PAPER - IX GENETICS, CYTOGENETICS AND PLANT BREEDING
UNIT- 4

Dr. M. PUGALENTHI,
Assistant Professor
Department of Botany,
Government Arts College (Autonomous),
Coimbatore - 641 018.
Mobile: 9894739777

Variation in chromosome structure:

(a) Deletion or Deficiency:

It is due to loss of a part of a chromosome. The chromosome becomes shorter due to loss of one or more genes (Fig. 5.21).

(b) Duplication:

Duplication of chromosome may take place due to attachment of some deleted part of another chromosome with it. This brings addition of some new genes not belonging to it.

(c) Inversion:

An inversion is produced when there are two breaks in a chromosome and the intercalary segment reunites in reverse order i.e., the segment rotate by 180°. For example, if the gene sequence in the original chromosome is ABCDEFGH, it may change to ADCBEFGH (Fig. 5.21). If the inverted segment includes the centromere, the inversion is called pericentric inversion; if it does not include centromere the inversion is called as paracentric inversion.

(d) Translocation:

Translocation involves transfer of a segment of a chromosome to a different part of the same chromosome or to a different chromosome. In the latter case the transfer may take place between non-homologous chromosomes (Fig. 5.21). The genes in new or changed location may alter the

phenotypic expression or may even cause death of the individual. **Reciprocal translocations:** Pieces of two non-homologous chromosomes are exchanged without any net loss of genetic material.

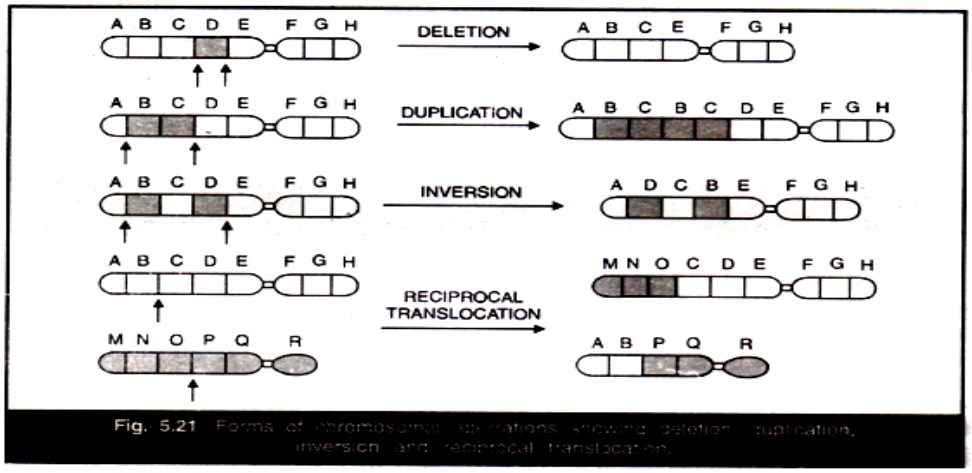
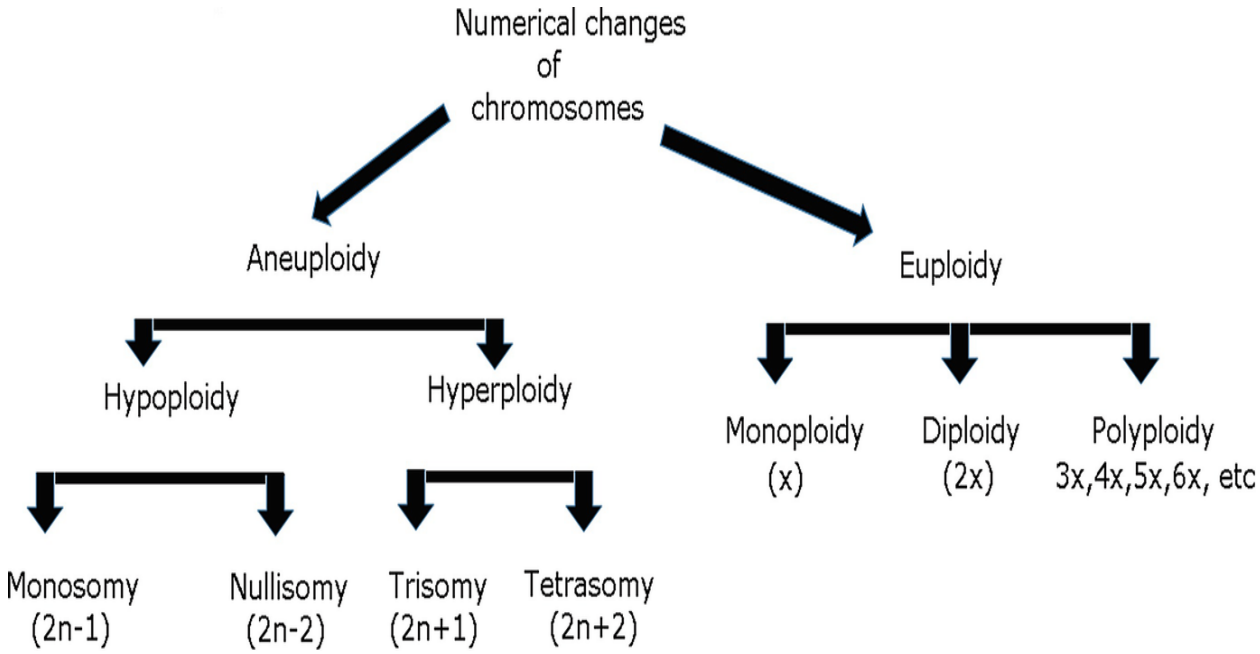


Fig. 5.21 Forms of chromosomal aberrations showing deletion, duplication, inversion and reciprocal translocation.

Variation in chromosome number:

The organisms are usually diploid (2n), i.e., they possess two sets of chromosomes. Variation in the normal diploid chromosome number is termed ploidy. Numerical change in chromosome or variations in chromosome number (heteroploidy), can be mainly of two types, namely (i) aneuploidy and (ii) euploidy.



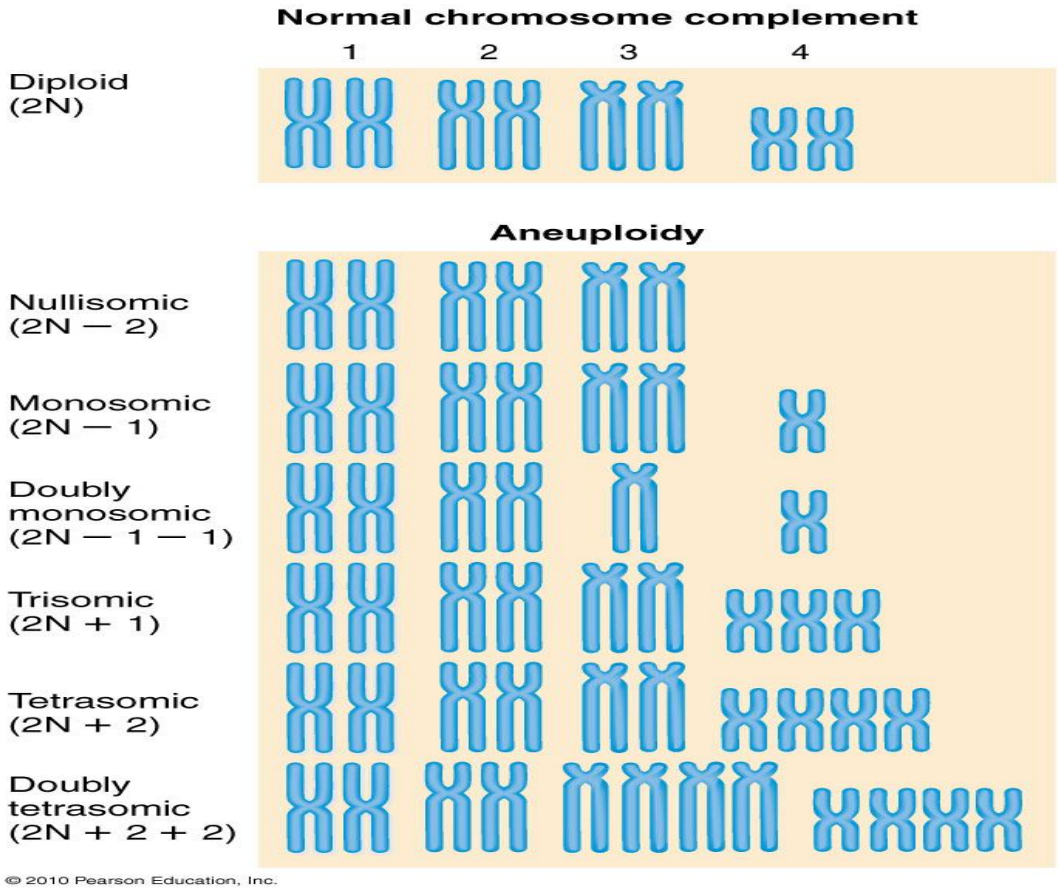
Hypoploidy. Loss of one or more chromosomes
Hyperploidy. Addition of one or more chromosomes.

(a) Aneuploidy:

It involves addition or deletion of one or few chromosomes to the usual diploid set of chromosomes. Aneuploids arise due to failure of the separation of homologous chromosomes of particular pair during meiosis. It is known as non-disjunction.

As a result two types of gametes are produced; one type contains more chromosomes than the normal number and the other type of gamete contain less chromosomes.

Aneuploids are of following types:



(i) Monosomics:

They arise by the loss of one chromosome from the diploid set i.e., 2n-1. They can form two types of gametes, (n) and (n-1).

(ii) Nullisomics:

These arise by the loss of a particular pair of chromosomes i.e., 2n-2. They arise by the fusion of two (n-1) types of gametes.

(iii) Trisomics:

These arise by addition of an extra chromosome to the normal diploid set with the genetic formula, 2n+1. Such individuals are formed by the union of a (n+1) gamete with a normal gamete (n).

1. Primary Trisomic:

In this type of trisomic, the extra chromosome is normal and completely homologous to one pair of homologues in the chromosome complement. Each chromosome exerts a separate effect on the phenotype of the plant and therefore, trisomics for different chromosomes can be identified. In *Datura stramonium*, primary trisomics (2n + 1 = 25) for each chromosome were distinguished according to the differences in capsule size and shape; size and length of spines; size of plants; growth habit; size, shape and forms of leaf, flower and stigma.

2. Secondary Trisomic:

When the extra chromosome is an iso-chromosome, the aneuploid is called secondary trisomic; its formula is "2n + iso". One chromosome arm is represented four times in the secondary trisomic. Univalent chromosome may produce iso-chromosome by misdivision of centromere. Each chromosome may produce two iso-chromosome, one for each arm; thus for each primary trisomic, two types of secondary trisomics are possible. Thus in *Datura* (2n – 24), 12 primary and 24 secondary trisomics are possible.

3. Tertiary Trisomic:

The cell or individual carrying a trans-located extra chromosome is called tertiary trisomic. The ends of the extra chromosome are homologous to the ends of two different chromosomes that are non-homologous. In a reciprocal translocation, there are two trans-located chromosomes and thus there are two possible types of tertiary trisomy.

4. Acrotrisomic:

Acrocentric chromosomes are produced due to terminal deletion of one arm. The designation of the acrotrisomic is made as the intact long (L)/short (S) arm with the superscript of deleted arm. For example, acrocentric chromosome produced by deletion of short arm of chromosome 3 is written as (3L3S) and the trisomic for this fragment is written as (Triple 3L3S). Acrotrisomic plants are obtained in the progeny of lelotrisomics, primary trisomics and triploids.

5. Telocentric Trisomic:

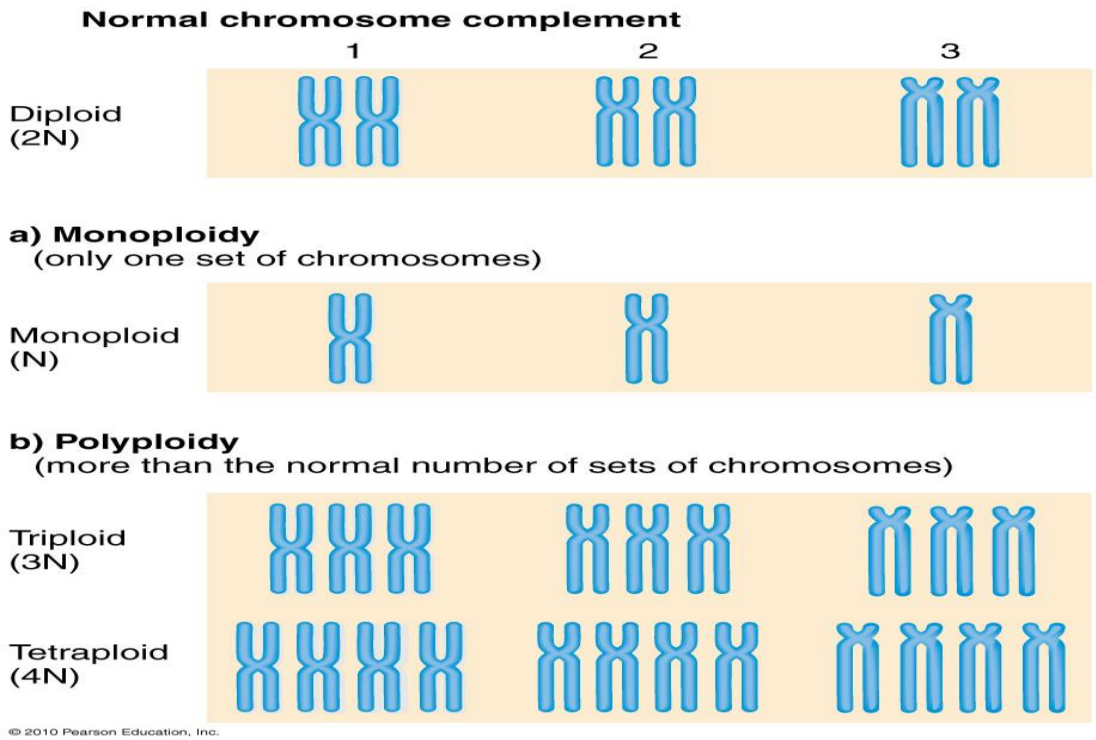
An individual with a normal chromosome complement plus an extra telocentric chromosome is called telotrisomic or telosomic trisomic or telocentric trisomic; the formula is "2n + t". Thus a telocentric fragment chromosome is homologous to one arm of a chromosome pair in the standard complement. In wheat nomenclature, it is called mono-telotrisomic. In barley, the telotrisomics are designated by the number of chromosomes involved, followed by the letter S or L to indicate the short or long arm involved. If the long arm of chromosome 2 is involved, it will be written as "telosomic 2L". Such trisomics are designated as Triplo 1L, Triplo 2L, Triplo 2S, and so on.

(iv) Tetrasomics:

These arise by the addition of an extra pair of chromosome to the diploid set with a chromosomal formula 2n + 2. By this a particular chromosome is represented in four doses instead of normal two.

(b) Euploidy:

Normally organism possesses two sets of chromosomes i.e., they are diploid (2n). At times there is addition or loss of complete one set (n) or more than one set of chromosomes is observed. It is called as euploidy. Euploidy is of following types:



(i) Monoploidy:

Out of two sets of chromosomes of a normal organism when one set is lost, the resulting offspring's contains only one set of chromosomes is called Monoploidy.

(ii) Polyploidy:

Organisms having more than two normal sets of chromosomes (2n) are called polyploids. Organisms with three sets of chromosomes (2n + n) = 3n are triploids ; those with four sets of chromosomes (2n + 2n) = 4n are tetraploids and those with five sets (2n + 3n) = 5n and six sets (2n + 4n) = 6n are known as pentaploids and hexapioids respectively.

Polyploidy in Plants:
An organism having more than two sets of homologous chromosomes is known as polyploid and the phenomenon polyploidy. It was discovered by Lutz. It is rarely found in animals but is of general occurrence in plants. A typical diploid is rare in nature. Most of the so called diploids are really polyploids but their behaviour is like diploids. Many of our cultivated plants are considered diploids but actually these are polyploids of two types namely primary and secondary polyploids.

1. Primary Polyploids are of two types:
(i) Autopolyploid

(ii) Allopolyploids which may be distinguished on the basis of the source of the chromosome.

(i) Autopolyploid:

Autopolyploid are those polyploids, which have the same basic set of chromosomes multiplied. For example, if a diploid species has two similar sets of chromosomes or genomes (AA) an auto-tri-polyploid will have three similar genomes (AAA) and an autotetraploid will have four such genomes (AAAA). In most cases tetraploids are normal.
Autotetraploid condition occurs when diploid gametes fuse. One of the very common example of natural auto-ploidy relevant to Northern India pertains to ‘doob’ grass (Cynodon dactylon).

(a) Auto-triploids:

Auto-triploids are also known in water lemons, sugar beet, tomato, banana, grapes etc. These are some times more vigorous than diploids. These are comparatively more leafy and tending to perenniality. In some cases, disturbances may be present in floral parts. The plants usually are highly sterile and rarely any seeds set. In nature, seeds propagated triploids do not occur. On the other hand, vegetatively propagated plants can exist as triploids. This advantage is taken of in Horticulture specially for ornamental plants.It was first reported by Gates (1908) in Oenothera.

(b) Autotetraploids:

Auto-tetraploids are known in rye (Secale cereale), berseem (Trifolium alexandrium), marigolds (Tagetes), corn (Zea mays), apples, Phlox and Oenothera lamarckiana (an American plant, a giant mutant), etc. These usually show greater vigour, increased cell size, mainly in stomata and guard cells. The auto-tetraploidy leads the plant to perenniality and may show reduced fertility. Autotetraploids are slower in growth, have greater adaptability, variability and sometimes show disease resistance. Because of their greater economic importance and breeding possibility, auto-tetraploids are now induced artificially.

(c) Auto-pentaploids:

These behave like tetraploids. The phenotype may differ. At meiosis pentavalents, quadrivalents, trivalents, bivalents and univalents may be formed. Gametes produced are fully sterile as meiosis is quite irregular.

(d) Auto-hexaploids:

These are more stable. Meiosis may be more regular and fertility high. Multivalents already occur.

(ii) Allopolyploids:

Polyploidy may also result from doubling of chromosome number of F1 hybrid which is derived from two distinctly different species. This will bring two sets of chromosomes in Ft hybrid. Let A represent a set of chromosome (= genome = a complete set of genes present in a haploid set of chromosomes) in species X, and let B represent another genome in a species Y. The F1 then will have one A genome and another B genome. The doubling of chromosome in this F1 hybrid (AB) will give rise to a tetraploid with two A and two B genomes. Such a polyploid is called an allopolyploid or amphidiploid.

An allotetraploid has been produced by the Russian Geneticist G.D. Karpechenko (1927) by crossing *Raphanus sativus* (2n = 18) and *Brassica oleracea* (2n = 18). The hybrid formed by crossing these two species is itself a diploid (2n = 18). It contains only one set of radish chromosome (n = 9) and one set of cabbage (n = 9) chromosomes. The hybrid differs from both the parents and showed many characters of both. It resembled the cabbage in its lower portion and the radish in its apical portion. The allotetraploid bred true, hence of no practical value. As it combines characters of both radish and cabbage, therefore, has been named Raphanobrassica. Some of the synthetic allotetraploids resemble closely with the existing species. Various species like wheat, cotton, tobacco etc. might have developed by this method. During the recent years a new genus Triticale has been synthesised by combining the chromosome of Triticum duram and Secale cereale (rye). This new genus Triticale is a very useful allopolyploid (2n = 56).

Evolution of Polyploidy in Wheat:

Polyploidy is believed to be a method for the origin of new species. As a general rule, species with a higher chromosome number are regarded more advanced than those with lower number from evolutionary point.

Plants with a higher chromosome number are considered to have released from either by direct increase of the lower number or by crossing with the other species, hence the three species of wheat, Triticum monococcum (n = 7), Triticum duram (n = 14) and Triticum vulgare (n = 21), have been evolved by polyploidy. Several species which already remain in nature have been synthesised in the laboratory by inducing polyploidy.

According to Danish geneticist O.Winje (1917) 1/2 to 1/3 species of angiosperms are polyploids. The maximum number (about 70%) is found in Gramineae family. In Cruciferae 42% and in Leguminosae 23% are available as polyploids. Despite it, other families where polyploids are found in plenty are notable e.g., Malvaceae, Cyperaceae etc. All these species are produced by hybridization.

Any organism where the chromosome number is highly increased, the genetic differences also are increased. This is due to increase in number of genes on the chromosomes. Hence, polyploidy is of great importance in the development of taxonomic series. The varieties which are produced in this way are very important for production of crops.

An example for clear understanding of polyploidy role in evolution is given below:

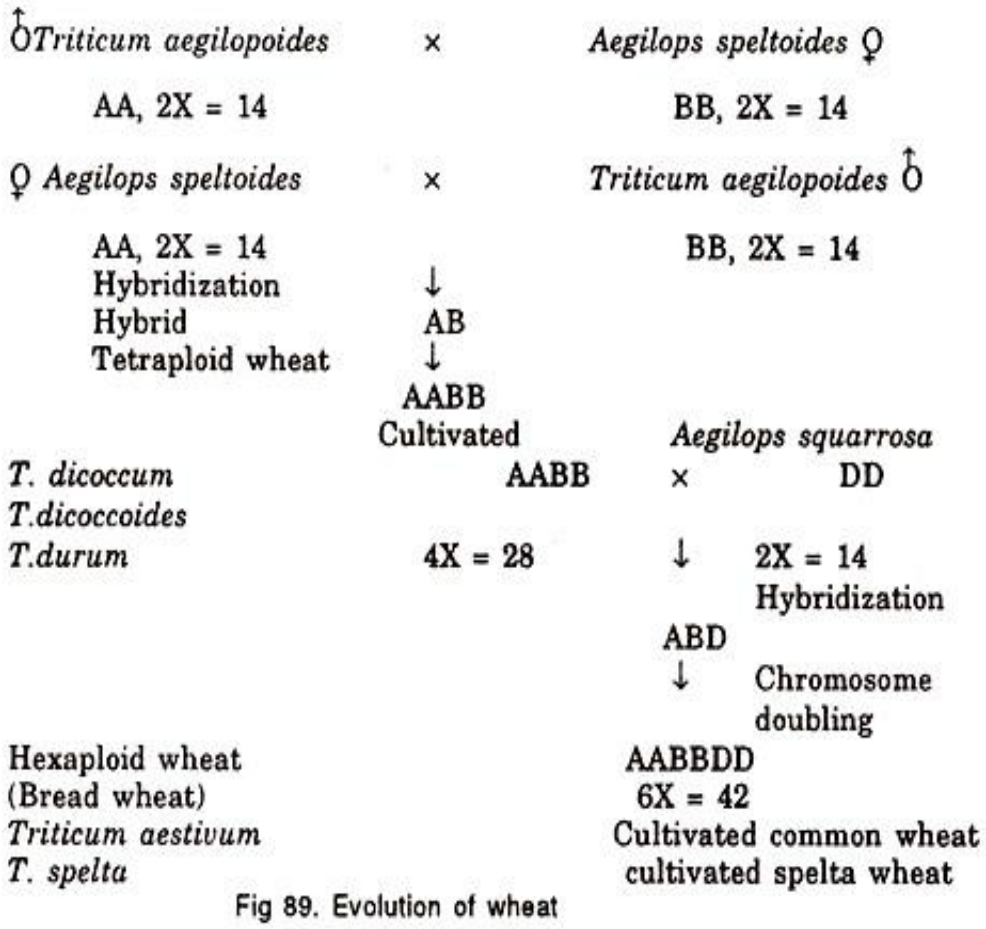


Fig 89. Evolution of wheat

It has been found that completive ability is more in polyploids. It has got more adaptability and their geographical distribution is found maximum.

Polyploids are better adjusted to tolerate unfavorable climates. Some of the most important polyploid (allopolyploid) crops are wheat, cotton, oats, tobacco, Brassica species etc. Allopolyploidy has played an important role in the evolution of plant species e.g., In allotetraploid cabbage and tomato ascorbic acid content is high. Polyploidy is believed to be a means for the origin of new species, especially in the plants in which this phenomenon is more common. As a general rule, species with a higher chromosome number are regarded more advanced from an evolutionary point than those with lower number.

Plants with a higher chromosome number are thought to have evolved either by the direct increase of the lower number, or by crossing with the other species. Thus, as described earlier the three species of wheat, *Triticum monococcum* (n = 7), *T. durum* (n = 14), and *T. vulgare* (n = 21) have been evolved by polyploidy. Several species which already exist in nature have been synthesised in the laboratory by inducing polyploidy. Induced polyploidy has important practical

application. By artificially induced polyploidy, it is possible to produce disease resistant plants having desirable qualities. Polyploids are larger in size and produce large seeds and fruits. They are more vigorous too.

Population Genetics:

Study of the frequency of genes and genotypes in a mendelian population is known as population genetics. In other words, it is a branch of genetics which deals with the frequency of genes and genotypes in mendelian populations. Before dealing with population genetics, it is essential to define mendelian population, gene frequency and genotype frequency.

Gene Frequency:

Gene frequency refers to the proportion of different alleles of a gene in a random mating population. It is also known as genetic frequency. In other words, the proportion of each type of allele at a particular locus in a random mating population is referred to as gene frequency. The composition of a population is described in terms of gene frequencies.

Calculation of gene frequency:

Suppose a random sample of 100 individuals was drawn from a random mating population of four 'O' clock plant (*Mirabilis jalapa*). Out of 100 plants, 30 were with red flower, 40 with pink flower and 30 with white flower.
Now, the allele frequency will be worked out as follows:

(a) In four o'clock plant, a cross between red and white flowered strains produces pink flower in Fi and red, pink and white flowered plants in 1: 2: 1 ratio in F2 generation. Thus, plants with red colour are homozygous for dominant allele (RR) and individuals with white flower colour are homozygous for recessive allele (rr).

(b) Each heterozygous individual with pink colour will have dominant (R) and recessive (r) alleles in equal number.

1. Number of R alleles in the Sample (30 individuals) = 2 (No. of red individuals) + No. of pink individuals

$$= (2 \times 30) + 40 = 100$$

2. Proportion of R alleles in the sample = Number of RR Alleles/2 (Total plants in a sample)

$$= 100/ (2 \times 100) = 100/200 = 0.50$$

Similarly,
the number of r alleles = (2 x30) + 40 = 100

Proportion of r alleles = 100/ (2 x 100) = 100/200 = 0.50

Therefore, the frequency of RR and rr alleles is 0.50 each.

Genotype Frequency:

It refers to the ratio of different genotypes in a mendelian population. Genotypic frequency is also known as zygotic frequency. The estimation of genotypic frequency for a gene in a population also consists of three important steps mentioned above.
Thus, the genotypic frequency of three types of individuals from the above sample will be calculated as ratio of each individual, class or genotypes to the total individuals in a sample.
Thus,

1. Frequency of Red (RR) individuals = 30/100 = 0.30

2. Frequency of Pink (Rr) individuals = 40/100 = 0.40

3. Frequency of White (rr) individuals = 30/100 = 0.30

Hardy-Weinberg Law:

Foundation of population genetics was laid by G.H. Hardy, an English mathematician and W. Weinberg, a German physician in 1908. They independently discovered a principle concerned with the frequency of genes (alleles) in a population. Their principle is commonly known as Hardy-Weinberg Law.

The Hardy-Weinberg Law states that:

1. In a random mating population, the frequency of genes and genotypes remains constant generation after generation, if there is no selection, mutation, migration and random genetic drift.

2. They also developed a mathematical relationship to describe the equilibrium between alleles. According to this relationship, the frequencies of three genotypes for a single locus with two alleles (A and a) are in the ratio of P^2AA: 2PqAa: q^2aa where P and q are the frequencies of allele 'A' and 'a' respectively. P + q are always equal to 1 or P = q = 0.50.

$$\boxed{\mathbf{P + q = 1}}$$

When gene frequencies are in equilibrium, it indicates absence of mutation, selection, migration and genetic drift in a population.

Factors Affecting Gene Frequency:

Mutation: Although mutation is the original source of all genetic variation, mutation rate for most organisms is pretty low. So, the impact of brand-new mutations on allele frequencies from one generation to the next is usually not large.

Non-random mating: In non-random mating, organisms may prefer to mate with others of the same genotype or of different genotypes. Non-random mating won't make allele frequencies in the population change by itself, though it can alter genotype frequencies. This keeps the population from being in Hardy-Weinberg equilibrium, but it’s debatable whether it counts as evolution, since the allele frequencies are staying the same.

Gene flow: Gene flow involves the movement of genes into or out of a population, due to either the movement of individual organisms or their gametes. Organisms and gametes that enter a population may have new alleles, or may bring in existing alleles but in different proportions than those already in the population. Gene flow can be a strong agent of evolution.

Non-infinite population size (genetic drift): Genetic drift involves changes in allele frequency due to chance events – literally, "sampling error" in selecting alleles for the next generation. Drift can occur in any population of non-infinite size, but it has a stronger effect on small populations.

Natural selection: Natural selection occurs when one allele (or combination of alleles of different genes) makes an organism more or less fit, that is, able to survive and reproduce in a given environment. If an allele reduces fitness, its frequency will tend to drop from one generation to the next.