (triploid or higher ploidy).

A mutation is a permanent change in the sequence of DNA. In order for an observable effect, mutations must occur in gene exons or regulatory elements. Changes in the non-coding regions of DNA (introns and junk DNA) generally do not affect function. Mutations can be caused by external (exogenous) or endogenous (native) factors, or they may be caused by errors in the cellular machinery. Physical or chemical agents that induce mutations in DNA are called mutagens and are said to be mutagenic. *Exogenous factors*: environmental factors such as sunlight, radiation, and smoking can cause mutations. *Endogenous factors*: errors during DNA replication can lead to genetic changes as can toxic by-products of cellular metabolism. Mutations can be advantageous and lead to an evolutionary advantage of a certain genotype. Mutations can also be deleterious, causing disease, developmental delays, structural abnormalities, or other effects. There are several classes of mutations, viz. deletion, frameshift, insertion, missense, nonsense, point, silent, splice site, translocation etc.
The present chapter discusses about the ploidy systems and mutations in plants and animals.

4.3 POLYPLOIDY

Polyploidy is the state where all cells have multiple sets of chromosomes beyond the basic set, usually 3 or more. Specific terms are triploid (3 sets), tetraploid (4 sets), pentaploid (5 sets), hexaploid (6 sets), heptaploid or septaploid (7 sets) octoploid (8 sets), nonaploid (9 sets), decaploid (10 sets), undecaploid (11 sets), dodecaploid (12 sets), tridecaploid (13 sets), tetradecaploid (14 sets), etc. Some higher ploidies include hexadecaploid (16 sets), dotriacontaploid (32 sets), and tetrahexacontaploid (64 sets), though Greek terminology may be set aside for readability in cases of higher ploidy (such as "16-ploid"). Polytene chromosomes of plants and fruit flies can be 1024-ploid. Ploidy of systems such as the salivary gland, elaiosome, endosperm, and trophoblast can exceed this, up to 1048576-ploid in the silk glands of the commercial silkworm *Bombyx mori*.

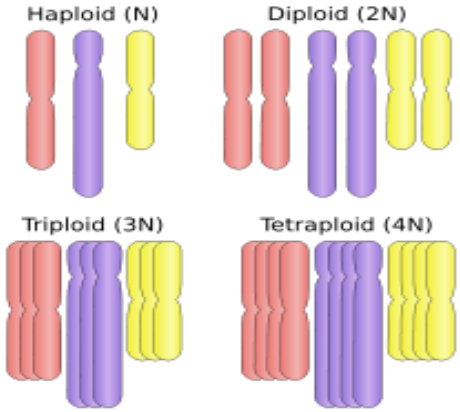


Fig.4.1 Haploid (single), diploid (double), triploid (triple), and tetraploid (quadruple) sets of chromosomes. Triploid and tetraploid chromosomes are examples of polyploidy

The chromosome sets may be from the same species or from closely related species. In the latter case, these are known as allopolyploids (or amphidiploids, which are allopolyploids that behave as if they were normal diploids). Allopolyploids are formed from the hybridization of two separate species. In plants, this probably most often occurs from the pairing of meiotically unreduced gametes, and not by diploid–diploid hybridization followed by chromosome doubling. The so-called *Brassica* triangle is an example of allopolyploidy, where three different parent species have hybridized in all possible pair combinations to produce three new species.

Polyploidy occurs commonly in plants, but rarely in animals. Even in diploid organisms, many somatic cells are polyploid due to a process called endoreduplication where duplication of the genome occurs without mitosis (cell division).

The extreme in polyploidy occurs in the fern genus *Ophioglossum*, the adder's-tongues, in which polyploidy results in chromosome counts in the hundreds, or, in at least one case, well over one thousand.

It is also possible for polyploid organisms to revert to lower ploidy by means of haploidisation.

Mechanisms of Polyploidy

How does an organism become polyploid? Polyploids arise when a rare mitotic or meiotic catastrophe, such as nondisjunction, causes the formation of gametes that have a complete set of duplicate chromosomes. Diploid gametes are frequently formed in this way. When a diploid gamete fuses with a haploid gamete, a triploid zygote forms, although these triploids are generally unstable and can often be sterile. If a diploid gamete fuses with another diploid gamete, however, this gives rise to a tetraploid zygote, which is potentially stable. Many types of polyploids are found in nature, including tetraploids (four sets of chromosomes), hexaploids (six sets of chromosomes), and other chromosome-pair multiples.

Researchers usually make a distinction between polyploids that arise within a species and those that arise due to the hybridization of two distinct species. The former are known as autopolyploids, while the latter are referred to as allopolyploids. Autopolyploids are essentially homozygous at every locus in the genome. However, allopolyploids may have varying degrees of heterozygosity depending on the divergence of the parental genomes. Heterozygosity is apparent in the gametes that polyploids produce. Allopolyploids can generally be distinguished from autopolyploids because they produce a more diverse set of gametes.

Different species exhibit different levels of tolerance for polyploidy. For example, polyploids form at relatively high frequency in flowering plants (1 per 100,000 individuals), suggesting that plants have a remarkably high tolerance for polyploidy. This is also the case for some species of fish and frogs. However, higher vertebrates do not appear to tolerate polyploidy very well; in fact, it is believed that 10% of spontaneous abortions in humans are due to the formation of polyploid zygotes.

Advantages of Polyploidy

Due to the high incidence of polyploidy in some taxa, such as plants, fish, and frogs, there clearly must be some advantages to being polyploid. A common example in plants is the observation of hybrid vigor, or heterosis, whereby the polyploid offspring of two diploid progenitors is more vigorous and healthy than either of the two diploid parents. There are several possible explanations for this observation. One is that the enforced pairing of homologous chromosomes within an allotetraploid prevents recombination between the genomes of the original progenitors, effectively maintaining heterozygosity throughout generations. This heterozygosity prevents the accumulation of recessive mutations in the genomes of later generations, thereby maintaining hybrid vigour. Another important factor is gene redundancy. Because the polyploid offspring now have twice as many copies of any particular gene, the offspring are shielded from the deleterious effects of recessive mutations. This is particularly important during the gametophyte life stage. One might envision that, during the haploid stage of the life cycle, any allele that is recessive for a deleterious

mutation will not be masked by the presence of a dominant, normally functioning allele, allowing the mutation to cause developmental failure in the pollen or the egg sac. Conversely, a diploid gamete permits the masking of this deleterious allele by the presence of the dominant normal allele, thus protecting the pollen or egg sac from developmental dysfunction. This protective effect of polyploidy might be important when small, isolated populations are forced to inbreed.

Another advantage conferred by gene redundancy is the ability to diversify gene function over time. In other words, extra copies of genes that are not required for normal organism function might end up being used in new and entirely different ways, leading to new opportunities in evolutionary selection.

Interestingly, polyploidy can affect sexuality in ways that provide selective advantages. One way is by disrupting certain self-incompatibility systems, thereby allowing self-fertilization. This might be the result of the interactions between parental genomes in allopolyploids. Another way is by favoring the onset of asexual reproduction, which is associated with polyploidy in both plants and animals. This switch in reproductive strategies may improve fitness in static environments.

Disadvantages of Polyploidy

For all the advantages that polyploidy can confer to an organism, there are also a great number of disadvantages, both observed and hypothesized. One of these disadvantages relates to the relative changes between the size of the genome and the volume of the cell. Cell volume is proportional to the amount of DNA in the cell nucleus. For example, doubling a cell's genome is expected to double the volume of space occupied by the chromosomes in the nucleus, but it causes only a 1.6-fold increase in the surface area of the nuclear envelope. This can disrupt the balance of factors that normally mediate interactions between the chromosomes and nuclear components, including envelope-bound proteins. The peripheral positioning of telomeric and centromeric heterochromatin may be disturbed as well, because there is less relative surface space on the nuclear envelope to accommodate this positioning.

Polyploidy can also be problematic for the normal completion of mitosis and meiosis. For one, polyploidy increases the occurrence of spindle irregularities, which can lead to the chaotic segregation of chromatids and to the production of aneuploid cells in animals and yeast. Aneuploid cells, which have abnormal numbers of chromosomes, are more readily produced in meioses involving three or more sets of chromosomes than in diploid cells. Autopolyploids have the potential to form multiple arrangements of homologous chromosomes at meiotic metaphase I, which can result in abnormal segregation patterns, such as 3:1 or 2:1 plus one laggard. (Laggard chromosomes do not attach properly to the spindle apparatus and thus randomly segregate to daughter cells.) These abnormal segregation patterns cannot be resolved into balanced products, and random segregation of multiple chromosome types produces mostly aneuploid gametes. Chromosome pairing at meiosis I is

more constrained in allopolyploids than in autopolyploids, but the stable maintenance of the two parental chromosomal complements also requires the formation of balanced gametes.

Another disadvantage of polyploidy includes potential changes in gene expression. It is generally assumed that an increase in the copy number of all chromosomes would affect all genes equally and should result in a uniform increase in gene expression. Possible exceptions would include genes that respond to regulating factors that do not change proportionally with ploidy. We now have experimental evidence for such exceptions in several systems. In one interesting example, investigators compared the mRNA levels per genome for 18 genes in 1X, 2X, 3X, and 4X maize. While expression of most genes increased with ploidy, some genes demonstrated unexpected deviations from expected expression levels. For example, *sucrose synthase* showed the expected proportional expression in 2X and 4X tissues, but its expression was three and six times higher, respectively, in 1X and 3X tissues. Two other genes showed similar, if less extreme, trends. Altogether, about 10% of these genes demonstrated sensitivity to odd-numbered ploidy.

Epigenetic instability can pose yet another challenge for polyploids. Epigenetics refers to changes in phenotype and gene expression that are not caused by changes in DNA sequence.

Evolutionary Potential of Polyploid Organisms

At first sight, the epigenetic changes observed in polyploids would seem to be deleterious because of their disruptive effects on regulatory patterns established by selection. However, these epigenetic changes might instead increase diversity and plasticity by allowing for rapid adaptation in polyploids. One example may be the widespread dispersal of the invasive allopolyploid *Spartina angelica*. However, it is not clear whether the success of this species can be attributed to fixed heterosis or to the increased variability that results from epigenetic remodeling. Polyploidy is also believed to play a role in the rapid adaptation of some allopolyploid arctic flora, probably because their genomes confer hybrid vigor and buffer against the effects of inbreeding. However, fertility barriers between species often need to be overcome in order to form successful allopolyploids, and these barriers may have an epigenetic basis.

4.4 MUTATION

In biology, a mutation is a permanent change of the nucleotide sequence of the genome of an organism, virus, or extrachromosomal DNA or other genetic elements. Mutations result from damage to DNA which is not repaired or to RNA genomes (typically caused by radiation or chemical mutagens), errors in the process of replication, or from the insertion or deletion of segments of DNA by mobile genetic elements. Mutations may or may not produce discernible changes in the observable characteristics (phenotype) of an organism. Mutations play a part in both normal and abnormal biological processes including: evolution, cancer, and the development of the immune system, including functional diversity.

Mutation can result in several different types of change in sequences. Mutations in genes can either have no effect, alter the product of a gene, or prevent the gene from functioning properly or completely. Mutations can also occur in nongenic regions. One study on genetic variations between different species of *Drosophila* suggests that, if a mutation changes a protein produced by a gene, the result is likely to be harmful, with an estimated 70 percent of amino acid polymorphisms that have damaging effects, and the remainder being either neutral or weakly beneficial. Due to the damaging effects that mutations can have on genes, organisms have mechanisms such as DNA repair to prevent or correct (revert the mutated sequence back to its original state) mutations.

Mutations can involve the duplication of large sections of DNA, usually through genetic recombination. These duplications are a major source of raw material for evolving new genes, with tens to hundreds of genes duplicated in animal genomes every million years. Most genes belong to larger families of genes of shared ancestry. Novel genes are produced by several methods, commonly through the duplication and mutation of an ancestral gene, or by recombining parts of different genes to form new combinations with new functions.

Here, domains act as modules, each with a particular and independent function, that can be mixed together to produce genes encoding new proteins with novel properties. For example, the human eye uses four genes to make structures that sense light: three for colour vision and one for night vision; all four arose from a single ancestral gene. Another advantage of duplicating a gene (or even an entire genome) is that this increases redundancy; this allows one gene in the pair to acquire a new function while the other copy performs the original function. Other types of mutation occasionally create new genes from previously noncoding DNA.

Changes in chromosome number may involve even larger mutations, where segments of the DNA within chromosomes break and then rearrange. For example, in the Homininae, two chromosomes fused to produce human chromosome 2; this fusion did not occur in the lineage of the other apes, and they retain these separate chromosomes. In evolution, the most important role of such chromosomal rearrangements may be to accelerate the divergence of a population into new species by making populations less likely to interbreed, thereby preserving genetic differences between these populations.

Sequences of DNA that can move about the genome, such as transposons, make up a major fraction of the genetic material of plants and animals, and may have been important in the evolution of genomes. For example, more than a million copies of the Alu sequence are present in the human genome, and these sequences have now been recruited to perform functions such as regulating gene expression. Another effect of these mobile DNA sequences is that when they move within a genome, they can mutate or delete existing genes and thereby produce genetic diversity.

Nonlethal mutations accumulate within the gene pool and increase the amount of genetic variation. The abundance of some genetic changes within the gene pool can be reduced by

natural selection, while other "more favorable" mutations may accumulate and result in adaptive changes.

For example, a butterfly may produce offspring with new mutations. The majority of these mutations will have no effect; but one might change the colour of one of the butterfly's offspring, making it harder (or easier) for predators to see. If this colour change is advantageous, the chance of this butterfly's surviving and producing its own offspring are a little better, and over time the number of butterflies with this mutation may form a larger percentage of the population.

Neutral mutations are defined as mutations whose effects do not influence the fitness of an individual. These can accumulate over time due to genetic drift. It is believed that the overwhelming majority of mutations have no significant effect on an organism's fitness. Also, DNA repair mechanisms are able to mend most changes before they become permanent mutations, and many organisms have mechanisms for eliminating otherwise-permanently mutated somatic cells.
Beneficial mutations can improve reproductive success.

4.4.1-Spontaneous Mutation

Spontaneous mutations on the molecular level can be caused by:

- **Tautomerism** — A base is changed by the repositioning of a hydrogen atom, altering the hydrogen bonding pattern of that base, resulting in incorrect base pairing during replication.
- **Depurination** — Loss of a purine base (A or G) to form an apurinic site (AP site).
- **Deamination** — Hydrolysis changes a normal base to an atypical base containing a keto group in place of the original amine group. Examples include C → U and A → HX (hypoxanthine), which can be corrected by DNA repair mechanisms; and 5MeC (5-methylcytosine) → T, which is less likely to be detected as a mutation because thymine is a normal DNA base.
- **Slipped strand mispairing** — Denaturation of the new strand from the template during replication, followed by renaturation in a different spot ("slipping"). This can lead to insertions or deletions.

Error-prone replication bypass

There is increasing evidence that the majority of spontaneously arising mutations are due to error-prone replication (translesion synthesis) past a DNA damage in the template strand. Naturally occurring oxidative DNA damages arise at least 10,000 times per cell per day in humans and 50,000 times or more per cell per day in rats. In mice, the majority of mutations are caused by translesion synthesis. Likewise, in yeast, it was found that more than 60% of the spontaneous single base pair substitutions and deletions were caused by translesion synthesis.

Errors introduced during DNA repair

Although naturally occurring double-strand breaks occur at a relatively low frequency in DNA, their repair often causes mutation. Non-homologous end joining (NHEJ) is a major pathway for repairing double-strand breaks. NHEJ involves removal of a few nucleotides to allow somewhat inaccurate alignment of the two ends for rejoining followed by addition of nucleotides to fill in gaps. As a consequence, NHEJ often introduces mutations

4.4.2-Induced Mutation

Induced mutations on the molecular level can be caused by:

1-Chemicals

- Hydroxylamine NH_2OH
- Base analogs (e.g., BrdU)
- Alkylating agents (e.g., *N*-ethyl-*N*-nitrosourea) These agents can mutate both replicating and non-replicating DNA. In contrast, a base analog can mutate the DNA only when the analog is incorporated in replicating the DNA. Each of these classes of chemical mutagens has certain effects that then lead to transitions, transversions, or deletions.
- Agents that form DNA adducts (e.g., ochratoxin A metabolites)
- DNA intercalating agents (e.g., ethidium bromide)
- DNA crosslinkers
- Oxidative damage
- Nitrous acid converts amine groups on A and C to diazo groups, altering their hydrogen bonding patterns, which leads to incorrect base pairing during replication.

2-Radiation

- Ultraviolet radiation (nonionizing radiation). Two nucleotide bases in DNA — cytosine and thymine — are most vulnerable to radiation that can change their properties. UV light can induce adjacent pyrimidine bases in a DNA strand to become covalently joined as a pyrimidine dimer. UV radiation, in particular longer-wave UVA, can also cause oxidative damage to DNA.

4.5 SUMMARY

Polyploids - organisms that have multiple sets of chromosomes - are common in certain plant and animal taxa, and can be surprisingly stable. The evidence that has emerged from genome analyses also indicates that many other eukaryotic genomes have a polyploid ancestry, suggesting that both humans and most other eukaryotes have either benefited from or endured polyploidy. Studies of polyploids soon after their formation have revealed genetic and epigenetic interactions between redundant genes. These interactions can be related to the phenotypes and evolutionary fates of polyploids

Diploid organisms carry two copies (alleles) of each gene, whereas haploid organisms carry only one copy. Mutations are alterations in DNA sequences that result in changes in the structure of a gene. Both small and large DNA alterations can occur spontaneously.

Treatment with ionizing radiation or various chemical agents increases the frequency of mutations. Recessive mutations lead to a loss of function, which is masked if a normal copy of the gene is present. For the mutant phenotype to occur, both alleles must carry the mutation. Dominant mutations lead to a mutant phenotype in the presence of a normal copy of the gene. The phenotypes associated with dominant mutations may represent either a loss or a gain of function.

In meiosis, a diploid cell undergoes one DNA replication and two cell divisions, yielding four haploid cells. The members of each pair of homologous chromosomes segregate independently during meiosis, leading to the random reassortment of maternal and paternal alleles in the gametes. Dominant and recessive mutations exhibit characteristic segregation patterns in genetic crosses.

4.6 GLOSSARY

Polyploidy: Polyploidy is the heritable condition of possessing more than two complete sets of chromosomes. Polyploids are common among plants, as well as among certain groups of fish and amphibians. For instance, some salamanders, frogs, and leeches are polyploids. Many of these polyploid organisms are fit and well-adapted to their environments. In fact, recent findings in genome research indicate that many species that are currently diploid, including humans, were derived from polyploid ancestors. These species that have experienced ancient genome duplications and then genome reduction are referred to as paleopolyploids. This article discusses the mechanisms underlying polyploidy, and both the advantages and disadvantages of having multiple sets of chromosomes.

Polyploid types are labeled according to the number of chromosome sets in the nucleus. The letter *x* is used to represent the number of chromosomes in a single set.

- **triploid** (three sets; 3*x*), for example seedless watermelons, common in the phylum Tardigrada.
- **tetraploid** (four sets; 4*x*), for example Salmonidae fish, the cotton *Gossypium hirsutum* .
- **pentaploid** (five sets; 5*x*), for example Kenai Birch (*Betula papyrifera* var. *kenaica*)
- **hexaploid** (six sets; 6*x*), for example wheat, kiwifruit.
- **heptaploid** or **septaploid** (seven sets; 7*x*)
- **octaploid** or **octoploid**, (eight sets; 8*x*), for example *Acipenser* (genus of sturgeon fish), dahlias.
- **decaploid** (ten sets; 10*x*), for example certain strawberries.
- **dodecaploid** (twelve sets; 12*x*), for example the plant *Celosia argentea* or the invasive one *Spartina anglica* or the amphibian *Xenopus ruwenzoriensis*.

Euploidy: Changes in chromosome number can occur by the addition of all or part of a chromosome (aneuploidy), the loss of an entire set of chromosomes (monoploidy) or the gain

of one or more complete sets of chromosomes (euploidy). Each of these conditions is a variation on the normal diploid number of chromosomes.

Mutation: **A** sudden departure from the parent type in one or more heritable characteristics, caused by a change in a gene or a chromosome. Various types of mutations include:

Deletion: Genetic material is removed or deleted. A few bases can be deleted (as shown on the left) or it can be complete or partial loss of a chromosome.

Frameshift: The insertion or deletion of a number of bases that is not a multiple of 3. This alters the reading frame of the gene and frequently results in a premature stop codon and protein truncation.

Insertion: When genetic material is put into another region of DNA. This may be the insertion of 1 or more bases, or it can be part of one chromosome being inserted into another, non-homologous chromosome.

Missense: A change in DNA sequence that changes the codon to a different amino acid. Not all missense mutations are deleterious, some changes can have no effect. Because of the ambiguity of missense mutations, it is often difficult to interpret the consequences of these mutations in causing disease.

Nonsense: A change in the genetic code that results in the coding for a stop codon rather than an amino acid. The shortened protein is generally non-function or its function is impeded.

Point: A single base change in DNA sequence. A point mutation may be silent, missense, or nonsense.

Silent: A change in the genetic sequence that does not change the protein sequence. This can occur because of redundancy in the genetic code where an amino acid may be encoded for by multiple codons.

Splice Site: A change in the genetic sequence that occurs at the boundary of the exons and introns. The consensus sequences at these boundaries signal where to cut out introns and rejoin exons in the mRNA. A change in these sequences can eliminate splicing at that site which would change the reading frame and protein sequence.

Translocation: A structural abnormality of chromosomes where genetic material is exchanged between two or more non-homologous chromosomes.

4.7 SELF ASSESSMENT QUESTIONS

4.7.1 Multiple choice questions:

1- Which one of the following corresponds to polyploidy in man-

(a) 66 autosomes + 2x chromosomes + 1y chromosome

(b) 21 autosomes + 1x chromosome + 1y chromosome

(c) 44 autosomes + 2x chromosomes + 2y chromosomes

(d) 43 autosomes + 1x chromosome + 2y chromosomes

2- During ploidy there is a change in the-

(a) Number of chromosomes (b) Number of genes

(c) Arrangement of genes (d) Arrangement of chromosomes

3- The term genome refers to the-
(a) Haploid set of chromosomes (b) Diploid set of chromosomes
(c) Triploid set of chromosomes (d) Tetraploid set of chromosomes
4- This is commonly found in the plants-
(a) Haploidy (b) Diploidy
(c) Polyploidy (d) Trisomy

5- One of the following is not the kind of euploidy-
(a) Monoploidy (b) Diploidy
(c) Hyperploidy (d) Polyploidy

6- Point mutation involves-
(a) Deletion (b) Insertion
(c) Duplication (d) Change in single base pair

7- Gene mutation occurs at the time of-
(a) DNA repair (b) DNA replication
(c) Cell division (d) RNA transcription

8- X-ray causes mutation by-
(a) Deletion (b) Transition
(c) Transversion (d) Base substitution

9- In mutational events when adenine is replaced by guanine, it is case of-
(a) Transition (b) Transcription
(c) Transversion (d) Frame shift mutation

10- Muller was first to produce induced mutation in---- by exposing them to X-rays-
(a) *Paramecium* (b) *Arabidopsis*
(c) *Drosophila* (d) *Xenopus*

4.7.1 Answer Keys: 1-(c), 2-(a), 3-(a), 4-(c), 5-(c), 6-(a), 7-(b), 8-(c), 9-(a), 10-(c)

4.8 REFERENCES

- Adams, Keith L; Wendel, Jonathan F (2005). "Polyploidy and genome evolution in plants". Current Opinion in Plant Biology 8 (2): 135–41. doi:10.1016/j.pbi.2005.01.001. PMID 15752992.
- Ainouche, M. L.; Fortune, P. M.; Salmon, A.; Parisod, C.; Grandbastien, M.-A.; Fukunaga, K.; Ricou, M.; Misset, M.-T. (2008). "Hybridization, polyploidy and invasion:

Lessons from Spartina (Poaceae)". Biological Invasions 11 (5): 1159–73. doi:10.1007/s10530-008-9383-2.

- Otto, Sarah P; Whitton, Jeannette (2000). "Polyploidincidence Andevolution". Annual Review of Genetics 34: 401–437. doi:10.1146/annurev.genet.34.1.401. PMID 11092833.
- Meyers, Lauren Ancel; Levin, Donald A. (2006). "On the Abundance of Polyploids in Flowering Plants". Evolution 60 (6): 1198–206. doi:10.1111/j.0014-3820.2006.tb01198.x. PMID 16892970.
- Rieseberg, L. H.; Willis, J. H. (2007). "Plant Speciation". Science 317 (5840): 910–4. Bibcode:2007Sci...317..910R. doi:10.1126/science.1137729. PMC 2442920. PMID 17702935.
- Otto, Sarah P. (2007). "The Evolutionary Consequences of Polyploidy". Cell 131 (3): 452–62. doi:10.1016/j.cell.2007.10.022. PMID 17981114.
- Debodt, S; Maere, S; Vandepeer, Y (2005). "Genome duplication and the origin of angiosperms". Trends in Ecology & Evolution 20 (11): 591–7. doi:10.1016/j.tree.2005.07.008. PMID 16701441.
- Wood, T. E.; Takebayashi, N.; Barker, M. S.; Mayrose, I.; Greenspoon, P. B.; Rieseberg, L. H. (2009). "The frequency of polyploid speciation in vascular plants". Proceedings of the National Academy of Sciences 106 (33): 13875–9. Bibcode: 2009PNAS..10613875W. doi:10.1073/pnas.0811575106. JSTOR 40484335. PMC 2728988. PMID 19667210.
- Comai, Luca (2005). "The advantages and disadvantages of being polyploid". Nature Reviews Genetics 6 (11): 836–46. doi:10.1038/nrg1711. PMID 16304599.
- Chen, Z. Jeffrey; Ni, Zhongfu (2006). "Mechanisms of genomic rearrangements and gene expression changes in plant polyploids". BioEssays 28 (3): 240–52. doi:10.1002/bies.20374. PMC 1986666. PMID 16479580.
- Chen, Z. Jeffrey (2007). "Genetic and Epigenetic Mechanisms for Gene Expression and Phenotypic Variation in Plant Polyploids". Annual Review of Plant Biology 58: 377–406. doi:10.1146/annurev.arplant.58.032806.103835. PMC 1949485. PMID 17280525.
- Manyuan Long; Betrán, Esther; Thornton, Kevin; et al. (November 2003). "The origin of new genes: glimpses from the young and old". Nature Reviews Genetics (London: Nature Publishing Group) 4 (11): 865–875. doi:10.1038/nrg1204. ISSN 1471-0056. PMID 14634634.
- Hurst, Gregory D. D.; Werren, John H. (August 2001). "The role of selfish genetic elements in eukaryotic evolution". Nature Reviews Genetics (London: Nature Publishing Group) 2 (8): 597–606. doi:10.1038/35084545. ISSN 1471-0056. PMID 11483984.
- Häsler, Julien; Strub, Katharina (November 2006). "Alu elements as regulators of gene expression". Nucleic Acids Research (Oxford, UK: Oxford University Press) 34 (19): 5491–5497. doi:10.1093/nar/gkl706. ISSN 0305-1048. PMC 1636486. PMID 17020921.
- Eyre-Walker, Adam; Keightley, Peter D. (August 2007). "The distribution of fitness effects of new mutations" (PDF). Nature Reviews Genetics (London: Nature Publishing Group) 8 (8): 610–618. doi:10.1038/nrg2146. ISSN 1471-0056. PMID 17637733. Retrieved 2015-10-02.

- Montelone, Beth A. (1998). "Mutation, Mutagens, and DNA Repair". www-personal.ksu.edu. Retrieved 2015-10-02.
- Keightley, Peter D.; Lynch, Michael (March 2003). "Toward a Realistic Model of Mutations Affecting Fitness". Evolution (Hoboken, NJ: John Wiley & Sons for the Society for the Study of Evolution) 57 (3): 683–689. doi:10.1554/0014-3820(2003)057[0683:tarmom]2.0.co;2. ISSN 0014-3820. JSTOR 3094781. PMID 12703958.
- Barton, Nicholas H.; Keightley, Peter D. (January 2002). "Understanding quantitative genetic variation". Nature Reviews Genetics (London: Nature Publishing Group) 3 (1): 11–21. doi:10.1038/nrg700. ISSN 1471-0056. PMID 11823787.
- Kimura, Motoo (February 17, 1968). "Evolutionary Rate at the Molecular Level". Nature (London: Nature Publishing Group) 217 (5129): 624–626. doi:10.1038/217624a0. ISSN 0028-0836. PMID 5637732.
- Akashi, Hiroshi (September 30, 1999). "Within- and between-species DNA sequence variation and the 'footprint' of natural selection". Gene (Amsterdam, the Netherlands: Elsevier) 238 (1): 39–51. doi:10.1016/S0378-1119(99)00294-2. ISSN 0378-1119. PMID 10570982.
- Eyre-Walker, Adam (October 2006). "The genomic rate of adaptive evolution". Trends in Ecology & Evolution (Cambridge, MA: Cell Press) 21 (10): 569–575. doi:10.1016/j.tree.2006.06.015. ISSN 0169-5347. PMID 16820244.
- Gillespie, John H. (September 1984). "Molecular Evolution Over the Mutational Landscape". Evolution (Hoboken, NJ: John Wiley & Sons for the Society for the Study of Evolution) 38 (5): 1116–1129. doi:10.2307/2408444. ISSN 0014-3820. JSTOR 2408444.
- Orr, H. Allen (April 2003). "The Distribution of Fitness Effects among Beneficial Mutations". Genetics (Bethesda, MD: Genetics Society of America) 163 (4): 1519–1526. ISSN 0016-6731. PMC 1462510. PMID 12702694. Retrieved 2015-10-07.
- den Dunnen, Johan T.; Antonarakis, Stylianos E. (January 2000). "Mutation Nomenclature Extensions and Suggestions to Describe Complex Mutations: A Discussion". Human Mutation (Hoboken, NJ: Wiley-Liss, Inc.) 15 (1): 7–12. doi:10.1002/(SICI)1098-1004(200001)15:1<7::AID-HUMU4>3.0.CO;2-N. ISSN 1059-7794. PMID 10612815.

4.9 SUGGESTED READINGS

- Snustad, D. Peter; et al. (2006). Principles of Genetics (4th ed.). Hoboken, NJ: John Wiley & Sons. ISBN 0-471-69939-X.
- The Arabidopsis Genome Initiative (2000). "Analysis of the genome sequence of the flowering plant Arabidopsis thaliana". Nature 408 (6814): 796–815. doi:10.1038/35048692. PMID 11130711.
- Gregory, T.R.; Mable, B.K. (2005). "Polyploidy in animals". In Gregory, T.R. The Evolution of the Genome. San Diego: Elsevier. pp. 427–517.
- Soltis DE, Buggs RJA, Doyle JJ, Soltis PS (2010). "What we still don't know about polyploidy". Taxon 59: 1387–403. JSTOR 20774036.

- Tate, J.A.; Soltis, D.E.; Soltis, P.S. (2005). "Polyploidy in plants". In Gregory, T.R. The Evolution of the Genome. San Diego: Elsevier. pp. 371–426.
- Van de Peer, Y.; Meyer, A. (2005). "Large-scale gene and ancient genome duplications". In Gregory, T.R. The Evolution of the Genome. San Diego: Elsevier. pp. 329–68.
- Wolfe, Kenneth H. (2001). "Yesterday's polyploids and the mystery of diploidization". Nature Reviews Genetics 2 (5): 333–41. doi:10.1038/35072009. PMID 11331899.
- Kimura, Motoo (1983). The Neutral Theory of Molecular Evolution. Cambridge, UK; New York: Cambridge University Press. ISBN 0-521-23109-4. LCCN 82022225. OCLC 9081989.
- Bernstein, Harris; Hopf, Frederic A.; Michod, Richard E. (1987). "The Molecular Basis of the Evolution of Sex". In Scandalios, John G. Molecular Genetics of Development. Advances in Genetics 24. San Diego, CA: Academic Press. doi:10.1016/S0065-2660(08)60012-7. ISBN 0-12-017624-6. ISSN 0065-2660. LCCN 47030313. OCLC 18561279. PMID 3324702.
- Carroll, Sean B.; Grenier, Jennifer K.; Weatherbee, Scott D. (2005). From DNA to Diversity: Molecular Genetics and the Evolution of Animal Design (2nd ed.). Malden, MA: Blackwell Publishing. ISBN 1-4051-1950-0. LCCN 2003027991. OCLC 53972564.

4.10 TERMINAL QUESTIONS

4.10.1 Short answer type Questions:

1. Advantage and disadvantage of polyploidy.
2. Are mutations ever beneficial?
3. Can mutation be the mechanism for evolution?
4. Can any genetic information be gained from mutations?
5. Describe some common chromosomal mutations.
6. Why are mutations so important to living organisms?

4.10.2 Long answer type Questions:

1. What is gene mutation? Give its types.
2. What are mutagens? Give its types.
3. Describe the purpose and process of mutation breeding?
4. What are neutral mutations?

UNIT-5 SEX DETERMINATION AND SEX-LINKED INHERITANCE

Contents:

5.1 OBJECTIVES

After reading this unit students will be able-

- To understand about various sex determination systems.
- To discuss about sex-linkage and sex-linked inheritance.

5.2 INTRODUCTION

Most animals and many plants show sexual dimorphism; in other words, an individual can be either male or female. In most of these cases, sex is determined by special sex chromosomes. In these organisms, there are two categories of chromosomes, sex chromosomes and autosomes (the chromosomes other than the sex chromosomes). The rules of inheritance considered so far, with the use of Mendel's analysis as an example, are the rules of autosomes. Most of the chromosomes in a genome are autosomes. The sex chromosomes are fewer in number, and, generally in diploid organisms, there is just one pair. The genes on the differential regions of the sex chromosomes show patterns of inheritance related to sex. The inheritance patterns of genes on the autosomes produce male and female progeny in the same phenotypic proportions, as typified by Mendel's data (for example, both sexes might show a 3:1 ratio). However, crosses following the inheritance of genes on the sex chromosomes often show male and female progeny with different phenotypic ratios. In fact, for studies of genes of unknown chromosomal location, this pattern is a diagnostic of location on the sex chromosomes.

The present chapter discusses about the sex chromosomes, different sex determination systems and sex-linked inheritance for various traits.

5.3 SEX DETERMINATION

A sex-determination system is a biological system that determines the development of sexual characteristics in an organism. Most organisms that create their offspring using sexual reproduction have two sexes. Occasionally, there are hermaphrodites in place of one or both sexes. There are also some species that are only one sex due to parthenogenesis, the act of a female reproducing without fertilization.

In many species, sex determination is genetic: males and females have different alleles or even different genes that specify their sexual morphology. In animals this is often accompanied by chromosomal differences, generally through combinations of XY, ZW, XO, ZO chromosomes, or haplodiploidy. The sexual differentiation is generally triggered by a main gene (a "sex locus"), with a multitude of other genes following in a domino effect.

In other cases, sex is determined by environmental variables (such as temperature) or social variables (e.g. the size of an organism relative to other members of its population).

Environmental sex determination preceded the genetically determined systems of birds and mammals; it is thought that a temperature-dependent amniote was the common ancestor of amniotes with sex chromosomes. Some species do not have a fixed sex, and instead change sex based on certain cues. The details of some sex-determination systems are not yet fully understood.

Chromosomal determination

1- XX/XY sex chromosomes

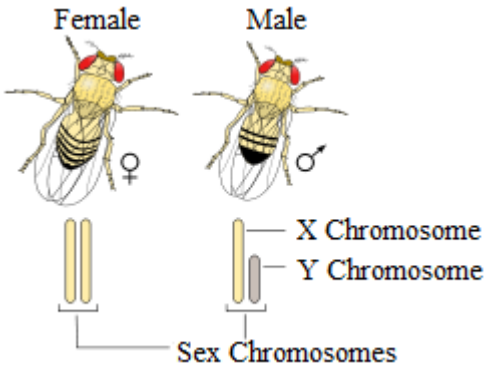


Fig.5.1 Drosophila sex-chromosomes

The **XX/XY sex-determination system** is the most familiar, as it is found in humans. In the system, females have two of the same kind of sex chromosome (XX), while males have two distinct sex chromosomes (XY). The XY sex chromosomes are different in shape and size from each other, unlike the autosomes, and are termed allosomes. Some species (including humans) have a gene SRY on the Y chromosome that determines maleness; others (such as the fruit fly) use the presence of two X chromosomes to determine femaleness. Because the fruit fly, as well as other species, use the number of Xs to determine sex, they are nonviable with an extra X. SRY-reliant species can have conditions such as XXY and still live. Human sex is determined by containing SRY or not. Once SRY is activated, cells create testosterone and anti-müllerian hormone to turn the genderless sex organs into male. With females, their cells excrete estrogen, driving the body down the female pathway. Not all organisms remain gender indifferent for a time after they're created; for example, fruit flies differentiate into specific sexes as soon as the egg is fertilized. In Y-centered sex determination, the SRY gene is not the only gene to have an influence on sex. Despite the fact that SRY seems to be the main gene in determining male characteristics, it requires the action of multiple genes to develop testes. In XY mice, lack of the gene DAX1 on the X chromosome results in sterility, but in humans it causes adrenal hypoplasia congenita. However, when an extra DAX1 gene is placed on the X, the result is a female, despite the existence of SRY. Also, even when there are normal sex chromosomes in XX females, duplication or expression of SOX9 causes testes to develop. Gradual sex reversal in developed mice can also occur when the gene FOXL2 is removed from females. Even though the gene DMRT1 is used by birds as their sex locus, species who have XY chromosomes also rely upon DMRT1, contained on chromosome 9, for sexual differentiation at some point in their formation.

The XX/XY system is also found in most other mammals, as well as some insects. Some fish also have variants of this, as well as the regular system. For example, while having an XY format, *Xiphophorus nezahualcoyotl* and *X. milleri* also have a second Y chromosome, known as Y', that creates XY' females and YY' males. At least one monotreme, the platypus, presents a particular sex determination scheme that in some ways resembles that of the ZW sex chromosomes of birds, and also lacks the SRY gene, whereas some rodents, such as several Arvicolinae (voles and lemmings), are also noted for their unusual sex determination systems. The platypus has ten sex chromosomes; males have an XYXYXYXYXY pattern while females have ten X chromosomes. Although it is an XY system, the platypus' sex chromosomes share no homology with eutherian sex chromosomes. Instead, homologous with eutherian sex chromosomes lie on the platypus chromosome 6, which means that the eutherian sex chromosomes were autosomes at the time that the monotremes diverged from the therian mammals (marsupials and eutherian mammals). However, homologous to the avian DMRT1 gene on platypus sex chromosomes X3 and X5 suggest that it is possible the sex-determining gene for the platypus is the same one that is involved in bird sex-determination. More research must be conducted in order to determine the exact sex determining gene of the platypus.

2-XX/X0 sex chromosomes

In this variant of the XY system, females have two copies of the sex chromosome (XX) but males have only one (X0). The *0* denotes the absence of a second sex chromosome. Generally in this method, the sex is determined by amount of genes expressed across the two chromosomes. This system is observed in a number of insects, including the grasshoppers and crickets of order Orthoptera and in cockroaches (order Blattodea). A small number of mammals also lack a Y chromosome. These include the Amami spiny rat (*Tokudaia osimensis*) and the Tokunoshima spiny rat (*Tokudaia tokunoshimensis*) and *Sorex araneus*, a shrew species. Transcaucasian mole voles (*Ellobius lutescens*) also have a form of XO determination, in which both genders lack a second sex chromosome. The mechanism of sex determination is not yet understood.

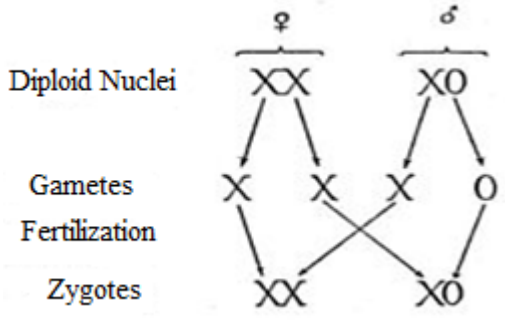


Fig. 5.2 Heredity of sex chromosomes in XO sex determination

The nematode *C. elegans* is male with one sex chromosome (X0); with a pair of chromosomes (XX) it is a hermaphrodite. Its main sex gene is XOL, which encodes XOL-1

and also controls the expression of the genes TRA-2 and HER-1. These genes reduce male gene activation and increase it, respectively.

3- ZZ/ZW sex chromosomes

The *ZW sex-determination system* is found in birds, some reptiles, and some insects and other organisms. The ZW sex-determination system is reversed compared to the XY system: females have two different kinds of chromosomes (ZW), and males have two of the same kind of chromosomes (ZZ). In the chicken, this was found to be dependent on the expression of DMRT1. In birds, the genes FET1 and ASW are found on the W chromosome for females, similar to how the Y chromosome contains SRY. However, not all species depend upon the W for their sex. For example, there are moths and butterflies that are ZW, but some have been found female with ZO, as well as female with ZZW. Also, while mammals inactivate one of their extra X chromosomes when female, it appears that in the case of Lepidoptera, the males produce double the normal amount of enzymes, due to having two Z's. Because the use of ZW sex determination is varied, it is still unknown how exactly most species determine their sex. However, reportedly, the silkworm *Bombyx mori* uses a single female-specific piRNA as the primary determiner of sex. Despite the similarities between ZW and XY, the sex chromosomes do not line up correctly and evolved separately. In the case of the chicken, their Z chromosome is more similar to human's autosome 9. The chicken's Z chromosome also seems to be related to the X chromosomes of the platypus. When a ZW species, such as the Komodo dragon, reproduces parthenogenetically, usually only males are produced. This is due to the fact that the haploid eggs double their chromosomes, resulting in ZZ or WW. The ZZ become males, but the WW are not viable and are not brought to term.

4- UV Sex Chromosomes

In some Bryophyte and some algae species, the gametophyte stage of the life cycle, rather than being hermaphrodite, occurs as separate male or female individuals that produce male and female gametes, respectively. When meiosis occurs in the sporophyte generation of the life cycle, the sex chromosomes known as U and V assort in spores that carry either the U chromosome and give rise to female gametophytes, or the V chromosome and give rise to male gametophytes.

5- Haplodiploidy

Haplodiploidy is found in insects belonging to Hymenoptera, such as ants and bees. Unfertilized eggs develop into haploid individuals, which are the males. Diploid individuals are generally female but may be sterile males. Males cannot have sons or fathers. If a queen bee mates with one drone, her daughters share ¾ of their genes with each other, not ½ as in the XY and ZW systems. This is believed to be significant for the development of eusociality, as it increases the significance of kin selection, but it is debated. Most females in the Hymenoptera order can decide the sex of their offspring by holding received sperm in their spermatheca and either releasing it into their oviduct or not. This allows them to create more workers, depending on the status of the colony.

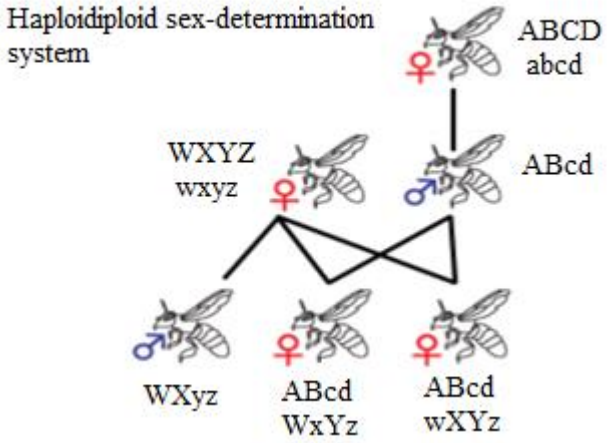


Fig.5.3 Haplodiploid sex chromosomes

Non-Genetic Sex-Determination Systems

1-Temperature-dependent sex determination

In some species of reptiles, including alligators, some turtles, and the tuatara, sex is determined by the temperature at which the egg is incubated during a temperature-sensitive period. There are no examples of temperature-dependent sex determination (TSD) in birds. Megapodes had formerly been thought to exhibit this phenomenon, but actually exhibit temperature-dependent embryo mortality. For some species with TSD, sex determination is achieved by exposure to hotter temperatures resulting in the offspring being one sex and cooler temperatures resulting in the other. For others species using TSD, it is exposure to temperatures on both extremes that results in offspring of one sex, and exposure to moderate temperatures that results in offspring of the opposite sex. These systems are known as Pattern I and Pattern II, respectively. The specific temperatures required to produce each sex are known as the female-promoting temperature and the male-promoting temperature. When the temperature stays near the threshold during the temperature sensitive period, the sex ratio is varied between the two sexes. Some species' temperature standards are based on when a particular enzyme is created. These species that rely upon temperature for their sex determination do not have the SRY gene, but have other genes such as DAX1, DMRT1, and SOX9 that are expressed or not expressed depending on the temperature. The sex of some species, such as the Nile tilapia, Australian skink lizard, and Australian dragon lizard, is initially determined by chromosomes, but can later be changed by the temperature of incubation.

It is unknown how exactly temperature-dependent sex determination evolved. It could have evolved through certain sexes being more suited to certain areas that fit the temperature requirements. For example, a warmer area could be more suitable for nesting, so more females are produced to increase the amount that nest next season.

Other sex-determination systems

Although temperature-dependent sex determination is relatively common, there are many other environmental systems. Some species, such as some snails, practice sex change: adults start out male, then become female. In tropical clown fish, the dominant individual in a group becomes female while the other ones are male, and bluehead wrasses (*Thalassoma bifasciatum*) are the reverse. In the marine worm (*Bonellia viridis*), larvae become males if they make physical contact with a female, and females if they end up on the bare sea floor. This is triggered by the presence of a chemical produced by the females, bonellin. Some species, however, have no sex-determination system. Hermaphrodite species include the common earthworm and certain species of snails. A few species of fish, reptiles, and insects reproduce by parthenogenesis and are female altogether. There are some reptiles, such as the boa constrictor and Komodo dragon that can reproduce both sexually and asexually, depending on whether a mate is available.

Evolution of Sex-Determination Systems

Origin of sex chromosomes

The accepted hypothesis of XY and ZW sex chromosome evolution is that they evolved at the same time, in two different branches. However, there is some evidence to suggest that there could have been transitions between ZW and XY, such as in *Xiphophorus maculatus*, which have both ZW and XY systems in the same population, despite the fact that ZW and XY have different gene locations. A recent theoretical model raises the possibility of both transitions between the XY/XX and ZZ/ZW system and environmental sex determination. The platypus' genes also back up the possible evolutionary link between XY and ZW, because they have the DMRT1 gene possessed by birds on their X chromosomes. Regardless, XY and ZW follow a similar route. All sex chromosomes started out as an original autosome of an original amniote that relied upon temperature to determine the sex of offspring. After the mammals separated, the branch further split into Lepidosauria and Archosauromorpha. These two groups both evolved the ZW system separately, as evidenced by the existence of different sex chromosomal locations. In mammals, one of the autosome pair, now Y, mutated its SOX3 gene into the SRY gene, causing that chromosome to designate sex. After this mutation, the SRY-containing chromosome inverted and was no longer completely homologous with its partner. The regions of the X and Y chromosomes that are still homologous to one another are known as the pseudoautosomal region. Once it inverted, the Y chromosome became unable to remedy deleterious mutations, and thus degenerated. There is some concern that the Y chromosome will shrink further and stop functioning in 10 million years, but other evidence has shown that the Y chromosome has been strictly conserved after its initial rapid gene loss.

There are some species, such as the medaka fish, that evolved sex chromosomes separately; their Y chromosome never inverted and can still swap genes with the X. These species are still in an early phase of evolution with regard to their sex chromosomes. Because the Y does not have male-specific genes and can interact with the X, XY and YY females can be formed as well as XX males.

5.4 SEX LINKED INHERITANCE

The inheritance of a trait (phenotype) that is determined by a gene located on one of the sex chromosomes. Genetic studies of many species have been facilitated by focusing on such traits because of their characteristic patterns of familial transmission and the ability to localize their genes to a specific chromosome. As the ability to map a gene to any of an organisms chromosome has improved markedly, reliance on the specific pattern of inheritance has waned.

The expectations of sex-linked inheritance in any species depend on how the chromosomes determine sex. For example, in humans, males are heterogametic, having one X chromosome and one Y chromosome, whereas females are homogametic, having two X chromosomes. In human males, the entire X chromosome is active (not all genes are active in every cell), whereas one of a female's X chromosomes is largely inactive. Random inactivation of one X chromosome occurs during the early stages of female embryogenesis, and every cell that descends from a particular embryonic cell has the same X chromosome inactivated. The result is dosage compensation for X-linked genes between the sexes. A specific gene on the long arm of the X chromosome, called XIST at band q13, is a strong candidate for the gene that controls X inactivation. This pattern of sex determination occurs in most vertebrates, but in birds and many insects and fish the male is the homogametic sex.

In general terms, traits determined by genes on sex chromosomes are not different from traits determined by autosomal genes. Sex-linked traits are distinguishable by their mode of transmission through successive generations of a family. In humans it is preferable to speak in terms of X-linked or Y-linked inheritance.

Red-green color blindness was the first human trait proven to be due to a gene on a specific chromosome. The characteristics of this pattern of inheritance are readily evident. Males are more noticeably or severely affected than females; in the case of red-green color blindness, women who have one copy of the mutant gene (that is, are heterozygous or carriers) are not at all affected. Among offspring of carrier mothers, on average one-half of their sons are affected, whereas one-half of their daughters are carriers. Affected fathers cannot pass their mutant X chromosome to their sons, but do pass it to all of their daughters, who thereby are carriers. A number of other well-known human conditions behave in this manner, including the two forms of hemophilia, Duchenne muscular dystrophy, and glucose-6-phosphate dehydrogenase deficiency that predisposes to hemolytic anemia.

Refined cytogenetic and molecular techniques have supplemented family studies as a method for characterizing sex-linked inheritance and for mapping genes to sex chromosomes in many species. Over 400 human traits and diseases seem to be encoded by genes on the X chromosome, and over 200 genes have been mapped. Among mammals, genes on the X

chromosome are highly conserved. Thus, identifying a sex-linked trait in mice is strong evidence that a similar trait, and underlying gene, exists on the human X chromosome.

Sex chromosomes and sex-linked inheritance

Most animals and many plants show sexual dimorphism; in other words, an individual can be either male or female. In most of these cases, sex is determined by special sex chromosomes. In these organisms, there are two categories of chromosomes, ***sex chromosomes*** and ***autosomes*** (the chromosomes other than the sex chromosomes). The rules of inheritance considered so far, with the use of Mendel's analysis as an example, are the rules of autosomes. Most of the chromosomes in a genome are autosomes. The sex chromosomes are fewer in number, and, generally in diploid organisms, there is just one pair.

Let us look at the human situation as an example. Human body cells have 46 chromosomes: 22 homologous pairs of autosomes plus 2 sex chromosomes. In females, there is a pair of identical sex chromosomes called the X chromosomes. In males, there is a nonidentical pair, consisting of one X and one Y. The Y chromosome is considerably shorter than the X. At meiosis in females, the two X chromosomes pair and segregate like autosomes so that each egg receives one X chromosome. Hence the female is said to be the homogametic sex. At meiosis in males, the X and the Y pair over a short region, which ensures that the X and Y separate so that half the sperm cells receive X and the other half receive Y. Therefore the male is called the heterogametic sex.

The fruit fly *Drosophila melanogaster* has been one of the most important research organisms in genetics; its short, simple life cycle contributes to its usefulness in this regard. Fruit flies also have XX females and XY males. However, the mechanism of sex determination in *Drosophila* differs from that in mammals. In *Drosophila*, the number of X chromosomes determines sex: two X's result in a female and one X results in a male. In mammals, the presence of the Y determines maleness and the absence of a Y determines femaleness. This difference is demonstrated by the sexes of the abnormal chromosome types XXY and XO, as shown in Table below.

Chromosomal Determination of Sex in *Drosophila* and Humans

	Sex chromosomes			
Species	**XX**	**XY**	**XXY**	**XO**
Drosophila	♀	♂	♀	♂
Human	♀	♂	♂	♀

Vascular plants show a variety of sexual arrangements. ***Dioecious*** species are the ones showing animal-like sexual dimorphism, with female plants bearing flowers containing only ovaries and male plants bearing flowers containing only anthers. Some, but not all, dioecious plants have a non-identical pair of chromosomes associated with (and almost certainly

determining) the sex of the plant. Of the species with nonidentical sex chromosomes, a large proportion has an XY system. For example, the dioecious plant *Melandrium album* has 22 chromosomes per cell: 20 autosomes plus 2 sex chromosomes, with XX females and XY males. Other dioecious plants have no visibly different pair of chromosomes; they may still have sex chromosomes but not visibly distinguishable types.

Cytogeneticists have divided the X and Y chromosomes of some species into homologous and nonhomologous regions. The latter are called *differential* regions. These differential regions contain genes that have no counterparts on the other sex chromosome. Genes in the differential regions are said to be hemizygous ("half zygous") in males. Genes in the differential region of the X show an inheritance pattern called X linkage; those in the differential region of the Y show Y linkage. Genes in the homologous region show what might be called X-and-Y linkage. In general, genes on sex chromosomes are said to show sex linkage.
Differential and pairing regions of sex chromosomes of humans and of the plant *Melandrium album.* The regions were located by observing where the chromosomes paired up in meiosis and where they did not.

The genes on the differential regions of the sex chromosomes show patterns of inheritance related to sex. The inheritance patterns of genes on the autosomes produce male and female progeny in the same phenotypic proportions, as typified by Mendel's data (for example, both sexes might show a 3:1 ratio). However, crosses following the inheritance of genes on the sex chromosomes often show male and female progeny with different phenotypic ratios. In fact, for studies of genes of unknown chromosomal location, this pattern is a diagnostic of location on the sex chromosomes. Let's look at an example from *Drosophila.* The wild-type eye color of *Drosophila* is dull red, but pure lines with white eyes are available. This phenotypic difference is determined by two alleles of a gene located on the differential region of the X chromosome. When white-eyed males are crossed with red-eyed females, all the F_1 progeny have red eyes, showing that the allele for white is recessive. Crossing the red-eyed F_1 males and females produces a 3:1 F_2 ratio of red-eyed to white-eyed flies, but all the white-eyed flies are males. This inheritance pattern is explained by the alleles being located on the differential region of the X chromosome; in other words, by X-linkage. The reciprocal cross gives a different result. A reciprocal cross between white-eyed females and red-eyed males gives an F_1 in which all the females are red eyed, but all the males are white eyed. The F_2 consists of one-half red-eyed and one-half white-eyed flies of both sexes. Hence in sex linkage, we see examples not only of different ratios in different sexes, but also of differences between reciprocal crosses.

In *Drosophila,* eye color has nothing to do with sex determination, so we see that genes on the sex chromosomes are not necessarily related to sexual function. The same is true in humans, for whom pedigree analysis has revealed many X-linked genes, of which few could be construed as being connected to sexual function.

5.5 SUMMARY

The nature of the genetic basis of sex determination varies a great deal among the various forms of life. Most sexually reproducing species produce two different kinds of gametes. The relatively large and sessile form, an ovum or egg, usually accumulates nutriments in its cytoplasm for the early development of the offspring. The relatively mobile form, a sperm (or pollen grain in many plants), contributes little beyond a haploid chromosome set. Thus the primary form of sex differentiation determines which kind of gamete will be produced. The formation of gametes usually involves the concomitant differentiation of specialized organs, the gonads, to produce each kind of gamete. The ova-producing gonad is usually known as an archegonium or ovary (in flowering plants it is part of a larger organ, the pistil or carpel); the gonad producing the more mobile gametes is usually known as a testis in animals and an antheridium or stamen in plants. n most animals and many plants, individuals become specialized to produce only one kind of gamete. These individuals usually differ not only in which kind of gonad they possess but also in a number of other morphological and physiological differences, or secondary sex characteristics. The latter may define a phenotypic sex when present, even if the typical gonad for that sex is absent or nonfunctional. The form that usually produces ova is known as female; the one that usually produces sperm or pollen is known as male. Since some sexual processes do not involve gametes, the more universal application of the term "gender" refers to any donor of genetic material as male and the recipient as female. Sex differentiations are often accompanied by consistent chromosomal dimorphisms, leading to the presumption that the chromosomal differences are related to, and possibly responsible for, the sex differences. Indeed, the chromosomes that are not alike in the two sexes were given the name sex chromosomes. Some workers use the term "heterosomes" to distinguish them from the autosomes, which are the chromosomes that are morphologically identical in the two sexes. In most species, one of the sex chromosomes, the X chromosome, normally occurs as a pair in one gender but only singly in the other. The gender with two X chromosomes is known as the homogametic sex, because each of its gametes normally receives an X chromosome after meiosis. The gender with only one X chromosome generally also has a morphologically different sex chromosome, the Y chromosome. The X and Y chromosomes usually pair to some extent at meiosis, with the result that the XY is the heterogametic sex, with half its gametes containing an X and half containing a Y. Geneticists noted that the fundamental dimorphism of X and Y chromosomes lies in their genic contents: X chromosomes of the species share homologous loci, just as do pairs of autosomes, whereas the Y chromosome usually has few, if any, loci that are also represented on the X. Thus X and Y chromosomes are sometimes very similar in shape or size but are almost always very different in genetic materials.

The inheritance of a trait (phenotype) that is determined by a gene located on one of the sex chromosomes. Genetic studies of many species have been facilitated by focusing on such traits because of their characteristic patterns of familial transmission and the ability to localize their genes to a specific chromosome. As the ability to map a gene to any of an

organism's chromosomes has improved markedly, reliance on the specific pattern of inheritance has waned. The expectations of sex-linked inheritance in any species depend on how the chromosomes determine sex. For example, in humans, males are heterogametic, having one X chromosome and one Y chromosome, whereas females are homogametic, having two X chromosomes. In human males, the entire X chromosome is active (not all genes are active in every cell), whereas one of a female's X chromosomes is largely inactive. Random inactivation of one X chromosome occurs during the early stages of female embryogenesis, and every cell that descends from a particular embryonic cell has the same X chromosome inactivated. The result is dosage compensation for X-linked genes between the sexes. A specific gene on the long arm of the X chromosome, called XIST at band q13, is a strong candidate for the gene that controls X inactivation. This pattern of sex determination occurs in most vertebrates, but in birds and many insects and fish the male is the homogametic sex. In general terms, traits determined by genes on sex chromosomes are not different from traits determined by autosomal genes. Sex-linked traits are distinguishable by their mode of transmission through successive generations of a family. In humans it is preferable to speak in terms of X-linked or Y-linked inheritance. Refined cytogenetic and molecular techniques have supplemented family studies as a method for characterizing sex-linked inheritance and for mapping genes to sex chromosomes in many species. Over 400 human traits and diseases seem to be encoded by genes on the X chromosome, and over 200 genes have been mapped. Among mammals, genes on the X chromosome are highly conserved. Thus, identifying a sex-linked trait in mice is strong evidence that a similar trait, and underlying gene, exists on the human X chromosome.

5.6 GLOSSARY

Sex chromosome: A sex chromosome is a type of chromosome that participates in sex determination.

Sex-linked gene: A gene located on a sex chromosome, usually the X-chromosome**.**

Sex-linked trait: A trait associated with a **gene** that is carried only by the male or female parent.

Sex-linked inheritance: Pattern of inheritance that may result from a mutant gene located on either X or Y chromosomes.

Sex determination: The change in the fetus to a male or female configuration; the process by which the sex of an organism is fixed, associated, in animals, with the presence or absence of the Y chromosome.

Sex-linkage: Includes X-linked (much the most common) and Y-linked loci.

5.7 SELF ASSESSMENT QUESTIONS

5.7.1 Fill in the blanks:

1-A gamete without any sex chromosome is called--------- gamete.

2- ---------- pattern of sex determination is found in Drosophila, man and many other organisms.

3- -------- type of sex-determination pattern is common in birds, butterflies and moths.
4-Presence of ---------- gene on Y chromosome is essential for starting the development of maleness in humans.
5- XXY set of chromosomes in Drosophila produces a---------- female.

5.7.2 Multiple choice questions:

1- **Sex chromosomes were discovered by-**
(a) Carl Correns (b) Nettie Stevens
(c) Morgan (d) Mendel

2- Sex-linked genetically inherited traits-
(a) Can appear in both males and females
(b) Are only found in males
(c) Are only found in females
(d) Result from premarital sexual relationships

3- Y-linked traits are inherited:
(a) Only by females (b) Only by males
(c) By both males and females (d) None of these

4- Harmful X-linked traits are:
(a) Inherited only from mothers
(b) More numerous than Y-linked ones
(c) Most likely to show up in the phenotype of daughters
(d) Most likely to show up in the phenotype of sons

5- What would be the sex of an XXY individual?
(a) Male (b) Female
(c) Hermaphrodite (d) Mosaic

6- Men with red-green color blindness inherited the genes for it from-
(a) Their mothers (b) Their fathers
(c) Either their mothers or fathers (d) Their grandmother

7- On which on the following chromosomes are sex-linked traits carried?
(a) 13 (b) Y
(c) 18 (d) X

8- The genotype of an individual with Turner syndrome is-
(a) XO (b) YO
(c) XXX (d) XXY

5.7.1 Answer Keys: 1. Nullo; 2. XX-XY; 3. ZZ-ZW; 4. SRY; 5. sterile

5.7.2 Answer Key: 1-(b), 2-(a), 3-(b), 4-(b), 5-(a), 6-(a), 7-(d), 8-(a)

5.8 REFERENCES

- Penalva, Luiz O. F.; Sánchez (September 2003). "RNA Binding Protein Sex-Lethal (Sxl) and Control of Drosophila Sex Determination and Dosage Compensation". Microbiology and Molecular Biology **67** (3): 343–359. doi:10.1128/MMBR.67.3.343-359.2003. PMC 193869. PMID 12966139.
- Hake, Laura (2008). "Genetic Mechanisms of Sex Determination". Nature Education **1** (1). Retrieved 8 December 2011.
- Bachtrog, D.; Kirkpatrick, M.; Mank, J.E.; McDaniel, S.F.; Pires, J.C.; Rice, W.; Valenzuela, N. (2011). "Are all sex chromosomes created equal?" Trends in genetics: TIG **27** (9): 350–357. doi:10.1016/j.tig.2011.05.005.
- Namekawa, Satoshi; Lee, Jeannie T. (2009). "XY and ZW: Is Meiotic Sex Chromosome Inactivation the Rule in Evolution?". PLoS Genetics (Public Library of Science) **5** (5): 3. doi:10.1371/journal.pgen.1000493.
- Vallender, Eric; Lahn, B. T. (28 November 2006). "Multiple independent origins of sex chromosomes in amniotes". Proceedings of the National Academy of Sciences (Proceedings of the National Academy of Sciences) **103** (5): 18031–2. Bibcode: 2006PNAS.10318031V. doi: 10.1073/ pnas.0608879103. PMC 1838700. PMID 17116892.
- Graves, Jennifer (1 September 2000). "Human Y Chromosome, Sex Determination, and Spermatogenesis-A Feminist View". Biology of Reproduction **63** (3): 667–676. doi:10.1095/biolreprod63.3.667b (inactive 2015-02-02). PMID 10952906.
- Quinn, A. E.; Stephen D. Sarre; Jennifer A. Marshall Graves; Arthur Georges; Georges, A. (6 January 2011). "Evolutionary transitions between mechanisms of sex determination in vertebrates" (PDF). Biology Letters **7** (3): 443. doi:10.1098/rsbl.2010.1126. PMID 21212104.
- Graves, Jennifer (10 March 2006). "Sex Chromosome Specialization and Degeneration in Mammals". Cell **124** (5): 901–914. doi:10.1016/ j.cell.2006.02.024. PMID 16530039.
- "The evolution of the sex chromosomes: Step by step" (Press release). University of Chicago Medical Center. 28 October 1999. Retrieved 23 October 2011.
- Charlesworth, Brian (14 August 2003). "The organization and evolution of the human Y chromosome". Genome Biology **4** (9): 226. doi:10.1186/gb-2003-4-9-226. PMC 193647. PMID 12952526.
- Graves, Jennifer (22 July 2004). "The degenerate Y chromosome – can conversion save it?". Reproduction, Fertility, and Development **16** (5): 527–34. doi:10.1071/RD03096. PMID 15367368.
- Morgan, Thomas Hunt 1919. The physical basis of heredity. Philadelphia: J.B. Lippincott Company.
- Morgan T.H. 1910. Sex-limited inheritance in Drosophila. Science **32**: 120-122

- Zirkle, Conrad 1946. The discovery of sex-influenced, sex limited and sex-linked heredity. In Ashley Montagu M.F. (ed) Studies in the history of science and learning offered in homage to George Sarton on the occasion of his sixtieth birthday. New York: Schuman, p167–194.
- Ford E.B. 1965. *Genetic polymorphism*. p17-25. MIT Press 1965.

5.9 SUGGESTED READINGS

- *Majerus, M. E. N. (2003).* **Sex wars: genes, bacteria, and biased sex ratios**. *Princeton University Press. p. 250.* **ISBN 0-691-00981-3**. Retrieved 4 November 2011.
- Beukeboom, L. & Perrin, N. (2014). *The Evolution of Sex Determination*. Oxford University Press. Online resources.

5.10 TERMINAL QUESTIONS

1. What is sex linked inheritance? Discuss its different types.
2. Discuss sex linkage in *Drosophila*.
3. Discuss genetics of colour blindness in man.
4. Discuss different pattern of sex determination.
5. Describe ZZ-ZW system of sex determination.
6. Write note on sex-limited traits.

BLOCK-2 PLANT BREEDING

UNIT-6 BASIC TECHNIQUES OF PLANT BREEDING

Contents:

6.1 OBJECTIVES

After reading this unit you will be able to know:

- Aim of plant breeding
- Objectives of plant breeding
- Techniques of plant breeding

6.2 INTRODUCTION

Plant breeding can be defined as a science as well as an art of improving the genetic makeup of plants in relation to their economic use. Recently plant breeding has been described as a technology of developing superior crop plants for various purposes.

> *"Plant breeding is the art and science of improving the heredity of plants for the benefit of mankind."*
>
> *"Plant breeding deals with the genetic improvement of crop plants also known as science of crop improvement*."
>
> *"Science of changing and improving the heredity of plants."*

6.3 AIM OF PLANT BREEDING

Plant breeding aims to improve the characteristics of plants so that they become more desirable agronomically and economically. The specific objectives may vary greatly depending on the crop under consideration.

History of plant breeding

Plant breeding started with sedentary agriculture and particularly the domestication of the first agricultural plants, a practice which is estimated to date back 9,000 to 11,000 years. Initially early farmers simply selected food plants with particular desirable characteristics, and employed these as progenitors for subsequent generations, resulting in an accumulation of valuable traits over time.

Gregor Mendel's experiments with plant hybridization led to his establishing law of inheritance. Once this work become well known, it formed the basis of the new science of genetics, which stimulated research by many plant scientists dedicated to improving crop production through plant breeding.

Modern plant breeding is applied genetics, but its scientific basis is broader, covering molecular biology, cytology, systematics, physiology, pathology, entomology, chemistry, and statistics (biometrics). It has also developed its own technology.

Some Indian Plant Breeders and their contributions

T.S. Venkatraman - An eminent sugarcane breeder, he transferred thick stem and high sugar contents from tropical noble cane to North Indian Canes. This process is known as noblization of sugarcane.

B.P. Pal - An eminent Wheat breeder, developed superior disease resistant N.P. varieties of wheat.

M.S. Swaminathan - Responsible for green revolution in India, developed high yielding varieties of Wheat and Rice.

Pushkarnath - Famous potato breeder.

N.G.P. Rao - An eminent sorghum breeder.

K. Ramaiah - A renowned rice breeder.

Ram Dhan Singh - Famous wheat breeder.

D.S. Athwal - Famous pearlmillet breeder.

Bosisen - An eminent maize breeder.

Dharampal Singh - An eminent oil-seed breeder.

C.T. Patel - Famous cotton breeder who developed world's first cotton hybrid in 1970.

V. Santhanam - Famous cotton breeder.

Steps of Plant Breeding

The following are the major activities of plant breeding:

1. Collection of variation
2. Selection
3. Evaluation
4. Release
5. Multiplication
6. Distribution of the new variety

6.4 OBJECTIVES OF PLANT BREEDING

1. Higher yield: The ultimate aim of plant breeding is to improve the yield of "*economic produce on economic part"***.** It may be grain yield, fodder yield, tuber yield, cane yield or oil yield depending upon the crop species.

2. Improved quality: The quality characters vary from crop to crop. e.g. grain size, colour, milling quality in barley, colour and size of fruits, nutritive and keeping quality in vegetables, protein content in pulses, oil content in oilseeds, fibre length, strength and fineness in cotton. The production of improved quality of crop plants, like: rice, barley, wheat, etc.

3. Abiotic resistance: Crop plants also suffer from abiotic factors such as drought, soil salinity, extreme temperatures, heat, wind, cold and frost, breeder has to develop resistant varieties for such environmental conditions.

4. Biotic resistance: Crop plants are attacked by various diseases and insects, resulting in considerable yield losses. Genetic resistance is the cheapest and the best method of minimizing such losses.

5. Change in maturity Duration/ Earliness: Earliness is the most desirable character which has several advantages. It requires less crop management period, less insecticidal sprays, permits new crop rotations and often extends the crop area. Maturity has been reduced from 270 days to 170 days in cotton, from 270 days to 120 days in pigeon pea, from 360 days to 270 days in sugarcane.

6. Dormancy: In some crops, seeds germinate even before harvesting in the standing crop if there are rains at the time of maturity, e.g., green gram, black gram, barley and Pea, etc. A period of dormancy has to be introduced in these crops to check loss due to germination. In some other cases, however, it may be desirable to remove dormancy.

7. Desirable Agronomic Characteristics: It includes plant height, branching, tillering capacity, growth habit, erect or trailing habit etc., is often desirable. For.eg. dwarfness in cereals is generally associated with lodging resistance and better fertilizer response. Tallness, high tillering and profuse branching are desirable characters in fodder crops.

8. Elimination of Toxic Substances: It is essential to develop varieties free from toxic compounds in some crops to make them safe for human consumption. For example, removal of neurotoxin in khesari-lentil (*Lathyruys sativus*) which leads to paralysis of lower limbs, erucic acid from *Brassica* which is harmful for human health, and gossypol from the seed of cotton is necessary to make them fit for human consumption. Removal of such toxic substances would increase the nutritional value of these crops.

9. Photo and Thermo insensitivity: Development of varities insensitive to light and temperature helps in crossing the cultivation boundaries of crop plants. Photo and thermo-insensitive varities of wheat and rice has permitted their cultivation in new 7 areas. Rice is now cultivated in Punjab, while wheat is a major *rabi* crop in West Bengal.

10. Wider adaptability: Adaptability refers to suitability of a variety for general cultivation over a wide range of environment conditions. Adaptability is an important objective in plant breeding because it helps in stabilizing the crop production over regions and seasons.

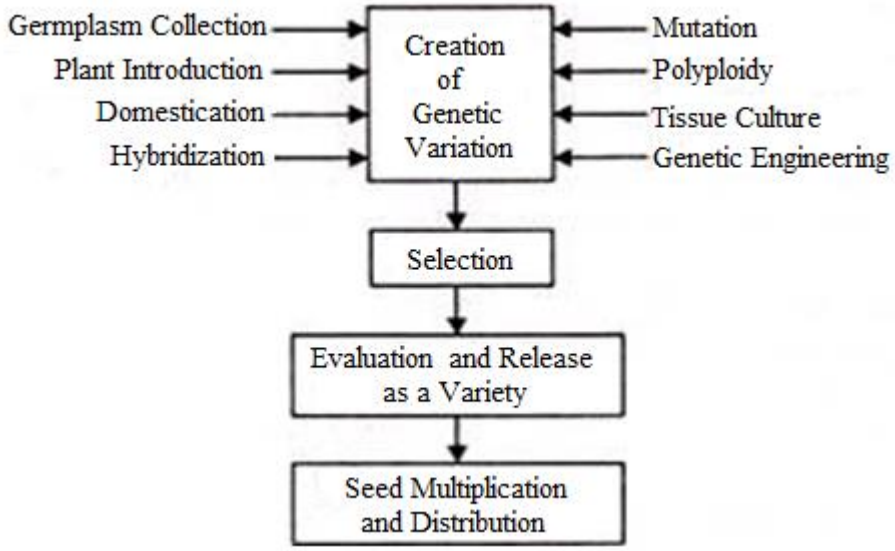
6.5 BASICS TECHNIQUES OF PLANT BREEDING

The various methods of breeding used for crop improvement are as follows:-

1. Domestication
2. Plant introduction
3. Hybridization
4. Polyploidy breeding

5. Mutation breeding
6. Tissue culture technique
7. Genetic engineering

1. Domestication: Domestication is the process of growing plants and keeping animals under human care and management. This is the very first step aimed at increasing food production. Domestication of plants is an artificial selection process conducted by humans to produce plants that have more desirable traits than wild plants, and which renders them dependent on artificial environments for their continued existence. The domestication of wheat provides an example of how natural selection and mutation can play a key role in the process. A large number of agricultural, horticultural and medicinal plants have been domesticated by humans since the beginning of civilization. Crop plants include a long list of food, vegetables, oilseeds, pulses, fodders, fibre and sugar yielding crops.



2- Plant Introduction

(a) It is the process of introducing plants or germplasms either from a foreign country or introducing plants or germplasm from one region to other regions of the same country.

(b) Plant introduction is followed by *acclimatisation*, i.e., the adaptation of an individual plant or a population of plants, under the changed climate. It is an ancient method of crop improvement.

(c) Introduction of plants from a foreign country is called *intercontinental* plant introduction**.**
For example:

(i) Groundnut has been introduced in India from Brazil,
(ii) Rubber has been introduced from South and Central America to India,
(iii) Mexican wheat varieties have been introduced from Mexico to India.

(d) Examples of introduced ornamental plants are innumerable, such as Jacaranda, Bougainvillea, Salvia, Cosmos, Dianthus, Antirrhinum etc.

(e) Introduction of plants from one state of a country to another state of the same country is called interstate plant introduction. For example, N.P. wheat varieties were introduced from Delhi to different states of India.

(f) Purposes of Plant Introduction

(i) For use in agriculture, forestry and industry.
(ii) For genetically improvement of economical crops.
(iii) For studying the origin, distribution, classification and evolution of the plants.

(g) Plant Introduction in India: Following agencies carry out plant introduction in India:

(i) Plant Introduction Division of IARI, New. Delhi,
(ii) Forest Research Institute, Dehradun.
(iii) Botanical Survey of India.
(iv) Some universities, gardens and agricultural departments also play an important role in introducing plants.

Types of plant introduction:

1. **Primary introduction:** Introduction that can be used for commercial cultivation as a variety without any change in the original genotype is referred to as primary introduction. Example- Sonora 64, Lerma Roja. It is also called as direct introduction.
2. **Secondary introduction:** Introduction that can be used as a variety after selection from the original genotype or used for transfer of some desirable gene to the cultivated variety is known as secondary introduction. Example- Kalyan Sona and Sonalika. It is also called as indirect introduction.

Disadvantages of Plant Introduction: Along with economically important plants, introduction of harmful crop diseases, insect pests and weeds also occurs sometimes.

(a) Diseases Introduced

(i) Late blight of potato (*Phytophthora infestans*)
(ii) Fire blight of apple and pear *(Erwinia amylovora*)

(b) Insect Pests Introduced:

(i) Potato tuber moth
(ii) Woolly aphis

(c)Weeds Introduced:

(i) *Argemone mexicana*, Lantana.

All introductions are subjected to quarantine, i.e., they are examined for the presence of insects, weeds and disease-causing organisms, and only those introductions that are free from the above are allowed to enter a country.

3. Hybridization

Hybridization may be defined as *"The mating or crossing of two plants or lines of dissimilar genotype."* The chief objective of hybridization is to create genetic variation. When two

genotypically different plants are crossed, the genes from both the parents are brought together in F1 generation.

Segregation and recombination produce many new gene combinations in F2 and the later generations, i.e., segregating generations. The degree of variation produced in the segregating generations would, therefore, depend on the number of heterozygous genes in the F1. This will, in turn, depend upon the number of genes for which the two parents differ.

If the two parents are closely related, they are likely to differ for a few genes only. But if they are not related, or are only distantly related, they may differ for several, even a few hundred genes. However, it is most unlikely that the two parents will ever differ for all the genes. Therefore, when it is said that the F1 is 100 percent heterozygous, it has reference only to those genes for which two parents differ. The aim of hybridization may be transfer of one or few qualitative characters, improvement of one or more quantitative characters, or use of the F1 as a hybrid variety.

Technique of Hybridization: Before performing hybridisation, a plant breeder should have all the information about the time of flowering, the time when the anther and. stigma are ready for pollination, how long do the pollen grains remain viable, etc.

The actual technique consists of the following steps:

(i) The first step is the selection of parents from the available material possessing desired characters.

(ii) Second step is the selfing of plants to obtain homozygosity in desired characters. This step is not practiced in self pollinated crops because they are already homozygous.

(iii) Third step is emasculation. In this, the anthers are removed before they mature and have shed their pollens. Purpose of emasculation is to prevent self-pollination. It is not practiced in unisexual crops.

(iv) Bagging, tagging and labeling of males as well as females to be used in crosses, is done.

(v) Fifth step is the crossing, in which the pollen from bagged males are dusted on to the bagged female plant.

(vi) Lastly, seeds are collected from the crossed plants after maturity. Seeds are maintained separately and sown in the coming season to raise F generation.

Hybridization in Self-Pollinated Crops: Several methods, like pedigree method, bulk method and back-cross method are in practice.

(a) Pedigree Method: In this method, F1 hybrids possessing desirable characters are selected. The seeds from each plant are collected and grown separately to raise F2 generation. This process is repeated for a number of generations. Finally, the plants with desired characters are recommended for cultivation.

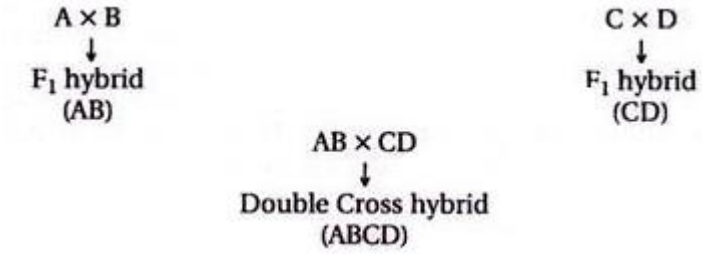
(b) Bulk Method: In this method, F1 hybrids rather than being grown separately are grown in bulk. Seeds, from F2 plants are also sown together and the process continued for 5-6 generations till homozygosity is obtained.

(c) Back-cross Method: F1 hybrids, in this method, are crossed by one of the above mentioned methods. This method is useful in the improvement of both self and cross-pollinated crops.

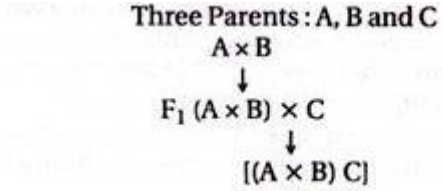
Hybridization in Cross-Pollinated Crops: Several methods like single cross, double cross, top cross and synthetic cross.

(a) Single Cross: It is a cross between two inbreeds. For example, A x B or C x D. The hybrids are distributed directly to farmers for cultivation.

(b) Double Cross: It is a cross between F1 hybrids of two different single crosses.



(c) Three-way Cross: It is a cross between F1 hybrid of a single cross and a third parent which is used as a male parent. For example,



(d) Top Cross: It is a cross between an inbred and an open-pollinated variety.

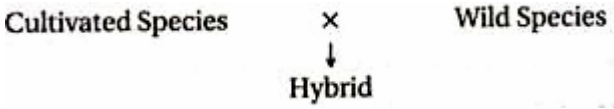
Variety x Inbred

(e) Synthetic Cross: A number of inbreeds are crossed in order to combine different desirable characters into one variety.

Types of Hybridization: There are two types**:** (i) Inter-specific and (ii) Inter-generic.

(i) Inter-specific Hybridization: Here the plants of two different species belonging to the same genus are crossed together. It is also known as intra- generic hybridisation (within the same genus). All the disease, insect, drought and frost resistant varieties in wheat, tomato, sugarcane, etc., have been evolved by this method.

(a) Sugarcane: Two species of sugarcane are cultivated in India-*Saccharum officianarum* in Central and South India, while S. barberi is grown in northern India. Both these species are susceptible to red rot, lodging and drought.



(50% characters of cultivated species, 50% characters of wild species)

It was found that the hybrid shows some bad features of wild species, like no sugar content. So bad characters have to be got rid of. For this, back crossing is carried out. In back

crossing, hybrid is crossed with the cultivated species, which has the characters to more sugar content.

Hybrid × Cultivated Species
(50% cultivated + 50% wild) ↓ (100% cultivated Hybrid)
(75% cultivated + 25% wild)

So by continued backcrossing, canes with high sugar content have been obtained.

(b) Potato: *Solanum rybinii* is a wild diploid species of potato and is resistant to frost and virus infection. Another species *S. tuberosum* is cultivated and tetraploid species. The characters of wild species can be introduced into the cultivated one by hybridisation.

(ii) Inter-generic Hybridization: Crosses made between plants belonging to two different genera constitute inter- generic hybridisation.

(a) Cross between Sugarcane and Sorghum

(b) Cross between Triticum and Secale: By crossing Triticum (wheat) with Secale, inter-generic hybrid Triticale has been evolved.

4. Mutation Breeding: "Mutation is a sudden and heritable change in a character of an organism."

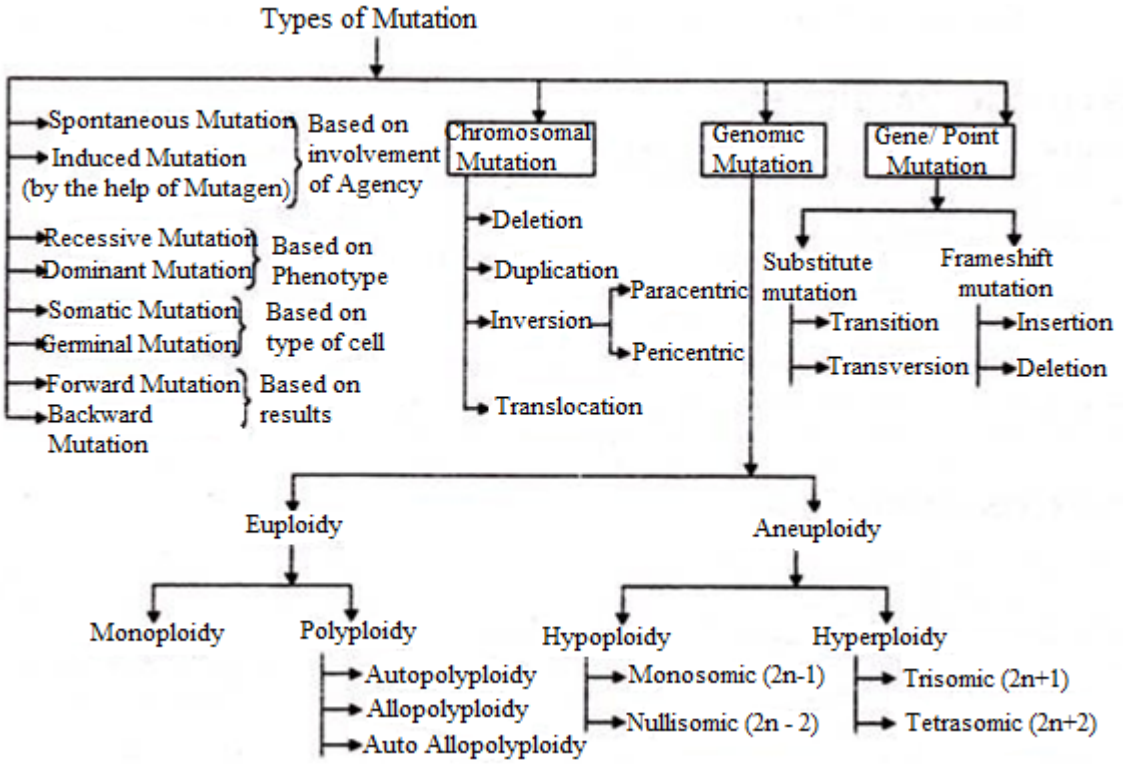
1. A number of crop varieties have been developed through mutation breeding.

2. The first commercial success with induced mutations was reported in 1934 with the release of a new tobacco cultivar 'Chlorina' through X-ray irradiation. The Indian dwarf wheat's which contain the dwarfing gene was from a Japanese cultivar 'Norin- 10', which itself was a mutant.

3. Many varieties of barley contain artificially mutated genes which contribute to reduction in height, increase in yield, insensitivity to day length and resistance to mildew diseases. Sharbati Sonara and Pusa Lerma are two amber grain colour mutants of wheat produced from the red grained Sonara 64 and Lerma Rojo 64A, respectively. A mutant gene that induces semi-dwarfing in rice has been produced by X-ray treatment. Induced mutations have also become recently important in developing parents useful in hybridization programmes. Forty-five rice cultivars have been developed by the year 1982, either by direct radiation or by crossing with induced mutants.

4. Many crop plants are propagated vegetatively even though they can bear seed. Potato, tapioca and sugarcane are classical examples of such crops. In these, genetic improvement is carried out using sexual reproduction but the maintenance of the improved varieties is by cloning. For examples, potatoes are multiplied by tubers, apples by cuttings, and strawberries by runners.

5. Spontaneous mutations in somatic cells of a vegetatively propagated plant are commonly referred to as SPORTS. Such desirable sports occurring in well- adapted, asexually reproducing plants may result in quick improvements such as the colour sports in many apple varieties and superior shrub types in coffee plants.



6. The characters improved through mutation breeding include flowering time, flower shape, fruit shape, changes in oil content, and protein quality.

7. Some of the important limitations of the use of mutation breeding for crop improvement are:

(i) Most induced mutations are undesirable and have no value to the breeder. Many induced mutations are lethal.

(ii) The mutation rate is extremely low and a very large number of plants must be screened to identify the few individuals that may have desirable mutations. It is equally difficult to grow such useful mutants and include them in breeding programmes.

(iii) The stability of a mutant must be thoroughly tested as some mutants have a tendency to revert.

(iv) Most induced mutations are recessive; these have to be in double dose to be expressed phenotypically.

(v) Unless mutations are induced in gametes—especially in pollen—they will not be easily incorporated into the breeding line.

5. Polyploidy: Any organism in which the number of complete chromosome set is higher than the diploid number is called POLYPLOID and the phenomenon is known as polyploidy.

Characteristics of Polyploids: Polyploids are characterized by:

1. Leaves large, thick and deep green.
2. Increase in number of floral parts but poor flowering.
3. Formation of large pollen grains.
4. Fruits and seeds much larger.

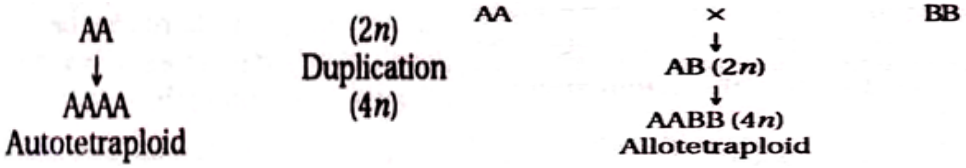
5. Increase in cell size with more prominent nuclei.
6. Increase osmotic pressure of cell sap.
7. High conc. of Ca, Mg & K.

Types of Polyploids: There are two types of polyploids:

(i) **Euploids** are those forms in which the chromosome number has changed in such a way that an organism has an exact multiple of haploid number, such as triploids (3n), tetraploids (4n), pentaploids (5n), hexaploids (6n) and so on.

(ii**) Aneuploids or Heteroploids** are those forms in which the chromosome number has changed in such a way that an organism does not have an exact multiple of the haploid number. For example, 2n-1 (monosomics), 2n-2 (nullisomics), 2n+1 (trisomic), 2n+2 (tetrasomic), and likewise.

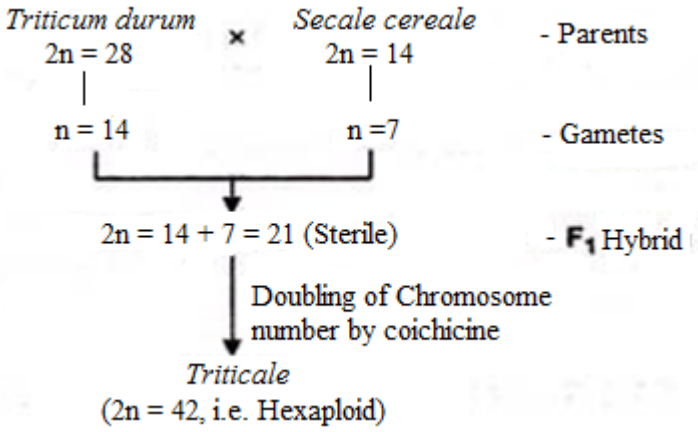
Euploidy has been used in plant breeding and improvement work. **Euploids are of two types: autopolyploids and allopolyploids.**



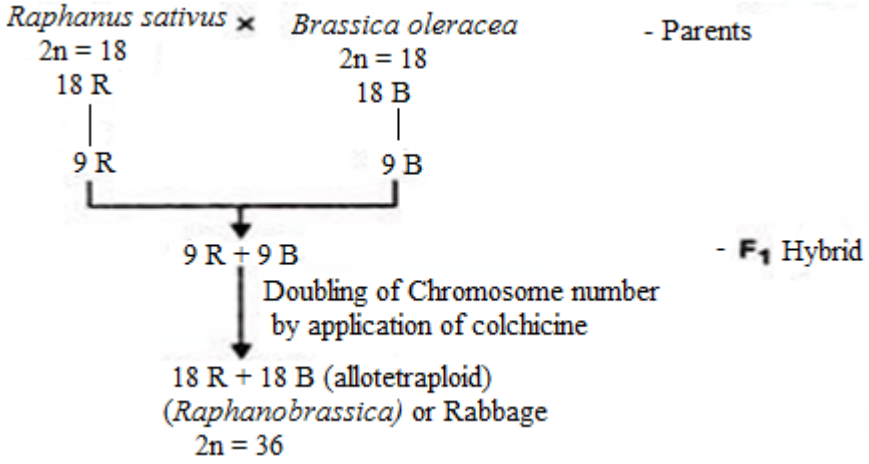
Induction of Polyploidy:

1. Polyploidy in plants can be induced by colchicine treatment.
2. Colchicine is an alkaloid obtained from the corms of Colchicum autumnale (Liliaceae).
3.Colchicine inhibits the formation of the spindle in the dividing cells and hence chromosomes do not separate at anaphase. Thus, a restitution nucleus (it is a nucleus in which the chromosomes have divided but could not separate into two daughter nuclei) is formed. Effect of colchicine is temporary. As a cell recovers from treatment, a new spindle is formed and the restitution nucleus undergoes normal mitosis as a polyploidy cell.

Origin of Triticale: It is a man-made cereal, an allopolyploid between Triticum (wheat) and Secale (rye). The released varieties of Triticale are hexaploid (2n = 42) and have been synthesized by doubling the chromosome complements of sterile hybrids between *T. turgidum* (durum wheat, 2n = 28) and S. cereale (rye, 2n = 14).



Origin of a new genus, allotetraploid: *Raphano brassica* (2n = 36) from diploid parents, viz, *Raphanus sativus* (2n = 18) and *Brassica oleracia* (2n = 18).



6. Selection: Selection is one of the oldest methods for crop improvement. It can be natural or artificial and is possible only if there exist variation in the crop.

(A) Natural Selection acts as a sieve in favour of the well adapted strains and varieties. Natural selection is a rule in nature and has resulted in evolution, according to which only the fittest can survive. All local varieties of crops are the result of natural selection. Many differences between species and sub-species have arisen due to this selection pressure. It is always operating in nature and is one of the natural factors which create variations in the already existing varieties of crops.

(B) Artificial selection involves picking out of the plants having desired combination of characters from a mixed population where the individuals differ in characters. The various methods of artificial selection are:

a. Mass Selection: It is practiced in those plants which are cross-pollinated like Zea, Brassica. In this method, plants are selected based on the phenotypic expression from the mixed population of a crop. Then, the seeds of these selected plants are obtained. All the seeds are mixed in a single lot and therefore, the method is known as mass selection. The seeds so obtained are used for raising the next crop. Again from these plants, selection is made as earlier. This process is continued till the plants show uniformity in the desired characters.

Merits:

(A) It is more of an art than a science because it needs no scientific knowledge.

(B) Simplest, easiest and quickest method of crop improvement.

(C) Pollination need not to be controlled to provide a new variety.

(D) To meet the need of the farmers, it is the only method for improving the local or wild varieties.

Demerits:

(A) Importance is given to phenotypic characters only.

(B) There is no control over pollination, which causes greater heterozygosity and as a result the desirable qualities gradually diminish.
(C) It is not possible to increase the yield because:
(a) Importance is given to material characters only.
(b) Environmental effects cannot be separated out.
(c) Pollination may be both by superior and inferior pollens.
(D) This method of crop improvement is not applicable to self-pollinated crops
(due to less amount of heterozygosity).
(E) In cross pollinated crops variety produced is heterozygous i.e., mixture of different genotypes.

Procedure:

Step I. Seeds of desired plants with similar phenotypes (500-1000) are selected. **(I Year)** harvested and thrashed together.

Step II. Seeds selected in I year are grown in isolated plots compartments **(II Year)** with standard varities as check for comparision. Best performers are selected and other are discarded

Step III. Main yield trials are carried out to determine the performance **(III-V Year)** and adaptation in comparison to standard varieties as check.

Step IV. Trials on the selected seeds are conducted on the experimental **(VI-VIII Year)** forms of regional research stations or cultivators holding for three consecutive years to determine the adaptability of strains in different regions. In the eighth year variety is produced, named and distributed.

b. Pure Line Selection: It is practiced in self-pollinated crops such as wheat, barley, rice, legumes. Here also the selection is made on the basis of phenotypic expression. But the seeds of one plant are not mixed with the seeds of another. So, it involves testing the progeny of single individual plant separately. Selection is again made from the progenies arising from the seeds of a single individual. This method of selection from a single individual is continued till a true breeding type is obtained.

Merits:

1. This is the only method to improve the local varieties of self-pollinated crops. Best genotype for yield, disease resistance, insect resistance, earliness, quality etc. can be isolated from a heterogeneous or mixed population of an old variety.
2. This method is easier than hybridization (emasculation and crossing over)
3. The variety developed by this method is extremely in appearance and performance and, therefore, are more attractive.

4. This method is also used both in self and cross-pollinated crops for production of pure lines and inbreeds.

Demerits:

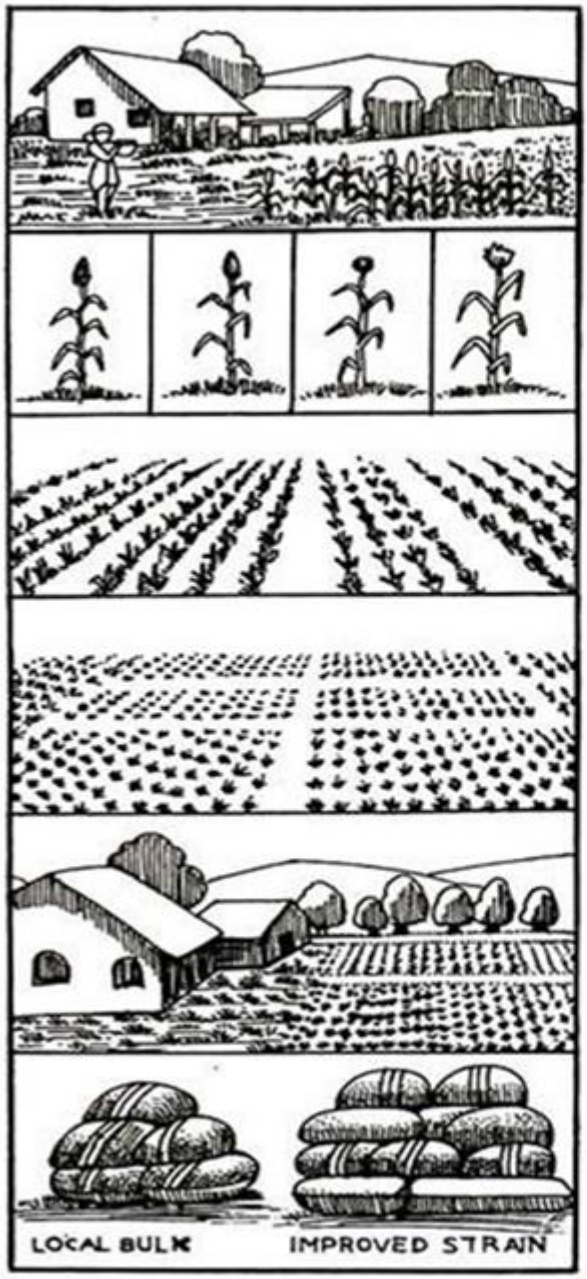
1. It is very lengthy and laborious process.
2. This method is applicable to self-pollinated crops. It cannot be used for development of varieties in cross-pollinated crops.
3. This method can isolate only superior genotypes from the mixed population. It cannot develop new genotypes.
4. Extremely homozygosity may result in low yield and other undesirable characters.
5. Due to high degree of homozygosity, variations among the varieties are also limited. Therefore, their adaptability to varied environmental condition is also poor.

Step I.	At the times of harvest large number of single plants (200-1000) are selected from the mixed population of ryot's field. Produce from individual plants are picked, separated and numbered.	**I Year**
Step II.	20 to 50 seeds of individual plants are grown in individual rows for observations. Defective rows (like susceptibility of diseases) are discarded and the superior, *i.e.*, the desired progenies of rows are harvested. Seeds from plants within each row are composited together and this composite produce of each row becomes an **experimental strain.**	**II Year**
Step III.	Preliminary yield trials are conducted by repeating step II. Desired progenies are selected on final visual observations and seeds are composited separately.	**III Year**
Step IV.	Selected plants of step III are tested in larger plots taking standard checks in replicated plots (These are main trials)	**IV to VI Year**
Step V.	Seeds selected in step IV are multiplied.	**VII Year**
Step VI.	Seed of superior strain is sent to progressive farmers in different regions for district yield trials on riot's field. On the basis of performance, one or two strains are selected, named, multiplied and distributed to the farmers for general cultivation in subsequent years.	**VIII to X Year**

Thus, a breeder by pure line selection renders a particular type, more or less homozygous. Unlike mass selection, here the progeny consists of a uniform population. Pure line lacks variability.

c. Clonal Selection: This method is practiced in vegetatively propagated crops such as banana, potato, onion, citrus, etc. Clones are plants propagated vegetatively from a single individual. The genotypic constitution of plants propagated in this way is not likely to change.

Here in, superior clones are selected on the basis of their phenotypic characters. The selection is always between clones and never within a clone, as all the individuals of a clone have the same genetic constitution.



Royl's Bulk

The Bulk is a mixture of types and can be sorted out. Single plants are selected.

The single plants are sown individually and tested for purity.

The promising ones are later tested for yield in bigger plots using the local types as standard for comparison

The yield trials are also conducted in the royl's fields

Improved selection is released as a strain from the research station.

Fig.6.1 Diagram to illustrate the various steps involved in pure line selection

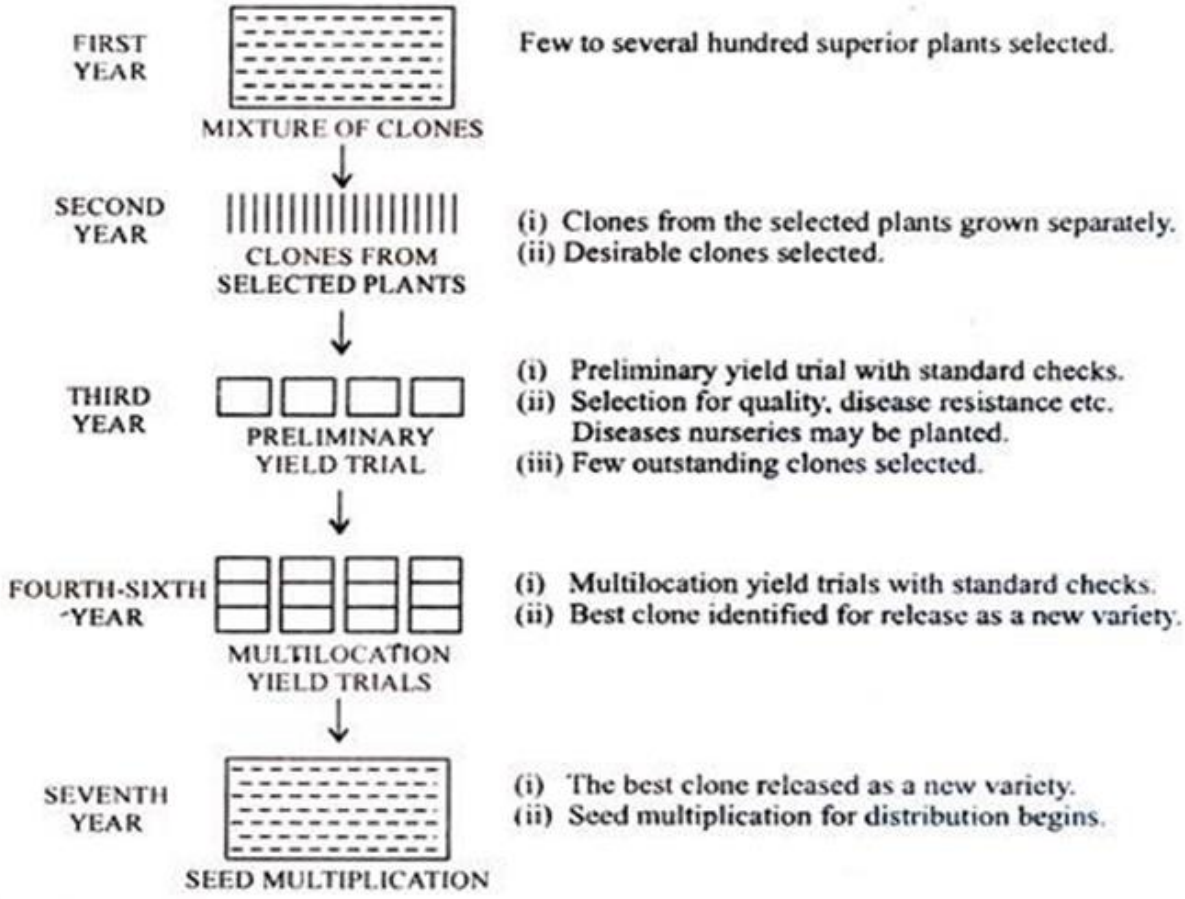


Fig.6.2 Procedure of clonal selection in asexually propagated crops. This method of selection applies to a crop in which one generation does not take more than one year.

Merits:

i. It is the only method to improve the clonal crops.
ii. It offers an opportunity to exploit desirable mutations in somatic parts of plants.
iii. It also helps to eliminate unproductive and undesirable types.
iv. This method is helpful in conserving hybrid vigour for several generations.
v. Varieties are as stable as pure lines and easy to maintain because there is no danger of deterioration due to segregation and recombination.

Demerits:

(i) In this method no new genetic variability can be created.
(ii) This method is applicable only to vegetatively propagated crops.

Achievements:

(i) New varieties of potato like Kufri red and Kufri safed; Pedda Nelum in mango- Pidi Monthan; Bombay green, high gate in Banana etc.

7. Plant Tissue Culture in Crop Improvement Programme: Lately, the tissue culture technology has played a very crucial role in crops improvement programme.

Essentially the methodology of tissue culture consists of separating cells, tissues or organs of a plant and growing them aseptically in suitable containers on a nutrient medium under controlled conditions of temperature and light. The cultured parts (termed explants) require a source of energy (usually sucrose), salts, providing macro-and microelements, a few vitamins and generally the amino acid, glycine, in the nutrient medium. The amounts and the nature of salts used vary as there are several formulations developed by different scientists. Hormones and mixtures of substances such as yeast extract, coconut water, bean seed extract are included in the medium by some workers. An excised embryo or a shoot bud may develop into a whole plant. Pollinated ovaries have also been grown to mature fruits. Nevertheless, portions of organs or tissues generally give rise to an unorganized mass of cells called CALLUS.

In the early 1950's Skoog and Miller showed that shoot or roots can be induced in the callus (organogenesis) by an appropriate balance of amounts of cytokinin and auxin in the medium. We now know that the type of growth response in tissue cultures depends on the source of the explants, composition of the medium and conditions in the culture room.

The following are the benefits of tissue culture in crop improvement:

1. Rapid multiplication of desired plants (Micro propagation)
2. Multiplication of rare plants which reproduce through seeds with great difficulty.
3. To rescue embryos which fail to reach maturity.
4. Multiplication of sterile hybrids.
5. Production of virus-free plants.
6. Protoplast fusion or somatic hybridization.
7. To shortern the period for development of new varieties of plants.
8. To induce weedicides resistance in plants.
9. Induction and selection of mutants.
10. Somoclonal variation and DNA recombinant technology.

There are a few other uses of plant tissue culture such as production of artificial seeds, and germplasm storage and exchange.

8. Genetic Engineering and Biotechnology in Plant Breeding:

"Genetic engineering is a term used for the directed manipulation of genes, i. e. The transfer of genes between organisms or changes in the sequence of a gene."

The latest interest in crop improvement is not to involve whole genome (as in conventional plant breeding or in protoplast fusion). The objective of genetic engineering or recombinant DNA technology is to introduce one or more genes into an organism that normally does not possess them. This requires isolation of a fragment of DNA corresponding to a desirable character (or function), inserting it into a vector (such as the plasmid in a bacterium, *Agrobacterium tumifaciens*), and transferring it to a cell.

Genetic transformation is also possible through co-cultivation (incubating recipient protoplast with purified DNA), electroporation (by applying high electric potential for a few micro-seconds to change the porosity of protoplast to take up DNA) and by micro-injection of DNA

into the cell by fine needles. Although the above account may sound simplistic and exciting, there are several obstacles in realizing the objectives.

Successful genetic engineering requires identification of the desired genes, their transfer to the cells of a target crop plant, their integration and expression. We know a good deal about genome organisation in a prokaryotic organism such as *E. Coli.* However, the genetic material of the eukaryotes is quite complex. Our present knowledge of the location and function of the specific genes in crop plants is so poor that genetic engineering is still very problematic. Each crop plant contains one to ten million genes. Detailed study of genome organisation is needed for major crops and their wild relatives.

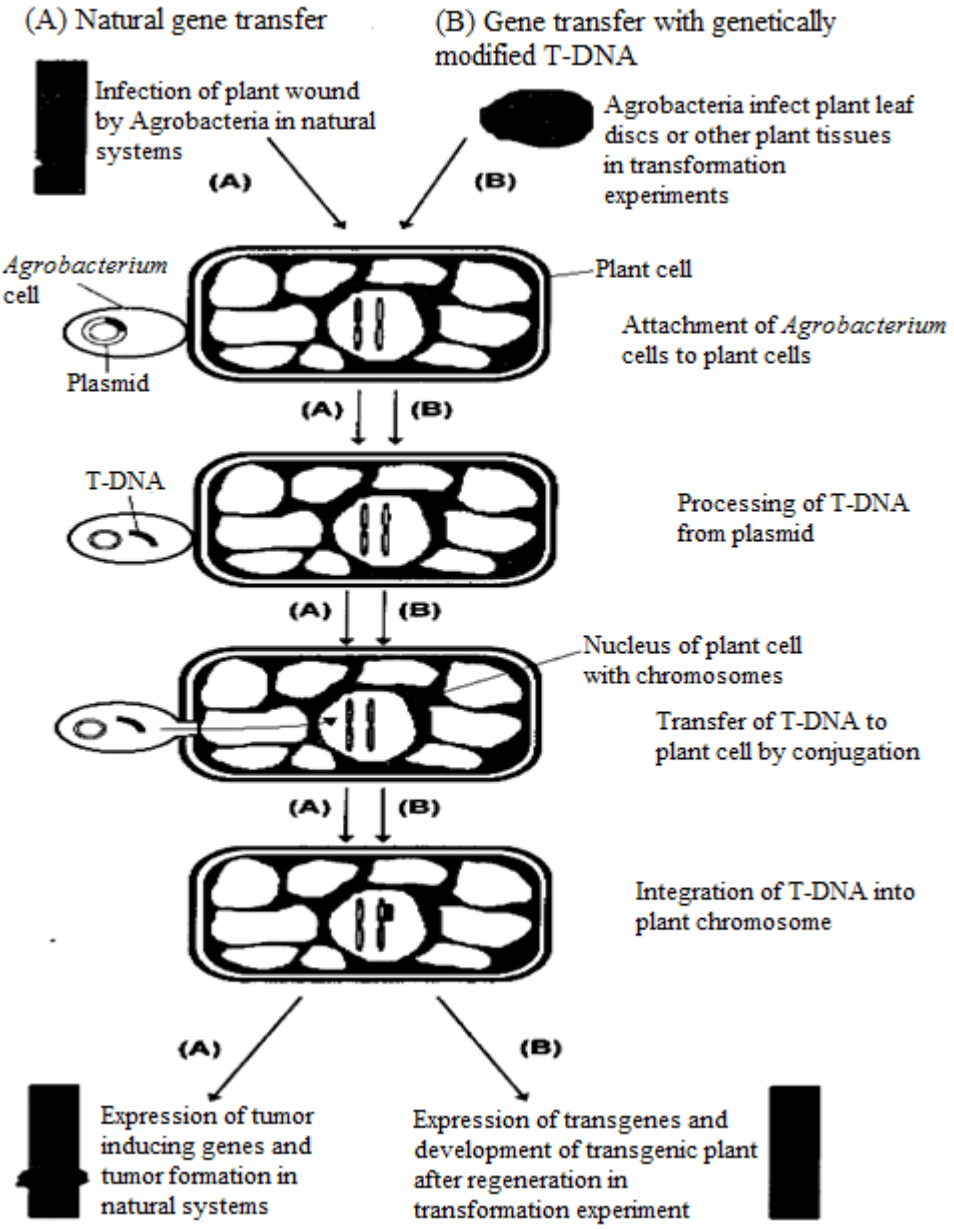


Fig. 6.3 (A) Natural gene transfer, (B) Gene transfer with genetically modified T-DNA

Gene transfer method: In the direct gene transfer methods, the foreign gene of interest is delivered into the host plant cell without the help of a vector. The following are some of the common methods of direct gene transfer in plants:

(a) Chemical mediated Gene transfer- Certain chemicals like polyethylene glycol (PEG) and dextran sulphate induce DNA uptake into plant protoplasts.

(b) Microinjection- Here the DNA is directly injected into plant protoplasts or cells using fine tipped glass needle or micropipette.

(c) Electroporation-In this case, a pulse of high voltage is applied for protoplasts/cells/tissues, which makes transient pores in the plasma membrane which facilitates the uptake of foreign DNA.

(d) Particle Gun- In this method, the foreign DNA is coated (precipitated) on to the surface of minute gold or tungsten particles (1-3 micrometer) and bombarded (shot) on to the target tissue or cells using a particle gun (also called as gene gun/shot gun/micro projectile gun).

Transgenic Breeding: Individuals which are developed through genetic engineering are called transgenic. A transgenic may be a plant, an animal or a microbe. Foreign genes present in a modified organism is called transgene. Transgenic plants contain transgenes. Using techniques of genetic engineering and biotechnology, useful genes can now be transferred into plants from a wide range of organisms including unrelated plant species, microbes, animals and from DNA synthesized in the laboratory. In the development of transgenic, sexual process is bypassed.

Transgenic plants have been developed in various field crops, such as wheat, barley, oat, maize sugarcane, rapeseed, soybean, peanut, cotton, tobacco, tomato, potato, sunflower etc. BT-cotton, a transgenic, is now successfully grown by farmers in India. BT-cotton is insect resistant and high yielding. Some of the most outstanding limitations of transgenic breeding are that polygenic characters cannot be manipulated, instable performance, low frequency and costly method of crop improvement. In-spite of many limitations and practical difficulties, genetic engineering offers immense possibilities for improving crops that were unthinkable before.

Improved Seed: The primary objective of plant breeding is to develop superior varieties of crops. The benefits from superior varieties can only be realized when they are grown commercially on a large scale. Seeds of improved varieties must be multiplied at a large scale in order to make them available to farmers for large scale cultivation. Here the word "seed" refers to seed or any other propagating material used for raising a crop. For example, grain produced for general consumption is not seed; only grain produced for raising a crop would be known as 'seed'.

On the other hand potato tubers produced for planting a new crop are known as seed potato. During multiplication of varieties for use as seed, it is essential that genetic purity of the variety must be maintained. If the genetic purity is not maintained, superiority of the variety is likely to be lost. In addition, for best results the farmer should use new pure seed every year in case of self-pollinated crops, and every year (hybrid varieties) or every few years (composite and synthetic varieties) in case of cross-pollinated crops. This would require

maintenance of seeds of superior varieties in genetically pure state, which would be multiplied every year to supply new seed to the farmers.

The improved seed has four classes:
(1) Breeder seed
(2) Foundation seed
(3) Registered seed
(4) Certified seed
The seed produced by the breeder who developed the variety, or by the institution where the variety was developed is the breeder seed. Foundation seed is the progeny of the breeder seed and is used to produce registered seed or certified seed.
Certified seed is grown by various agencies and is certified for use as seed by the State Seed Certification Agency.

The requirements of good seed are:
(1) Genetic purity
(2) Physical purity
(3) Good germination
(4) Freedom from weed seeds
(5) Freedom from diseases, and
(6) An optimum moisture level
The minimum standards for certification vary to some extent from one crop to another. To ensure availability of pure seed of different crops to farmers, elaborate seed programmes (production and distribution) exist in most of the countries. Our country also has a well-organized seed production and distribution programme in the form of National Seeds Corporation (NSC), State Seeds Corporation (SSC) and State Seed Certification Agency (SSCA). These organizations are responsible for seed certification and its distribution.

6.5 SUMMARY

1. Plant breeding programs begin by selecting plants with superior characteristics.
2. In traditional breeding programs commercial cultivars are produced by a series of crossing and selections.
3. New cultivars can be produced by genetic engineering.
4. The commercial rights of plant breeders are protected by legislation.

6.6 GLOSSARY

Plant Breeding: A science, an art and a technology which deals with genetic improvement of crop plants in relation to their economic use for mankind, also called as crop improvement.
Breeding Techniques: Various breeding procedures which are used for genetic improvement of crop plants in relation to their economic use.

Domestication: The process of bringing wild plants under human management referred to as plant domestication.

Plant Introduction: Transposition of crop plants from the place of their cultivation to suchareas where they never grown.

Exotic Variety: A foreign variety which is directly recommended for cultivation.

Acclimatization: Adaptation of an introduced variety to the new environment.

Selection: The process that favours survival and further propagation of some plants having more desirable characters than others. It is of two types, *viz.*, natural and artificial.

Pureline Selection: Development of new variety through identification and isolation of a single best plant progeny.

Mass Selection: A method of crop improvement in which individual desirable plants are selected on the basis of phenotype from a mixed population, their seeds are bulked and used to grow the next generation (positive mass selection). Sometimes, only undesirable off type plants are removed from the field and rest are allowed to grow further (negative mass selection).

Clone: Progeny of a single plant obtained by asexual reproduction.

Clonal Selection: A procedure of selecting superior clones from the mixed population of asexually propagated crops such as sugarcane, potato etc.

Hybridization: Crossing between genetically dissimilar plants. It may involve two genotypes of the same species (intervarietal hybridization) or two species of the same genus (interspecific hybridization) or two genera of the same family (intergeneric hybridization).

Mutation: Sudden heritable change in the phenotype of an individual or permanent change in the number, kind and sequence of nucleotides in the genetic material.

Polyploidy: An organism or individual having more than two basic or monoploid sets of chromosomes is called polyploid and such condition is known as polyploidy.

Heteroploidy: Any changes in the chromosome number from the diploid state.

Euploidy: Numerical change in the entire genome.

Autopolyploids: Polyploids which originate by multiplication of chromosomes of a single species.

Allopolyploid: A polyploid individual which combines complete genomes from two or more species.

Interspecific Hybridization: Crossing between two different species of the same genus. Such crosses are called interspecific crosses.

Intergeneric Hybridization: Crossing between two different genera of the same family. Such crosses are called intergeneric crosses.

Biotechnology: A technology based on the knowledge of life process which is used for mass production of useful substance/products for industry, medicine and agriculture. Various branches of biotechnology are animal biotechnology, medical biotechnology, industrial biotechnology, environmental biotechnology and plant biotechnology.

Tissue culture: The growth of tissues of living organisms in a suitable culture medium (in vitro).

Explant: The plant part which is used for regeneration in culture medium.

Callus: A mass of unorganized regenerated cells in culture medium.

Somaclonal Variation: The variability generated by the use of tissue culture.
Genetic Engineering: Isolation, introduction and expression of foreign DNA in plants and animals.
Transgenic plants: Genetically engineered plants.
Protoplast: Naked cells without cell wall.
Transgenic Breeding: Genetic improvement of crop plants, domestic animals and useful micro - organisms through biotechnology.

6.7 SELF ASSESSMENT QUESTIONS

6.7.1 Very short type questions:

1. Which selection methods will be suitable for maintaining purity of a variety in a self pollinated crop?
2. Name two vegetatively grown crops where interspecific hybrids are used for Clonal Selection.
3. Triticale is which type of cross?
4. Name the method of rapid multiplication of desirable plants.
5. By which method genes are transferred into an organism?
6. Famous cotton breeder who developed world's first cotton hybrid in 1970.
7. Name the chemical, used to induce polyploidy.

6.7.2 Objective type questions:

1. Polyploidy is induced through
(a) Irradiation (b) Mutagenic chemicals
(c) Ethylene (d) Colchicine

2. The quickest method of plant breeding is
(a) introduction (b) Selection
(c) Hybridisation (d) Mutation Breeding

3. The new varieties of plants are produced by
(a) Introduction and mutation (b) Selection and hybridisation
(c) Mutation and Selection (d) Selection and Introduction

4. Pure line breed refers to
(a) heterozygosity only (b) homozygosity only
(c) homozygosity and self assortment (d) heterozygosity and linkage

5. Bagging is done to
(a) Aavoid cross pollination (b) Avoid self pollination
(c) Achieve desired pollination (d) Prevent contamination from foreign pollen

6. Which of the following is a cross pollinated crop

(a) Wheat (b) Rice

(c) Ground nut (d) Maize

6.7.3 Fill in the blanks:

1. ----------refers to unorganized mass of cells, which are generally parenchymatous in nature.
2. Triticale is a new variety of plant produced by cross breeding of _____.
3. Commonly used technique in plant breeding is_____.
4. No single plant progenies are grown during_____.
5. _____refers to sudden heritable change in the phenotype of an individual.

6.7.4 True/False

1) Mass selection cannot be practiced in cross pollinated crops.
2) One of the disadvantages of all selection methods of plant breeding is that no variability can be introduced or generated due to recombination.
3) For transfer of a simple inherited trait, back cross method is normally used.
4) Hybrid varieties are never produced in self pollinated crops.
5) Explant is used for regeneration in culture medium.

6.7.1 Answer Key: **1.** Mass selection, **2.** Potato and sugarcane, **3.** Intergeneric, **4.** Micropropagation, **5.** Genetic Engineering, **6.** C.T. Patel, **7.** Colchicine

6.7.2 Answer Key: 1. (d), 2. (d), 3. (b), 4. (b), 5. (d), 6. (d)

6.7.3 Answer key: 1-callus, 2- Wheat plant and rye plant, 3- Hybridization, 4- Mass selection, 5- Mutation

6.7.4 Answer key: 1- False, 2- True, 3- True, 4- False, 5- True

6.8 REFERENCES

- Breeding Field Crops. 1995. Sleper and Poehlman. Page 3
- Piperno, D. R.; Ranere, A. J.; Holst, I.; Iriarte, J.; Dickau, R. (2009). "Starch grain and phytolith evidence for early ninth millennium B.P. maize from the Central Balsas River Valley, Mexico". PNAS. 106 (13): 5019–5024. doi : 10.1073/ pnas.0812525106 . PMC 2664021 . PMID 19307570 .
- Deppe, Carol (2000). Breed Your Own Vegetable Varieties. Chelsea Green Publishing. |page=237-244
- "Plant breeding".
- Spring Seed Catalogue 1899, Gartons Limited
- Noel Kingsbury (2009). Hybrid: The History and Science of Plant Breeding . University of Chicago Press. p. 140.
- Suzie Key; Julian K-C Ma & Pascal MW Drake (1 June 2008). "Genetically modified plants and human health" . Journal of the Royal Society of Medecine. pp. 290–298. Retrieved 11 March 2015.

- Davis, D.R.; Epp, M.D.; Riordan, H.D. (2004). "Changes in USDA Food Composition Data for 43 Garden Crops, 1950 to 1999". Journal of the American College of Nutrition . 23 (6): 669–682. doi 10.1080/07315724.2004.10719409 .
- Costa-Font, J.; Mossialos, E. (2007). "Are perceptions of 'risks' and 'benefits' of genetically modified food (in)dependent?". Food Quality and Preference . 18 : 173–182. doi : 10.1016/j.foodqual.2005.09.013 .
- Connoly, Kate (2009-04-14). "Germany deals blow to GM crops" . The Guardian. Retrieved 2009-06-25.
- a b Murphy, Kevin M.; K.G. Campbell; S.R. Lyon; S.S. Jones (2007). "Evidence of varietal adaptation to organic farming systems". Field Crops Research . 102 (3): 172–177. doi : 10.1016/j.fcr.2007.03.011 .
- a b c Lammerts van Bueren, E.T.; S.S. Jones; L. Tamm; K.M. Murphy; J.R. Myers; C. Leifert; M.M. Messmer (2010). "The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review". NJAS- Wageningen Journal of Life Sciences . 58 (3–4): 193–205. doi : 10.1016/j.njas.2010.04.001 .
- Lammerts van Bueren, E. T.; G. Backes; H. de Vriend; H. Ostergard (2010). "The role of molecular markers and marker assisted selection in breeding for organic agriculture". Euphytica. 175 : 51–64. doi : 10.1007/s10681-010-0169-0 .
- Oldeman, l (1994). "The global extent of soil degradation" (PDF). Soil resilience and sustainable land use . 32 (5967): 818–822. Retrieved 7-11-2013. Check date values in: |access-date= (help)
- Tester, Mark; Langridge, Peter (February 2010). "Breeding technologies to increase crop production in a changing world" . Science . AAAS: American Association for the Advancement of Science. 327 (5967): 818–822. doi : 10.1126/ science.1183700 .
- Haddad, Lawrence ; Godfray, H.Charles J.; Beddington, John R.; Crute, Ian R.; Lawrence, David; Muir, James F.; Pretty, Jules; Robinson, Sherman; Thomas, Sandy M. and Toulmin, Camilla (12 February 2010). "Food security: the challenge of feeding 9 billion people" . Science. AAAS: American Association for the Advancement of Science. 327 (5967): 812–818. doi : 10.1126/ science.1185383 . PMID 20110467 . Cite uses deprecated parameter |coauthor= (help)
- Bänziger (2000). "Breeding for drought and nitrogen stress tolerance in maize: from theory to practice" . From Theory to Practice : 7–9. Retrieved 7-11-2013. Check date values in: |access- date= (help)

6.9 SUGGESTED READINGS

- General Plant Breeding by A.R. Dabholkar
- A text book of Plant breeding, by B.D. Singh, Kalyani publication, Ludhiana
- Cell Biology, Genetics and Plant Breeding by P.C.Trivedi
- Plant Breeding by Sandhu S.S.

6.10 TERMINAL QUESTIONS

6.10.1 Long Answer Type Questions

1. What is plant breeding? Describe briefly the various objective of Plant Breeding with suitable examples.
2. Discuss the various selection methods of plant breeding.
3. Write down the various steps involve in hybridization. What are the methods of hybridization in self-pollinated and cross-pollinated crops.
4. **a)** What do you understand by the plant introduction.
   b) What is the purpose of plant introduction.
   c) Agencies carry out plant introduction in India.
   d) Disadvantages of plant introduction.
5. Write on the following:
   a) Name of different techniques of plant breeding
   b) Steps of plant breeding
   c) Aim of plant breeding
   d) Domestication
   e) Callus
   f) Explant
   g) Transgenic
   h) Transgenes
   i) Transgenic breeding
   j) Examples of transgenic breeding.

6.10.2 Short Answer Type Questions

1. What is mutation breeding? What is its limitations for crop improvement?
2. What is polyploidy? Write its characteristics and types.
3. What is tissue culture? What are its advantages.
4. What is hybridization? Mention its different types.
5. What are direct gene transfer? What are the methods of direct gene transfer?
6. Give the contributions of the following scientists:
   a) T.S. Venkataraman
   b) B.P. Pal
   c) M.S. Swaminathan
   d) Gregor Mendel
   e) C.T. Patel.

UNIT-7 CROP IMPROVEMENT

Contents:

7.1 OBJECTIVES

After reading this unit students will be able to:

- Undearstsand plant breeding.
- study of different breeding techniques.
- know importance of different plant breeding methods.

7.2 INTRODUCTION

The main object of plant breeding is to produce the new and higher vigor, disease resistant crop varieties superior in all aspects as compared to the existing types. To achieve these objectives different crop methods are applied by plant breeders and agronomists. The process of plant breeding is assumed about 7,000 years ago with the beginning of human civilization. Domestication of wild species under human management is used as source of food. Since beginning the human beings used nomadic practices and it helped the movement of cultivated plant species. Various approaches viz. selection, hybridization, mutation etc. that are used for genetic improvement of crop plants are referred to as plant breeding methods or plant breeding procedures or plant breeding techniques. The choice of breeding methods mainly depends on the mode of pollination, mode of reproduction, gene action and breeding objectives of crop species.

Various breeding procedures that are more commonly used for the genetic improvement of various crop plants are known as general breeding methods. Such breeding methods include introduction (pureline selection, mass selection, progeny selection etc.), hybridization (pedigree, bulk and back cross methods), heterosis breeding, synthetic and composite breeding. Similarly, there are some other breeding methods, rarely used for improvement of crop plants are referred to as special breeding methods, including- mutation breeding, polyploidy breeding, wide crossing or distant hybridization and biotechnology.

7.3 CROP IMPROVEMENT METHODS

The main object of plant breeding is to produce the new and high vigor, disease resistant crop varieties superior in all aspects as compared to the existing types. To achieve these objects different crop improvement as below-

A. Selection

B. Hybridization

C. Plant Introduction and acclimatization, and

D. Mutation Breeding

All these methods have been dealt in this unit only in brief while a detailed account of each has been given in the text separately.

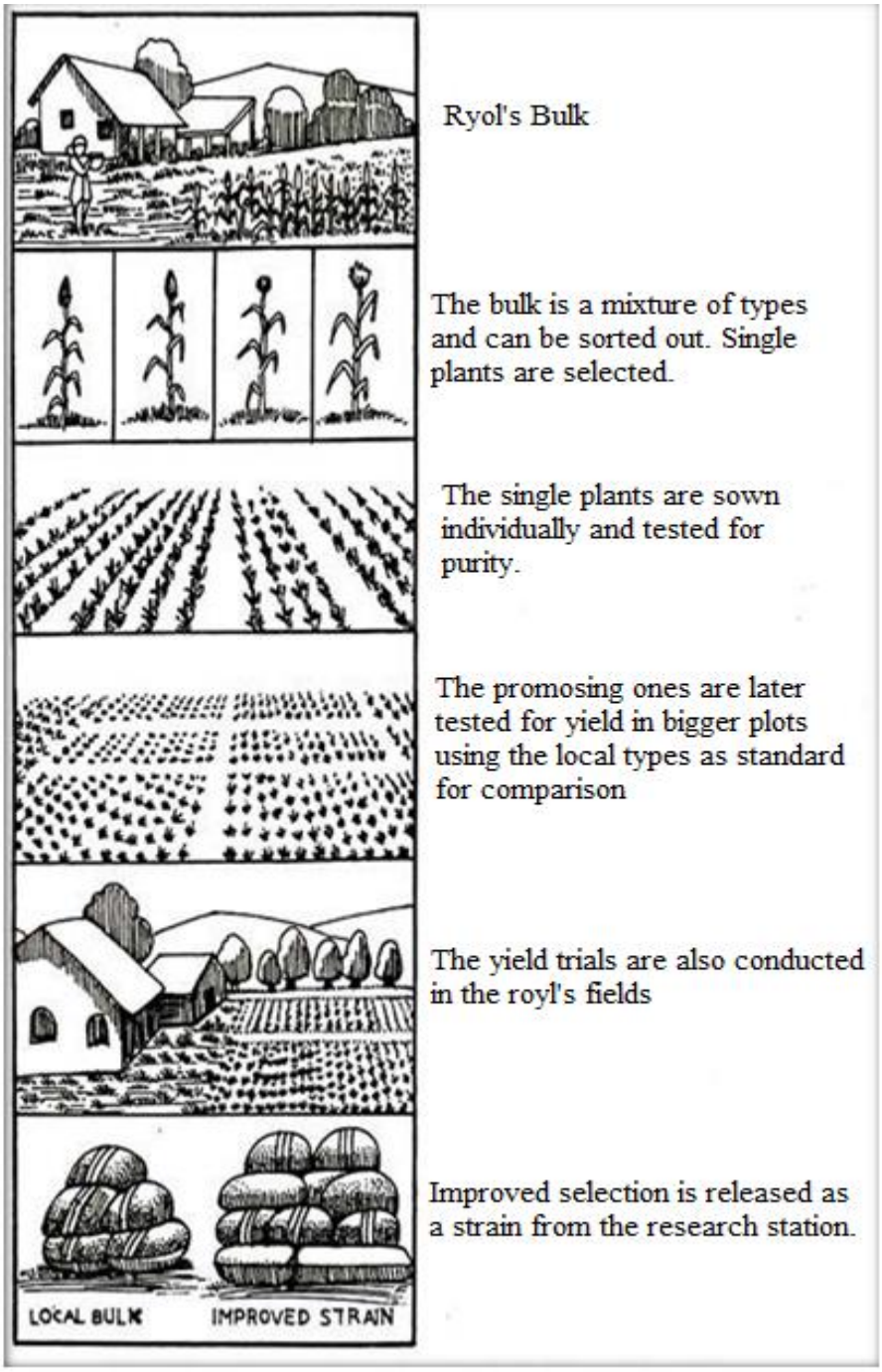


Fig.7.1 Schematic presentation of Crop Improvement Methods

A. Selection: Plant improvement is an ancient art or science started with the primitive man changing his mode of life from a nomad to agriculturists and might have the first crop from nature in wild form or he had never sown the seeds to ensure the first crop. So to obtain his first crop he unconsciously might have practiced the selection by selecting the best one. It is therefore, the oldest breeding method and is the basis of all crop improvements. It is the most common and popular method of crop improvement among the cultivators even today divided into two categories.

a. Natural selection and

b. Artificial selection

Fig.7.2 Presentation of different methods of plant breeding

a. Natural Selection: Natural selection as clear from its name that this selection is a rule in the nature that nature selects the best and fittest for future and discarded the inferior through evolution. According to natural law the fittest can survive and rest wipe out. This has given the cultivated crop and forms ecotypes in plants. Bases on climatic or regional specialties forms climatic or regional races are the basis of artificial selection and hybridization. Though this process local varieties of crops are produced. Sometimes many differences have arisen between species and sub- species due to selection pressure. It remains always operating in nature and is one of the natural factors resulted variations in the already existing varieties of crop in the nature. Besides natural selection, crop breeders and agriculturists also practiced artificial methods for selection and known as artificial selection.

b. Artificial Selection: The cultivators and plant breeders select special types of plants from the mixed population of crops for their own advantages. This type of selection is known as artificial selection and can be defined as "selection as to choose certain individual plants for the purpose of having better crop from a mixed population where the individuals differ in characters".

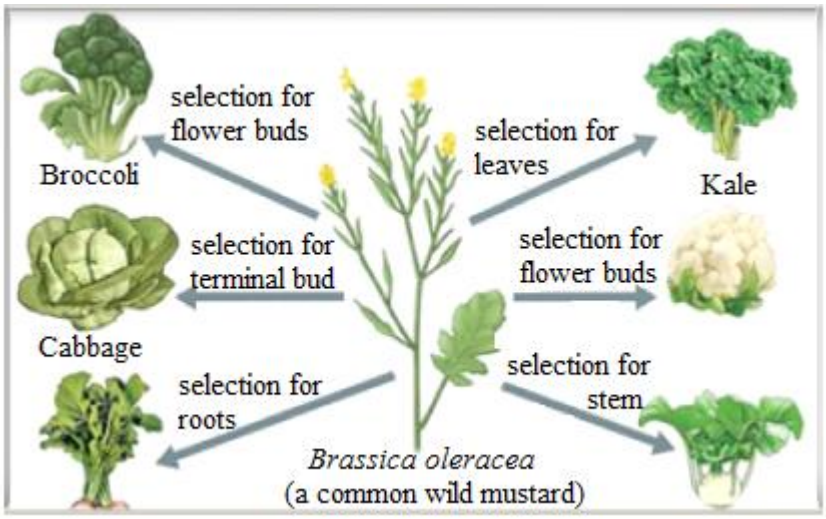


Fig. 7.3 Origin of different crops of Mustard family

Artificial selection is further categorized into two sub- divisions on the basis of nature of crop selection among a mixed population. It may be as below-

i. Mass selection

ii. Pure- line selection and

iii. Clonal selection.

In nature there is continuous selection by natural forces like temperature, soil, weather, pests, diseases**,** etc. The genotype which is more suited to a given environmental conditions leave behind others which are less adaptive in nature. The procedure selection involves the retention of superior phenotypic plants from mixed population. This can be done in different ways in different crops.

(i) Mass Selection: When a large number of plants of similar phenotypes are selected and their seeds are mixed together to constitute a new variety is called mass selection. The population obtained from the selected plants would be more uniform than the original or existing population. It is followed in both self- defective and cross- pollinated crops. Collecting and selecting the best, healthy and more vigorous plants or seeds from the mixed population of crop. All the selected plants are thrashed together and obtained a mixture of seeds. This mixture of seeds is a mass so, this method is known as mass selection. The mixture of seeds sown and raise a new crop. Again in the next year selection is made similarly by adopting the selection of best ones in the next year. This practice of selection is continued till the plants show uniformity in the desired characters and constitute a new variety. Mass selection cannot if the population is already uniform. Thus mass selection is based upon the presence of variability in the population. As a general rule it is known that greater the variability better are the results of selection. The new varieties developed by mass selection is more or less pure or similar in external features because the plants are selected on the basis of external or phenotypical characters which may be easily observed and used in identifications.

Thus by using this method a number of varieties had been obtained and some of the outstanding strains till recently were the products of this selection.

The purpose of mass selection in case of self- pollinated crops, mass selection procedure has following objectives-

a. Improvement of local varieties.

b. Purification of existing pureline varieties and

c. Production of new varieties from heterogenous local, land races.

Merits and Demerits:

1. In this method since a large number of plants are selected hence the variety is more stable in performance over different environment as it is more adopted than a single pureline selection. Thus the varieties developed through mass selection are more widely accepted than pureline.

2. This method is less labor consuming extensive and prolonged field trials are not necessary and hence reduces the time and cost needed for developing a new variety.

3. Mass selection retains considerable genetic variability and no another mass selections after few years improves the variety.

4. This method can be applied to cross pollinated crops.

5. This method utilized only the variability which is already exists in the population improvement is done only through selection. So the limitation is that it cannot generate new genetic variability.

Achievements

Mass selection is effective when the population has the following characters-

a. The characters should be highly heritable in nature.

b. High genetic variability for different traits.

c. The crop is strictly grown under low population density.

(ii) Pure-line Selection

Comparatively to mass selection in pureline selection a large number of plants are selected from a population of self- pollinated crops, harvested individually and their individual progenies are cultivated separately and are evaluated and the best progeny is released as a pureline variety. Thus a pureline consists of a progeny of a single self- fertilized homozygous plant and is used for developing a variety. This method of production of a variety from the pure- line is known as pure- line selection. It is used in the mixed population of self-pollinated crops. In this method the progeny of single individual plants tested separately. Usually large number of single plants are selected and then progeny compare and to save the single most valuable progeny as a new variety for future. Therefore, this method is not materially different from mass selection except that comparatively to mass selection, in this method fewer plants are selected and each selected plant is tested separately. Thus the variety developed through pure- line selection is genetically pure and more durable than the previous

one. This method is not only practiced for self- pollinated crops but also in cross- pollinated crops during hybridization for production of pure- lines to serve as the parents in crossing.
As referred previously that the pure- line is a progeny of a single homozygous self- pollinated plant. In self- pollinated crops pureline selection method has several applications as below-
a. It is more favorite method of improvement of local varieties which have considerable genetic variability.
b. Pure- line selection for introduced varieties.

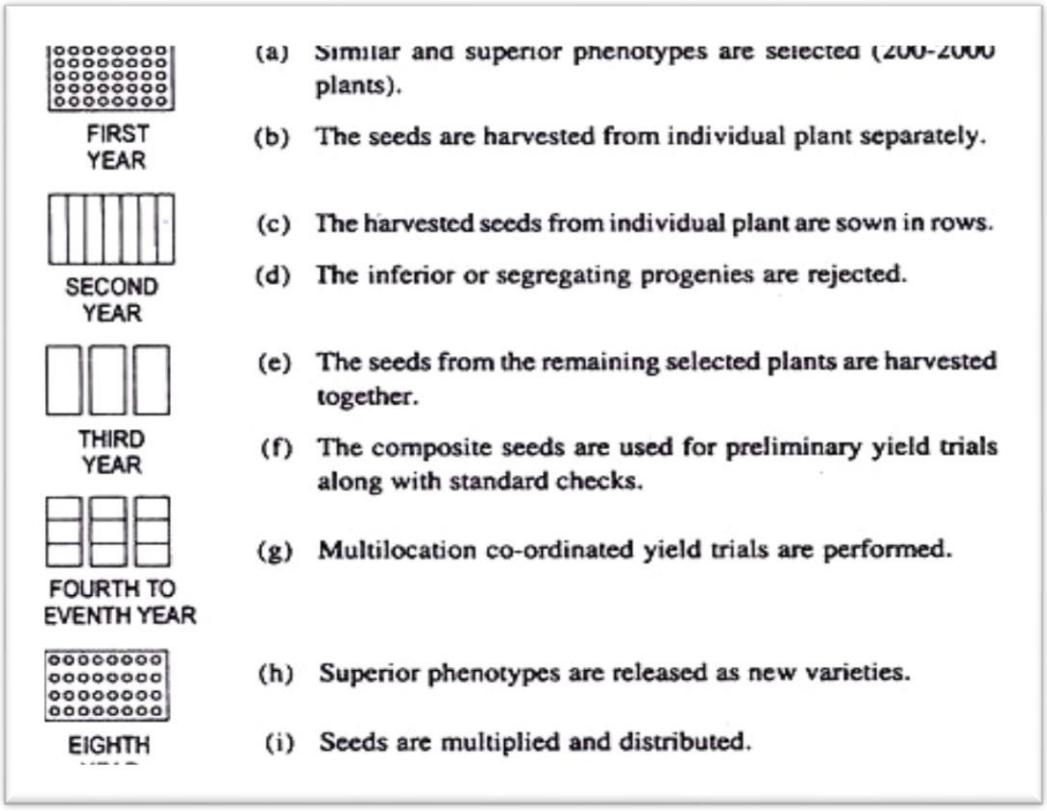


Fig.7.4. Presentation of Pure- line Selection Methodology

(iii) Clonal Selection

Clonal selection is generally practiced in vegetatively propagated crops such as potato, sweat potato, banana, sugarcane, mango, citrus, onion etc. In this case a group of plants obtained vegetatively from a single plant is known as a clone and the varieties are developing from the clones is known as clonal selection. After that on the basis of phenotypic characters the superior clones are selected. The fundamental basis of this selection is always between the clones and never within a clone because all the individuals of a clone has the same genetical constitution. These selected clones are multiplied vegetatively and compared with normal variety. The best ones are selected and multiplied and tried at different stations or areas continuously for three years. The best clones are given name and released as improved variety. Clonal selection is similar to pureline selection in vegetatively propagated crops, since vegetatively propagated pure- lines are the basis of improvement.

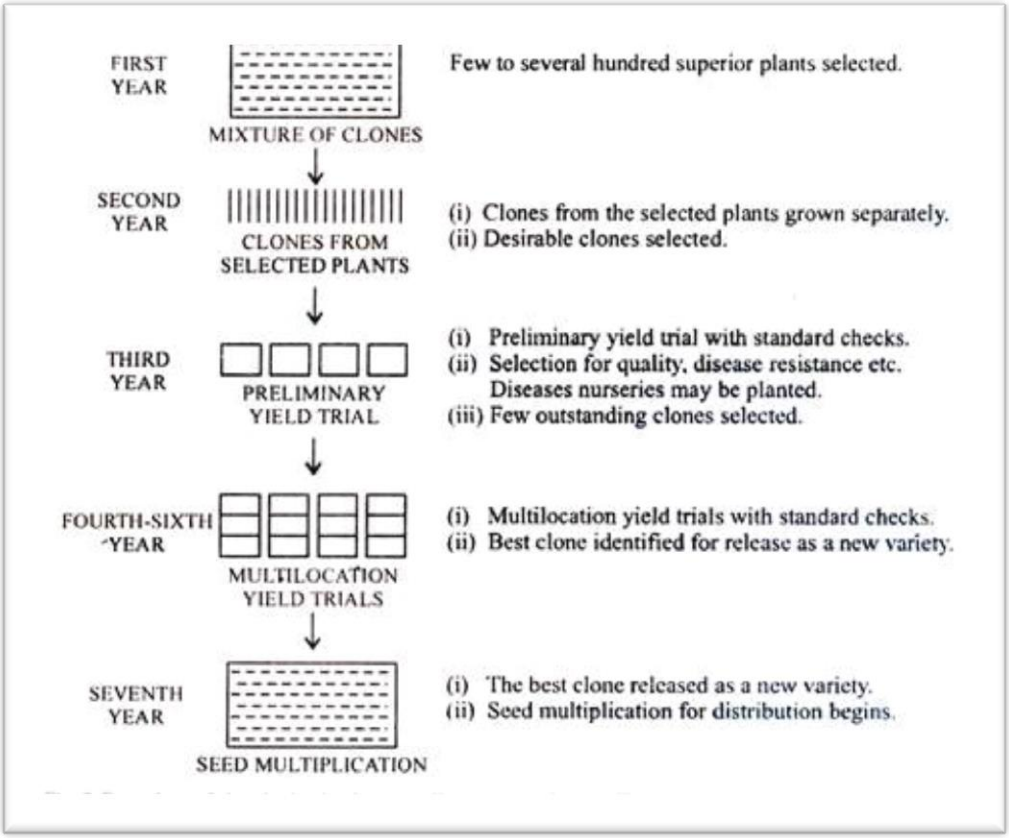


Fig.7.5 Presentation of Clonal Selection

Bud Selection

Bud selection is also a form of clonal selection where bud is the unit of selection. This method is applied in the improvement of fruit crops such as oranges and mangoes etc.

Hybridization

Hybridization is the best method among crop improvement. It is applicable for both type crops i.e. self and cross- pollinated ones, where two plants of different genetical constitution are crossed together. After domestication and crop selection, hybridization is the most potential breeding method for improvement of crop. Hybridization aims at to create new genetic variation of characters. It is the method of crossing of two pure- line plants of two dissimilar genotypes which will produce the F1 hybrids and then the subsequent generation will be segregating generations. The cross between two different varieties may be between two different species of the same species known as interspecific hybridization or may be between two different genera or intergenericis to create variation. The main object of hybridization new genes is not done yet variation is created by bringing new combination of genes already present in the parental stock. To select desirable characters, process of hybridization practiced between many plants, each possessing a separate combination of different characters. Out of them some may be selected possessing all the possible good characters together. To produce new variety and further selections practiced from these plants and thus ultimately by hybridization a variety containing as many economically valuable characters as possible may be produced.

Hybridization Process

To obtain improved variety there is a definite procedure of hybridization in which various steps are involved and they are briefly described below-

Hybridization between carefully chosen plants is now being used so extensively by plant between that the term breeding has become synonymous with the crossing of different varieties or species to evolve the desired types. Hybridization between cross- pollinated infact has been the only approach to transfer genes across different individuals. It is only with the development in tissue culture technology that somatic hybridization has also been used though on a limited scale, for this purpose.

Hybridization Procedure: To achieve the best results of hybridization techniques seven steps are involved as below-

1st step- Selection of Parents,
2nd step- Selfing of parents.
3rd step- Emasculation,
4th step- Bagging, tagging and labeling of males as well as females,
5th step- Crossing,
6th step- Collection of seeds from the crossed plants after maturity,
7th step- Handling of F_1 generations and
8th step- Raising the F_1 generation.

Selection of Parents

The first step of hybridization is selection of parents from the available material possessing all the desired characters second step of hybridization is the Selfing of parents to obtain homozygosity in desired characters so that they may easily be combined through hybridization. This step is not practiced in self- pollinated crops because they are already homozygous due to natural Selfing.

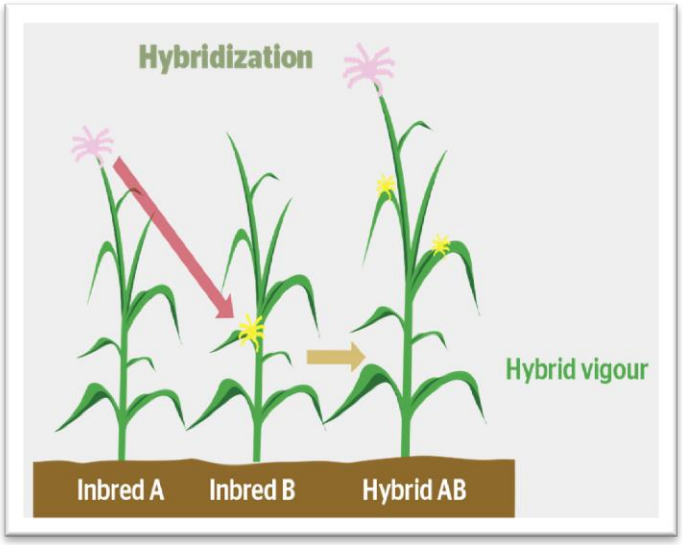


Fig. 7.6 Hybridization process

In the next step the anthers are removed or killed before maturation and have shed their pollens. This process is known as emasculation. The purpose of emasculation is only to prevent self- pollination. It is therefore, adopted only in those crops where there is self-pollinations, may be complete or up to some extent, it is not applied in unisexual crops. Bagging, logging and labeling of males as well as females is the fourth step of this process to be used in crosses.

To prevent natural cross pollination the females are bagged and males to prevent the contamination of pollen with foreign pollens and to collect the pollens for crossing.

The fifth step is the crossing, in which the pollens from already bagged males are collected and dusted on bagged females and labeled. The next or sixth step is the collection of seeds from the crossed plants after maturity. These seeds are sowing in the coming season to raise F_1 or first filial generation and hence maintain them separately. Plants obtained from this cross is known as **hybrids** and defined as **"Progenies of Cross".** The next step is the handling of F1 generation and subsequent generations for production of improved variety and last for raising the F1 generation.

Hybridization Methods:

Different selection methods of hybridization made by different selection methods for further selections from F1 to F5 generations, which are different for self and cross- pollinated crops as below-

For Cross- pollinated Crops-

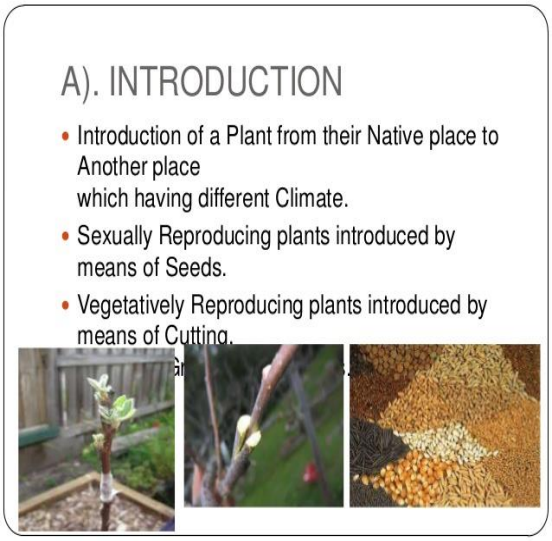
1. Single Cross (A x B),
2. Three Way Cross {(A x B) x C},
3. Double Cross {(A x B) - (C x D)}
4. Multiple Cross and
5. Synthetic Cross.

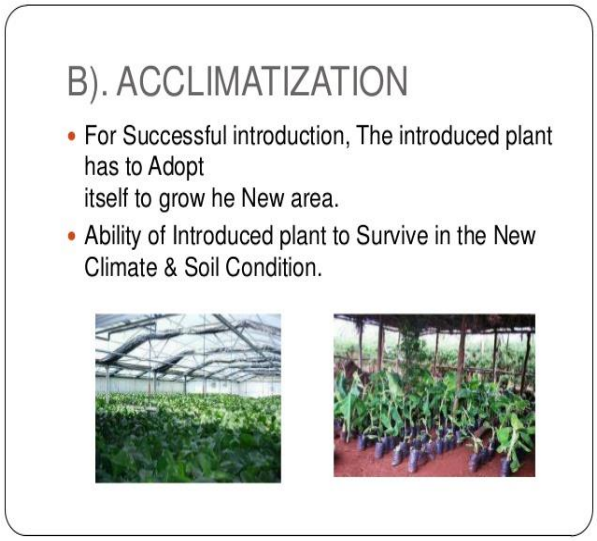
Self - Pollinated Crops-

1. Bulk Method,
2. Pedigree Method,
3. Backcross Method and
4. Multiple Cross Method.

All these methods have been given in details in the separate chapters of hybridization. The last and **eighth step is the testing, multiplication and distribution of the produced variety.** The testing of improved variety is done at various regional level research stations by research workers then multiplied by seed multiplication, farmers and final distributed to the farmers through Co- operative societies, panchayats and other agencies.

Hybridization has proved to be the best method of crop improvement and in the short period of 20th century is only due to this method is achieved in plant breeding and get great success





Introduction and Acclimatization: "Plant introduction and Acclimation" is the easiest and most rapid method of crop improvement in which the acclimatization follows the introduction and both the processes go by side. According to H.G. Chaudhary, "Plant introduction is the process of introducing plants from their growing locality to a new locality", or we can say that plants are transferred from one place to another having different climatic conditions. However,

Acclimatization is the segregation or adjustment of an individual plant or plant population controlled climate for a number of generations.

Introduction as a method of plant breeding involves the transfer of genotype or population from one environment of production to another. The plant material so introduced may reproduce its performance as such or may get adapted. This method is known as acclimatization, when new plant introduce into a new locality adapt itself according to new conditions.

To a new locality with different climate is termed as plant introduction, and further their adjustment under such changed climate of the new locality is known as acclimatization. Introduction of new crops as well as new varieties of crops may introduced either in the form of seeds or cuttings. In sexually propagated crops the cuttings are imported while in vegetatively propagated crops the cuttings are imported. The crops are generally introduced since in them there is greater frequency of gene recombinations owing to the frequent cross - pollinations and some of the combinations may be more favorably adopted in the environment. Introduction of crops may be done into a locality either from outside the country or from different regions within the country as per need and suitability. Infect, plant introduction within the country are very convenient but for introduction from another country followed a definite procedure as below-

1. The desired material is demanded from the concerned authority or agency of the foreign country through the plant introduction organization of the country.

2. After proper packing the material is sent by sea.
3. Before entering the country, this material is inspected at sea port by the plant protection authorities and
4. After certified fit according to quarantine rules, is permitted to enter in the country.
5. In the country it is handed over to the concerned institutions or workers.
6. Then it is grown under local climatic conditions and tested for acclimatization and presence of desired characters.
7. The material if proved fit for both, it is either utilized as such after selection or utilized as a material in hybridization for transferring the desired characters into the local varieties.

Hybridization method has been proved of great importance in crop improvement especially in recent years and used as a source of resistance material to some of our crop diseases. Most important among them is that rust resistance incorporated from foreign strains into Indian wheat variety.

Mutation Breeding: Sudden heritable variations in the plants other than those due to Mendelian segregation are known as mutation. These changes are due to rearrangement of genes or gene mutation or point mutation. When changes occurs in chromosomes size and structure, which is termed as chromosomal mutation, while changes in the chromosome number or ploidy. However, when changes occur in the plant body then it is known as somatic mutation. All these types cover up all types hereditary changes or changes in genotypes of the plants and give rise to inexhaustible variations which besides providing the new material for evolution are the basis of selection and production of new crop varieties in the plant breeding.

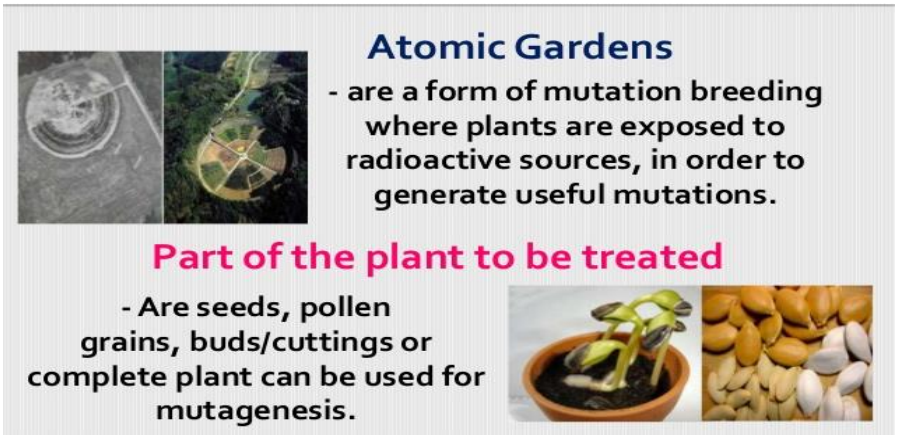


Fig.7.7 Different aspects of Mutation breeding

Certain chemicals, the agents responsible for mutation are known as mutagens. For this purpose two types radiations - ionic radiation i.e. x-rays, β-rays, γ- rays, radiation from radioactive isotopes, neutron, proton etc., Beside this, extreme temperature (Physical mutagens) and chemical mutagens- colchicine, Thiourea, HNO_3 etc. are important mutagenic agents, Recently the plant breeder can change the genotype and phenotype of the plant according to his need for production of new desired strains by using this technique of

mutation breeding. This is the recent and latest method of crop improvement and helps to produce rust resistance and increased baking quality in wheat, higher yield in mildew, resistance in barley, increased yield in cotton with superior fiber content. In mustard it helps to increase yield of seed and oil content. While in vegetatively propagated plants, selection from somatic mutation has led to improvements in dahlias, chrysanthemums, the ornamental plants, and crop plants like sugarcane and potato and fruit crops.

Table 1.Differences between Mass selection and Pure- Line selection

S.No.	Particulars	Mass Selection	Pure- line Selection
1.	Application	Used in both self and cross-pollinated species.	Used in self- pollinated species
2.	Genetic Constitution Variety	Homozygous but heterozygous in self-pollinated species. In cross pollinated species, hetero and homozygous.	Homozygous and homozygous.
3.	Basis of Selection	Selection is based on phenotype of plants	Selection is based on the progeny performance of plants.
4.	Component Lines	Mixture of several purelined in self- pollinated species. In cross pollinated species, mixture of several open genotypes pollinated.	It is a progeny of single homozygote
5.	Adaptation	Mass selected variety has wide adaptation	Pure- line variety has narrow genetic base.
6.	Produce of variety	Less uniform	Highly uniform
7.	Time Required	Release of new variety takes 6-7 years	Release of new variety takes 9-10 years
8.	Vulnerability	Low to new race of pathogen	High
9.	Genetic variation	Present	Absent

Table 2.Differences between Pure- line and Clonal Selection

S.No.	Particulars	Pure-line	Clonal
1.	Occurrence	In self-pollinated crops	In sexually propagated crops
2.	Genetic Constitution	Homogenous consisting Homozygous plants	Homogenous consisting of heterozygous plants
3.	Maintenance	Producing natural self-pollination	Produced by vegetative Propagation

4.	Type of progeny	Progenies of a single self-fertilized individual	Progenies of a single vegetatively propagated usually heterozygous individual
5.	Adaptation	Narrow	Wide
6.	Utilization	Utilized as improved variety and parents for hybridization also.	As variety and in hybridization

Conclusion:

The various above mentioned breeding methods have been developed on the basis of nature of crop propagation i.e. either it may reproduced sexually through self or cross- pollination or through vegetative propagation. The main basis of application of crop method to be used in a crop at any place depends on the amount of variation present in that particular crop in the past. The first method to improve the crops is selection, if no breeding work has been done so far in a crop. It may be mass, pure- line or clonal selection depending upon the type of propagation. Once if the variation is exhausted by selection then the next method of crop improvement is hybridization and selection from hybridization to meet the desired need. However, when recombination of hybridization may failed to obtain variation and improvement in a crop then to obtain the desired characters, plant introduction and acclimatization is adopted in which the desired material is introduced from outside and either utilized as such or incorporated in the local material. If all these methods did not succeeded to obtain any variation by any above methods, then at last the mutation breeding is employed in which inexhaustible variation is created artificially by inducing physical or chemical mutagens and utilized to produce new superior strain for future.

7.4 SUMMARY

Plant both domesticated as well as introduced, show considerable degrees of variations with respect to different characters. Some of these plants are superior whereas the others are inferior in performance. The process of selection of superior plants is an important method for the improvement of cultivated plants, which lead to the development of new varieties with more advantageous and superior characters. After selections i.e. mass selection, pure- line selection and clonal selection, the most frequently employed plant breeding technique is hybridization. The aim of hybridization is to bring together desired traits found in different plant lines into one line via cross pollination. Heterosis is an effective which is achieved by crossing highly inbred lines of crop plants, whereas, mutation refers to sudden heritable changes in the phenotype of an individual. Mutations do occur in nature either as spontaneous mutation or can be artificially introduced by various mutagenic agents known as induced mutation. Mutation breeding is the simple, quick and best way when a new character is to be induced in vegetatively propagated crops.

7.5 GLOSSARY

Acclimatization: The process by which a population adjusts and modifies itself to survive and reproduce normally under changed environmental or stress conditions.
Backcross: The cross of an F1 hybrid with either of the parents.
Breeding: The art and science of changing and improving heredity of living organisms.
Bud Selection: The form of clonal selection in which the bud is the unit of selection.
Clone: A group of plants produced through vegetative propagation from a single plant. It represents exact multiple copies of a genotype.
Colchicine: An alkaloid extracted from seed of colchicum autumnale that destroys spindle apparatus during mitosis and thus doubles chromosome number.
Emasculation: Manual removal of the anthers from a flower to make it ineffective for producing pollen.
Hybrid: The progeny of a cross between two or more individuals, plants or animals of unlike genetical condition.
Hybridization: A method of crop improvement in which two or more plants of unlike genetical constitution differing in one or more characters are crossed together.
Induced Mutation: The mutation which are artificially produced.
Mass Selection: The method of selecting plants on the basis of their phenotypic performance to bulk the seed in the form of new population.
Mutagen: An agent that can induce mutation.
Mutation: A sudden heritable change in a chromosome. It may involve change either in single gene or part of chromosome.
Pedigree Selection: A record of ancestry of an individual, family or strain.
Phenotype: External appearance of an organism as contrasted with its genetic makeup or genotype for particular character.
Pure- line: The progeny of a single homozygous individual produced through self-fertilization.
Male Sterility: The conditions in which the pollen is not produced or is non- functional for pollination.
Multiple Cross: A cross among many inbred with pollination between desired lines.
Three Way Cross: A cross between a single cross used as female and an inbred used as male i.e. (A x B x (C x D).
Single Cross: A cross between two inbred A x B
Variety: A group of similar plant within a species which are distinctly different for some structural features and performance from other varieties of the same species.

7.6 SELF- ASSESSMENT QUESTIONS

7.6.1 Fill in the blanks:

1. Mass selection is the simplest---------- and ----------method of crop improvement.
2. Mass selection is used in ----------and ----------plants.

3. Most frequently employed plant breeding technique is ----------.
4. In pure- line selection the expected results is a set of genetically---------- lines.
5. A cross {(A x B) - (C x D)} is known as----------Cross.
6. [(A x B) x C] represents----------Cross.

7.6.1 Answers Key: 1. common, oldest, 2. Self and cross-pollinated, 3.Hybridization, 4. Homozygous, 5. Double cross, 6. Three way cross.

7.7 REFERENCES

- B. D. Singh (1983). Plant Breeding, Principles and Methods.Kalyan Publications. New Delhi.
- G. S. Chahal and S. S. Gosal (2002). Principles and Procedures of Plant Breeding.Biotechnological and Conventional Approaches.NarosaPublishing House, 22 Daryaganj, Delhi Medical Road, New Delhi, 110002.(ISBN 81-204-0087-9).
- Phundan Singh (2010). Essentials of Plant Breeding.Published by Mrs. Usha Raj Kumar for Kalyani Publishers, New Delhi 110002.
- Sanjay Kumar Singh 2(005).Plant Breeding.Campus Book International 4831/ 24 Prahlad Street, Ansari Road Daryaganj, New Delhi 110002.(ISBN 81-8030-083-8).

7.8 SUGGESTED READINGS

- Deepak Kar and Soma Halder (2007).Plant Breeding Biometry Biotechnology. New Central Book Agency (P) Ltd. London.
- H. K. Chaudhary (1996). Elementary Principles of Plant Breeding (2nd Edition). Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi. (ISBN 81-204-0087-9).
- https:// www, Google .Com.

7.9 TERMINAL QUESTIONS

7.9.1 Long Answer Question:

1. What are the different methods of crop improvement and when and where are they used in particular crop?
2. Define artificial selection and what are its different types?
3. What are the different hybridization methods for self and cross - pollinated crops?
4. What do you mean by hybridization and what is its main purpose?
5. What do you mean by mutation breeding, what are its different kinds on the basis of origin, define briefly?
6. Define the following terms-
    a) Pure- line selection
    b) Clone
    c) Emasculation
    d) Hybrid

e) Acclimatization and Introduction

7. What are the differences between mass selection and pure- line selection?
8. Write are the different steps applied in hybridization technique?
9. What type of selection methods are used for the improvement in vegetatively propagated crops?
10. Define the merits and demerits of mass selection?
11. Define the achievements of mass selection?

UNIT-8 MUTATIONAL BREEDING

Contents:

8.1 OBJECTIVES

After reading this unit you will be able to know about:

- To increase yield
- To develop plants that is resistant to pests and diseases
- To improve quality
- To develop plants those have resistance to adverse conditions

8.2 INTRODUCTION

Mutations are sudden unpredictable heritable changes without any intermediate stage in characteristics of organism. In molecular terms, mutation is defined as the permanent and relatively rare change in the sequence of nucleotides. Mutations may be chromosomal, cytoplasmic or gene mutation (or point mutation).

Mutation was first discovered by Wright in 1791 in male lamb which had short legs. Later on mutation was discovered and studied in Oenothera by Hugo de Vries in 1900 Morgan in Drosophilla (white-eyed mutant) in 1910, and by several others in various organisms. However, the term "mutation" was coined by de Vries.

Mutations can be induced by some physical and chemical agents, called mutagens. Mutagens greatly enhance the frequency of mutations. Mutagenic action of X-ray was first discovered by Muller in 1927 and that of nitrogen mustards by Averbach and Robson in 1946. Based on their effect on survival, mutations are classified into four groups: lethal, sub-lethal, sub-vital, and vital. Mutation breeding utilizes vital mutations only.

Characteristics of Mutations:

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

Types of Mutation:

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

2. Induced mutation: Mutations may be artificially induced by a treatment with certain physical or chemical agents. Such mutations are known as induced mutations, and the agents used for producing them are termed as mutagen. The utilization of induced mutations for crop

improvement is known as mutation breeding. Induced mutations have a great advantage over the spontaneous ones, they occur at a relatively higher frequency so that it is practical to work with them.

Induced mutations are of two types:-

1. **Macro- Mutations:** Mutations with distinct morphological changes in the phenotype are referred to as macro-mutations. Identification of such mutations is easy.
2. **Micro-Mutations:** Mutations with invisible phenotypic changes are called micro-mutations. Identification of such mutations is very difficult. Micro mutations are of economic value in plant breeding.

Effects of Mutation: Depending upon the effect on the survival of an individual, induced mutations are of 4 types:

1) Lethal: They kill each & every individual that carry them in appropriate genotype.
Dominant lethal: It can't survive.
Recessive lethal: kill in homozygous state.

2) Sub-lethal & Sub-Vital:- Both mutation reduce viability but don't kill all the individual carrying them in appropriate genotype.
Sub lethal: kill more than 50%.
Sub vital: kill less than 50%.

3) Vital: All mutants survive. Crop improvement can utilize only such mutations.

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

(a) Physical Mutagen

The mutations inducing radiation's are of two kinds.
i. Ionizing radiation
ii. Non-ionizing radiation

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

X-rays: X-rays were first discovered by Roentgen in 1895. They are lightly ionizing and highly penetrating and are generated in X-rays machines. X-rays can break chromosomes and produce all types of mutations in nucleotides, *viz.* addition, deletion, inversion, transposition, transitions and transversions. X-rays were first used by Muller in 1927 for induction of mutation in *Drosophila*. In plants, Stadler in 1928 first used X-rays for induction of mutation in barley. Now X-rays are commonly used for induction of mutation in various crop plants. X-rays induce mutations by forming free radicals and ions.

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

of inducing mutations is ultra violet light. UV radiation can be obtained from a mercury vapour lamp. UV rays have much longer wave lengths (about 2500 Angstroms).

UV rays: UV rays are non ionizing radiations, which are produced from mercury vapour lamps or tubes. They are also present in solar radiation. UV rays can penetrate one or more cell layers. Because of low penetrating capacity, they are commonly used for radiation of micro-organisms like bacteria and viruses. UV rays can also break chromosomes.

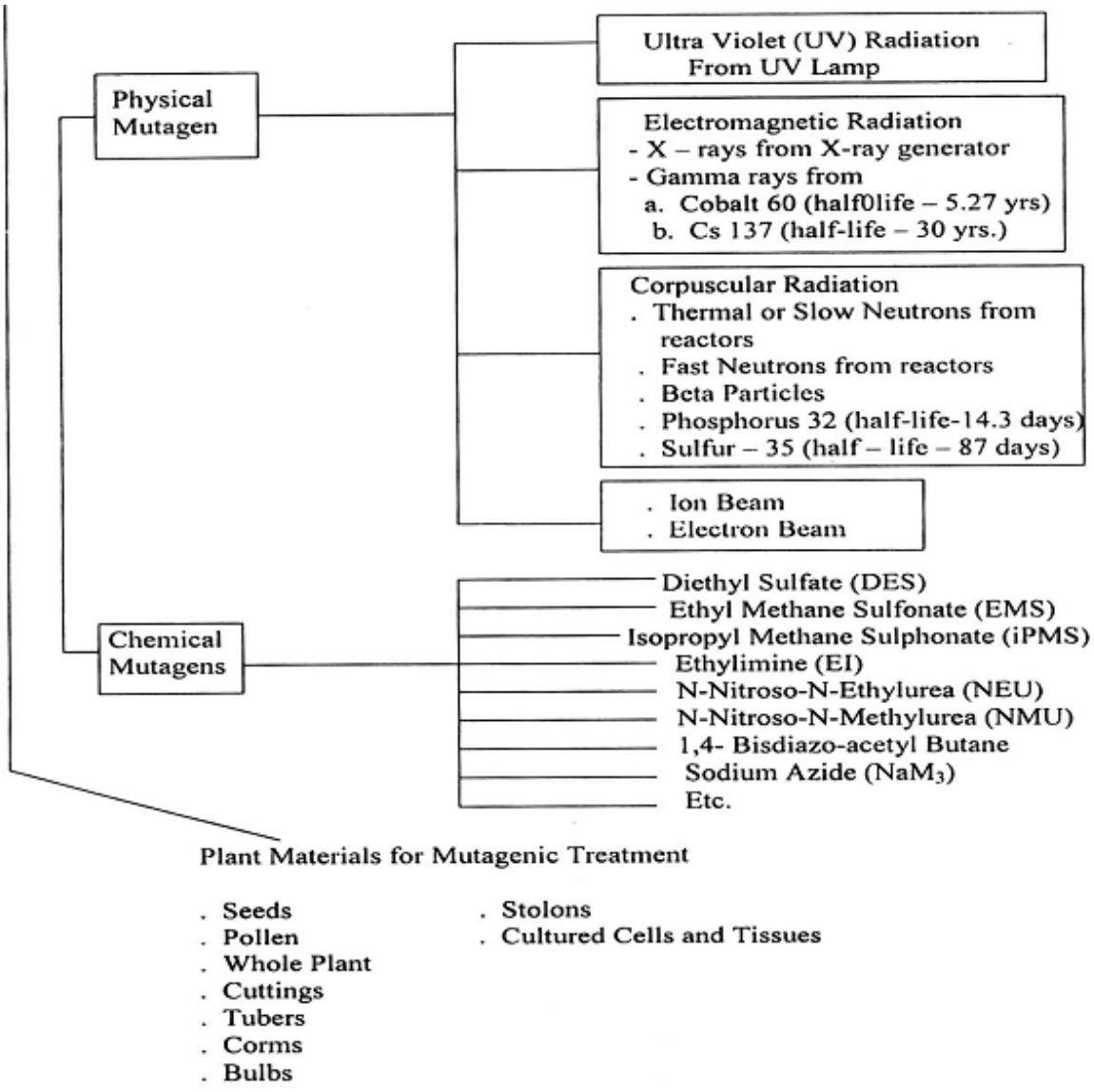
(b) Chemical Mutagens

1. Alkylating agents – This is the most powerful group of mutagens. They induce mutations especially transitions and transversion by adding an alkyl group (either ethyl or methyl) at various positions in DNA. Alkylation produces mutation by changing hydrogen bonding in various ways. eg., EMS (Ethyl Methane Sulphonate), MMS (Methyl Methane Sulphonate), ethylene imines (EI), sulphur mustard, nitrogen mustard, etc.

2. Acridine dyes- Dyes are very effective mutagens. eg., Ethidium Bromide, acriflavine, proflavine, acridine orange, acridine yellow.

3. Base analogue – Base analogue refer to chemical compounds which are very similar to DNA bases. They can cause mutation by wrong base pairing. eg. 5 Bromo uracil (5BU), 5 – Chloro uracil (5CU) and 2 amino purine (2AP).

4. Others – Other important chemical mutagens are:- Nitrous acid, hydoxylamine, sodium azide.



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

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

Mutagenesis

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

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

Dose of the mutagen

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

Mutagen treatment

The selected plant part is exposed to the desired mutagen dose. The case of chemical mutagens, seeds are usually presoaked for a few hours, to initiate metabolic activities, exposed to the desired mutagen and then washed in running tap water to remove the mutagen present in them. The treated seeds are immediately planted in the field to raise the M1 generation. M2, M3, M4 etc are the subsequent generations derived from M1, M2, M3 etc., plants through selfing.

Stage at which mutation occurs:

Mutation can occur at any stage during the life cycle of a living organism.

1. Before the formation of gametes
2. In gametes
3. In zygotes
4. In normal body cell or somatic cell

Frequency of Mutation:

The frequency at which gene mutate is called mutation rate. The mutation rate depends upon the position and nature of the genes. The genes with relatively low mutation rate are known as stable genes and those with high mutation rate as unstable genes. General range of frequency of mutation is 1 in 20,000 to 1 in 2, 00,000.

Rate of mutation is influenced by:

1. Mutator gene (this gene increases the rate of mutation), supressor gene (this gene decreases the rate of mutation).
2. Virus can increase the mutation rate (e.g., *Zea mays*)
3. Environment (temperature, different radiations and chemicals)

Chromosomal Mutation:

The change in chromosome structure is known as chromosomal mutation. It is also known as chromosomal aberration. It may be due to the following reason:

(a) Deletion: Loss of part of chromosome.

(b) Duplication: Addition or increase in a part of chromosome

(c) Inversion: Reversal in order of genes in a part of chromosome. It is of two types:
(i) Paracentric inversion (inversion segment does not carry centromere)
(ii) Pericentric inversion (inversion segment with centromere).

(d) Translocation: Exchange of genes between non-homologous chromosomes.

Gene Mutation: The change of nitrogenous base sequence in DNA or gene is known as Gene or Point mutation. In other words, change in the chemical structure of gene at the molecular level is also known as gene mutation. Phenotypic changes which are produced by gene mutation are reversible, whereas due to structural and numerical changes in chromosome are irreversible.
Gene mutations are of two types:
1. Substitute mutation: The change of base pair or nucleotide pair in a DNA segment or cistron is called substitute mutation. It is of two types:
(a) Transition: Exchange of purine base by purine base or pyrimidine by pyrimidine base in a DNA segment or cistron is known as transition.
(b) Trans-version: The substitution of a purine base by pyrimidine base or vice-versa is known as trans-version.
2. Frame shift mutation: Insertion or deletion of single nitrogenous base in DNA chain is known as frame shift or gibberish mutation. For example, if the antisense strand of DNA is
TAG AAA GGG GCC AAG AGA
Its DNA transcript will be:
AUG UUU GCC GGG UUG UGG UGU
Translated message will be
Methionine – Phenyl alanine – Proline, – Glycin – Phenyl alanine – Serine.
If a single base 'G' is inserted in between G and U of first codon then a new protein will be produced.
AUG GUU UGG GGG GUU GUG GUC.
Methionine – Valine – Serine – Arginine – Valine – Leucine – Leucine.

8.3 MUTATION BREEDING

The genetic improvement of crop plants for various economic characters through the use of induced mutation is referred to as mutation breeding. It is one of the special methods of crop improvement. Mutation breeding is commonly used in self-pollinated and asexually propagated species. However, this method is rarely used for genetic improvement of cross pollinated species.

Procedure of mutation breeding

Step1. Choice of material

The best adapted variety of a crop should be chosen. Only one or two features of such variety have to be altered through mutagenesis depending upon the objectives. Suppose a

variety is high yielding, but susceptible to a particular disease, the objectives of mutation breeding would be to induce resistance to that particular disease in the variety.

Step: 2.Choice of mutagen

It depends upon the plant parts to be treated. Generally, chemical mutagens are more preferred for seed treatment and radiations for the treatment of vegetative parts. The penetration of chemical mutagens can be enhanced dissolving the mutagen in solvents like dimethyl sulphoxide.

Step: 3. Mutagenic treatment

The procedure of mutagenic treatment takes three things into account: *viz.*

Plant species- Seeds, Pollens, Buds, Cuttings or Suckers.

Dose of mutagen –LD 50 refers to a dose of mutagen that kills 50% of the treated individuals

Duration of treatment- depends on the intensity of radiations or concentration. The seeds are water soaked before treatment. After treatment the seeds or cuttings are immediately planted and pollens are used for pollination. Plants obtained from treated seeds or cuttings are called M1 plants.

Step: 4 Handling of Treated Material:

Seed propagated species:-

M1 Generation

Several hundred (500 or more) treated seeds are space planted. All the M1populations are grown using wider spacings for easy identification. Generally the mutants are recessive. All the plants will be chimeras for the mutation present in heterozygous state. About 20 seeds from each M1 plant are harvested separately.

M2 Generation

About 2000 progeny rows are grown using wider spacings. Oligogenic mutants with distinct features are identified and selected. Only 1-3% of M2 rows may be expected to have beneficial mutations

M3 generation

Progeny rows form individual selected plants. Inferior mutant rows are eliminated. If the mutant progenies are homozygous, two or more M3 progenies containing the same mutation. Mutant M3 rows are harvested in bulk.

M4 generation

A preliminary yield trial is conducted with a promising mutant lines are selected for replicated multilocation trials.

M5-M8 generation

Selected lines are tested in coordinated Multilocation trials. The best performing line is released as a variety. In case of polygenic traits, identification of character is not possible through visual observations.

The material is tested in replicated trial and screening is done for the character under improvement using appropriate statistical methods.

Inferior plants are rejected in M3 and M4 generation based on screening tests and superior plants are bulked to raise next generation.

The homozygous progeny are tested in coordinated trial from M5 to M9 and the best line is released as a variety.

In India, over 200 varieties have been developed through mutation breeding.

Selection amongst Somaclonal Variation:

Genetic variation present among plant cells during tissue culture is called somaclonal variation. The term somaclonal variation is also used for the genetic variation present in plants regenerated from a single culture. This variation has been used to develop several useful varieties.

Some of the somaclonal variations are stable and useful, e.g., resistance to diseases and pests, stress tolerance, male sterility, early maturation, better yield, better quality, etc. Thus somaclonal variations have produced wheat tolerant to rust and high temperature, Rice to leaf ripper and Tungro virus, Potato to Phytophthora infestans (late blight of Potato), etc. Other useful variations include high protein content of Potato, short duration Sugarcane and increase shelf life of Tomato.

Achievements and Limitations of Mutation Breeding:

1. A number of crop varieties have been developed through mutation breeding.

2. The first commercial success with induced mutations was reported in 1934 with the release of a new tobacco cultivar ‘Chlorina’ through X-ray irradiation. The Indian dwarf wheat’s which contain the dwarfing gene was from a Japanese cultivar ‘Norin- 10’, which itself was a mutant.

3. Many varieties of barley contain artificially mutated genes which contribute to reduction in height, increase in yield, insensitivity to day length and resistance to mildew diseases. Sharbati Sonara and Pusa Lerma are two amber grain colour mutants of wheat produced from the red grained Sonara 64 and Lerma Rojo 64A, respectively. A mutant gene that induces semi-dwarfing in rice has been produced by X-ray treatment. Induced mutations have also become recently important in developing parents useful in hybridization programmes. Forty-five rice cultivars have been developed by the year 1982, either by direct radiation or by crossing with induced mutants.

4. Many crop plants are propagated vegetatively even though they can bear seed. Potato, tapioca and sugarcane are classical examples of such crops. In these, genetic improvement is carried out using sexual reproduction but the maintenance of the improved varieties is by cloning. For examples, potatoes are multiplied by tubers, apples by cuttings, and strawberries by runners.

5. Spontaneous mutations in somatic cells of a vegetatively propagated plant are commonly referred to as SPORTS. Such desirable sports occurring in well-adapted, asexually reproducing plants may result in quick improvements such as the colour sports in many apple varieties and superior shrub types in coffee plants.
6. The characters improved through mutation breeding include flowering time, flower shape, fruit shape, changes in oil content, and protein quality.
7. Some of the important limitations of the use of mutation breeding for crop improvement are:
(i) Most induced mutations are undesirable and have no value to the breeder. Many induced mutations are lethal.
(ii) The mutation rate is extremely low and a very large number of plants must be screened to identify the few individuals that may have desirable mutations. It is equally difficult to grow such useful mutants and include them in breeding programmes.
(iii) The stability of a mutant must be thoroughly tested as some mutants have a tendency to revert.
(iv) Most induced mutations are recessive; these have to be in double dose to be expressed phenotypically.
(v) Unless mutations are induced in gametes—especially in pollen—they will not be easily incorporated into the breeding line.

8.4 BREEDING FOR DISEASE RESISTANCE

Disease resistance is often defined as reduction of pathogen growth on or in the plant. It denotes less disease development in a genotype than that in the susceptible variety and is a relative attribute. Generally, the rate of reproduction is considerably reduced which limits the spread of disease. Plants are almost always resistant to certain pathogens but susceptible to other pathogens; resistance is usually pathogen species-specific or pathogen strain specific.

Types of Disease Resistance

Vertical resistance: Term coined by Vanderplank. It is qualitative resistance or race specific resistance governed by major genes and is characterized by phenotype specificity it is easily overcome by new races of the pathogen. Common in diseases caused by biotrophic pathogens e.g. rusts.

Horizontal resistance: Term coined by Vander plank Quantitative or durable resistance, controlled by polygenes and is host nonspecific. These genes provide the plants with defensive structures or toxic substances that slow down or stop the advance of the pathogen into the host tissues and reduce the damage caused by the pathogen, in diseases caused by non-biotrophic pathogens. The defenses in quantitative resistance develop slower and perhaps reach a lower level than those in the race specific resistance. It is durable resistance and never breaks down to new strains of disease, as does vertical resistance.

Plant breeders focus a significant part of their effort on selection and development of disease resistant plant lines. Plant diseases can also be partially controlled by use of pesticides, and by cultivation practices such as crop rotation, tillage, planting density, purchase of disease-free seeds and cleaning of equipment, but plant varieties with inherent (genetically determined) disease resistance are generally the first choice for disease control. Breeding for disease resistance has been underway since plants were first domesticated, but it requires continual effort. This is because pathogen populations are often under natural selection for increased virulence, new pathogens can be introduced to an area, cultivation methods can favor increased disease incidence over time, changes in cultivation practice can favor new diseases, and plant breeding for other traits can disrupt the disease resistance that was present in older plant varieties. A plant line with acceptable disease resistance against one pathogen may still lack resistance against other pathogens.

GENE-FOR-GENE Hypothesis

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

Mechanisms of disease resistance:

Three different mechanisms operate in plants for disease resistance; *viz.*

1) Resistance to establishments of the pathogen in the host tissue,
2) Resistance to the growth and development of the pathogen already established in the host tissue,
3) Ability of a host to perform well despite the establishment of the pathogen in the host tissue.

The first two mechanisms are considered as true forms of resistance and the last is termed as tolerance.

Sources of resistance

In crop plants, there are four important sources of disease resistance. These are:

1. Cultivated varieties
2. Germplasm collections
3. Wild species
4. Induced mutation

1. Cultivated varieties: In some crops, resistance to disease may be found in cultivated varieties. For example, cotton variety MCU 5 VT tolerant to *Verticillium* wilt was isolated from the commercial variety MCU 5 of *Gossypium hirsutum.* Cultivated varieties are the best sources of disease resistance, because they possess good agronomic characters besides disease resistance.

2. Germplasm collections: Germplasm collections are the potential sources of disease and insect resistance in all the cultivated crops. In cotton, several germplasm lines resistant to bacterial blight and *Fusarium* wilt have been identified based on screening of large number of germplasm in India. Generally, germplasm lines have poor agronomic characters. Hence, their use in breeding programmes poses some problems.

3. Wild Species: Related wild species are also potential sources of disease resistance. However, utilization of wild sources poses many problems such as cross incompatibility, hybrid inviability, hybrid sterility and linkages of several undesirable traits with desirable ones. Therefore, wild related species are only used as source of resistance when the desired resistance is not found within the cultivated species. Wild species of crops like wheat, barley, potato, tomato, sugarbeet, tobacco, cotton etc., are good sources of resistance to various diseases. Many disease resistant genes have been transferred from wild species to cultivated species in these crops.

4. Mutations: Both spontaneous and induced mutations are good sources of disease resistance. Disease resistance has been achieved in several crops through the use of induced mutations. Some examples of disease resistance induced by mutagenic agents are; resistance to Victoria blight and crown rusts in oats, to strip rust in wheat, to mildew in barley, to flax rust in flax, and to leaf spot and stem rust in peanut.

Steps in Breeding for Disease Resistance

Identification of resistant breeding sources: Plants that may be less desirable in other ways, but which carry a useful disease resistance trait. Ancient known plant varieties and wild relatives, cultivated varieties and land races are very important to preserve because they are the most common sources of enhanced plant disease resistance. Others include mutations, somaclonal variation & unrelated species.

Breeding methods: Crossing of a desirable but disease-susceptible plant variety to another variety that is a source of resistance, to generate plant populations that mix and segregate for the traits of the parents. The methods of crossing include selection, introduction, marker assisted selection, genetic engineering; hybridization includes backcross, pedigree, bulk methods. Among these methods marker assisted selection & backcross methods are important.

Screening: This is carried out under field and glasshouse conditions. The glasshouse tests are conducted under controlled conditions. The procedure of field inoculation differs for various types of diseases:

(a) Soil borne diseases- For soil borne diseases like root rots, collar rots, wilts, etc., sick plots are created for testing resistance to such diseases.

(b) Air borne diseases- For air borne diseases such as rusts, smuts, mildews, blights, leaf spots, etc., spraying a suspension of spores.

(c) Seed borne diseases- Dry spores are dusted on seeds or seeds may be soaked in a suspension of pathogen spores.

Selection of disease-resistant individuals

Breeders are trying to sustain or improve numerous other plant traits related to plant yield and quality, including other disease resistance traits, while they are breeding for improved resistance to any particular pathogen. Each of the above steps can be difficult to successfully accomplish, and many highly refined methods in plant breeding and plant pathology are used to increase the effectiveness and reduce the cost of resistance breeding.

Method of Breeding for Disease Resistance

The method of breeding for disease resistance is essentially the same as those for other agronomic characters. The following breeding methods are commonly used,

1) Selection,
2) Introduction,
3) Mutation,
4) Hybridization,
5) Somaclonal Variation, and
6) Genetic engineering.

1. Introduction: This is easy and rapid method of developing disease resistant variety. The resistant variety may be introduced and after testing, if found suitable, can be released in the disease prone area. In 1860, the grape crop in France was completely destroyed by the attack of Phylloxera Vertifolia. Introduction of resistant root stocks to this pest from USA saved the grape crop from extinction in France.

2. Selection: When the source of resistance is a cultivated variety, mass selection and pure lines selection in self pollinated crops, mass and recurrent selection in cross pollinated species, and clonal selection in the vegetatively propagated crops will be ideal for isolating disease resistant plants. The resistant plants may be multiplied, screened for disease resistance and released a variety.

3. Hybridization: Hybridization is used when resistant genes are available either in the germplasm or in wild species of crop plants. After hybridization, the hybrid material is handled either by pedigree method or by backcross method. The pedigree method is used when the resistance is governed by polygene and the resistant variety is an adapted one which also contributes some desirable agronomic traits. The backcross method is used when resistance to governed by oligogenes. Induced mutations are also use for disease resistance.

Many disease resistant varieties have been developed in various crops through induced mutations.

4. Mutation: We have already considered briefly the usefulness of spontaneous as well as induced.

5. Somaclonal Variation: Disease resistant soma clonal variants can be obtained in the following two ways, firstly, plants regenerated from cultured cells or their progeny are subjected to disease test and resistant plants are isolated. Secondly, cultured cells are selected for resistance to the toxin or culture filterate produced by the pathogen and plants are regenerated from the selected cell. In most cases, these plants are also resistant to the disease in question. Cell selection strategy is most likely to be successful in cases where the toxin is involved in disease development.

6. Genetic Engineering: Genes expected to confer disease resistance are isolated, cloned and transferred into the crop in question. In case of viral pathogens, several transgenes have been evaluated, viz, virus coat protein gene, DNA copy of viral satellite RNA, defective viral genome, antisense constructs of critical viral genes, and ribozymes. Viral coat protein gene approach seems to be the most successful. A virus transgenic variety of squash is in commercial cultivation in U.S.A.

Advantages of breeding for disease resistance

1. Resistant varieties offer the cheapest means of disease control.
2. Resistant varieties obviate the use of fungicides, thus reduce environmental pollution
3. Effectiveness of resistant varieties is not affected by environmental conditions.
4. It safeguards against the inadvertent release of such varieties that are most susceptible than earlier varieties.

Problems in breeding for disease resistance

1. Resistance breakdown (vertifolia effect, boom & bust cycle)
2. Horizontal resistance being durable but difficulty relates to an accurate & reliable assessment of the level of resistance.
3. Sometimes there is negative correlation between yield & disease resistance e.g wheat leaf rust gene Lr34 causes a 5% reduction in grain yield.
4. For introgression of multiple resistances in varieties against several diseases requires meticulous planning and far greater effort than that required for single resistance.

Plant Breeding for Developing Resistance to Insect Pests:

Insects and pest infestation are two major causes for large destruction of crop plant and crop. Insect resistance in host crop plants is due to morphological, biochemical or physiological characters. Hairy leaves of many plants are associated with resistance to insect pests. For example, resistance to jassids in cotton and cereal leaf beetles in wheat. Solid stems in wheat lead to non-preference by the

stem saw fly and smooth leaved and nectar-less cotton varieties does not attract bollworms. Low nitrogen, sugar and high aspartic acid in maize develops resistance to maize stem borers.

Breeding methods for insect pests resistance include the same steps as for any other agronomic character like yield or quality as described above. Sources of resistance genes may be cultivated varieties, germplasm collections of the crop or wild relatives of the crop.

Plant Breeding for Improved Food Quality

It is estimated that more than 840 million people in the world do not have adequate food to meet their daily requirements. Three billion people suffer from protein, vitamins and micronutrient deficiencies or 'hidden hunger' because these people cannot afford to buy adequate vegetables, fruits, legumes, fish and meat. Their food does not contain essential micronutrients especially iron, iodine, zinc and vitamin A. This increases the risk for disease, reduces mental abilities and life span. Breeding of crops with higher levels of vitamins and minerals or higher protein and healthier fats is called biofortification. This is the most practical aspect to improve the health of the people.

Plant breeding is undertaken for improved nutritional quality of the plants. Following are the objectives of improving:

(1) Protein content and quality
(2) Oil content and quality
(3) Vitamin content and
(4) Micronutrient and mineral content.

Indian Agricultural Research Institute (IARI), New Delhi, has also developed many vegetable crops that are rich in minerals and vitamins. For example, vitamin A enriched carrots, pumpkin, spinach, vitamin C enriched bitter gourd, Bathua, tomato, mustard, calcium and iron enriched spinach and bathua; and protein enriched beans (broad lablab, French and garden peas).

Single Cell Protein (SCP):

As we know demand of food is increasing due to increase in human and animal population, the shift from grain to meat diets does not solve the problem as it takes 3-10 kg of grain to produce 1 kg of meat by animal farming. More than 25 percent of human population is suffering from hunger and malnutrition. One of the alternate sources of proteins for animal and human nutrition is single cell protein (SCP).

Microorganisms are used for the preparation of fermented foods (e.g., cheese, butter, idlis, etc.). Some microorganisms (e.g., blue green algae- Spirulina and mushrooms-fungi) are being used as human food. Now efforts are being made to produce microbial biomass using low cost substrates. Microbes like Spirulina can be grown on waste water from potato processing plants (containing starch), straw, molases, animal manure and even sewage, to produce food rich in proteins, minerals, fat, carbohydrates and vitamins. This biomass is used as food by humans.

The cells from microorganisms such as bacteria, yeasts, filamentous algae, treated in various ways and used as food, are called single cell protein (SCP). The term SCP does not indicate its actual meaning because the biomass is not only obtained from unicellular microorganisms but also from multicellular microorganisms.

Thus SCP is produced using bacteria, algae, fungi (yeasts, etc). The substrates used for SCP production range from C0 (used by algae) through industry effluents like whey (water of curd), etc. to low-cost organic materials like saw dust and paddy straw. Commercial production of SCP is mostly based on yeasts and some other fungi, e.g., Fusarium graminearum. In most cases, SCP has to be processed to remove the excess of nucleic acids. SCP is rich in high quality protein and is poor in fats. Both high quality of protein and low quantity of fats constitute good human food. It has been estimated that a 250 kg cow produces 200 g of protein per day. In the same period 250 g of a microorganism like Methylophilus methylotrophus because of its high content of biomass production and growth, can produce about 25 tonnes of protein.

Some Common Microbes as SCP producers:

(i) Cyanobacteria – Spirulina
(ii) Bacteria – Methylophilus methylotrophus
(iii) Yeasts – Candida utilis
(iv) Filamentous fungi – Fusarium graminearum

Advantages of SCP:

(i) It is rich in high quality protein and poor in fat content,
(ii) It reduces the pressure on agricultural production systems for the supply of the required proteins,
(iii) SCP production is based on industrial effluents so it helps to minimise environmental pollution,
(iv) SCP can be produced in laboratories throughout the year.

Role of Plant Breeding:

Plant breeding has played an important role in enhancing food production:
(i) Triticale is a man-made alloploid developed from Triticum turgidum and Secale cereale.
(ii) Lysine-rich maize varieties like Shakti, Rattan and Protina have been developed.
(iii) Through mutation breeding, more than 200 varieties of crops have been developed.
(iv) Disease resistance in plants has been introduced through breeding.
(v) All the sugarcane varieties that are cultivated today are interspecific hybrids.
(vi) Plant breeding has also given us improved varieties of crops like Sonora-64 of wheat and Taichung Native -1 of rice.

Practical Achievements

Disease resistant varieties have been developed in many crops all over the world. In India, disease resistant varieties have been evolved in wheat, barley, maize, rice, sorghum, sugarcane, cotton, pulses, oilseeds and many other crops. Almost all the currently released varieties of *arboretum* cotton are resistant to *Fusarium* wilt. Many varieties of wheat are resistant to rusts. In sugarcane, several varieties are resistant to red rot and wilt. In okra, a yellow mosaic virus resistant variety Parbhani Kranti has been released. In uplant cotton, variety MCU 5 VT is tolerant to *Verticillium* wilt.

8.5 SUMMARY

Mutation is a heritable change in the genetic material of living organisms and therefore a major driver of species diversity and evolution. Mutation may be spontaneous or induced, and mutants that are better fitted to their environment (natural or man-made) have a selective advantage. Mutation has been a major factor in bringing wild species into domestication and agriculture. Purposeful mutation in plant breeding has been a highly successful strategy. There are currently over 3,220 officially released mutant cultivars in over 210 plant species. Mutant traits can be produced for most if not all breeding goals and include yield, quality, stature, disease, pest resistance, tolerance to abiotic stresses, postharvest degradation, and novel end-user characters. This chapter reviews the current progress and assesses the future directions in mutation breeding for crop improvement with particular reference to physical mutagenesis. It provides a background to plant mutation breeding (impact and challenges), strategies involved, basic and advanced techniques, and provides a critical review of this approach compared with other methods for the genetic improvement of crops. The various mutagens (physical, chemical, and biological) are described. Currently, the vast majority of mutations used in plant breeding and crop production are derived from treatments of physical mutagens. Their effects (biological consequences) and their utility (advantages and disadvantages) are discussed. Furthermore, standard procedures are described for the optimization of mutagenesis and subsequent handling of mutated materials.

All agricultural crops are severely damaged when not protected against pathogens. A comparison of different means of protection has shown that the application of resistance is highly preferable. The great economic importance of this cost-effective and biologically safe means of protection is obvious in all types and areas of plant production. Durability of resistance is a highly variable phenomenon. Insight into the basis of durability is still insufficient. Biotechnology will increase the economic importance of breeding for resistance. It gives us new possibilities not only for the recombination of genetic information, but also for the analysis of host-pathogen relationships and for the improvement of durability of resistance. The significance of resistance and its durability for plant production in all countries and especially in developing countries, justifies that breeding for resistance be given top priority worldwide.

8.6 GLOSSARY

Mutation: Sudden heritable change in the phenotype of an individual or permanent change in the number, kind and sequence of nucleotides in the genetic material.

Spontaneous Mutations: Mutations that occur in nature.

Induced Mutations: Mutations that are induced (produced) by the treatment of mutagenic agents.

Macro-Mutation: Mutation with distinct morphological changes in the phenotype, usually observed in qualitative characters.

Gene: A macro molecule composed of DNA or in some viruses RNA.

Mutant: The product of mutation**.** It may be a genotype, a cell or a polypeptide.
Mutagen: Physical or chemical agents which greatly enhance the frequency of mutation.
Alkylating Agent: Chemical mutagens which cause mutation by adding alkyl group at various position in DNA.
Base Analogues: Chemical compounds which are similar to DNA bases such as 5 bromo uracil and 2 amino purine.
Ionizing Radiations: Radiations which produce ions in the medium through which they pass.
Ultraviolet Rays: Non ionizing radiations produced from mercury vapour lamps or tubes and used for induction of mutation in lower organisms.
X-rays: Sparsely ionizing radiations used for induction of mutation.
Vertical resistance: Resistance of a host to the particular race of a pathogen. Also called major gene resistance, oligogenic resistance and qualitative resistance.
Horizontal Resistance: Resistance of a host to all the prevalent races of a pathogen. Also called general resistance, polygenic resistance, minor gene resistance and nonspecific resistance.
Gene for Gene Hypothesis: This hypothesis states that for each gene controlling resistance in the host, there is a corresponding gene controlling pathogenecity in the pathogen. Also called flor hypothesis after the name of the scientist who developed this concept.
Parasite: An organism or virus which lives upon or within another living organism.
Pest: Any animal or higher plant which parasitizes crop plants, *e.g.* insects, nematodes, birds and parasitic weeds.
Disease: Disorders of crop plants caused by pathogens.
Pathogenicity: Ability of a pathogen to attack a host.
Pathogen: Various disease causing organisms such as fungi, bacteria, viruses and mycoplasmas.
Immune: Completely resistant plants.
Host: The plant attacked by a disease, insect or parasitic weed.
Virulent: A race of pathogen capable of attacking a host with specific resistance.
Avirulent: A pathogen race unable to attack a host with specific resistance.

8.7 SELF ASSESSMENT QUESTION

8.7.1 Very Short Answer Type Questions:

1. Write an alternate source of protein for animal and human nutrition.
2. Name the organism commercially used for the production of SCP.
3. Who discovered the mutation?
4. Name two physical mutagens.
5. What is the full form of IARI?
6. Name one special method of crop improvement.
7. In India how much varieties have been developed through mutation breeding?
8. Name two mutant varieties of wheat.
9. Who give the concept Gene-For-Gene hypothesis?

10. Name the cotton variety tolerant to *Verticillium* wilt.

8.7.2 Objective Type Questions:

1. Sonalika and Kalyan Sona are varieties of :
(a) Wheat (b) Rice
(c) Millet (d) Tobacco

2. Use of certain chemicals and radiation to change the base sequences of genes of crop plants is termed :
(a)Recombinant DNA technology (b) Transgenic mechanism
(c)Mutation breeding (d) Gene therapy

3. Point mutation involves :
(a) Deletion (b) Insertion
(c) Duplication (d) Change in single base pair

4. The action of UV radiation on DNA to induce mutation is the :
(a) Formation of thymine dimmers (b) Methylation of base pairs
(c) Deletion of base pairs (d) Addition of base pairs

5. X-rays causes mutation by :
(a) Deletion (b) Transition
(c) Transversion (d) Base substitution

6. Which of the following is not ionizing radiation:
(a) X-rays (b) UV rays
(c) Cosmic rays (d) Alpha rays

7. Breeding for disease resistance requires:
(a) A good source of resistance (b) Planned hybridization
(c) Disease test (d) All of these

8. Muller was first to produce induced mutations in_____by exposing them X-rays.
(a) *Paramecium* (b) *Arabidopsis*
(c)*Drosophila* (d) *Xenopus*

9. In mutational event, when adenine is replaced by guanine, it is case of
(a) Transition (b) Transcription
(c) Transversion (d) Frame shift mutation

10. Plants can be made disease resistant by-------
(a) Heat treatment (b) Hormone treatment
(c) Colchicines treatment (d) Breeding with their wildly growing relatives

8.7.3 Fill in the blanks:

1. _____can be induced by some physical and chemical agents.
2. Mutation breeding utilizes_____only.
3. _____can break chromosomes and produce all types of mutations in nucleotides.
4. Spontaneous mutations in somatic cells of a vegetatively propagated plant are commonly referred to as_____.
5. The Gene-For-Gene hypothesis is also known as_____.

8.7.4 True/False

1. Resistant varieties offer the cheapest mean of disease control.
2. Insect and pest infestation are two minor causes for large destruction of crop plant and crop.
3. Micro-organisms are used for the preparation of fermented foods.
4. SCP can not be produced in laboratories throughout the year.
5. Disease resistance in plants has been introduced through breeding.

8.7.1 Answer key: 1-Single Cell Protein, 2-Spirulina, 3-Wright in 1791, 4-X-rays and UV rays, 5-Indian Agricultural Research Institute, 6-Mutation Breeding, 7-200, 8-Sharbati Sonara & Pusa Lerma, 9-By Flor in 1956, 10-MCU 5 VT

8.7.2 Answer key: 1-a, 2- c, 3- d, 4- a, 5- a, 6- b, 7- d, 8- c, 9- a, 10- d

8.7.3 Answer key: 1- Mutation, 2- Vital mutation, 3- X-rays, 4- SPORTS, 5- Flor hypothesis

8.7.4 Answer key: 1-True, 2- False, 3- True, 4- False, 5-True

8.8 REFERENCES

- *Schouten, H. J.; Jacobsen, E. (2007). "Are Mutations in Genetically Modified Plants Dangerous?". Journal of Biomedicine and Biotechnology. **2007**: 1. doi:10.1155/2007/82612.*
- *M.K. Maluszynsk, K. Nichterlein, L. van Zanten & B.S. Ahloowalia (2000). "Officially released mutant varieties – the FAO/IAEA Database". Mutation Breeding Review (12): 1–84.*
- *Ahloowali, B.S. (2004). "Global impact of mutation-derived varieties" (PDF). Euphytica. **135**: 187–204. doi:10.1023/b:euph.0000014914.85465.4f. Retrieved 20 April2011.*
- *"New Citrus Variety Released by UC Riverside is Very Sweet, Juicy and Low-seeded".*
- *Broad, William J. (28 August 2007). "Useful Mutants, Bred With Radiation". New York Times. Retrieved 20 April 2011.*
- *Smith, Peter (2011-04-12). "How Radiation is Changing the Foods that You Eat". GOOD. GOOD Worldwide, Inc. Retrieved 2011-07-16.*

- Pathirana, R. Plant Mutation Breeding in Agriculture. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 2011 6 No 032
- *Johnson, Paige. "Atomic Gardens". Retrieved 20 April 2011.*
- *Rowland, G.G. (2009). "Chapter 110: The Effect of Plants With Novel Traits (PNT) Regulation on Mutation Breeding in Canada". In Shu, Q. Y. Induced Plant Mutations in the Genomics Era. Plant Breeding Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria. pp. 423–424. ISBN 978-92-5-106324-8.*
- Useful Mutants, Bred With Radiation, by William J. Broad, New York Times, August 28, 2007.
- *Kotobuki, Kazuo. "Japanese pear tree named `Osa Gold`". Retrieved 20 April 2011.*
- *"Lift-off for Chinese space potato". BBC News. 12 February 2007.*
- *Ahloowalia, B. S.; Maluszynski, M. (2001). "Production Process in Old and Modern Spring Barley Varieties". Euphytica. **118** (2): 167. doi:10.1023/A:1004162323428.*
- *"Genetic Improvement of Durum Wheat in Casaccia. The Creso Case" (PDF).*
- (2008) NIAB - Plant Breeding & Genetics Division, Achievements Nuclear Institute for Agriculture and Biology, Faisalabad, Pakistan, Retrieved 16 May 2013
- (2012) Improved barley varieties - Feeding people from the equator to the arctic Joint FAO/IAEAProgramme, Nuclear Techniques in Food and Agriculture, Retrieved 25 October 2013
- Lipavsky, J. Petr, J. and Hradecká, D, (2002) "Production Process in Old and Modern Spring Barley Varieties" Die Bodenkultur, 53 (1) 2, Page 19
- *Forster, B. P. (2001). "Mutation genetics of salt tolerance in barley: An assessment of Golden Promise and other semi-dwarf mutants". Euphytica. **120** (3): 317–328.doi:10.1023/A:1017592618298.*
- *Broad, William (2007-08-28). "Useful Mutants, Bred With Radiation". New York Times. Retrieved 2013-06-19.*
- (2012) Successful Mutation Breeding Programmes in Vietnam Joint FAO/IAEAProgramme, Nuclear Techniques in Food and Agriculture, Retrieved 25 October 2013
- Vinh, M.Q. et al (2009) Current Status and Research Directions of Induced Mutation Application to Seeds Program in Vietnam in Induced Plant Mutations in the Genomics Era, FAO of the UN, Rome, Pp 341-345, Web page version retrieved 25 October 2013
- (2014) Successful Mutation Breeding Programmes in Vietnam Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Retrieved 31 July 2014
- Pathirana, Ranjith (September 6, 2011) Plant mutation breeding in agriculture CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources (CAB International); 20116 (032): 1 – 20; doi:10.1079/PAVSNNR20116032; ISSN 1749-8848; Retrieved August 6, 2014

8.9 SUGGESTED READING

- General Plant Breeding by A.R. Dabholkar
- A text book of Plant breeding, by B.D. Singh, Kalyani publication, Ludhiana
- Cell Biology, Genetics and Plant Breeding by P.C.Trivedi
- Plant Breeding by Sandhu S.S.

8.10 TERMINAL QUESTIONS

8.10.1 Long Answer Type Questions:

1. What is mutation? What are the characteristics of mutation? Write its type and stages & frequency at which mutation occurs.
2. What do you mean by mutation breeding? What is the procedure of mutation breeding? Write its achievements and limitations in crop improvements.
3. What do you understand by breeding for disease resistance? Define vertical and horizontal resistance to plant disease.
4. Describe various sources of disease resistance in crop plants. Discuss their usefulness in resistance breeding. Also write the steps in breeding for disease resistance.
5. Explain briefly the various breeding methods used for breeding of disease resistant varieties. Write the advantages of breeding for disease resistance.
6. Write short note on the following :
   a) Flor hypothesis
   b) SCP

8.10.2 Short Answer Type Questions:

1. What is induced mutation? Write its type.
2. What is gene mutation? Give its type.
3. What is mutagen? Give its type.
4. Define the following terms :
   a) Alkylating agents
   b) Base analogues
   c) Mutagenesis
   d) Parasite
   e) Pathogen
5. Write the role of plant breeding for improved food quality.
6. Write short note on the following :
   a) Dose of mutagens
   b) Mutagen treatment
   c) Chromosomal mutation
   d) Selection amongst somaclonal variation.

LABORATORY COURSE

UNIT-1(L) PROBLEMS BASED ON MENDAL'S LAW

Contents:

1.1 OBJECTIVES

After reading this section you will understand and able to -

- Explain the basic concepts of genetics.
- Describe understandable explanations of various laws of Mendelism.
- Provide multiple approaches of genetics problem.
- Solve different problems of genetics.

1.2 INTRODUCTION

Genetics is defined as the branch of biology concerned with the study of heredity and variation. The word genetics (from the Greek word *genno* = give birth) was first suggested by British scientist **William Bateson**. Genetics is a centre of every organism life. It influences an organism's physical characteristics, internal organization, metabolism and behaviour. The era of genetics began in the 1860s, when **Gregor Mendel** conducted a decade long series of experiments using pea plants in central Europe. He revealed that traits are transferred from parents to offspring in predictable ways.

Mendel was born in the Czech Republic, he did his graduation from Augustinian monastery in Brno in 1843 and monastery recommended him for further study at the University of Vienna. After 2 years of study in Vienna, Mendel returned to Brno, and started teaching at the school and also began his experimental work with pea plants. He conducted breeding experiments from 1856 to 1863 and presented his results publicly at the meetings of Brno Natural Science Society in 1865. Mendel's paper from these lectures was published in 1866. At the time, no one seemed to have noticed that Mendel had discovered the basic principles of inheritance. He died at the age of 61 on January 6, 1884, unrecognized for his contribution to genetics. The significance of Mendel's discovery was recognized in 1900, when three botanists- **Hugo de Vries**, **Erich von Tschermak** and **Carl Correns**; began independently conducting similar experiments with plants and arrived at conclusions similar to those of Mendel.

Throughout this unit, a number of concepts are interconnected; Mendel's principles of dominance, segregation and independent assortment, incomplete dominance and the interaction of genes. These concepts might at first appear to be unrelated, but they are actually different views of the same phenomenon, because the genes that undergo segregation and independent assortment are located on chromosomes. The principal aim of this unit is to examine these different concepts and to solve their relations in the form of genetic problems.

1.3 GENETIC PROBLEMS

Mendel's approach to the study of heredity was successful because of several reasons. One of the choice of experimental plants, *Pisum sativum* (garden pea), which offered clear advantages for genetic investigation and his interpretation of the result by using mathematics.

Mendel obtained many different true-breeding (homozygous) varieties of pea, each distinguished by a peculiar characteristic (Table-6.1).

Table – 6.1: Seven pairs of contrasting characters of pea plant

S. No.	Character	Contrasting Traits	F_1 Result	
			Phenotype	**Genotype**
1	Seed shape	Round/Wrinkled	Round	*Ww*
2	Seed colour	Yellow/Green	Yellow	*Gg*
3	Pod shape	Full/Constricted	Full	*Cc*
4	Pod colour	Green/Yellow	Green	*Yy*
5	Flower colour	Red/White	Red	*Ww*
6	Flower position	Axial/Terminal	Axial	*Tt*
7	Stem height	Tall/Dwarf	Tall	*Dd*

To understand Mendel's postulates, we must first introduce several new terms as well as a symbol convention for the unit factors (genes). Traits such as tall or dwarf are physical expressions of the information contained in unit factors. The physical expression or observable features of a trait is the **phenotype** of the individual. Mendel's unit factors represent units of inheritance called **genes** by modern geneticists. For any given character, such as plant height, the phenotype is determined by alternative forms of a single gene, called **alleles**. All alleles for any particular gene will be found at a specific place on a chromosome called the **locus** for that gene. For example, the unit factors representing tall and dwarf are alleles determining the height of the pea plant. Geneticists have several different systems for using symbols to represent genes. According to this convention, the first letter of the recessive trait symbolizes the character in question; in lowercase italic, it designates the allele for the recessive trait and in uppercase italic, it designates the allele for the dominant trait. Thus for Mendel's pea plants, we use *w* for the white flower allele and *W* for the red flower allele. When alleles are written in pairs to represent the two unit factors present in any individual (*WW*, *Ww* or *ww*), the resulting symbol is called the **genotype**. The genotype represents the genetic makeup of an organism for the trait or traits, it describes whether the individual is haploid or diploid. By reading the genotype, we know the phenotype of the individual; *WW* and *Ww* are red flowered and *ww* is white flowered. When both alleles are the same (*WW* or *ww*) the individual is **homozygous** for the trait; when the alleles are different (*Ww*) we use the terms **heterozygous**.

1.3.1 - Mendel's laws of inheritance

Mendel's simplest cross is a monohybrid cross, which involved only one pair of contrasting traits. A monohybrid cross is made by mating true-breeding (homozygous) individuals from two parent strains, each exhibiting one of the two contrasting forms of the character under study. Initially, we examine the first generation of offspring of such a cross, and then we consider the offspring of **selfing**, that is, of self-fertilization of individuals from this first generation. The original parents constitute the **parental generation** (P), their offspring are

the **first filial generation** (F_1) and the individuals resulting from the selfed F_1 generation are the **second filial generation** (F_2).

Step -1: Each parental homozygote produces one kind of gamete

P Red × White

WW *ww*

↓ ↓

W *w*

Step -2: The F_1 heterozygotes produce two kinds of gametes in equal proportions

F_1 Red

Ww

↓ ↓

Gametes- *W* *w*

Self-fertilization

Step -3: Self-fertilization of the F_1 heterozygotes yields red and white offspring in a 3:1 ratio

F_2

	W	*w*
W	*WW* (Red)	*Ww* (Red)
w	*Ww* (Red)	*Ww* (White)

F_2 Results -

Phenotypes	Genotypes	Genotypic ratio	Phenotypic ratio
Red	*WW*	1	3
	Ww	2	
White	*ww*	1	1

After a decade of careful work documenting the consistent patterns of inheritance, Mendel derived several principles which are known as **Mendel's laws of inheritance**.

1. **The Law of Dominance –** In a heterozygote, one allele may hide the presence of another allele. Mendel's observed that, in monohybrid cross, a phenotypic character which appears only in homozygous individuals is called a recessive character and the pair of alleles which specifies a recessive phenotypic character is called recessive pairs of alleles. Another phenotypic character which appear in homozygous as well as in heterozygous individuals of both F_1 and F_2 generation. Such a trait is called dominant character and such alleles which phenotypically expressed itself in the heterozygous as well as in the homozygous is called a dominant allele.

2. **The Law of Segregation -** In a heterozygote, two alleles of a gene are different entities that segregate from each other during the formation of gametes. According to this principle, hereditary characteristics are determined by genes that appear in pairs, one of each pair being inherited from each parent. During meiosis, the pairs of factors are separated or segregated. Hence, each gamete produced by an offspring at maturity contains only one member of the pair. This concept of a gene explained how a characteristic could persist from generation to generation without blending with other

characteristics, as well as how it could seemingly disappear and then reappear in a later generation.

3. **The Law of Independent Assortment** – The alleles of two different genes segregate independently of each other. According to this law, when the gametes are formed the members of the different pairs of genes segregate quite independently of each other and that all possible combinations of the genes concerned will be found among the progeny. Thus, besides obtaining the phenotypic ratio of 3:1 of a monohybrid cross, we got the different ratio of 9:3:3:1. This type of diversion in the ratio of F_2 progeny of a dihybrid cross was due to **independence assortment**.

Step -1: Each parental homozygote produces one kind of gamete

P Yellow, Round × Green, Wrinkled

GGWW ↓ *GW* — *ggww* ↓ *gw*

Step -2: The F_1 heterozygotes produce four kinds of gametes in equal proportions

F_1 Yellow, Round

GgWw

Gametes- *GW* *Gw* *gW* *gw*

Step -3: Self-fertilization of the F_1 heterozygotes yields four phenotypes in a 9:3:3:1 ratio

F_2 Self-fertilization

	GW	*Gw*	*gW*	*gw*
GW	*GGWW*	*GGWw*	*GgWW*	*GgWw*
Gw	*GGWw*	*GGww*	*GgWw*	*Ggww*
gW	*GgWW*	*GgWw*	*ggWW*	*ggWw*
gw	*GgWw*	*Ggww*	*ggWw*	*ggww*

$\mathbf{F_2}$ Results –

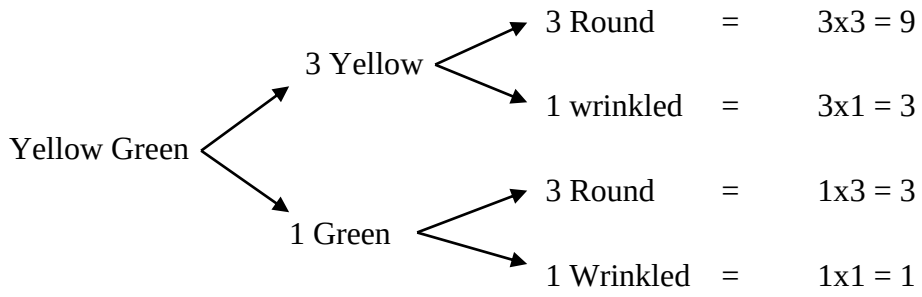
Phenotypes	**Genotypes**	**Genotypic ratio**	**Phenotypic ratio**
Yellow, Round	*GGWW*	1	
	GGWw	2	9
	GgWW	2	
	GgWw	4	
Yellow, Wrinkled	*GGww*	1	
	Ggww	2	3
Green, Round	*ggWW*	1	
	ggWw	2	3
Green, Wrinkled	*ggww*	1	1

1.3.2 – Methods of analysis

1. Punnett square Method – In above monohybrid and dihybrid cross, different combination of gametes are symbolized and put in a square box. This visual diagram of square is called the **Punnett square**. The genotype and phenotype which produces due to result of the different combination of gametes are easily determined by the help of Punnett square. This was discovered by R.C. Punnett, in which, each of the possible gamete is placed in an individual column or a row.

2. Forked line Method - A method for bringing the combinations of a cross together may be dihybrid illustrated as follows; first predict the dihybrid cross as two monohybrid crosses-that is, *Gg* x *Gg* and *Ww* x *Ww* – drawing together. If one member of each pair is dominant, a 3 : 1 phenotypic ratio would be predicted from each monohybrid cross. Since, the two pairs are independent, the ratio 3 : 1 from *Gg* x *Gg* may be combined with the ratio 3: 1 from *Ww* x *Ww*.

GgWw x *GgWw*



So, dihybrid phenotypic ratio is 9: 3: 3: 1

3. Test and Back cross - The genotype of an F_1 organism, produced by the breeding of homozygous dominant and homozygous recessive parents is heterozygous but shows the dominant phenotype. An organism displaying the recessive phenotype must have a genotype which is homozygous for recessive allele. When F_1 organism are back crossed with one of the

two parents (homozygous dominant or homozygous recessive) from which they were derived, then such a cross is called **back cross**. In such back crosses, when F_1 individual is back crossed with the homozygous dominant parent, no recessive progeny are obtained. But when F_1 individual is back crossed with its homozygous recessive parents, both the phenotype (dominant and recessive) obtained the progeny. While both of these crosses are back cross, but only the cross with the recessive parent is called **Test cross**. A monohybrid test cross gives a 1: 1 phenotypic ratio, while in dihybrid cross the phenotypic ratio is 1: 1: 1: 1.

P Tall × Dwarf
DD *dd*
↓ ↓
D *d*

F_1 Tall
Dd

A. Back cross: F_1 Tall x P_1 Tall

Dd *DD*

Back cross result: 50% *DD* and 50% *Dd* = 100% Tall

B. Test cross: F_1 Tall x P_1 Dwarf

Dd *dd*

Test cross result: 50% *Dd* and 50% *dd*
= test cross ratio is 1: 1

1.3.3 – Extension of Mendelism

Mendel's experiments established that genes can exist in alternate forms. This discovery suggested a simple functional dichotomy between alleles, as if one allele did nothing and other did everything to determine the phenotype. However, genes can exist in more than two allelic states and each allele can have a different effect on the phenotype. In the absence of Mendel's allelic inter relationship and number of existing allelic state, the phenotypic ratio has been found to be modified.

1. Incomplete dominance - When a dominant allele does not mask completely the phenotypic expression of the recessive allele in a heterozygote, then a mixing of both dominant and recessive characters takes place in the F_1 and F_2 progeny. This phenomenon is known as **incomplete dominance**, **partial dominance** and **semi-dominance**. In such cases, the mixing occurs only in the phenotype of the F_1 heterozygotes and the alleles maintain their

individual identities and segregate from each other during gamete formation. The F_1 gametes produce F_2 progeny having the same phenotypic and genotypic ratios of 1:2:1. For example- Four O'clock plant or *Antirrhinum majus* with red flowers (*WW*) are crossed with white flowered (*ww*) plants; the offspring have pink flowers (*Ww*).

Phenotype	**Genotype**	**Amount of gene product**
1. Red	*WW*	2X
2. White	*ww*	0
3. Pink	*Ww*	X

2. Co dominance – In the co dominance, both dominant and recessive alleles lack their dominant and recessive relationships and both have capability to express them phenotypically in the heterozygous condition. In co dominance, the dominant and recessive characters occur together side by side. Hence, heterozygote genotype gives rise to a phenotype which different from either of the homozygous genotypes. The F_1 heterozygotes produce a F_2 progeny in the phenotypic and genotypic ratio of 1:2:1 like the incomplete dominance. For example- MN blood group, Karl Landsteiner and Philip Levin discovered a glycoprotein molecule found on the surface of red blood surface that act as native antigen, two forms (M & N) of this glycoprotein exist. An individual may exhibit either one or both of them.

3. Multiple Alleles – In the Mendelism each characteristic has been controlled by a gene which may have appeared in one of two forms or alleles and an allele is a specific form of a given gene. When more than two alleles for the same gene are found within members of population for a single characteristic and occupy the same gene loci on homologous chromosomes. This is known as the multiple allele. For example- Human Blood Group, contain three different forms of alleles (I^A, I^B and I^o) for ABO blood group.

Possible Genotype	**Phenotype**
$I^A I^A$ or $I^A I^o$	A blood group (with A antigen)
$I^B I^B$ or $I^B I^o$	B blood group (with B antigen)
$I^A I^B$	AB blood group (with A&B antigen)
$I^o I^o$	O blood group (with no antigen)

1.4 SUMMARY

Mendelian genetics is based on the transmission of traits (genes) from parents to progeny and thus from generation to generation. Mendel studied the inheritance of seven different characters in pea, each characters being controlled by different gene. Mendel proposed three postulates on the basis of their research findings – (i) the alleles of a gene are either dominant or recessive, (ii) different alleles of a gene segregate from each other during the formation of gametes and (iii) the alleles of different genes assort independently. The result of genetic crosses can be predicted by Punnett squares, which use the principles of mathematical probability to follow the union of gametes. Mendel's revealed the phenotypic and genotypic

ratios, which are 3 : 1 and 1 : 2 : 1 for monohybrid crosses. A cross between F_1 individual and a recessive parent is called test cross. A test cross can distinguish the pure dominant individual from the hybrid dominant individual. In some cases, F_1 heterozygotes have intermediate phenotype are incomplete dominance and some genes have more than two alleles in a population are multiple allele.

1.5 GLOSSARY

Allele: One of two or more alternate forms of a gene.
Back cross: A cross between an individual offspring and one of its parents.
Character: An attribute or feature.
Co dominance: The condition in heterozygous where both members of an allelic pair contribute to phenotype.
Dihybrid cross: A cross in which inheritance of two pairs of contrasting characters is studied simultaneously.
Diploid: An organism or cell with two set (2*n*) of chromosome or two genomes.
Gene: A genetic factor (region of DNA) that helps determines a characteristic.
Genotype: Set of alleles possessed by an individual organism.
Haploid: An organism or cell having only one complete set (*n*) of chromosome or one genome.
Heterozygote: An individual organism possessing two different alleles at a locus.
Homozygote: An individual organism possessing two of the same alleles at a locus.
Locus: Specific place on a chromosome occupied by an allele.
Monohybrid cross: A cross between two parents in which inheritance of only one pair of contrasting characters is studied.
Multiple allele: More than two allelic forms exist for certain gene.
Phenotype: The appearance of a character.
Test cross: A cross between F_1 individual types with recessive parental type.

1.6 SELF ASSESSMENT QUESTIONS

1.6.1 – Very short answer questions

1- What is genetics?
2- Who is the father of genetics?
3- How many different contrasting characters did Mendel notice in garden pea?
4- What the term is used for a class of individuals which are morphologically similar?
5- What is Mendel's monohybrid phenotypic ratio?
6- What is Mendel's dihybrid phenotypic ratio?
7- What is Mendel's monohybrid genotypic ratio?
8- What is allele?

9- What is locus?
10-What is Punnett square?

1.6.2 – Multiple choice questions

1. Number of characters observed in garden pea by Mendel for his experiment is-
(a) Three (b) Five
(c) Seven (d) Nine

2. The various forms of a given gene are called-
(a) Genotype (b) Phenotype
(c) Gametes (d) Alleles

3. An individual with a pair of identical factor (allele) is-
(a) Hybrid. (b) Homozygous.
(c) Heterozygous. (d) None of the above.

4. Mendel's do not propose-
(a) Dominance. (b) Gamete segregation.
(c) Independent assortment of gene. (d) Incomplete dominance.

5. Recessive gene can be expressed in-
(a) Homozygous condition. (b) Heterozygous condition.
(c) Both of the above. (d) None of the above.

6. In monohybrid cross a typical genotypic ratio is-
(a) 3 : 1 (b) 9 : 7
(c) 1: 2: 1 (d) 9 : 3 : 3 : 1

7. In dihybrid cross a typical phenotypic ratio is -
(a) 1: 2: 1 (b) 1 : 1 : 1 : 1
(c) 9 : 3 : 3 : 1 (d) 9 : 3 : 4

8. The gene which exhibits multiple effects is known to be-
(a) Complementary (b) Multiple Allele
(c) Co dominance (d) Supplementary

9. Independent assortment of Mendel was proved by-
(a)Test cross (b) Back cross
(c) Monohybrid cross (d) Dihybrid cross

10. The Mendel's law was rediscovered by-
(a) Hugo de Vries (b) Erich von Tscermark

(c) Carl Correns (d) All the above

11. A gamete contains-
(a) Only one allele of gene (b) Two allele of gene
(c) All allele of gene (d) None of the above

12. A breeding experiment dealing with a single trait is called-
(a) Monohybrid cross (b) Dihybrid cross
(c) Trihybrid cross (d) All of the above

13. What will be the test cross ratio in the monohybrid cross-
(a) 1 : 1 (b) 1 : 2 : 1
(c) 9 : 3 : 3: 1 (d) All of the above

14. In which cross both phenotypic and genotypic ratio will be similar-
(a) Monohybrid cross (b) Dihybrid cross
(c) Incomplete dominance (d) Multiple allele

15. How many gametes are produced by *AaBb* genotype-
(a) 02 (b) 04
(c) 08 (d) None of the above

1.6.3 – Fill up the following blanks –

1-The term Genetics is coined by ……
2- Mendel was born in the …….
3- Mendel's choose …….. plant for his genetic experiments.
4- F1 progeny crossed with homozygous recessive parent is known as …… cross.
5- ABO blood group is example of …….. allele.
6- MN blood group is example of ……..
7- Offspring with intermediate phenotype is due to ……
8-…….. introduced the Punnett square method.
9-The test cross ratio in the dihybrid cross is …….
10-Law of segregation is also known as ……..

1.6.1 Answer Key – **1**. The study of various traits and genes and how they are inherited from one generation to next, **2**. G.J. Mendel, **3**. Seven, 4. Phenotype, **5**. 3:1, **6**. 9: 3: 3: 1, **7**. 1:2:1, **8**. Alternative forms of a gene, **9**. A point where an allele is located on the chromosomes, **10**. The representation of monohybrid or dihybrid crosses by making squares.

1.6.2 Answer Key – 1. (**c)**, 2. (d), 3. (b), 4. (d), 5. (a), 6. (c), 7. (c), 8. (b), 9. (d), 10. (d), 11. (a), 12. (a), 13.(a), 14. (c), 15. (b)

1.6.3 Answer Key – 1. William Bateson, 2. Czech Republic, 3. Pea, 4. Test, 5. Multiple Allele, 6. Co dominance, 7. Incomplete dominance, 8. R.C. Punnett, 9. 1: 1: 1 : 1, 10. Purity of gametes.

1.7 REFERENCES

- E. Novitski and S. Blixt (1978), Mendel, linkage and synteny. *BioScience* 28: 34-35.
- H. Stubbe (1972), History of genetics. MIT Press, Cambridge

1.8 SUGGESTED READINGS

- B.A. Pierce (2012), *Genetics - A Conceptual Approach* (fourth edition), W.H. Freeman & Company, New York.
- D.P. Snustad and M.J. Simmons (2010), *Principles of Genetics* (fifth edition), John Wiley & Sons (Asia) Pvt Ltd.
- W.S. Klug, M.R. Cummings, C.A. Spencer and M.A. Palladino (2012), *Concepts of Genetics* (tenth edition), Pearson Benjamin Cummings Publication, San Francisco.
- P.S. Verma and V.K. Agarwal (2012), *Genetics*, S. Chand & Company Pvt. Ltd.

1.9 TERMINAL QUESTIONS

1.9.1 - Long answer type questions-

1 – Explain the law of independent assortment with the help of an example?

2 – What are multiple allele? Explain the Human blood group as an example of multiple allele?

3 – Why did Mendel's choose the pea plant for genetic experiment? How did he make sure that plants were pure?

4 – What kind of plants will be produced in F_2 generation by crossing between pure tall (*DD*) and pure dwarf (*dd*)?

5 – A man with type 'A' blood has a wife with type 'B' blood. They have a child with type 'O' blood. What will be the possible genotype of husband and wife?

6 – How many different kinds of F_1 gametes, F_2 genotype and F_2 phenotype would be expected from AABB x aabb?

7 – What phenotypic ratio would be expected from a test cross of F_1 and a pure recessive (AaBb x aabb), if the F_2 resulting from F_1 x F_1 (selfing) was 9 : 3 : 3 : 1?

8 –In a case, woman of blood group O presented a baby of blood group O and suit against a man of blood group AB for father. What bearing might the blood type information have on the case?

1.9.2 - Short answer type questions-

1 – Describe the brief history of genetics.

2 – Why did Mendel select pea plant for his experiments?
3 – Point out the main findings of Mendel's experiments.
4 – Define the Law of inheritance.
5 – What do you understand by heterozygous and homozygous?
6 – What is the difference between the genotype and phenotype?
7 – Describe the test and back cross.
8 – Define the incomplete dominance.
9 – How you find out the phenotypic and genotypic ratio?
10 – Describe the dihybrid cross with example.

UNIT-2(L) PROBLEMS BASED ON ABERRATIONS

Contents:

2.1 OBJECTIVES

After reading this unit the learners will be able to:

- Define the terms and classify genetic and chromosomal aberrations
- Solve the problems based on Genetic and chromosomal Aberration

2.2 INTRODUCTION

Members of a species typically have a fixed number of chromosomes. For instance, *Zea mays*, (2n=20) chromosomes. However, some individuals exhibit genetic aberration is defined as an abnormality of the chromosome number in a cell i.e., structural or numerical variation in their chromosomes, which can lead to significant phenotypic consequences. These chromosomal mutations are now recognized as a major cause of spontaneous abortions and stillbirths.

This unit provides an overview of numerical and structural chromosomal aberrations, also known as chromosomal mutations. It covers the primary causes, inheritance patterns, and symptoms of selected syndromes. Additionally, it discusses the role of chromosomal mutations in evolution. In this unit you will be able to learn and solve the problems based on chromosomal aberrations to enhance your understanding of the topic.

2.3 CHROMOSOMAL ABERRATIONS

Chromosomal aberrations, or chromosomal mutations, can arise from changes in either the structure or the number of chromosomes. Structural variations include deletions, duplications, translocations, and inversions, while numerical changes manifest as aneuploidy or polyploidy. Each of these broad categories is further subdivided based on the specific type of change.

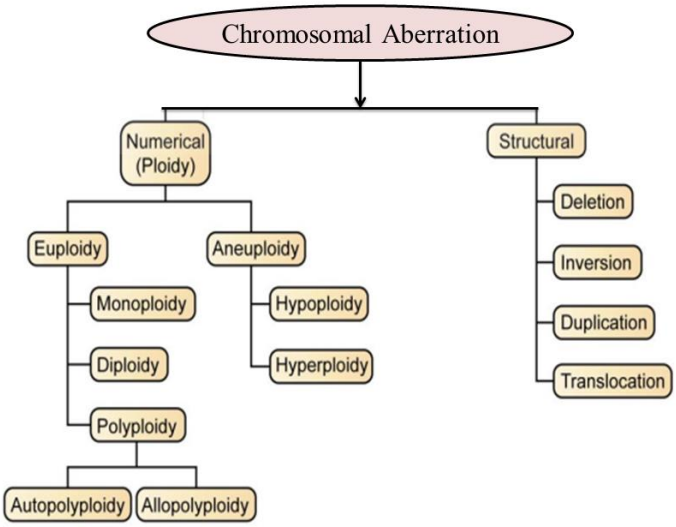


Figure- 2.1- Classification of Chromosomal Aberrations

An overview of the major types of numerical and structural chromosomal aberrations is depicted in Figure 2.1. In the following sections, we will explore how these aberrations occur and the potential consequences.Chromosomal aberrations play a crucial role in the development and progression of many cancers. For example, translocations can activate oncogenes, while deletions can remove tumor suppressor genes, both of which contribute to uncontrolled cell growth. Detecting specific chromosomal aberrations can also help in diagnosing cancer types and determining the most effective treatment strategies.

2.3.1 NUMERICAL ABERRATIONS

Numerical aberrations in chromosomes can range from the addition or loss of one or more chromosomes to an increase in the entire set of haploid chromosomes. The former leads to aneuploidy, while the latter results in polyploidy.

- **Aneuploidy**
  An aneuploidy organism has either more or fewer chromosomes than the typical wild-type member of its species. Numerical aberrations can occur in both haploid and diploid organisms. When a chromosome or a piece of a chromosome is under represented, the organism is termed hypoploid, and when over represented, it is termed hyperploid. Common types of aneuploidy observed in diploid organisms include monosomy (2n-1), trisomy (2n+1), tetrasomy (2n+2), and nullisomy(2n-2), each leading to specific genetic imbalances. In haploids, an extra chromosome results in a disomic condition (n+1). Let's now explore the representative types of aneuploidy in humans.
- **Nullisomy** is the loss of both members of a homologous pair of chromosomes, represented as (2n–2), where *n* denotes the haploid number of chromosomes. In humans, a nullisomic individual would have 44 chromosomes instead of the typical 46.
- **Monosomy** occurs due to the loss of a single chromosome, represented as (2n–1). Most human monosomies are not viable, with the exception of females who lack one X chromosome, as seen in Turner syndrome (45, XO).
- **Trisomy** involves the gain of a single chromosome, represented as (2n+1), resulting in three homologous copies of one chromosome. In humans, both autosomal and sex chromosome trisomies have been observed, with varying survival rates. Examples of viable trisomies include Primary Down syndrome (47, +21), Edward syndrome (47, +18), and Klinefelter syndrome (47, XXY). Some trisomic individuals are fertile, with the extra chromosome forming a trivalent during meiosis.
- **Tetrasomy** is characterized by the gain of two homologous chromosomes, represented as (2n+2). A human tetrasomic zygote would have 48 chromosomes, with four homologous copies of a particular chromosome.

Table 2.1 Different types of numerical changes

Type of Numerical Change	Description	Examples
Aneuploidy	Gain or loss of one or more chromosomes from a set.	Monosomy (2n-1), Trisomy (2n+1)
Monosomy	Loss of a single chromosome from the diploid set.	Turner syndrome in humans (45,X), 2n-1

Trisomy	Addition of an extra chromosome to the diploid set.	Down syndrome in humans (47, +21), 2n+1
Tetrasomy	Addition of two extra chromosomes to the diploid set.	2n+2
Nullisomy	Loss of both homologous chromosomes of a pair.	2n-2
Polyploidy	Presence of more than two complete sets of chromosomes.	Triploidy (3n), Tetraploidy (4n)
Autopolyploidy	Polyploidy resulting from duplication of the same genome.	Triploid banana (3n), Tetraploid alfalfa (4n)
Allopolyploidy	Polyploidy resulting from the combination of genomes from different species.	Bread wheat (6n), Triticale (6n)

- **Non-disjunction**: Non-disjunction is more commonly observed during meiosis, particularly in meiosis I. During meiosis I, if non-disjunction occurs, it results in four abnormal gametes: two containing an extra chromosome and two that are missing the same chromosome. However, if sister chromatids fail to separate during meiosis II, the outcome is different: 50% of the gametes will be normal, while the other 50% will be abnormal (Figure 2.2).

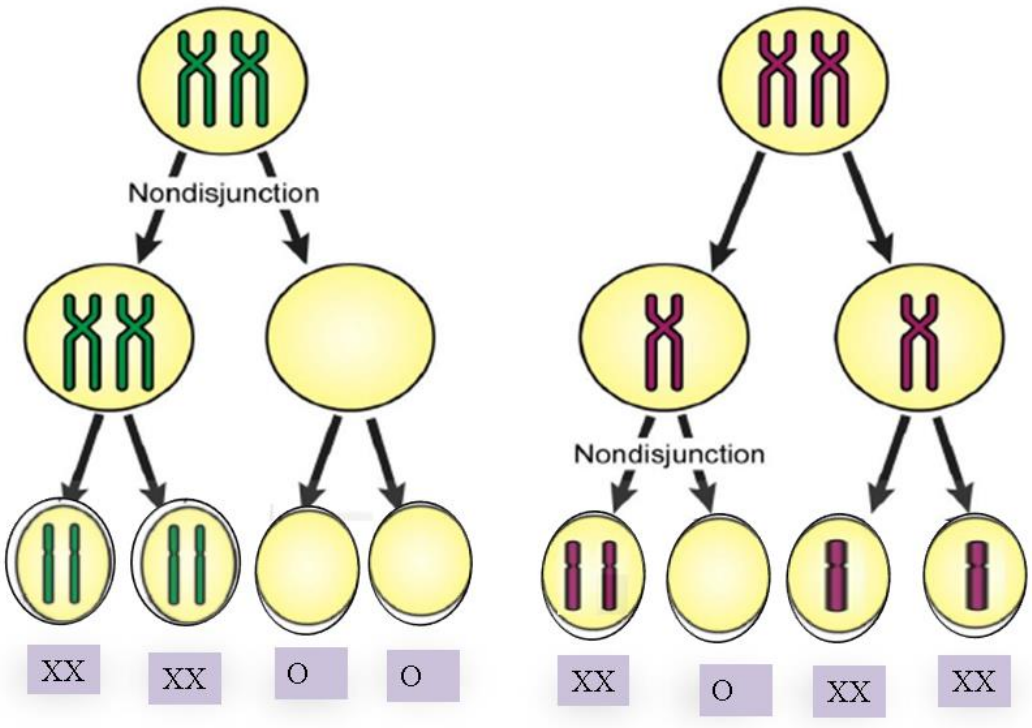


Figure 2.2 Non-disjunction of X-chromosomes in meiosis I and II

Table 2.2– Different Type of Aneuploidy in plants

Type of Aneuploidy	Chromosomal Abnormality	Example in Plants	Chromosome Affected	Phenotypic Characteristics
Monosomy	2n-1	Maize (*Zea mays)*	Various	Reduced growth, sterility, abnormal leaf morphology
Trisomy	2n+1	Datura (*Datura stramonium*)	Various	Altered seed shape, changes in flower morphology
Nullisomy	2n-2	Wheat (*Triticum aestivum*)	Specific chromosomes	Lethality or severe growth defects, reduced fertility
Tetrasomy	2n+2	Tobacco (*Nicotiana tabacum*)	Specific chromosomes	Larger leaves, increased flower size, altered growth patterns
Double Trisomy	2n+1+1	Barley (*Hordeum vulgare*)	Two specific chromosomes	Combination of traits from individual trisomies, often reduced fertility
Monosomic Polyploid	2n+x-1	Cotton (*Gossypium hirsutum*)	Various	Combination of polyploid traits with monosomic deficiencies
Trisomic Polyploid	2n+x+1	Oats (*Avena sativa*)	Various	Combination of polyploid traits with trisomic variations

Table 2.3 Types of aneuploidy in human

Type of Aneuploidy	Chromosomal Abnormality	Syndrome	Chromosome Affected	Phenotypic Characteristics
Monosomy	45,X	Turner Syndrome	X chromosome	Short stature, infertility, webbed neck, normal intelligence
Trisomy 21	47,XX,+21 or 47,XY,+21	Down Syndrome	Chromosome 21	Intellectual disability, distinct facial features, heart defects
Trisomy 18	47,XX,+18 or 47,XY,+18	Edwards Syndrome	Chromosome 18	Severe developmental delays, clenched fists, heart defects
Trisomy 13	47,XX,+13 or 47,XY,+13	Patau Syndrome	Chromosome 13	Severe intellectual disability, cleft lip/palate, polydactyly
Klinefelter Syndrome	47,XXY	Klinefelter Syndrome	X chromosome	Tall stature, reduced fertility, learning difficulties
XYY Syndrome	47,XYY	XYY Syndrome	Y chromosome	Normal fertility, taller than average, possible

				learning difficulties
Triple X Syndrome	47,XXX	Triple X Syndrome	X chromosome	Tall stature, mild learning disabilities, normal fertility

2.3.1.1- Problem based on Identifying Chromosome Numbers in Aneuploidy Plants

Problem 1 - In plant (2n = 46) how many chromosomes are present in the following conditions? i) Triploid ii) Double trisomic iii) Tetrasomic iv) Nullisomic

Solution - For a plant with a diploid chromosome number of 46 (2n = 46), here's how many chromosomes would be present in each of the following conditions:

1. **Triploid (3n):** A triploid organism has three sets of chromosomes.

   Calculation: 3n=3×23=69
   (3n) = 3 \times 23 =3×23=69 chromosomes.

2. **Double Trisomic (2n + 1 + 1):**

   A double trisomic organism has two additional chromosomes, one extra for each of two different chromosome pairs.
   Calculation: 2n+1+1=46+1+1=48 chromosomes.
3. **Tetrasomic (2n + 2):**
   A tetrasomic organism has two extra copies of a specific chromosome, making four copies of that particular chromosome.
   Calculation: 2n+2=46+2=48 chromosomes.

4. **Nullisomic (2n - 2):**

   A nullisomic organism is missing both members of a homologous pair of chromosomes.
   Calculation: 2n−2=46−2=44 chromosomes.

Problem 1.1- A plant species normally has a diploid chromosome number of 2n=24. You observe a mutant plant with a total of 23 chromosomes. What type of numerical chromosome aberration is this, and what are the potential effects on the plant's phenotype?

Solution- The plant has one less chromosome than the diploid number, indicating a monosomic condition (2n−1). Monosomy often leads to developmental abnormalities due to the loss of essential genes present on the missing chromosome. In plants, this could manifest as reduced growth, lower fertility, or morphological abnormalities such as altered leaf or flower shapes.

2.3.1.2- Problem based on Triploid Chromosome Count (3n)

Problem 2-In a certain species of plant, the diploid chromosome number is 2n=36. A triploid variant of this species is discovered. How many chromosomes does this triploid plant have, and what are the implications for its reproduction?

Solution: The diploid chromosome number is 2n=36

The Haploid chromosome number n= 36/2 = 18.

A triploid plant has three sets of chromosomes (3n). Therefore, The Chromosome would be 3x18 = 54 Triploid plants often have difficulty in meiosis because the odd number of chromosome sets cannot pair evenly, leading to reduced fertility or complete sterility. This is commonly seen in triploid fruits like seedless watermelons.

2.3.1.3- Problem based on Double Trisomic Chromosome Count (2n+1+1)

Problem 3 -A plant with a diploid chromosome number of 2n=18 is found to be double trisomic. What is the total number of chromosomes in this plant, and what might be the genetic and phenotypic consequences?

Solution: A double trisomic (2n+1+1) plant has one extra copy of two different chromosomes, so the total chromosome number would be 18+1+1=20. The genetic consequences include an imbalance in gene expression for the trisomic chromosomes, which may result in abnormal growth, development, or reproductive issues. Phenotypically, the plant may exhibit changes such as altered flower or fruit morphology or delayed maturity.

2.3.1.4- Problem based on Tetrasomic Condition in a Crop Plant

Problem 4- In a crop plant where the diploid chromosome number is 2n=32, a tetrasomic individual is identified. How many chromosomes are present in this plant, and what could be the possible impact on the crop's agricultural performance?

Solution: A tetrasomic (2n+2) plant has four copies of one specific chromosome, so the total chromosome number is 32+2=34. The presence of the extra chromosomes may result in overexpression of genes on that particular chromosome, leading to traits such as larger fruits or increased resistance to certain stresses. However, it could also cause developmental instability, leading to reduced crop uniformity and potential issues with fertility.

2.3.1.5- Problem based on Nullisomic Condition in an Experimental Plant

Problem 5-In a laboratory experiment, a plant species with a diploid number of 2n=16 is found to be nullisomic for one chromosome. What is the chromosome number of this plant, and how might the loss of this chromosome affect the plant's survival and reproduction?

Solution: A nullisomic (2n-2) plant lacks both copies of one specific chromosome, so the total chromosome number would be 16−2=14. The absence of an entire chromosome can lead to severe developmental defects or lethality, depending on the genes missing. The plant may exhibit poor growth, sterility, or even fail to survive to maturity.

2.3.1.6- Problem based on Predicting Fertility in an Aneuploid Hybrid

Problem: A hybrid plant is produced between two species, where one parent has a diploid chromosome number of 2n=28 and the other is trisomic for one chromosome, having 29 chromosomes. What challenges might arise in the fertility of the hybrid offspring, considering the potential for aneuploidy?

Explanation: The hybrid offspring may inherit an unequal number of chromosomes from the parents, leading to aneuploidy (such as monosomy or trisomy) in the hybrid. This imbalance can cause problems during meiosis, resulting in reduced fertility or sterility in the hybrid. The plant might produce seeds with lower viability or exhibit abnormal growth and development due to the genetic imbalance.

2.3.1.7- Problem based on Polyploidy and Chromosome Number

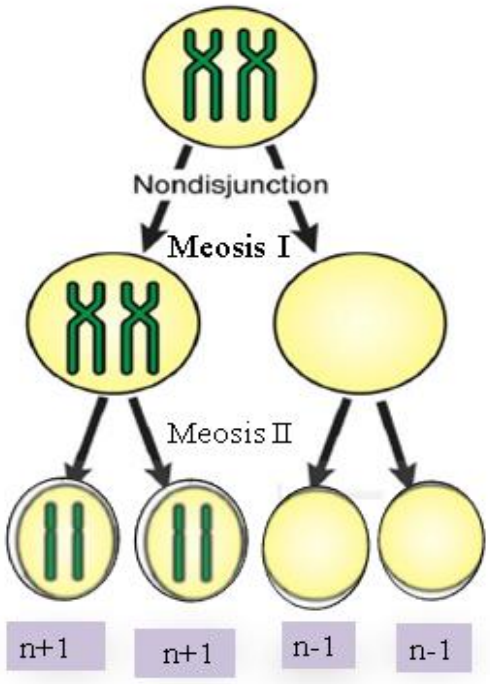
Problem7 : A botanist discovers a tetraploid (4n) version of a plant species where the normal diploid number is 2n=14. How many chromosomes does the tetraploid plant have, and what advantages might polyploidy confer in plants?

Explanation: Normal diploid Chromosome number is 2n=14
Haploid Chromosome number n = 14/2 = 7
A tetraploid plant has four sets of chromosomes (4n).
So, the total chromosome number would be 4n = 4x7=28.
Polyploidy can confer advantages such as increased cell size, greater genetic diversity, and improved tolerance to environmental stresses. It can also lead to the formation of new species due to reproductive isolation from the diploid ancestors.

Problem 2.3.1.8- Problem based on non-disjunction chromosomal aberration

Problem 8 – What kind of aneuploidy gametes will be generated if meiosis non- disjunction occurs at first division?(n represents the haploid number of chromosome)
A .) only n+1 and n B.) only n-1 and n C.) both n+1 and n-1 D.) either n+1 or n-1

Solution – Non-disjunction occurs when chromosomes fail to separate properly during mitosis or meiosis. Normally, during the anaphase stage of cell division, the two arms of a chromosome (in mitosis and meiosis-II) or the two homologous chromosomes (in meiosis-I) separate, ensuring that each daughter cell receives one copy. However, when non-disjunction happens showing in below figure both copies move to the same pole, resulting in one daughter cell with two copies of the chromosome and the other with none. This error leads to aneuploidy, where cells have either an extra chromosome or are missing one. Figure illustrates the normal processes of meiotic and mitotic division, as well as the effects of non-disjunction during anaphase in meiosis-I, meiosis-II, and mitosis division.



Therefore, in non- disjunction occurs at first meiosis division both n+1 and n-1 gametes are formed answer c is correct.

2.3.2 STRUCTURAL ABERRATIONS

Structural aberrations refer to changes in the structure of chromosomes. These include deletions, duplications, and rearrangements such as inversions and translocations. These structural changes occur when chromosomes break and then rejoin in a way that differs from their original configuration. If there is a net loss or gain of chromosomal segments, the change is referred to as an unbalanced structural change. Conversely, when there is no net loss or gain of chromosomal segments but only a rearrangement, it is known as a balanced structural change (Figure 2.2). Balanced changes typically do not result in abnormal phenotypes, whereas unbalanced changes often do. It's important to note that these changes do not involve mutations within individual genes; rather, they alter the number and arrangement of genes on the chromosome.

- **Deletions**: A portion of a chromosome is missing/ loss/delete.
- **Duplications**: A portion of a chromosome is duplicated, resulting in extra genetic material.
- **Inversions**: A segment of a chromosome breaks off, flips around, and reattaches in the reverse order.
- **Translocations**: A segment of one chromosome breaks off and attaches to another chromosome.

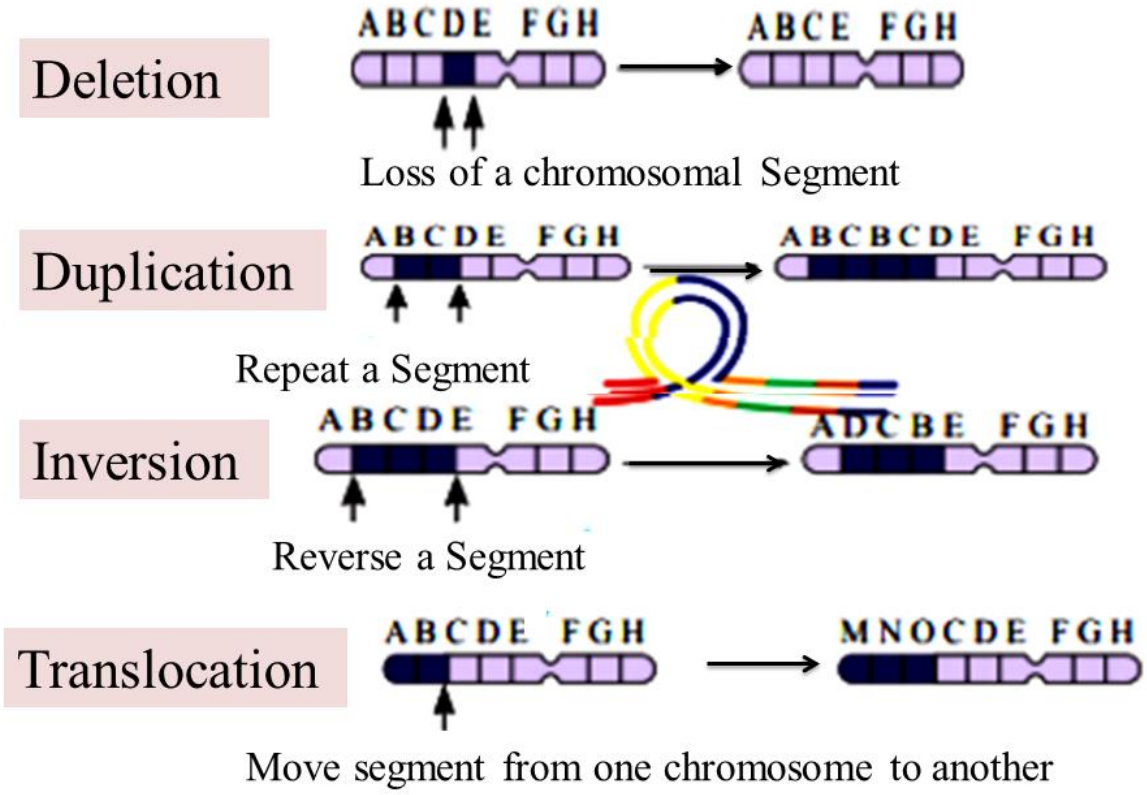


Figure 2.3 – Types of structural chromosome

2.3.2.1- Problem based on Deletion in a Chromosome and Its Impact on Gene Function

Problem 1: In a plant species, a deletion occurs on one of the chromosomes, removing a segment containing several genes. The wild-type chromosome has the gene sequence ABCDEFGH, but after the deletion, the sequence is ABGH. What could be the potential consequences of this deletion for the plant's development and physiology?

Solution: The wild-type chromosome has the gene sequence ABCDEFGH.

A_B_C_D_E_F_G_H

↓ After Deletion C D E F

A_B_G_H

Deletion has removed the segment containing genes CDEF.

Depending on the function of these genes, the deletion could have various impacts on the plant. If the deleted genes are involved in essential processes like photosynthesis, growth regulation, or reproductive development, the plant might exhibit stunted growth, reduced fertility, or abnormal morphology. Deletions can also unmask recessive mutations in the

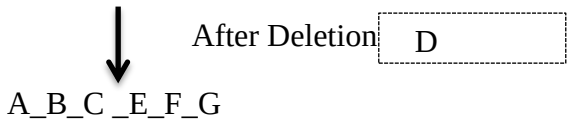
remaining homologous chromosome, leading to the expression of harmful traits that are normally suppressed by the presence of a dominant allele.

2.3.2.2- Problem based on Impact of Deletion on Plant Traits

Problem 2: A certain plant species has a chromosome with a segment deleted, which includes several genes involved in flower color. The normal chromosome has the sequence **A-B-C-D-E-F-G**, but the mutant chromosome has the sequence **A-B-C-E-F-G**. What are the potential effects of this deletion on the plant's phenotype particularly flower color?

Solution:

A_B_C_D_E_F_G



The deletion of the segment **D** from the chromosome results in the loss of genetic material, including genes that might be crucial for producing pigments in the flower. This could lead to a change in flower color, potentially resulting in a lack of color (white flowers) if the deleted genes were responsible for producing the pigments. In addition to affecting flower color, deletions can also cause other developmental issues if the missing genes are involved in critical pathways, potentially leading to reduced viability or fertility.

2.3.2.3 Problem based on Duplication

Problem 3 : Suppose a Chromosomal Aberration in a chromosome A-B.C_D_E_F_G leads to A_B._C_D_E_F_C_D_E_F_G The probable reason is?

Solution -Duplication is a structural chromosomal aberration where a segment of the chromosome is copied and inserted into the genome, resulting in an additional copy of that segment. The segment **C-D-E-F** has been duplicated and inserted next to its original position. The resulting chromosome now reads **A_B.C_D_E_F_C_D_E_F_G**, which includes an extra copy of the **C-D-E-F** segment.

This type of duplication can have various effects on the organism, depending on the genes involved and their expression levels. In some cases, duplications can lead to overexpression of certain genes, potentially causing abnormal traits or developmental issues.

2.4 SUMMARY

Chromosomal aberrations refer to structural and numerical changes in chromosomes that can have significant impacts on an organism's development and function. These alterations can be broadly categorized into two types: structural and numerical. Structural chromosomal aberrations involve changes in the structure of chromosomes and include deletions, duplications, inversions, and translocations. These changes can disrupt gene function or create new genetic combinations, often leading to developmental abnormalities or diseases.

Numerical chromosomal aberrations involve changes in the number of chromosomes and include conditions like aneuploidy, where there is an abnormal number of chromosomes. Aneuploidy can result from non-disjunction during cell division, leading to disorders like Down syndrome in humans or similar conditions in plants. These aberrations can occur spontaneously or be induced by environmental factors, and they play a crucial role in evolution, speciation, and genetic diversity. However, they can also lead to genetic disorders, reduced fertility, and other health issues in both plants and animals. Understanding chromosomal aberrations is essential in fields like genetics, medicine, and agriculture, where they have practical implications for breeding, disease management, and genetic research.

2.5 GLOSSARY

Aneuploidy: A condition in which the number of chromosomes is not the typical diploid number. This can include an extra chromosome (trisomy) or a missing chromosome (monosomy).

Balanced Translocation: A type of chromosomal translocation in which genetic material is exchanged between two chromosomes without any loss or gain of genetic material, typically resulting in no immediate health issues.

Chromosomal Aberration: A deviation from the normal structure or number of chromosomes, which can lead to genetic disorders or developmental abnormalities.

Chromosome: A structure within cells that contains DNA and carries genetic information. Humans typically have 46 chromosomes (23 pairs).

Copy Number Variation (CNV): A type of structural variation in the genome where the number of copies of a particular gene or DNA segment varies between individuals.

Deletion: A type of chromosomal aberration where a segment of a chromosome is missing, potentially leading to the loss of one or more genes.

Duplication: A chromosomal aberration where a segment of a chromosome is copied and added to the same or another chromosome, resulting in extra genetic material.

Epigenetic Change: A heritable change in gene expression that does not involve a change in the DNA sequences itself, often caused by chemical modifications like DNA methylation or histone modification.

Frame shift Mutation: A type of gene mutation caused by insertions or deletions that alter the reading frame of the gene, potentially leading to a completely different translation from the original gene sequence.

Gene Mutation: A permanent alteration in the DNA sequence of a gene. Gene mutations can be small-scale, affecting just one or a few nucleotides.

Inversion: A chromosomal aberration where a segment of a chromosome breaks off, flips around, and reattaches in the reverse orientation, which can disrupt gene function.

Karyotype: A visual representation of the complete set of chromosomes in an individual, used to detect chromosomal aberrations.

Monosomy: A type of aneuploidy where there is only one copy of a particular chromosome instead of the usual two, such as in Turner syndrome (45,X).
Mutation: A change in the DNA sequence of a gene or chromosome that can lead to genetic variation and, in some cases, disease.
Polyploidy: A condition in which a cell or organism has more than two complete sets of chromosomes, common in plants but usually lethal in animals.
Point Mutation: A small-scale mutation where a single nucleotide in the DNA sequence is altered.
Ring Chromosome: A rare chromosomal abnormality where the ends of a chromosome break and the broken ends fuse together to form a circular structure.
Structural Chromosomal Aberration: A type of chromosomal aberration that involves changes in the structure of a chromosome, such as deletions, duplications, inversions, and translocations.
Translocation: A chromosomal aberration in which a segment of one chromosome breaks off and attaches to another chromosome. Translocations can be balanced or unbalanced.
Trisomy: A type of aneuploidy where there is an extra copy of a chromosome, leading to three copies instead of the usual two. An example is Trisomy 21, which causes Down syndrome.
Unbalanced Translocation: A type of translocation where genetic material is lost or gained, which can result in developmental abnormalities or genetic disorders.
Progeny: A genetic descendant or offspring, Collective offspring progeny.

2.6 SELF ASSESSMENT QUESTION

2.6.1 Multiple Choice Questions:

1. Chromosomal Aberrations are commonly observed in

a.) Brain cells b.)Neurons
c.) **Cancer cells** d.)None of these

2. Chromosomal Aberrations occurs due to

a.) Deletion & Duplication b.)Inversion & Translocation
c.)All of these **d.)** None of these

3. Which of the following is a type of chromosomal aberration?

a.) Point mutation b.) Translocation
c.) Frame-shift mutation d.) Silent mutation

4. In which chromosomal aberration does a segment of a chromosome break off and attach to a non-homologous chromosome?

a) Deletion b) Duplication
c) Inversion d)Translocation

5. What is the result of a deletion chromosomal aberration?

a) Duplication of a gene segment b) Loss of a gene segment
c) Inversion of a gene segment d) Transfer of a gene segment to another chromosome

6. Which of the following is a consequence of nondisjunction during meiosis?

a.)Translocation b.)Inversion

c.)Aneuploid d.)Deletion

7.) Which of the following is an example of a numerical chromosomal aberration?

a.) Deletion b.) Duplication
c.) Aneuploidy d.) Translocation

8.) **What is the chromosomal composition of an individual with Turner syndrome?**

a) 47, XXY b) 46, XY
c) 45, XO d) 46, XX

9.) **Which condition results from trisomy 21?**

a) Turner syndrome b) Klinefelter syndrome
c) Down syndrome d) Patau syndrome

10.) Which of the following is a cause of numerical chromosomal aberrations?

a) Crossing over b) Nondisjunction
c) Translocation d) Inversion

2.6.1 Answerkey - 1. C) **2.** C) **3.**B) 4.D) 5.B) 6.C) 7.C) 8.C) 9. C) 10.B)

2.7 REFERENCES

Smith, J. A., & Doe, R. L. (2023). Chromosomal aberrations in plant genetics: A comprehensive review. **Journal of Botanical Genetics**, **45**(3), 234-256. https://doi.org/10.1016/j.jbg.2023.05.012

Jones, M. B. (2021). Chromosomal aberrations in flowering plants. In R. L. Doe (Ed.), **Advanced plant genetics** (pp. 89-112). Academic Press.

2.8 SUGGESTED READINGS

Brooker, R. 2015. Genetics: Analysis and Principles (5th Eds.). McGraw-Hill Publishing Company.

Gardner, E.J., Simmons, M.J. and Snustad, D.P. 2006. Principles of Genetics (8th Ed.). Wiley.

Pierce, B. A. 2017.Genetics: A Conceptual Approach (6th Ed.). W.H. Freeman.

Singh, B.D. 2014. Fundamentals of Genetics. Kalyani Publshers, India.

Singh, B.D. 2016. Genetics (2nd Ed.). Kalyani Publishers, India.

2.9 TERMINAL QUESTIONS

Short answer type questions:

1. What is Chromosomal aberration?
2. Consider a hypothetical sequence where • represents the centromere: A B • C D E F GH

What types of chromosome mutation(s) are required to change the above sequence into each of the following?
i) A B A B • C D E F G H
ii) A B • C D E A B F G H
iii) A B • C F E D G H
iv) A • C D E F G H
v) A B • C F E D F E D G H
vi) A B • C D E F C D F E G H

3. Differentiate between structural and numerical chromosomal aberrations?

2.9.2 Long answer type questions:

1. Give a detailed account of classifications of Chromosomal aberration?
2. What are the structural chromosomal aberrations, give a note with examples?

UNIT-3(L) STUDY OF THE FLORAL BIOLOGY OF SOME OF THE LOCALLY AVAILABLE CROP PLANTS

Contents:

3.1 OBJECTIVES

After reading this unit students will be able -

- To Elucidate the Systematic position of Wheat, Pea, Mustard, Brinjal, Tomato
- To Describe Flower morphology and floral characters of Wheat, Pea, Mustard, Brinjal, Tomato

3.2 INTRODUCTION

Floral biology means the study of flowering part of the plant which includes inflorescence, flower structure, flower parts, arrangement, pollination & fertilization.Floral biology is an area of ecological research that studies the evolutionary factors that have moulded the structures, behaviour and physiological aspects involved in the flowering of plants.

3.3 FLORAL BIOLOGY OF WHEAT

WHEAT-Triticum aestivum (Verna.-Gehun): Wheat is a grass widely cultivated for its seed, a cereal grain which is a worldwide staple food, giving about one third of the total production. In temperate regions it is the major source of food. There are many species of wheat which together make up the genus *Triticum*; the most widely grown is common wheat (*T. aestivum*).

Systematic position

Kingdom - Plantae (Plants)

Subkingdom -Tracheobionta (Vascular plants)

Super division -Spermatophyta (Seed plants)

Division -Magnoliophyta - (Flowering plants)

Class -Liliopsida - (Monocotyledons)

Subclass - Commelinidae

Order - Cyperales

Family -Poaceae (Grass family)

Genus - Triticum L. (wheat)

Species- Triticum aestivum L.

Habitat: Wheat is a grass that is cultivated worldwide. It is an annual grass that usually planted at the end of the summer, grown in dry and mild climate.

Root: Adventitious, fibrous root system.

Stem: The stem is 3 to 4 feet in height or more, herbaceous, erect, cylindrical sometimes furrowed, and either glabrous or scabrous, with distinct nodes (each node is swollen and solid) and internodes (generally hollow), unbranched, with a number of tillers.

Leaves: The normal leaf of wheat is divisible into two parts, the leaf-sheath and the leaf blade (lamina). The leaf also having accessory organs, the ligule and the auricle.
The sheath is inserted on the node and envelops the stem. The blade is long, narrow, lanceolate and acuminate with parallel venation. Two claw-like appendages near the ligule region are prominent, these are known as auricles (usually hairy and pale green)

Inflorescence: Spike of spikelets. This is a compound spike bearing two rows of lateral spikelets on its axis and a single terminal spikelets. There are many short internodes on the main axis. Each internode is narrow at the base and broader at the apex.
The spikelets are sessile and arranged alternately, the spikelet is inserted on the apex of internode.

Spikeletes: The solitary and sessile flowers (florets) are arranged on a short, joined axis, the rachilla. The flowers are alternately placed on the spikelet. At the base of each spikelet, two glumes occur, appear to be opposite of each other (actually one glume overlaps the other).
The normal glume is somewhat boat shaped, with a thick main nerve, dividing it into two unequal halves. In each spikelet the number of flowers varies. Usually two grains, sometimes three and very rarely four mature in a single spikelet.

Flower: Sessile, bracteate, two bracts- lemma (inferior palea) and palea (superior palea). They are situated opposite to each other. The **lemma** is somewhat boat-shaped with many nerves. The colour of lemma is greenish white, sometimes pink.
The **palea** is a thin membranous bract just opposite the lemma. It is slipper shaped with two prominent nerves. The flower is small, zygomorphic, hermaphrodite, hypogynous, incomplete, irregular and not showy.

Perianth: It is represented by two thin membranous structures, the **lodicules**. They are colourless, narrow and scale-like, and sometimes hairy.

Androecium: Stamens 3, polyandrous, filaments are long, slender and free; the anthers dorsifixed when young and versatile when mature.

Gynoecium: Single median carpel (monocarpellary), theoretically tricarpellary. The ovary is superior, unilocular, hairy and triangular. From the tip of the ovary two style arise, single ovule, basal placentation, style short; stigma 2, feathery.

Fruit: A caryopsis (achene with pericarp completely united or adherent with the seed coat), the seed coat firmly united to the ovary wall.

Seed: Albuminous, Endospermic and containing a single cotyledon called scutellum, which is shield shaped and pressed against the endosperm.

Floral formula: Br, ·|·, ♀, P_2 (lodicules), A_3, $G_{(1)}$.

Floral Diagram:

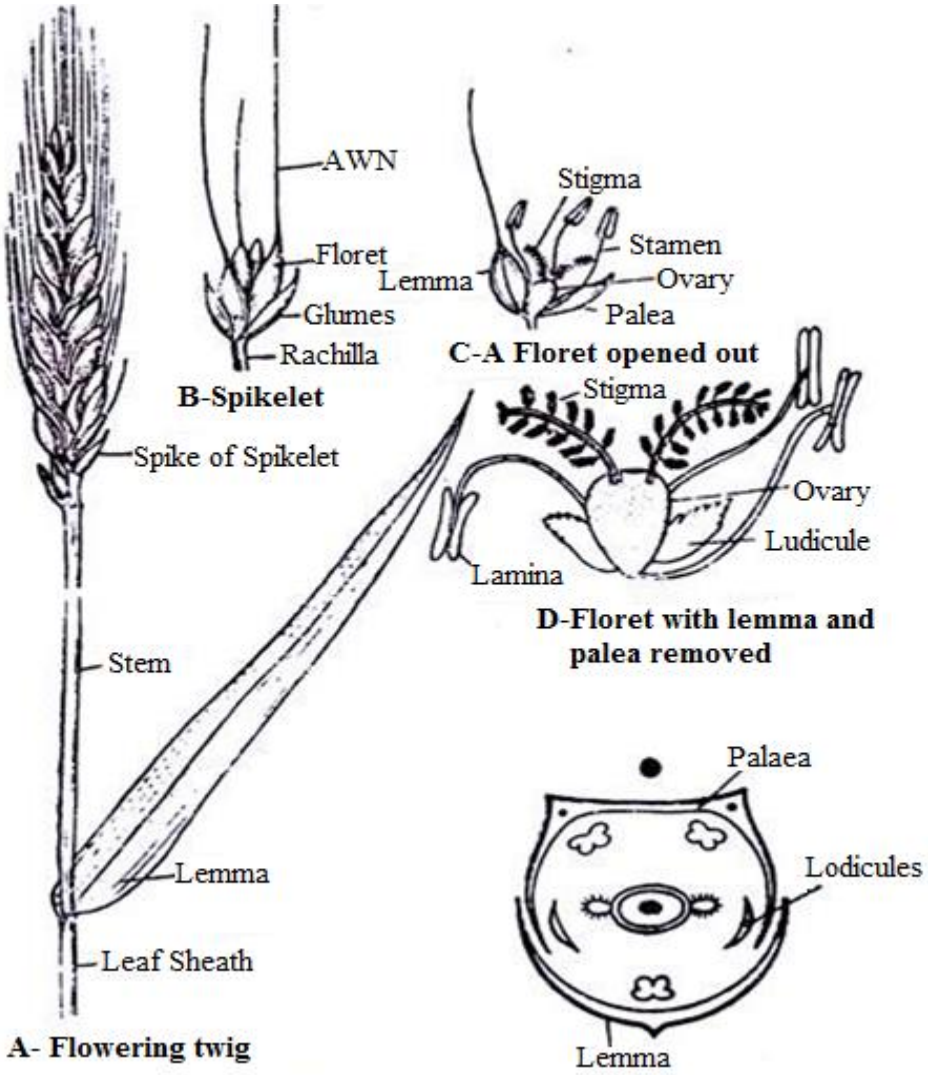


Fig. 3.1- Triticum aestivum L. *(Verna.-Gehun)*

3.4 FLORAL BIOLOGY OF PEA

PEA (Pisum satvium)- (Verna.- Matar)**:** The **pea** is most commonly the small spherical seed or the seed-pod of the pod fruit ***Pisum sativum***. Each pod contains several peas. Pea pods are botanically fruit, since they contain seeds and developed from the ovary of a (pea) flower. *P. sativum* is an annual plant, with a life cycle of one year. It is a cool-season crop grown in many parts of the world; planting can take place from winter to early summer depending on location.

Systematic position

Kingdom - Plantae – Plants

Subkingdom -Tracheobionta – (Vascular plants)

Super division -Spermatophyta – (Seed plants)

Division -Magnoliophyta – (Flowering plants)

Class -Magnoliopsida – (Dicotyledons)

Subclass - Rosidae

Order - Fabales

Family -Fabaceae / Leguminosae –(Pea family)

Genus - Pisum L. – (pea)

Species-Pisum sativum L. – (garden pea)

Habit: Annual herb; cultivated.

Root: Tap, branched, with nodules containing nitrogen fixing bacteria *(Rhizobium radicicola).*

Stem: Herbaceous, weak, climbing with the help of leaf tendrils, cylindrical, branched, smooth, Glaucous.

Leaves: Alternate, compound, imparipinnate, stipulate (stipules large Foliaceous, ovate, semicordate, irregularly toothed at the base), leaflets 4 or 6, the common rachis ends in a branched tendril; the leaflets entire, smooth, net veined, oval to oblong, mucronate tips, green and Glaucous, the terminal leaflet is always a tendril.

Inflorescence: Racemose, flowers arranged in axillary racemes or solitary.

Flower: Pedicellate, zygomorphic, irregular, hermaphrodite, papilionaceous, white or pink, complete, hypogynous to perigynous, bracteate or Ebracteate.

Calyx: 5 sepals, gamosepalous, campanulate calyx tube, teeth long or the upper short; Sepaloid, ascending imbricate aestivation.

Corolla: 5 petals, 1 standard, 2 wings, 2 keels united, keels shorter than wings and enclose the pistil and stamens; corolla papilionaceous, white or pink in colour; descending imbricate (vexillary) aestivation; inferior.

Androecium: 10 stamens in two bundles (diadelphous) of 9 + 1, nine stamens unite at the base and form a tube around ovary tenth is posterior and free; anthers bi-lobed, basifixed, Introrse, dehiscence by longitudinal splitting.

Gynoecium: Carpel one (monocarpellary); ovary superior, unilocular; marginal placentation; ovules many; style bent and long, stigma simple; terminal and hairy; ovary also hairy.

Fruit: A legume (pod), broad.

Seeds: Rounded, uniform, white.

Floral formula: Br, ·|· , ♂ ,$K_{(5)}$,$C_{1+2+(2),}$ $A_{(9)+1}\underline{G}_1$

Floral Diagram:

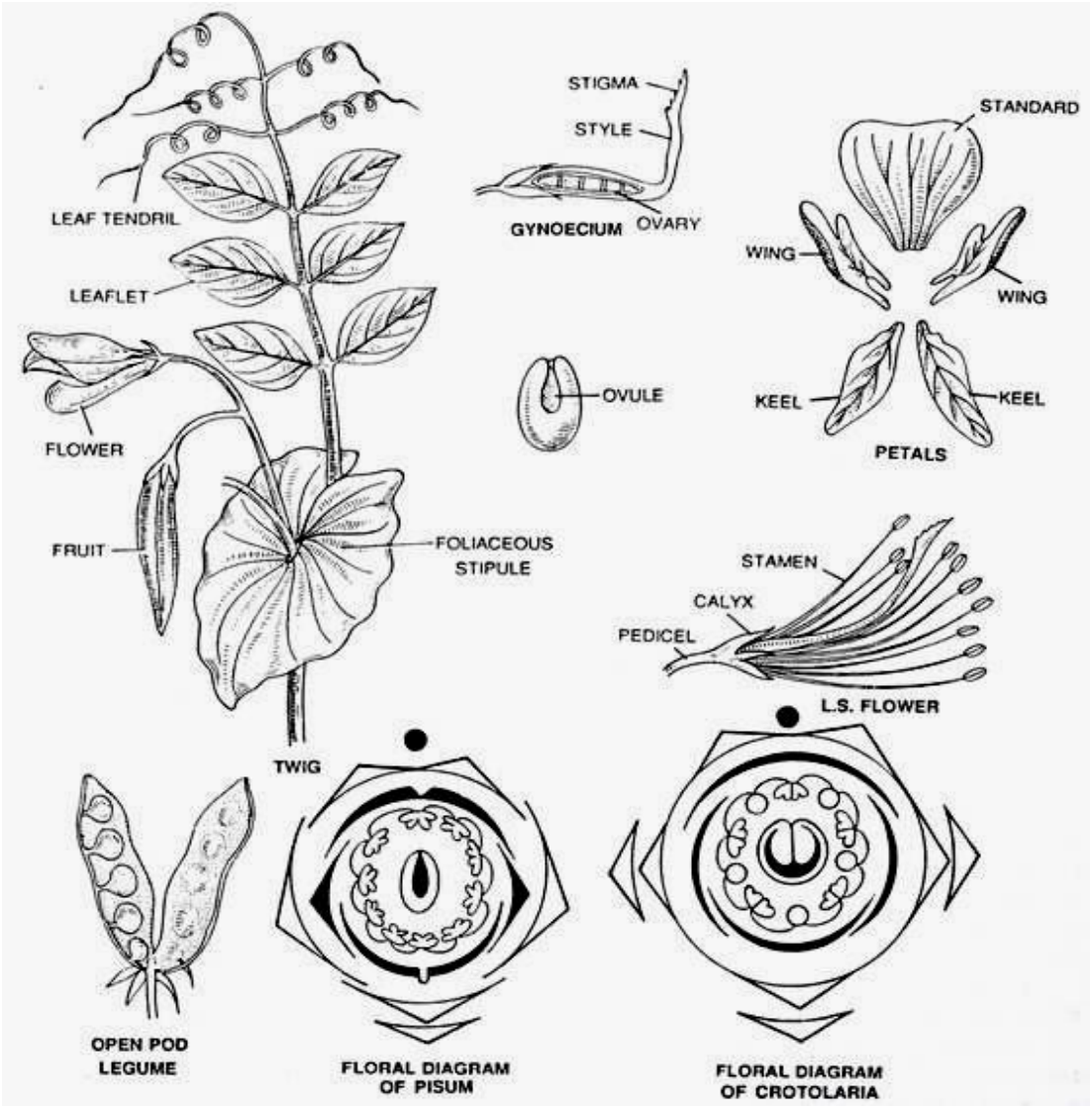


Fig. 3. 2- Pisum satvium L. (Verna.- Matar)

3.5 FLORAL BIOLOGY OF MUSTARD

MUSTARD (Brassica campestris)- (Verna.- Sarson): Flowers contain flavonol glycoside brassicoside. Seeds contain epi-progoitrin (major thioglucoside). Seeds used in exacerbations, cancer and tumours. Roots emollient and diuretic, juice used in chronic cough and bronchial catarrh.

Systematic position

Kingdom - Plantae – (Plants)

Subkingdom -Tracheobionta – (Vascular plants)

Super division -Spermatophyta – (Seed plants)

Division -Magnoliophyta – (Flowering plants)

Class -Magnoliopsida – (Dicotyledons)

Subclass - Dilleniidae

Order - Capparales

Family -Brassicaceae / Cruciferae – (Mustard family)

Habit and habitat: An annual herb, cultivated for seeds which yield oil.

Root: Tap and branched.

Stem: Herbaceous erect, cylindrical, solid, glabrous or hairy.

Leaf: Simple, alternate, Exstipulate, lower ones lyrate and upper oblong or lanceolate, unicostate reticulate venation, hairy, sessile.

Inflorescence: A Corymbose-raceme.

Flower: Ebracteate, Pedicellate, complete, Actinomorphic, hermaphrodite, cruciform, tetramerous, hypogynous, and yellow.

Calyx: Sepals 4 (2 + 2) in two whorls, outer whorl antero-posterior, the two lateral one saccate, green, polysepalous, inferior.

Corolla: Petals four, polypetalous, cruciform, Valvate, inferior, yellow.

Androecium: Stamens six, Tetradynamous, in two whorls, the outer with two short lateral stamens and inner with four long stamens arranged in two median pairs. Basifixed, polyandrous, Introrse. Four green nectarines are present, on the inner side of each short stamen and a similar one at the base but outside each pair of long median stamens, inferior.

Gynoecium: Bicarpellary, syncarpous, superior, unilocular becoming bilocular by the development of false septum called – replum; parietal placentation, style short, stigma bilobed.
Fruit: Siliqua.

Seed: Non-endospermic, Numerous, minute, Ex-Albuminous.

Floral formula: Ebr, ⊕ , ♀ , K_{2+2}, C_4, A_{2+4}, $G_{(2)}$

Floral Diagram:

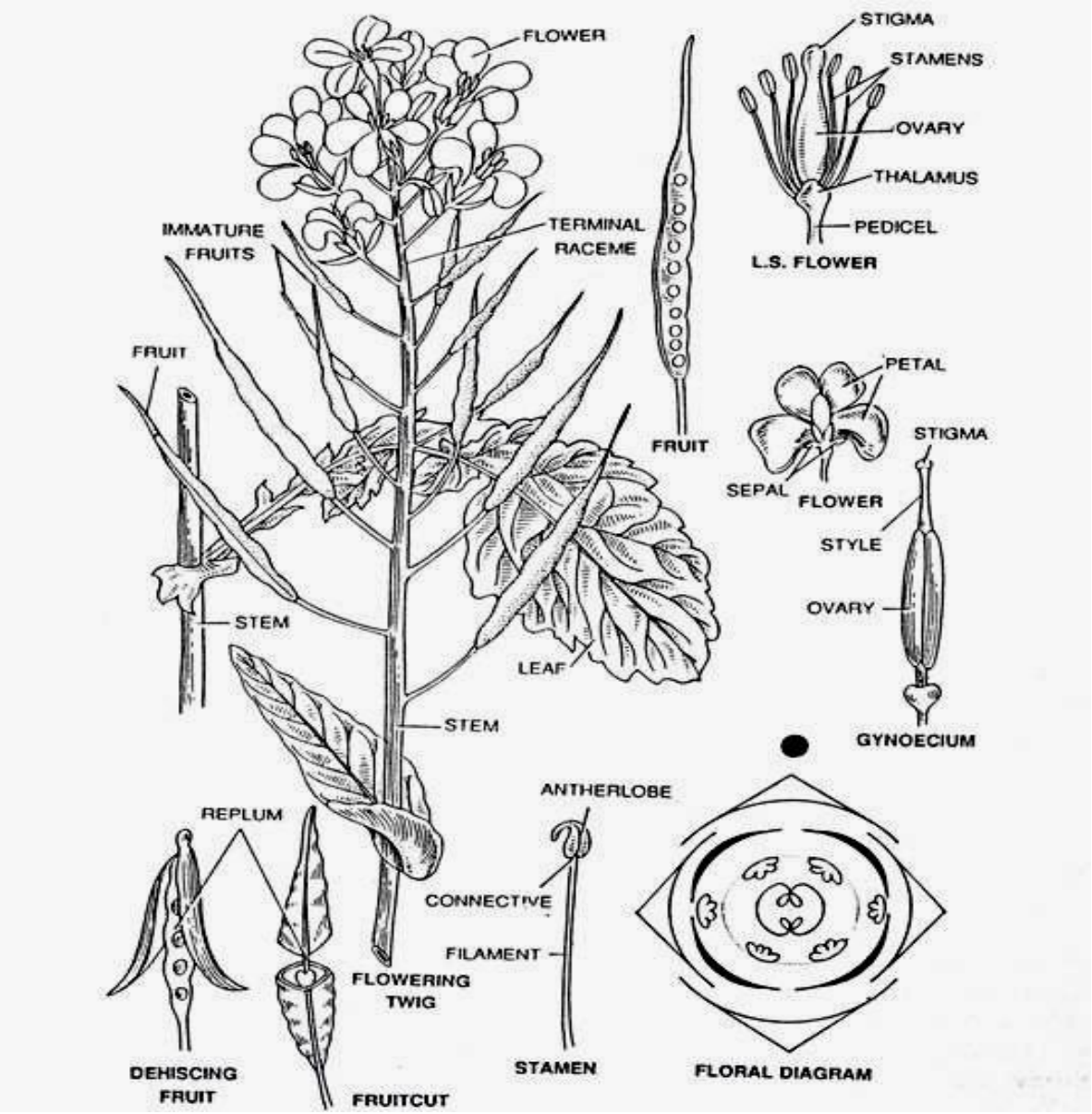


Fig. 3. 3- Brassica campestris L. (Verna. - Sarson)

3.6 FLORAL BIOLOGY OF BRINJAL

BRINJAL (Solanum melongena L.)- (Verna.- Baingan): Eggplant (*Solanum melongena*), or aubergine, is a species of nightshade, grown for its edible fruit. It is known in South Asia and South Africa as *brinjal*.

The fruit is widely used in cooking. As a member of the genus *Solanum*, it is related to the tomato and the potato. The eggplant is a delicate, tropical perennial often cultivated as a tender or half-hardy annual in temperate climates. The stem is often spiny.

Systematic position:

Kingdom - Plantae – (Plants)

Subkingdom -Tracheobionta – (Vascular plants)

Super division -Spermatophyta – (Seed plants)

Division -Magnoliophyta – (Flowering plants)

Class -Magnoliopsida – (Dicotyledons)

Subclass - Asteridae

Order - Solanales

Family -Solanaceae – (Potato family)

Genus - Solanum L. – (Nightshade)

Species- Solanum melongena L. – (eggplant)

Habit: Brinjal is an annual herbaceous plant, under shrub.

Root: Branched tap root system.

Stem: Erect, aerial, woody below and herbaceous above, cylindrical with distinct ribs, solid, branched, green.

Leaves: Alternate, simple, Exstipulate, Petiolate, ovate, repand, acute, glabrous, unicostate reticulate venation.

Inflorescence: Cymose. Often solitary Cyme or clusters of 2-5 flowers.

Flower: Ebracteate, Actinomorphic, hermaphrodite with pistil surrounded by stamens, Pedicellate, Heteroclamydeous, hypogynous, white or pinkish in colour.

Calyx: Sepals 5, gamosepalous, pentafid, Valvate, persistent, light green colour, hairy, inferior.

Corolla: 5 petals, Gamopetalous, Valvate, rotate, white to light purple colour.

Androecium: Stamens 5, free, epipetalous, polyandrous alternate to petals, small filament inserted deep in the corolla tube, large anthers dithecous, usually basifixed or dorsifixed, Introrse.

Gynoecium: Bicarpellary, syncarpous, hypogynous, ovary superior, carpels placed obliquely in diagonal plane, bilocular, placentation axile, ovules many in each locules, placentae swollen, a nectariferous disc or lobes may be present, stigma Capitate or lobed.

Fruit: A many seeded berry

Seed: Endospermic.

Floral formula: Ebr, ⊕ , ♂ , $K_{(5)}C_{(5)}$, $A_{(5)}$, $\underline{G}_{(2)}$

Floral Diagram:

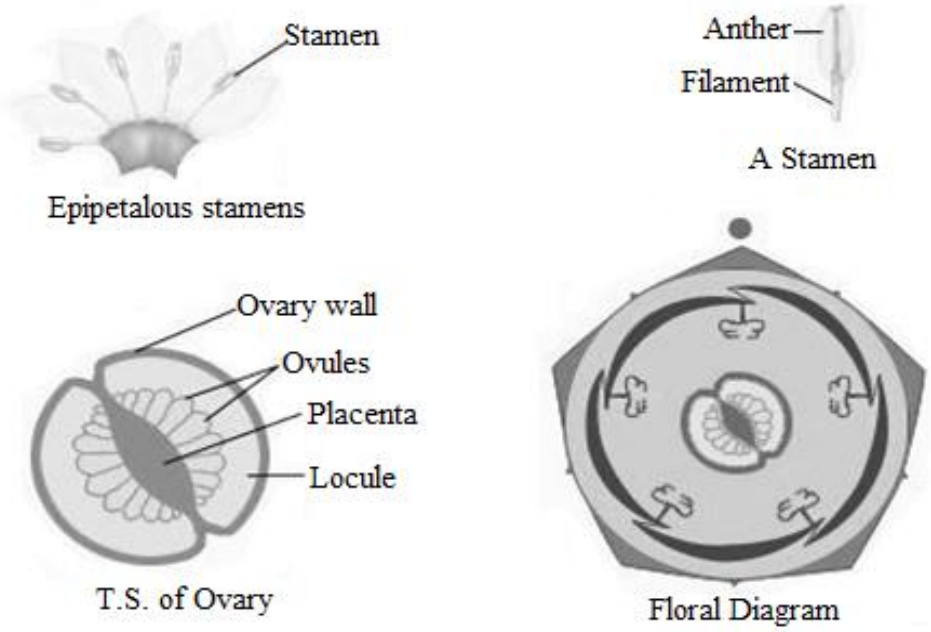


Fig. 3.4- Solanum melongena L. (Verna.- Baingan)

3.5 FLORAL BIOLOGY OF TOMATO

TOMATO (<u>Solanum lycopersicum L.</u>)- (Verna.-Tamatar) : The tomato is the edible fruit of *Solanum lycopersicum*, commonly known as a tomato plant, which belongs to the nightshade family, <u>Solanaceae</u>. The species originated in Central and South America. Tomato is consumed in diverse ways, including raw, as an ingredient in many dishes, sauces, salads, and drinks. While tomatoes are botanically berry-type fruits, they are considered culinary vegetables, being ingredients of savory meals.

Systematic position:

Kingdom - Plantae – (Plants

Subkingdom -Tracheobionta –(Vascular plants)

Super division -Spermatophyta –(Seed plants)

Division -Magnoliophyta – (Flowering plants)

Class - Magnoliopsida – (Dicotyledons)

Subclass - Asteridae

Order - Solanales

Family - Solanaceae – (Potato family)

Habit: A short lived, Perennial & annual plant.

Root: Branched tap root system.

Stem: Erect, aerial, woody below and herbaceous above, cylindrical with distinct ribs, solid, branched, green.

Leaves: Alternate, simple, Exstipulate, Petiolate, ovate, repand, acute, glabrous, unicostate reticulate venation.

Inflorescence: Extra-axillary helicoids cymes. Extra-axillary position is due to fusion.

Flower: Ebracteate, Pedicellate, complete, hermaphrodite, Actinomorphic, Pentamerous, hypogynous, small and yellow.

Calyx: Sepals 5, gamosepalous, pentafid, Valvate, persistent, green, hairy, inferior.

Corolla: Petals 5, Gamopetalous, rotate, Valvate, five lobed, bright yellow, inferior.

Androecium: Stamens 5, polyandrous epipetalous, alternipetalous, filaments shorts, equal in length, anthers long and conniving, basifixed, dithecous, and dehiscence by apical pores.

Gynoecium: Bicarpellary, syncarpous, ovary superior, bilocular, axile placentation, placentae swollen, ovules many in each loculus, ovary obliquely placed; style single, hairy; stigma bilobed.

Fruit: Many seeded berry.

Seed: Endospermic.

Floral formula: Ebr, $\oplus$, ♂ , $K_{(5)}C_{(5)}$, $\overset{\frown}{A_5}$, $\underline{G}_{(2)}$

Floral Diagram:

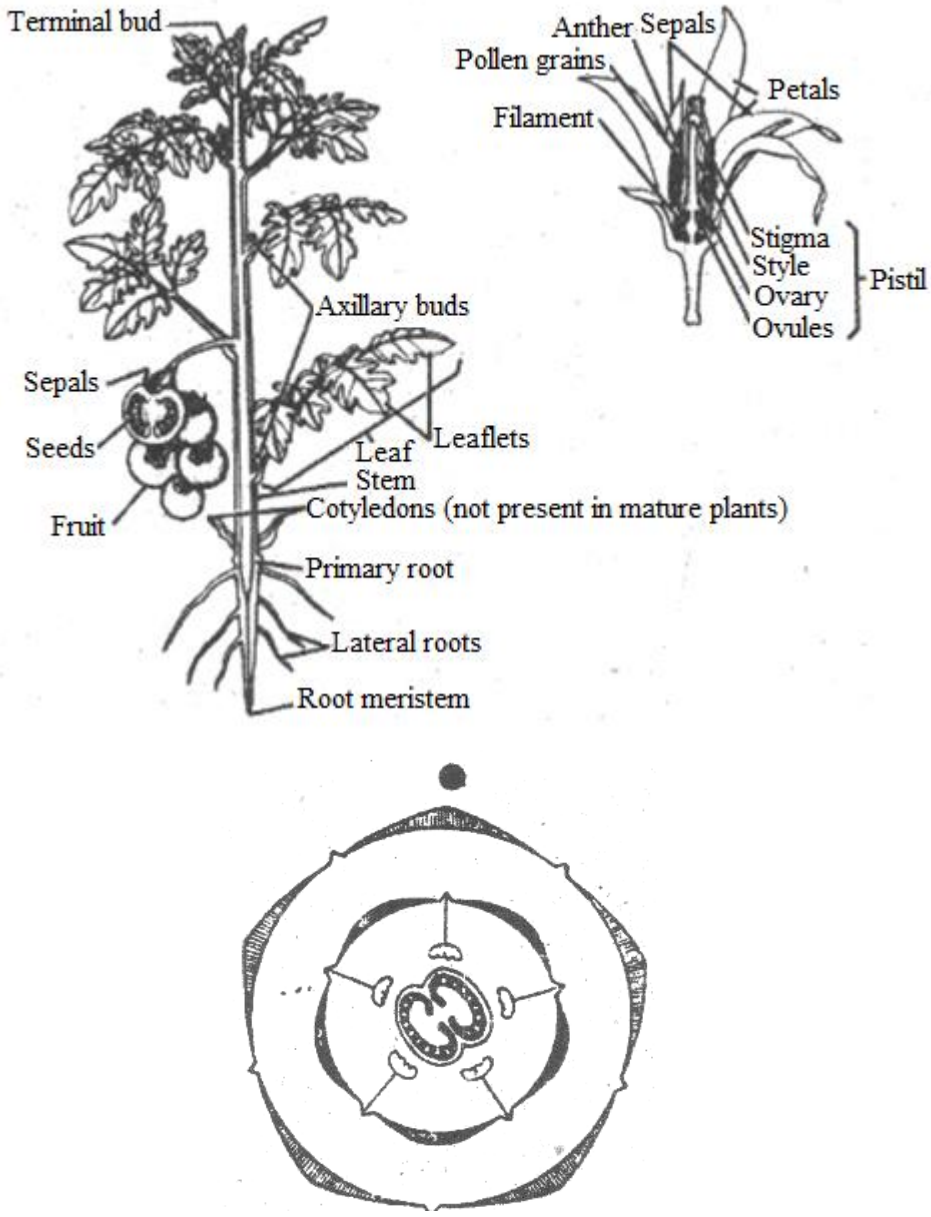


Fig. 3.5- <u>Solanum lycopersicum L.</u>- (Verna - Tamatar)

3.6 SUMMARY

Flowers are the reproductive structures of angiosperms. The flower is composed of four whorls of modified leaves, the calyx, corolla, androecium, and gynoecium. Each of these whorls contains one of the flower organs, the sepals, petals, stamens, or pistils, respectively. Sepals and petals are not directly involved in reproduction, while the stamens and pistils are the male and female reproductive organs.

In addition, each flower possesses an ovary is formed from modified leaves called carpel. This ovary, an exclusive feature of angiosperms, encloses the ovules and develops into a fruit after fertilization. The calyx is made up of sepals, green leaf-like structures that enclose the unopened bud. They serve a protective role for the flower before it opens, and afterward extend from the base of the flower.

The corolla is made up of the petals of the flower, which are usually brightly colour in order to attract insects. Together, the corolla and calyx make up the Perianth, the non-reproductive portion of the flower. The Androecium is composed of the male reproductive organs, the stamens. Each stamen consists of a long, slender filament topped by a pollen-producing anther. The anther contains numerous sporangia, which give rise to microspores. These microspores develop, and turn, into pollen grains, which carry sperm cells to the female reproductive organs.

The Gynoecium, composed of a pistil, lies in the very middle of the flower. The top of the pistil, where pollen grains land, is called the stigma and the shaft leading down into the ovary is called the style. The ovary, containing ovules and egg cells, makes up the very bottom of the pistil.

The floral formula is a way to represent the structure of a flower using specific letters, numbers and symbols, presenting substantial information about the flower in a compact form. It can represent a taxon, usually giving ranges of the numbers of different organs, or particular species. The structure of a flower can also be expressed by the means of *floral diagrams*. The use of schematic diagrams can replace long descriptions or complicated drawings as a tool for understanding both floral structure and evolution. Such diagrams may show important features of flowers, including the relative positions of the various organs, including the presence of fusion and symmetry, as well as structural details.

3.5 GLOSSARY

Actinomorphic: having radial symmetrical, regular.
Acuminate: ending in a pointed tapering apex.
Acute: tapering more broadly than acuminate.
Adnate: With unlike parts integrally fused, not easily separable.
Adventitious: appearing in an abnormal or unusual position or place, as a root.
Aestivation: Referring to position, arrangement, and overlapping of floral parts.
Albuminous: containing albumen.
Androecium: The male parts of a flower, collectively.
Angiosperm: a plant having its seeds enclosed in an ovary; a flowering plant.
Anther: The structure in a flower bearing the pollen.
Apetalous: Having no petals or corolla
Apocarpous: With carpels distinct, the pistil or ovary simple
Auricle: a claw-like appendage.
Axile: the angle formed by an axis and lateral members (e.g., stem and leaf).
Axillary: pertaining to or growing from the axil.

Basifixed: fixed to the filament (stalk) at the base.
Bilobed: consisting of or divided into two lobes.
Bilocular: divided into two chambers or containing two compartments internally (two celled).
Bract: A leaf-like element below a flower or on an inflorescence. They are usually green, but occasionally are brightly coloured and petal-like.
Bracteate: having bracts.
Bracteolate: possessing bracteoles.
Calyx: The whorl of sepals of a flower collectively forming the outer floral envelope or layer of the perianth enclosing the bud
Campanulate: bell-shaped, as a corolla.
Capitate: forming or shaped like a head or dense cluster or knob like (swollen).
Carpel: Female structure in the fourth or outermost whorl in flowers of angiosperms compound ovary
Caryopsis: the grain (fruit) of cereals and grasses one-seeded, indehiscent.
Chronic: continuing a long time or recurring frequently.
Compound: composed of several similar parts that combine to form a whole.
Connivent: the bending towards each other of two or more similar organs.
Corolla: The whorl of petals of a flower that collectively form an inner layer of the perianth.
Corymbose: A form of inflorescence in which the flowers form a flat topped or convex cluster, the outermost flowers being the first to open (corymb like arrangement)
Cyme: the main axis terminates in a flower.
Dehiscence: In pollen, the opening of the anther to release the pollen or to expose the ripe pollen to pollinators.
Diadelphous: united into two sets by their filaments.
Diandrous: flowers having two stamens.
Dithecous: arranged alternately in two opposite rows.
Dorsifixed: attached to the dorsal side.
Ebracteate: without bracts.
Endosperm: nutritive matter in seed-plant ovules, derived from the embryo sac.
Epigynous: having all floral parts conjoint and generally divergent from the ovary at or near its summit
Epipetalous: having the stamens attached to the petals.
Exalbuminous: without stipules.
Exstipulate: without stipules.
Extra-axillary: situated away from the axil of the leaf.
Extrorse: Facing outward; e.g., describing the anther-sac opening facing away from the ovary
Extrorse: turned or facing outward, as anthers that open toward the perianth.
Filament: The usually narrow and often threadlike part of the stamen which supports the pollen-bearing anther
Flower: The organ in an angiosperm that comprises the group of structures used for sexual reproduction. The parts of a flower are arranged in whorls.

Foliaceous: consisting of leaf-like plates or laminae; foliated.
Fruit: The structure that develops after fertilization. In angiosperms, it develops from a carpel or aggregation of carpel's
Gamopetalous: united petals (corolla).
Gamosepalous: united sepals (calyx).
Glabrous: not hairy, smooth.
Glaucous: covered with a whitish bloom, as a plum.
Glume: the bracts and bracteoles of the spikelets of Gramineae.
Gynoecium: the pistil or pistils of a flower; the female parts.
Hermaphrodite: bisexual, flower having both Androecium and Gynoecium.
Heteroclamydeous: having a perianth consisting of distinct sepals and petals
Hypogynous: situated on the receptacle beneath the pistil and free of the ovary, as stamens, petals, or sepals.
Imbricate: overlapping like tiles, as scales or leaves. A mode of aestivation in which one member of the whorl is outside all the others (i.e., its margin are free) and one inside all the others (i.e., both the margins are overlapped), the others overlap by one margin only.
Inferior: epigynous condition
Inflorescence: A reproductive shoot on a flowering plant, bearing one or more partial or complete flowers.
Introrse: Facing inwards usually referred for anthers.
Lamina: leaf blade.
Lanceolate: lance-head shaped, a leaf broad below the middle and tapering towards apex.
Leaflet: one of the blades of compound leaf.
Legume: the pod of pea family, dehiscing along both sutures.
Ligule: a membranous outgrowth at the junction of leaf blade and leaf sheath in grasses.
Lobed: having lobes or divisions extending less than halfway to the middle of the base.
Locule: The cavity or chamber in an ovary.
Lodicules: rudimentary membranous perianth at the base of the ovary in grass family.
Monocarpellary: Having only one carpel
Nectary: a nectar secreting gland.
Nectaferous: producing nectar.
Node: the place of insertion of a leaf on the stem.
Nodule: a small node or tubercle.
Ovary: The female reproductive structure that contains the ovules and becomes the fruit, it is derived from the carpels.
Ovule: The haploid female reproductive cell, located in the ovary, which receives a haploid nucleus from the germinating pollen grain to form the diploid zygote.
Palea: The scale like, membranous organ in the flowers of grasses that is situated upon a secondary axis in the axil of the flowering glume and envelops the stamens and pistil.
Parietal: borne or peripheral region reference for placenta.
Pedicel: The short stem growing from the top of the peduncle and carrying the flower bud at its top

Pedicellate: Having the flower carried above the peduncle on a stem called a pedicel
Pendent: Hanging downward from the vertical axis of the pedicel or plant
Pentamerous: with five members in each whorl.
Perennial: can live for more than two years.
Perianth: The structures surrounding the sexual parts of a flower, that is, the petals and sepals or the calyx plus the corolla
Pericarp: The structure developing from the wall of the ovary that protects or encloses the seed or seeds in an angiosperm
Perigynous: situated around the pistil on the edge of a cuplike receptacle, as stamens or petals.
Persistent: not falling off.
Petal: Leaf-like structures that enclose the rest of the structures in a flower. The second lowest whorl in a floral structure; petals collectively, the corolla
Petiolate: the leaf with petiole.
Pistil: Female sexual organ of a flower, comprised of the ovary, style, and stigma
Placentation: the disposition or arrangement of a placenta or placentas.
Pollen: Male sexual structure that transmits the male gamete to the female stigma
Polyandrous: having an indefinite number of stamens.
Polypetalous: with free petals.
Polysepalous: with free sepals.
Raceme: a flower cluster with the separate flowers attached by short equal stalks at equal distances along a central stem. The flowers at the base of the central stem develop first.
Racemose: an inflorescence in which the main axis continues to grow and remain stronger than the laterals which arise from it, the youngest lateral comes out from nearest apex.
Rachilla: the axis of the spikelet of the grasses.
Rachis: the axis of an inflorescence or of a compound leaf.
Repand: having a wavy margin, as a leaf.
Reticulate venation: veins are interconnected and form a web like network
Sepal: a segment of calyx. Leaf-like structures that enclose the rest of the structures in a flower. The first or lowest whorl in a floral structure; sepals collectively, the calyx
Sepaloid: resembling or functioning as a sepal.
Sessile: without a stalk. Having a flower or leaf born directly on the stem or peduncle rather than on an elongated stalk.
Spike: a racemose elongated inflorescence bearing sessile flowers.
Spikelets: the laterals of the inflorescence of grasses, the small spikes.
Stamen: The male sexual organ in a flower comprised of a filament and an anther.
Stigma: The female structure at the tip of the pistil. This is the receptive organ for pollen germination
Stipulate: having stipule.
Stipule: a leaf-like outgrowth at the base of petiole, usually in parts.
Style: The structure in the pistil that extends from the ovary and bears the stigma at its distal end.

Superior: situated above another member. A superior ovary has its base above the insertion of calyx; a superior calyx or corolla is inserted above the ovary.
Syncarpous: united carpels, compound ovary.
Tendrils: they are either modified branches or leaves. They are filament like usually coiling round the support.
Tepal: The petals and the sepals collectively.
Tetradynamous: with four long and two short stamens.
Umbel: an inflorescence having aerial branches of equal length from a common point.
Unilocular: one chambered ovary.
Valvate: an aestivation with the segments of calyx or corolla are so placed that their edges touch each other not overlap.
Whorl: a pattern of spirals or concentric circles.
Zygomorphic: having only one plane of symmetry, as in a pea or snapdragon; bilaterally symmetrical.

3.6 SELF ASSESSMENT QUESTION

3.6.1 Short answer type questions:

1. Why is flower called as modified shoot?
2. The structures surrounding the sexual parts of a flower, i.e., the petals and sepals is called?
3. When Gynoecium matures earlier than the androecium in bisexual flower it is called?
4. A membranous outgrowth at the junction of leaf blade and leaf sheath in grasses?
5. A flower with essential & non- essential whorls is termed as?
6. The leaf-like outgrowth at the base of petiole, usually in parts is called?
7. *Raphanus sativus*, belongs to which family?
8. What is the botanical name of Garden Tomato and Eggplant?
9. A flower is said to be incomplete when it has:
10. A flower is brightly coloured, scented and secrete nectar. It is most probably pollinated by:

3.6.2 Fill in the blanks:

1. If male and female flowers are borne on different plants, the plant is called _____
2. Placentation in Tomato is _____
3. A characteristic of angiosperms is _____
4. A flower is said to be complete when it has all the _____
5. Botanical name of Mustard is _____
6. Tomato belongs to _____family.
7. A leaf like outgrowth at the base of the petiole, called _____
8. Third whorl in flower is of _____

3.6.3 Multiple choice questions:

1. Sessile flowers have

(a) No scent (b) Irregular shape
(c) No pedicles (d) No petals

2. Bicarpellary ovary with parietal placentation is found in
(a) Solanaceae (b) Poaceae
(c) Brassicaceae/ Cruciferae (d) Leguminosae

3. Corolla refers to the
(a) Collection of sepals (b) Collection of petals
(c) Collection of carpels (d) Collection of stamens

4. A landing platform is provided to insects through
(a) Calyx (b) Epicalyx
(c) pedicel (d) petals

5. Pollen grains are produced inside the
(a) Stamen (b) Pistil
(c) Anther (d) Pollen sacs

6. In order to attract insects for pollination,
(a) Petals are brightly coloured (b) Petals are protected by calyx
(c) Epicalyx is essential (d) Petals have large surface area

7. Tetradynamous condition of Androecium is one of the striking features of
(a) Solanaceae (b) Poaceae
(c) Brassicaceae/ Cruciferae (d) Leguminosae

8. 'Families of Flowering Plant' book was written by-
(a) Bentham and Hooker (b) John Hutchinson
(c) Engler Prantl (d) None of the above

9. Inflorescence of wheat is
(a) Spike (b) Catkin
(c) Panicle (d) Verticillaster

10. Aubergine is another name of
(a) Pea (b) Tomato
(c) Mustard (d) Brinjal

11. A flower with essential and non-essential whorls
(a) Incomplete (b) Irregular
(c) Sessile (d) Complete

12. A bisexual flower which never open in its life span is called
(a) Homogamous (b) Cleistogamous
(c) Heterogamous (d) Polygamous

13. Third whorl in a flower is of
(a) Petal (b) Sepal
(c) Stamen (d) Pistil

14. Parallel venation are found in
(a) Monocot (b) Dicot stem
(c) Dicot root (d) None of these

15. Arrangement of leaves on branches
(a) Phyllotaxy (b) Vernation
(c) Venation (d) Phytotaxy

3.6.1 Answer Key: 1. Because in some flowers thalamus become elongated & show distinct node, internodes, 2. Perianth, 3. Protogyny, 4. Ligule, 5. Complete flower, 6. Stipule, 7. Brassicaceae, 8. *Solanum lycopersicum* (Tomato), and *Solanum melongena* (Eggplant), 9. Only two whorls, 10. Insects.

3.6.2 Answers Key: 1-unisexual, 2-axile, 3-flower, 4-four whorls, 5-*Brassica campestris*, 6-Solanaceae, 7-Stipule, 8-stamen.

3.6.3 Answers Key: 1-(c), 2-(c), 3-(b), 4-(d), 5-(d), 6-(a), 7-(c), 8-(b), 9-(a), 10-(d), 11-(d), 12-(b), 13-(c), 14-(a), 15-(a)

3.7 REFERENCES

- Pandey, B.P. 2009. *Taxonomy of Angiosperms.*
- Bendre, A.M. and Ashok Kumar 2010. *A Text Book of Practical Botany.*
- Chhabra, A.K. 2006. *Practical Manual of Floral Biology of Crop Plants*.
- *www.Plants.usda.gov, Natural Resources Conservation Service (NRCS) Plants Database,*
- *www.biologydiscussion.com,*
- *www.itis.gov, Integrated Taxonomic Information System*

3.8 SUGGESTED READINGS

- Rangaswamy, N.G., 1996, Floral diagram & Formulae; A reappraisal, Sci. & Cult. 31(1): 33-34.
- Schaffner, J.H. 1916, A general system of Floral Diagram, Ohio jour. sci., 16: 300-360.
- Hooker, J.D. 1875-1897. Flora of British India. 7 vols.
- Hutchinson, J. 1959. The Families of Flowering Plants. 2 vols. oxford.

- Lawrence, G.H.M. 1955. An Introduction to Plant Taxonomy. N.Y.
- Poster, C.L. 1959. Taxonomy of Flowering Plants.
- Puri, V. 1958. Floral Anatomy and Taxonomy. Ind. Bot. Soc. Mem. 1: 15-18.
- Kochhar, S.L. 2009 Economic Botany in Tropic. Macmillan and Co. New Delhi.

3.9 TERMINAL QUESTIONS

3.9.1 Long Answer Type Question:

1. Describe the floral biology of Wheat?

2. Give five important floral characters of Fabaceae. Mention the two economically important plants belonging to the family?

3. Give floral formula and floral diagram with examples to distinguish between following pair of family: Poaceae and Solanaceae.

4. Give the comparative account of Solanaceae and Brassicaceae with reference to their floral characteristics.

5. Given only the androecium and gynoecium, how would you distinguish any one pair of the following families from each other:

(a) Poaceae and Brassicaceae

(b) Fabaceae and Solanaceae.

6. Write a short assay on Floral biology, what is the role of it in taxonomy.

7. Write the systematic position of Mustard and Garden Pea. Also describe their Floral formula and Floral diagram.

8. Mention the significance features of the following genera and assign it to its respective family: (a) *Triticum* and *Pisum*

9. Describe the general characteristics and Floral diagram of the any two:

(a) Wheat (b) Brinjal (c) Pea

10. Write an account on complete Floral Biology and systematic position of *Brassica compestris*.

11. Define the following terms (any five):

(a) Aestivation

(b) Placentation

(c) Actinomorphic

(d) Zygomorphic

(e) Superior ovary

(f) Perigynous flower

(g) Epipetalous stamen

UNIT- 4(L) EMASCULATION TECHNIQUES IN THE FIELD ALONG WITH BAGGING AND LABELLING

Contents:

4.1 OBJECTIVES

After reading this unit students will be able-

- To describe the emasculation technique in the field
- To know bagging and labeling technique

4.2 INTRODUCTION

Plant breeding is the genetic improvement of the crop in order to create desired plant types that are better suited for cultivation, give better yields and are disease resistant. Conventional plant breeding is in practice from 9,000-11,000 years ago. Most of our major food crops are derived from the domesticated varieties. But now due to advancements in genetics, molecular biology and tissue culture, plant breeding is being carried out by using molecular genetics tools. Classical plant breeding includes hybridization of pure lines, artificial selection to produce plants with desirable characters of higher yield, nutrition and resistance to diseases.

When the breeders wish to incorporate desired characters (traits) into the crop plants, they should increase yield and improve the quality. Increased tolerance to salinity, extreme temperatures, drought, resistance to viruses, fungi, bacteria and increased tolerance to insect pests should also be the desired traits in these crop plants. The main objective of plant breeding is to produce the new crop varieties superior in all aspects as compared to the existing types. This objective is achieved by different methods of crop improvement:

(1) Selection
(2) Plant Introduction and acclimatization
(3) Mutational breeding
(4) Hybridization

1. Selection Method for Crop Improvement

It is the simplest and oldest breeding method. It is also called as German method or German method of broad breeding because once it was used nicely in Germany for improving the sugar beets and small grains such as rye and wheat.

It can be defined as preservation of certain individual plants of desirable characters. In simplest form selection means choosing plants of one's choice. It is the basis of all crop improvement. Even today it is most common method of crop improvement among the cultivators.

Types of Selection Method

(a) Natural Selection: This is a natural process. It operates in the nature without human interference. According to the Darwin's principle "**Survival of the fittest**" plants which survive through the adversities of nature are preferred and the weaker ones are wiped out. Thus, nature itself selects the fittest organisms.

So, natural selection favors these characters which are essential for survival of a species. The selection pressure ultimately resulted in the appearance of many differences

between species and subspecies. Natural selection has given the cultivated crops and '**ecotypes**' in plants.

(b) Artificial Selection: It can be defined as to choose certain individual plants for the purpose of having better crop from a mixed population where the individuals differ in characters. Here the selecting agent is man. Man exploits the variations existing among the species. He picks of a few plants of better qualities from mixed populations and tries to propagate them.

2. Plant Introduction & Acclimatization

Plant introduction usually means the introduction of the plants from places outside the county, may be of same or another continent. It can be defined as the "**process of introducing plants from their growing locality to a new locality**". The introduction of the genotypes from the place where it is grown to an entirely new area. It is the easiest or most common method of crop improvement.

Acclimatization follows the introduction and both processes go side by side. Acclimatization is the adaptation or adjustment of an individual plant or a population of plants under the changed climate for a number of generations: Thus, it is a sort of natural selection operating into the introduced plant material.

3. Mutation Breeding

A sudden heritable change in a characteristic of an organism is called mutation; function of mutations with the aid of mutagens is called mutagenesis. Breeding method utilizing variation created through mutagenesis is called mutation breeding. In this method, gamma rays and X-rays are the most commonly used physical mutagens, while EMS (ethyl methane sulphonate), EI (ethylene imines) and sodium azide are the most commonly used chemical mutagens.

4. Hybridization

Hybridization is the most common method of creating genetic variation. Hybridization is crossing of two or more types of plants for bringing their traits together in the progeny. It brings about useful genetic/ heritable variations of two or more lines together. Line is a group of individuals related to descent and have similar genotype. The individuals or lines used in hybridization are called parents. Hybridization takes a lot of time.

Objectives of Hybridization:

1. To artificially create a variable population for the selection of types with desired combination of characters.
2. To combine the desired characters into a single individual, and
3. To exploit and utilize the hybrid varieties.

Hybridization may be of following types**:**

(i) Intra-varietal hybridization: The crosses are made between the plants of the same variety.
(ii) Inter-varietal or Intraspecific hybridization: The crosses are made between the plants belonging to two different varieties.
(iii) Interspecific hybridization or intrageneric hybridization: The crosses are made between two different species of the same genus.
(iv) Introgressive hybridization: Transfer of some genes from one species into the genome of the other species is known as introgressive hybridization. The crosses between different species of the same genus or different genera of the same family are also known as distant hybridization or wide crossing. Such crosses are called distant crosses.

The above procedure of hybridization are described as follows-
(a) Selection of Parents with Desired Characters.
(b) Selfing or self-fertilization.
(c) Emasculation.
(d) Bagging.
(e) Tagging.
(f) Artificial Pollination (Crossing).

(a) Selection of Parents: The selection of parents depends upon the aims and objectives of breeding. Parental plants must be selected from the local areas and are supposed to be the best suited to the existing conditions.

(b) Selfing of Parents or Artificial Self-Pollination: It is essential for inducing homozygosity for eliminating the undesirable characters and obtaining inbreeds.

(c) Emasculation: Emasculation is a method of '**Artificial Hybridization**' generally used to promote cross pollination in plants and avoid self pollination. This is done to achieve the beneficial variations which are not established due to inbreeding by self pollination. Cross Pollination is a necessary requirement for bisexual and monoecious plants only because unisexual plants are in no way capable to self pollinate. Dioecious plants have to undergo cross pollination as pollen and stigma are present on the flowers of two different plants. Out breeding devices are the artificial ways to promote cross pollination in bisexual or monoecious plants. This can be achieved by the means of "**Emasculation and Bagging**" techniques.

Emasculation, the process in which the anther/stamen of the bisexual flowers are being removed by means of forceps or by hand, taking care that other floral parts do not get damaged. This process is to be done before the Maturity or stage of release of pollens from Anthers. Bagging, after the anthers are being plucked out, the flower is being bagged by means of a butter paper to avoid the entry of any undesired pollen. Once the stigma becomes receptive the bagging is removed, stigma is dusted with the desired pollen and the flower is being bagged again. When the fertilization has taken place and flowering is initiated the

bagging is removed and hence the "**Employment of Cross pollination in a Bisexual flower has been achieved**"

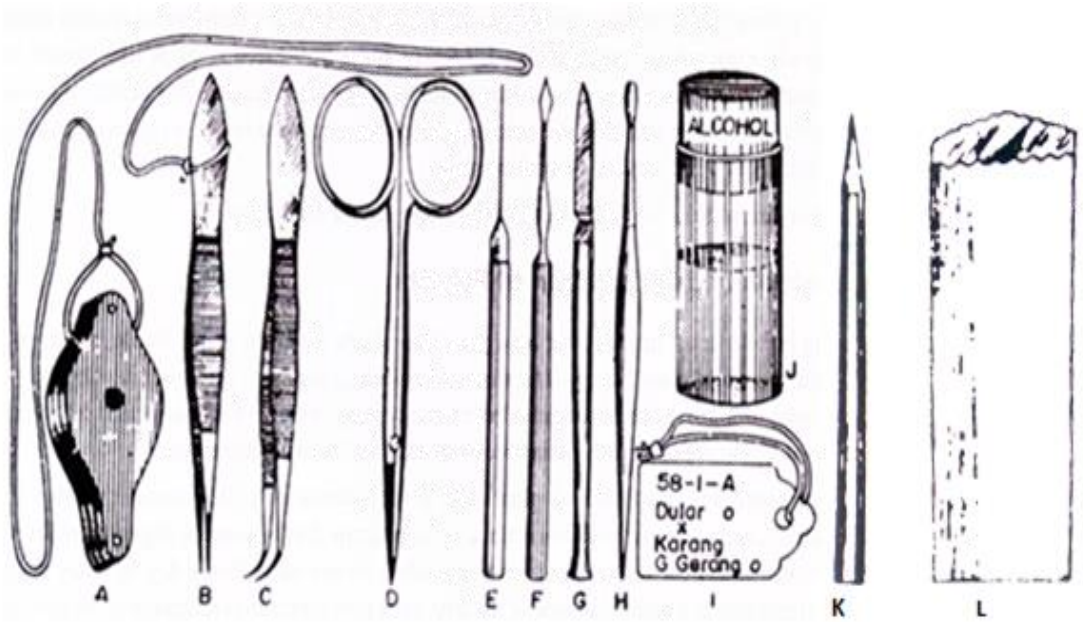


Fig. 4.1-Plant breeding kit: (A) Magnifying glass, (B & C) Forceps, (D) Scissors, (E & F) Needles, (G) Scalpel, (H) Brush (I) Label (J) Alcohol tube (K) Pencil and (L) Bag.

(d) Bagging: Bagging involves covering flowers on male as well as female parents separately by using suitable bags made up of polythene, muslin or paper. It is necessary for female flowers to protect them from cross pollination by unwanted pollen grains. Bagging is also carried out for the male parent flowers to protect the pollen from contamination and also to collect the pollen in the bag. For artificial cross pollination, these flowers are uncovered and after pollination once again they are bagged till they develop seeds.

(e) Tagging: The emasculated flowers are tagged just after bagging. Generally circular tags of about 3 cm or rectangular tags of about 3 x 2 cm are used. The tags are attached to the base of flower or inflorescence with the help of thread.

(f) Crossing: It can be defined as the artificial cross-pollination between the genetically unlike plants. In this method mature, fertile and viable pollens from the male parent are placed on the receptive stigma of emasculated flowers to bring about fertilization. Pollen grains are collected in Petridish (e.g., Wheat, cotton etc.) or in paper bags {e.g., maize) and applied to the receptive stigmas with the help of a camel hair brush, piece of paper, tooth pick or forceps. In some crops (e.g., Jowar, Bajra) the inflorescences of both the parents are enclosed in the same bag.

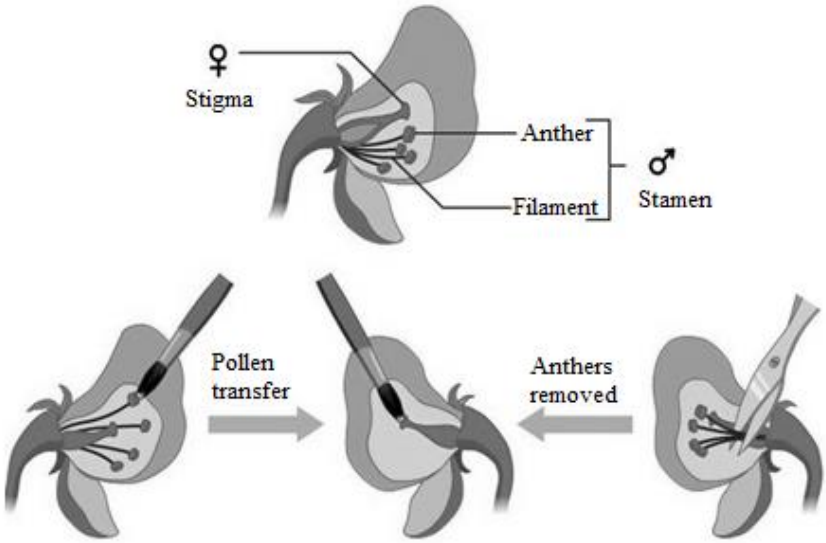


Fig.4.2 Cross-pollination, transfer of pollen from one flower to the stigma of another flower

Pollination

Pollination is the process by which pollen is transferred to the female reproductive organs of a plant, thereby enabling fertilization to take place. The two most important operations that determine the amount of seed set in hybridization are emasculation and pollination. In case of pollination, mature, fertile and viable pollen should be placed on a receptive stigma to bring about fertilization. The duration of pollen viability after anther dehiscence varies greatly from one species to another e.g., a few minutes in that fresh pollen from mature anthers should be used for pollination. The time of anther dehiscence falls within the duration of stigma receptivity and both generally coincide with the opening of flowers.

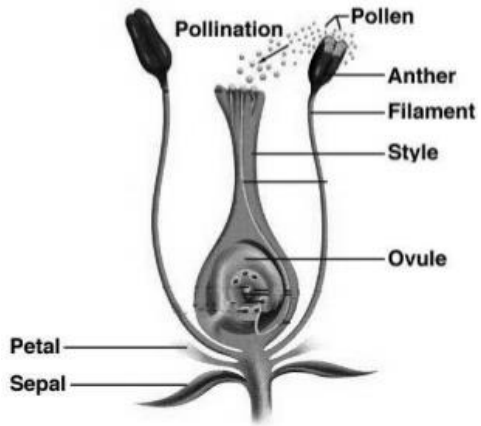


Fig.4.3 Pollination in a flower

Pollen grains are collected in a bag, and are used for dusting stigmata of female inflorescence or of emasculated flowers, the e.g., in maize, bajra etc.

Mature anthers are collected from the flowers of male parent. The pollen is liberated and applied to the stigma with the help of a camel hair brush, pieces of paper, tooth pick or forceps. Anthers are collected and allowed to burst directly over the stigma.

In rice, oats, wheat and barley, one anther is generally inserted in each floret where it dehisces and covers the stigma with pollen grains. The spike of male inflorescence is shaken over the emasculated inflorescence just when the anthers are about to dehisce. The lemma and palea of the spike of male parent are also clipped of to expose the anthers, which are used as the source of pollen.

In species like maize, the male inflorescence may be detached and enclosed in the bag covering the female inflorescence. In case of bajra and jawar, panicles from the male parent may be enclosed in the same bags that enclose the panicles of female parent.

4.3 EMASCULATION TECHNIQUE IN THE FIELD

The removal of stamens or anthers or the killing of pollen grains of a flower without affecting in any way the female reproductive organs is known as emasculation. The purpose of emasculation is to prevent self-fertilization in the flowers of female parent. In dioecious plants, male plants are removed, while in monoecious species the male flowers, e.g., in castor, or the male inflorescence, e.g., in maize, are removed to prevent self-pollination. But emasculation is essential in bisexual flowers. In species with relatively large flowers, hand emasculation may be adequate in most hybridization programmes. The efficiency of an emasculation technique may be tested by bagging the emasculated flowers without pollination. The amount of seed thus set would indicate the frequency of chance self-fertilization during emasculation. If the seeds are to be used in genetic studies, there should be no self-pollination during emasculation.

Emasculation is done before the anthers are mature and the stigma has become receptive to minimize accidental self-pollination. Emasculation is generally done in the evening, between 4 and 6 p.m., one day before the anthers are expected to dehisce or mature and the stigma is likely to become fully receptive. Therefore, the flowers selected for emasculation are likely to open the next morning. Generally, it is desirable to remove the older and the younger flowers located close to the flower to be emasculated in order to avoid confusion in identification of crossed pods etc.

Hand emasculation

This method is generally used in those plants which have large flowers. In this method the corolla of the selected flowers is opened and the anthers carefully removed with the help of fine-tip forceps.

Following are the important precautions while performing this method:

i. Flowers should be selected at proper stage.

ii. Stigma should be receptive and anthers should not have dehisced.

iii. All the anthers should be removed from the flowers without breaking

iv. Stigma and ovary of the flower should not be damaged.

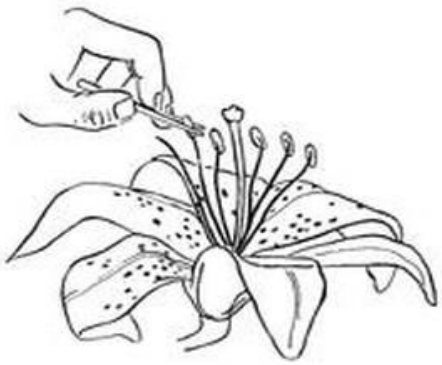


Fig.4.4-Hand emasculation

Suction method

This method is useful in species with small flowers. Emasculation is done in the morning just before or immediately after the flowers open. The petals are generally removed with forceps exposing the anthers and the stigma. A thin rubber or glass tube attached to a suction hose is used to suck the anthers from the flowers. The tube is also passed over the stigmas to suck any pollen grains present on their surface. The suction may be produced by an aspirator attached to water tap or by a small suction pump. The suction should be enough to suck the stamens and pollen grains, but not the flowers or the gynoecium. Washing the stigma with a jet of water may help in reducing self-pollination.

Hot water emasculation

Pollen grains are more sensitive than the female reproductive organs to both genetic and environmental factors. This property is utilized to kill the pollen grains with hot water or other agents like alcohol treatment or cold water treatment without damaging the female reproductive organs. In the case of hot water emasculation, the temperature of water and the duration of treatment vary from crop to crop. For jowar-42-48°C for 10 minutes. Rice-40-44°C for 10 minutes. The hot water is generally carried in thermos flasks and the whole spike is immersed in the water.

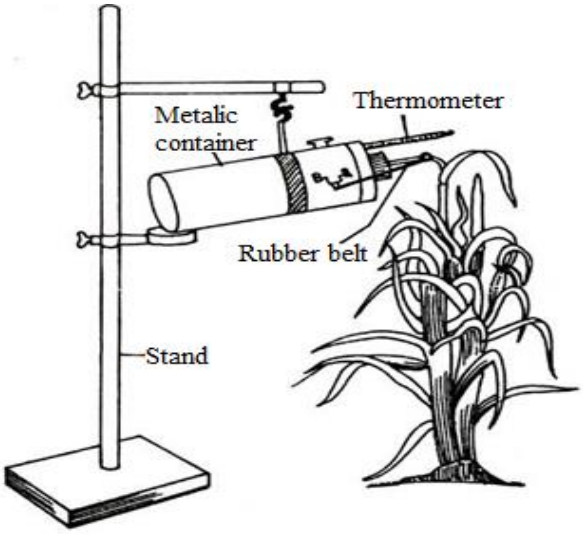


Fig.4.5- Hot water treatment method

Alcohol treatment

It is not a commonly used method of emasculation. The method consists of immersing the flower or the inflorescence. Immersing the flower or the inflorescence in alcohol of a suitable concentration for a brief period, followed by rinsing with water. However, the duration of treatment is of utmost importance. Even a slightly, prolonged period of treatment, a few seconds more than the recommended, would greatly reduce seed set. This is because the female reproductive organs would also be killed by a longer treatment.

Cold treatment

Cold treatment, like hot water treatment, kills pollen grains without damaging gynoecium. In case of rice, treatment with cold water at 0-6° C kills pollen grains without affecting gynoecium. Keeping wheat plants at 0-2°C for 15-24 hours kills the pollen grains. The amount of self-pollination is generally greater in cold treatment than in the case of hot water treatment.

Genetic emasculation

Genetic or cytoplasmic male sterility may be used to eliminate the necessity of emasculation. Many species are self-incompatible. In such cases, emasculation is not necessary because self-fertilization will not take place. For commercial hybrid seed production, male sterility is the most feasible method of emasculation. Protogyny facilitates crossing the anthers mature, hand pollination ensures seed set from cross pollination and prevent self-fertilization, i.e., in bajra (*Pennisetum americanum*).

Use of Chemical Gametocide

Certain chemical agents are capable of causing male sterility, when sprayed before flowering. These chemicals are also known as chemical hybridizing agents (CHA), the chemicals which selectively kills the male gamete without affecting the female gamete. e.g. FW450 in cotton, Ethrel, Sodium methyl arsenate, Zinc ethyl arsenate in rice, Maleic hydrazide for cotton and wheat.

4.3.1-Bagging

Immediately after emasculation, the flowers or the inflorescences are enclosed in suitable bags of appropriate size to prevent random cross-pollination. Usually these bags are kept till seed-setting is complete. In cross-pollinated crops, like maize, the male flowers are also bagged to maintain the purity of pollen used for pollination. The pollens are also collected only from already bagged males for crossing purpose.

Fig.4.6- Bagging method

The bagging is usually done in the evening of previous day of crossing, since most of the crops become receptive in the morning. These bags are kept on the females as such till seed setting is complete while in males they are removed as soon as the crossing is over.

The bags may be made of paper, butter paper, glassine or fine cloth. Butter paper or vegetable parchment bags are the most commonly used. The size of bags is according to the size of flowers of a crop in which they are to be used. In many cases ordinary muslin cloth and paper bags are satisfactory. The thin paper bags immersed in oil or paraffin are best for withstanding the insect attacks as well as for the plants having very delicate flowers.

In some cases, it is essential to puncture the bags with numerous minute holes to provide ventilation and prevent moulds development inside the envelope. Many special devices such as cylindrical muslin cloth bags, glass or celluloid cylinders plugged with cotton and with firm support, are used occasionally.

Fig.4.7- Different methods of bagging

The bags are tied to the base of inflorescence or to the stalk of flower with the help of thread, wire or pins designed for the purpose. Fungus development on the fruit or the spike may be prevented by removing the bags after the danger of cross-pollination is over usually 2-3 days after pollination.

4.3.2-Labelling

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

The labelling is done either on the bag itself or on the labels specially designed for this purpose. They are of different sizes and shapes, and either may be purchased from the market or made in the laboratory from the ordinary, but somewhat hard, paper. They are tagged to bags with the help of threads. The labelling on them must be as brief as possible but complete, bearing the following information;

1. Number referring to the field record.
2. Date of emasculation.

Fig.4.8-Tagging method

3. Date of crossing or pollination.
4. Details of parents, names of the female and the male parents. The name of the female parent is written first, and that of the male parent is written later.
5. No. of flowers emasculate.

The first and second information are entered with the emasculation, while the third and fourth steps are entered after crossing. All other necessary particulars must be entered in a handy field- record book in which the observations are also recorded from time to time.

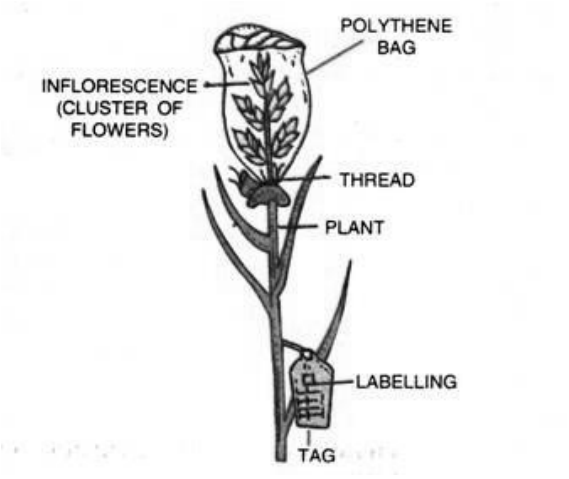


Fig 4.9- Bagging and tagging at the time of hybridization

4.4 PROCEDURE OF EMASCULATION

Objective: To emasculate flowers of given crop in field for hybridization.

Requirements: Needle, forceps, scalpel, scissors, pocket lens, absolute alcohol or rectified spirit.

Principle: Emasculation is the process of removal of anthers from bisexual flowers to prevent self-pollination before anthesis.

Procedure:

1. Sterilize all equipments in absolute alcohol or rectified spirit.
2. Sterilize finger and hand before emasculation by rinsing in alcohol.
3. Remove calyx and corolla with the help of forceps and scalpel etc.
4. Carefully remove stamens with the help of forceps etc.
5. Gynoecium should not be touched and it must remain as such.

Precautions:

1. Unwanted flowers must be removed before emasculation.
2. Only those floral buds are emasculated in which anthesis has not occurred.
3. Emasculated flowers must be covered with bag soon after the process is completed.

Procedure of Bagging & Labelling

Objective: Bagging and labelling of emasculated flowers.

Requirements: Butter paper bag of suitable size, U-pin, hard paper, tag, etc.

Principle: Bags cover the emasculated flowers. These bags protect the emasculated flowers from insects, pollen grains, dust, drew, rain etc. This process is called as bagging. Labelling is tagging of label containing desirable information for future reference.

Procedure:

1. Prepare a small bag of butter paper of suitable size.
2. Cover the emasculated flower carefully with this paper bag.
3. U-pin or thread is used to tie the bag to the floral axis of the plant.
4. A label of hard paper is made containing following information and this is tagged with a thread to the emasculated flower.

Information that has to be written on the tag is:

i. Specific reference no._____

ii. Date of emasculation_____

iii. Date & time of pollination_____

iv. Name of plant _____

v. Date of harvesting_____

vi. Name of plant breeder_____

4.5 SUMMARY

Emasculation is a method of artificial hybridization generally used to promote cross pollination in plants and avoid self pollination. It is the process of removing anthers from bisexual flowers without affecting the female reproductive part i.e. pistil, which is used in various plant hybridization techniques. This is done to achieve the beneficial variations which are not established due to inbreeding by self pollination. Cross Pollination is a necessary requirement for bisexual and monoecious plants only because unisexual plants are in no way capable to self pollinate. Dioecious plants have to undergo cross pollination as pollen and stigma are present on the flowers of two different plants. Outbreeding devices are the artificial way to promote cross pollination in bisexual or monoecious plants. This can be achieved by the means of **'Emasculation and Bagging"** techniques.

Emasculation is necessarily followed by controlled pollination. Emasculation is done during early morning between 6 and 8 am in spikelets, due to open on the same day. Emasculation should be over well ahead of the time of anthesis. It is performed by plant breeders in bisexual flowers to obtain the desired variety of a plant by crossing a particular plant with the desired pollen grain. To remove the anthers, the flowers are covered with a bag before they open. This ensures that the flower is pollinated by pollen grains obtained from desirable varieties only. Later, the mature, viable, and stored pollen grains are dusted on the bagged stigma by breeders to allow artificial pollination to take place and obtain the desired plant variety.

Various artificial hybridization techniques (under various crop improvement programmes) involve the removal of the anther from bisexual flowers without affecting the

female reproductive part through the process of emasculation. Then, these emasculated flowers are wrapped in bags to prevent pollination by unwanted pollen grains. This process is called bagging. The bagging is usually done in the evening of previous day of crossing, since most of the crops become receptive in the morning. The emasculated flowers are tagged just after bagging. The tags are attached to the flower or the inflorescence with the help of thread. The information is recorded on the tags with a carbon pencil. The crossed flowers are properly tagged and labeled. This technique is an important part of the plant breeding programme as it ensures that pollen grains of only desirable plants are used for fertilization of the stigma to develop the desired plant variety.

4.6 GLOSSARY

Acclimatization: The physiological adaptation of an organism to changes in climate or environment, such as light, temperature, or altitude.
Anther: The pollen-bearing part of a stamen.
Artificial pollination: Occurs when humans intervene with the natural pollination process. They carry pollen, or plant sperm, from one flower to another, allowing the pollen to fertilize the ovaries and create seeds that will develop into fruits and new plants.
Aspirator: An apparatus or device employing suction.
Bagging: Put (something) in a bag.
Bisexual flower: A flower that has both male (androecium or stamens) and female (gynoecium or carpels) functional reproductive parts in the same flower.
Calyx: The sepals of a flower, typically forming a whorl that encloses the petals and forms a protective layer around a flower in bud.
Corolla: The petals of a flower, typically forming a whorl within the sepals and enclosing the reproductive organs.
Cross-pollination: Pollination of a flower or plant with pollen from another flower or plant.
Cytoplasm: The cell substance between the cell membrane and the nucleus, containing the cytosol, organelles, cytoskeleton, and various particles.
Dehiscence: The release of materials by the splitting open of an organ or tissue.
Dioecious: Having the male and female organs in separate and distinct individuals; having separate sexes.
Emasculation: The removal of the anthers of a flower in order to prevent self-pollination or the undesirable pollination of neighboring plants.
Feasible: Capable of being done, effected, or accomplished.
Genotype: The genetic makeup, as distinguished from the physical appearance, of an organism or a group of organisms.
Gynoecium: The pistil or pistils of a flower; the female parts.
Heritable: Capable of being inherited.
Hybrid seed: In agriculture and gardening, hybrid seed is seed produced by cross-pollinated plants.

Hybridization: The process of an animal or plant breeding with an individual of another species or variety.

Inbreeding: The production of offspring from the mating or breeding of individuals or organisms that are closely related genetically.

Inflorescence: The arrangement of flowers on the axis.

Inherited: To receive (a characteristic) from a parent or ancestor by genetic transmission.

Labelling: Is describing someone or something in a word or short phrase.

Lemma: A phyto-morphological term used in botany referring to a part of the spikelet of grasses.

Male sterility: An absence or non-function of pollen grain in plant or incapability of plants to produce or release functional pollen grains.

Monoecious: Having both male and female organs in the same individual; hermaphroditic.

Muslin cloth: A cotton fabric of plain weave.

Mutational breeding: Or "**Variation breeding**", is the process of exposing seeds to chemicals or radiation in order to generate mutants with desirable traits (or lacking undesirable ones) to be bred with other cultivars.

Outbreeding: Breed from parents not closely related.

Palea: The palea is the uppermost of the two chaff-like bracts that enclose the grass floret (the other being the lemma).

Panicle: A loose branching cluster of flowers, as in oats.

Paraffin: A waxy white or colorless solid hydrocarbon mixture used to make candles, wax paper, lubricants, and sealing materials. Also called paraffin wax.

Vegetable parchment: A paper-like material made from a base of cotton rags or alpha cellulose called waterleaf, and containing no sizing or filling materials; used for documents and food packaging.

Pistil: The ovule-bearing or seed-bearing female organ of a flower, consisting when complete of ovary, style, and stigma.

Pollen: The fertilizing element of flowering plants, consisting of fine, powdery, yellowish grains or spores, sometimes in masses.

Pollination: The transfer of pollen from the anther to the stigma.

Protogyny: The condition of flowers whose female parts mature before the male ones.

Pure-line: An inbred line of genetic descent or a uniform strain of organisms that is relatively pure genetically because of continued inbreeding and artificial selection.

Receptive: Having the quality of receiving, taking in, or admitting.

Rectified spirit: Or "**Rectified alcohol**", is highly concentrated ethanol which has been purified by means of repeated distillation, a process that is called rectification.

Rinsing: To wash lightly with water.

Scalpel: A small, light, usually straight knife used in surgical and anatomical operations and dissections.

Self-fertilization: Fusion of male and female gametes (sex cells) produced by the same individual.

Self-incompatible: A widespread mechanism in flowering plants that prevents inbreeding and promotes out-crossing.

Self-pollination: The pollination of a flower by pollen from the same flower or from another flower on the same plant.
Spike: A kind of inflorescence in which sessile flowers are arranged on an unbranched elongated axis.
Stigma: The apex of the pistil of a flower, on which pollen grains are deposited and germinate.
Tag: A strip of leather, paper, metal, or plastic attached to something or hung from a wearer's neck to identify, classify, or label.
Tagging: To label, identify, or recognize with a tag or other identifier.
Viable pollen: Pollen which perform its function of delivering the sperm cells to the embryo sac following compatible pollination

4.7 SELF ASSESSMENT QUESTION

8.7.1 Short answer type questions:

1. Give name of two chemical Gametocide used for emasculation of flowers for hybridization?
2. What temperature are generally used in hot water & cold water treatments for emasculation?
3. In crops having small flowers, which emasculation method is generally avoided?
4. Pollination of a flower or plant with pollen from another flower or plant?
5. Mechanism in flowering plants that prevents inbreeding and promotes out-crossing?
6. The condition of flowers whose female parts mature before the male ones?
7. The phyto-morphological term used in botany referring to a part of the spikelet of grasses?
8. The production of offspring from the mating or breeding of individuals or organisms that are closely related genetically?
9. The pollination of a flower by pollen from the same flower or from another flower on the same plant?
10. Pollen which perform its function of delivering the sperm cells to the embryo sac following compatible pollination?
11. Genetic emasculation also known as?
12. The bag used in bagging method is made up of other than paper and butter paper?
13. The information is recorded on the tags with help of?
14. The bag are kept on the female as such till seed setting is complete, while in males they are removed as soon as the ?
15. The crops in which the inflorescence of both the parents are enclosed in the same bag?

4.7.2 Fill in the blanks:

1. _____is the process of an animal or plant breeding with an individual of another species or variety.
2. The physiological adaptation of an organism to changes in climate or environment, such as light, temperature, or altitude are known as_____

3. _____having the male and female organs in separate and distinct individuals; having separate sexes.
4. _____occurs when humans intervene with the natural pollination process.
5. The breed from parents not closely related are called_____
6. _____is the fusion of male and female gametes produced by the same individual.
7. The apex of the pistil of a flower, on which pollen grains are deposited and germinate are called_____
8. _____ is also known as variation breeding.
9. _____ is the condition of flowers whose female parts mature before the male ones.
10. The absence or non-function of pollen grain in plant or incapability of plants to produce or release functional pollen grains is known as _____
11. The bags used after emasculation, are kept on _____till seed-setting is complete.
12. The emasculated flowers are tagged just after _____
13. The tags are attached to the flower or the_____ with the help of thread.
14. The name of the _____is written first and that of the _____is written later.
15. Cold or hot treatment kills pollen grains without damaging_____

4.7.3 Multiple choice questions:

1. Hand emasculation is generally recommended in crops with
(a) Large flowers (b) Very small flowers
(c) Monoecious condition (d) Dioecious condition

2. In the following situation, emasculation will not be needed, although hermaphrodite flower are present and pollen is fully fertile
(a) Genetic male sterility (b) Cytoplasmic male sterility
(c) Self incompatibility (d) Homogamy

3. Cytoplasmic male sterility is commonly used in
(a) All breeding methods involve in hybridization
(b) Pedigree method of plant breeding
(c) In back-cross method of plant breeding
(d) Hybrid seed production
4. The quickest method of plant breeding is
(a) Introduction (b) Selection
(c) Hybridization (d) Mutation breeding

5. Bagging is done to
(a) Avoid cross pollination (b) Avoid self pollination
(c) Achieve desired pollination (d) Prevent contamination from foreign pollen

6. Pure line breed refers to
(a) Heterozygosity only (b) Homozygosity only

(c) Homozygosity and self assortment (d) Heterozygosity and linkage

7. The process of removing stamen from the flower during hybridization is called
(a) Capping (b) Selfing
(c) Emasculation (d) Crossing

8. A plant bearing both male and female flowers is said to be
(a) Dioecious (b) Monoecious
(c) Polygamous (d) None of above

9. A plant breeder is interested to control pollination to
(a) Prevent cross-pollination (b) Control pollination
(c) Both of these (d) None of these

10. Acclimatization is
(a) A process of adjustment by crop plants to environment
(b) Related with the clay
(c) Removal of female parts of a flower
(d) Changing of climatic condition

4.7.1 Answer key: 1. Ethrel and Sodium methyl arsenate. **2.** >40°C, <6°C, 3. Hand emasculation, 4. Cross-pollination, 5. Self-incompatible, 6. Protogyny, 7. Lemma, 8. Inbreeding, 9. Self-pollination, 10. Viable pollen, 11. Genetic or cytoplasmic male sterility, 12. Glassine or fine cloth, 13. Carbon pencil, 14. Crossing is over, 15. Jowar and Bajra.

4.7.2 Answer key: 1-Hybridization, 2-Acclimatization, 3-Dioecious, 4-Artificial pollination, 5-Outbreeding, 6-Self-fertilization, 7-Stigma, 8- Mutational breeding, 9-Protogyny, 10-Male sterility, 11- Females, 12- Bagging, 13- Inflorescence, 14- Female parent, Male parent, 15- Gynoecium

4.7.3 Answer key: 1-(a), 2-(c), 3-(d), 4-(d), 5-(d), 6-(b), 7-(c), 8-(b), 9-(c), 10-(a).

4.8 REFERENCES

- H.K. Chaudhari, 2004 2nd edition, *Elementary Principles of Plant Breeding*, Oxford & IBH pub. New Delhi
- P. K. Gupta, 2005 2nd Ed., *Plant Breeding Plant Propagation and Biotechnology*, Rastogi Pub.
- R.K. Gupta, M. Dhiman & A. Swami, 2007-8, *Practical Botany*, Anand pub.
- www.biologydiscussion.com
- www.indiaagronet.com
- www.agritech.tnau.ac.in
- www.biology.lifeeasy.org
- www.en.wikipedia.org

- www.dictionary.com
- www.thefreedictionary.com

4.9 SUGGESTED READINGS

- H.K. Chaudhari, 2004 2nd Ed., *Elementary Principles of Plant Breeding*, Oxford & IBH pub. New Delhi
- Allard R.W. (1960), *Principles of Plant Breeding*, John Wiley & Sons, Inc., New York.
- Hayes, H.K. Immer, F.R. & Smith, D.C. (1955), *Methods of Plant Breeding*, McGraw-Hill Book Co., Inc. New York
- Briggs, F.N. and Knowles, P.F. (1967), *Introduction to Plant Breeding*, Reinhold pub. co., New York
- B.D. Singh, 2015, *Plant Breeding principles & Methods*, Kalyani pub.
- Kochhar, P.L., 1961, Plant Ecology, Genetics and Evolution, S. Nagir Co., Jullundur City
- Chaudhary, R.C., 2005 2nd Ed., *Principles Of Plant Breeding*
- Singh, H.B., 1962, Exploitation of hybrid vigour in Vegetables, I.C.A.R. Research Series No. 33.

4.10 TERMINAL QUESTIONS

1. Define the term hybridization and state its objects of application.
2. What is bagging technique? How is it useful in a plant breeding programme?
3. What is meant by emasculation? When and why does a plant breeder employ this technique?
4. What is the necessity of labelling and when is it done? Described how is it done and illustrate with the help of diagram?
5. Define the term 'crossing' and discuss its operation in different crops.
6. What is bagging? When and why is bagging done in the hybridization?
7. Describe the process of pollination and its role in emasculation. Illustrate with the help of diagram?
8. How many steps are involved in the hybridization procedure? Describe only three most important in detail.
9. Write a short note on:
   a) Emasculation
   b) Bagging
   c) Hot water treatment
   d) Suction method
   e) Genetic emasculation

10. Describe the procedure to emasculate flowers of given crop in field for hybridization. Also describe the procedure of bagging and labelling of emasculated flowers.

UTTARAKHAND OPEN UNIVERSITY

Teenpani Bypass Road, Behind Transport Nagar,
Haldwani- 263139, Nainital (Uttarakhand)
Phone: 05946-261122, 261123; Fax No. 05946-264232
Website: www.uou.ac.in; e-mail: info@uou.ac.in
Toll Free No.: 1800 180 4025