Unit 2 : Linkage and Recombination

2.1 Linkage: Definition, Linkage group, Types, Coupling and Repulsion phase, Significance.

Introduction:

Morgan noted that while crossing a set of characters, two genes did not follow Mendel's law as they did not divide as per the law. The likelihood of achieving a parental combination if two genes are situated on the same chromosome was relatively higher in the subsequent generation in comparison to the non-parental combination. The physical connection of genes was referred to as linkage.

Genes are said to be linked when genes for different traits are located in similar chromosomes and hence are tied to each other. It is a deviation from the Mendelian principle of independent assortment that is appropriate to be applied to the genes that are situated on different chromosomes.

- The term genetic recombination described the non-parental gene combinations in a dihybrid cross. Each **chromosome** contains more than one gene.
- The genes for different characters may be either situated in the same chromosome or in different chromosomes.
- When the genes are situated in different chromosomes, the characters they control appear in the next generation together or apart, depending on the chance alone. They assort independently according to Mendel's law of independent assortment.
- But if the genes are situated in the same chromosome and are fairly close to each other, they tend to be inherited together.
- This type of coexistence of two or more genes in the same chromosome is known as linkage.

In linkage, two or more genes linked together are always inherited together in the same combination for more than two generations, whereas in recombination the genetic material is exchanged between different organisms which leads to the production of offsprings with the combination of traits.

- All the situations and examples discussed with inheritance of character according to Mendel's law are inheritance of genes situated on different chromosomes.
- Cytological study have reveals that human possess 46 chromosomes in all somatic cells (Vegetative cells). Since human possess thousands of characters such as blood group, eye color, insulin production etc, it follows that each chromosome must carry a large number of genes.
- Genes situated on same chromosome are said to be linked. All genes on a single chromosome form a linkage group and usually pass into same gamete and are inherited together.
- According to Mendel's law of independent assortment, the genes situated in different chromosomes assort and appear independently in next generation either appear together or apart.
- But if the genes are situated in the same chromosome and are fairly close to each other, they tend to be inherited together. This type of inheritance of linked genes in the same chromosome is known as Linkage.
- As a result of linkage, genes belonging to the same linkage group usually do not show independent assortment. Since these genes do not conform to Mendel's principle of independent assortment they fail to produce the expected 9:3:3:1 ratio in a breeding situation involving the inheritance of two pairs of contrasting characters (Dihybrid cross). In linkage, a variety of ratios are produced.

Biologists developed the chromosomal theory of inheritance.

In most breeding experiments involving linkage produces approximately equal numbers of parental phenotypes and a significant smaller number of recombinant phenotypes (new combination of characters) in equal numbers. Therefore, two genes are said to be linked when phenotypes with recombinant characters occur less frequently than the parental characters.The theory of chromosomal inheritance of linked gene was proposed by T. H Morgan in 1911 as experiments shows linked genes in a same chromosome tend to remain in their original combinations.

Chromosomal theory of linkage: by T. H Morgan

- **Bateson and Punnett** failed to explain the exact reasons of coupling and repulsion
- Later, **T.H. Morgan** who found coupling and repulsion hypothesis incomplete, while performing experiments with *Drosophila,* in 1910. Therefore, he proposed that the two genes are found in coupling phase because they are present on same chromosome and similarly on repulsion phase because they are preset on two different homologous chromosomes. There genes are then called **linked genes** and the phenomenon of inheritance of such linked genes is called **linkage** by Morgan.
- And the term coupling and repulsion were replaced by the terms, **cis** and **trans** by (**Haldane**, 1942).
- **Morgan** stated the linked genes have the tendency to remain together in original combination because they are located on same chromosome. And the strength of linkage depends upon the distance between the linked genes in the chromosome.
- The concept of linkage by Morgan establish the foundation of Cytogenetics and develop the theory of linear arrangement of genes in the chromosomes and helps to construct genetic map of the chromosome.
- According to Chromosomal theory of linkage:
- Chromosome contains genes and Genes lie in a linear order in a chromosome and distance between them is variable.
    - Each gene has a definite locus in a chromosome. The genes which are close to each other, shows the phenomenon of linkage
    - The linked genes cannot be separated during gametogenesis (inheritance process), they inherited together
    - Tendency of genes to remain linked is due to their presence on same chromosome
    - The distance between the linked genes determines the strength of linkage. The closer the distance stronger is the linkage strength.
- The genes which show the phenomenon of linkage are situated in the same chromosomes and these linked genes usually remain bounded by the chromosomal material so that they cannot be separated during the process of inheritance.
- The distance between the linked genes determines the strength of linkage. The closely located genes show strong linkage than the widely located genes which show the weak linkage.
- The genes are arranged in linear fashion in the chromosomes.
- The linkage is not due to any relation between two genes but is simply because they happens to be located in the same chromosome
- Before Morgan, W. Sutton and T. Boveri 1902), Sutton (1903) and Bateson and Punnett (1906) had put forward some hypothesis about the phenomenon of linkage.

Coupling and Repulsion hypothesis of linkage: by Bateson and Punnett

- Bateson and Punnett in 1906 described a cross in sweat pea (*Latharus odoratus)*, where they find gene pairs do not assort independently as expected.
- While they were working on sweet pea, they noticed two variety of plant-plant with Blue flowers (BB) with long pollen grains (LL) and red flower (bb) with round pollen grain (ll).

- When the sweat pea variety having blue flower and long pollen grain (BBLL) were crossed with those of another variety having red flower and round pollen (bbll).
- In F1 generation, all the offspring having blue flower and long pollen (BbLl) were observed as expected. Because, blue color is dominant over red and long pollen is dominant over round.
- When these F1 offspring (BbLl) were test crossed with red flower and round pollen variety (bbll), they obtained (BbLl), (Bbll), (bbLl), (bbll) in the ration 7:1:1:7 instead of 1:1:1:1.
- This indicates that the dominant characters (Blue color and long pollen) tends to remain together. Similarly, the recessive characters (red color and round pollen) tends to remain together. This deviation or phenomenon is explained by **Coupling and Repulsion hypothesis** by Bateson and Punnett.
- Bateson and punnett conclude that- the pairs of genes from homozygous parents try to remains together in a cross due to which parental characters is more frequent. This is due to **coupling.** Two dominant gene for Blue flower and long pollen (BL) are linked in one plant while in other plant two recessive gene for red flower and round pollen (bl) are linked. Such linkage is called coupling.
- In another experiment, when a cross was made between sweet pea variety having blue flower and round pollen (BBll) with another variety having red flower and long pollen (bbLL)
- In F1 generation, all offspring with blue flower and long pollen were obtained (BbLl).
- When these F1 offspring (BbLl) were test crossed with red flower and round pollen variety (bbll), they obtained (BbLl), (Bbll), (bbLl), (bbll) in the ratio 1:7:7:1 instead of 1:1:1:1.
- It was observed in both experimental cases that plants with parental characters are obtained in excess number than the plants with recombinant characters. Also when dominant alleles are from different parents (heterozygous) the frequency of recombination is more because of repulsion of gene (repulsion).
- In First experiment, **BL** are linked and such linkage is known as **Coupling** and in second experiment **bL** are linked and such linkage is known as **Repulsion**.
- The coupling and repulsion hypothesis is now discarded.

Linkage group:

- Genes situated on a chromosome are linked and all the genes on a single chromosome forms a linkage group. The gene located in different chromosome are unlinked genes.
- Usually linkage group as a whole passes into gamete during gametogenesis and are inherited together.
- The number of linkage group is equal to total number of chromosome in a cell. But actual number is restricted to haploid number of chromosome
- Human has 23 pairs of chromosomes and 23 linkage groups.
    - Male: 22 autosome + X-chromosome + Y chromosome= 24 linkage group
- *Drosophila* has 4 pairs of chromosomes and 4 linkage groups.
- *Maize (Zea mays*) has 10 pairs of chromosomes and 10 linkage groups.

Types of Linkage:

I) Based on crossing over, there are two types of linkage; **complete linkage** and **incomplete linkage**

Complete Linkage:

- When genes are very closely associated to each other, they tends to remains together and have no chance of separation from each other during inheritance. These genes are called linked genes and the phenomenon is known as complete linkage.
- In complete linkage the parental combination of characters appear together for two or more generations in a continuous and regular fashion.

Examples:

- Red eyed Normal winged Female Drosophila **(RRWW)** crossed with purple eyed vestigial wing male Drosophila **(rrww).**
- In F1 progeny, all the Drosophila obtained were heterozygous with red eyed normal winged **(RrWw)**
- When F1 males (**RrWw**) were test crossed to homozygous recessive female **(rrww),** only two types of F2 progeny individuals were produced (one type with red eyed normal winged **(RrWw)** and other type with purple eyed vestigial winged (**rrww)** in ratio 1:1).
- Recombinant type are absent. Frequency of recombination is **Zero**
- This is due to complete linkage between gene for eye color and wings. The F1 males produced only two types of gametes ie (**RW)** and **(rw)** instead of all possible four types of gametes.
- In most of the organism, crossing over takes places during gametogenesis. But in male Drosophila and in female Silkworm, the frequesncy of crossing over is either very area or not at all.
- Because of this, linked genes remains together during inheritance, showing complete linkage phenomenon.
- However, in practice, total linkage is rare.
- When F1 males were crossed with F1 females, the ratio would be 3:1 of parental characters. However, in practice 3:1 ratio never achieve, this is because **total linkage is rare.**

Incomplete Linkage

- The linked genes which are located at farther distance in a chromosome, do not always remains together and separate during gametogenesis are said to be incompletely linked gene and the phenomenon is known as Incomplete linkage.
- These linked genes separates because of crossing over between the homologous non-sister chromatids during pachytene stage of Prophase-I of meiosis.
- The incomplete linkage have been reported in various organisms including female *Drosophila.*
- When dominant sweat pea homozygous for blue flower and long pollen **(BBLL)** cross with double recessive homozygous for red flower and round pollen **(bbll).**
- In **F1 generation** all the progeny plants obtained hybrid plant (heterozygous) for blue flower and long pollen **(BbLl).**
- When **F1** hybrids weretest crossed with doule recessive parent **(bbll),** all four types of progeny (**BbLl, BbLl, bbLl and bbll)** were obtained in F2 generation in the ratio 7:1:1:7 instead of 1:1:1:1.
- The parental phenotype ie blue flower-long pollen (BbLl) and red flower-round pollen (bbll) accounts for 87.4% whereas the recombinant phenotype ie. blue flower-round pollen (Bbll) and red flower-long pollen (bbLl) accounts for only 12.6%.
- This experiment shows that, the genes for color of flower and shape of pollen are linked genes and located at a distant position in a chromosome. During gametogenesis these linked genes tends to remains together, however being distant and due to crossing over they separated.

II) Based on chromosomal involved i. e. location of genes on the chromosomes, linkage is grouped into-

a) Autosomal linkage- In this type genes are located in autosomes (other than sex chromosome)

b) Allosomal linkage / Sex linkage – In this type genes are located on Sex chromosomes either X or Y

Example on Linkage:-

- When two or more characters of parents are transmitted to the offsprings of few generations such as F_1, F_2, F_3 etc. without any recombination, they are called as the linked characters and the phenomenon is called as linkage. This is a deviation from the Mendelian principle of independent assortment. Mendel's law of independent assortment is applicable to the genes that are situated in separate chromosomes. When genes for different characters are located in the same chromosome, they are tied to one another and are said to be linked.
- They are inherited together by the offspring and will not be assorted independently. Thus, the tendency of two or more genes of the same chromosome to remain together in the process of inheritance is called linkage.
- Bateson and Punnet (1906), while working with sweet pea (Lathyrus odoratus) observed that flower colour and pollen shape tend to remain together and do not assort independently as per Mendel's law of independent assortment.
- When two different varieties of sweet pea—one having red flowers and round pollen grain and other having blue flower and long pollen grain were crossed, the F_1 plants were blue flowered with long pollen (blue long characters were respectively dominant over red and round characters). When these blue long (heterozygous) hybrids were crossed with double recessive red and round (homozygous) individuals (test cross), they failed to produce expected 1:1:1:1 ratio in F_2 generation. These actually produced following four combinations in the ratio of 7 : 1 : 1 : 7 (7 blue long : 1 blue round : 1 red long : 7 red round) (Fig. 5.6).

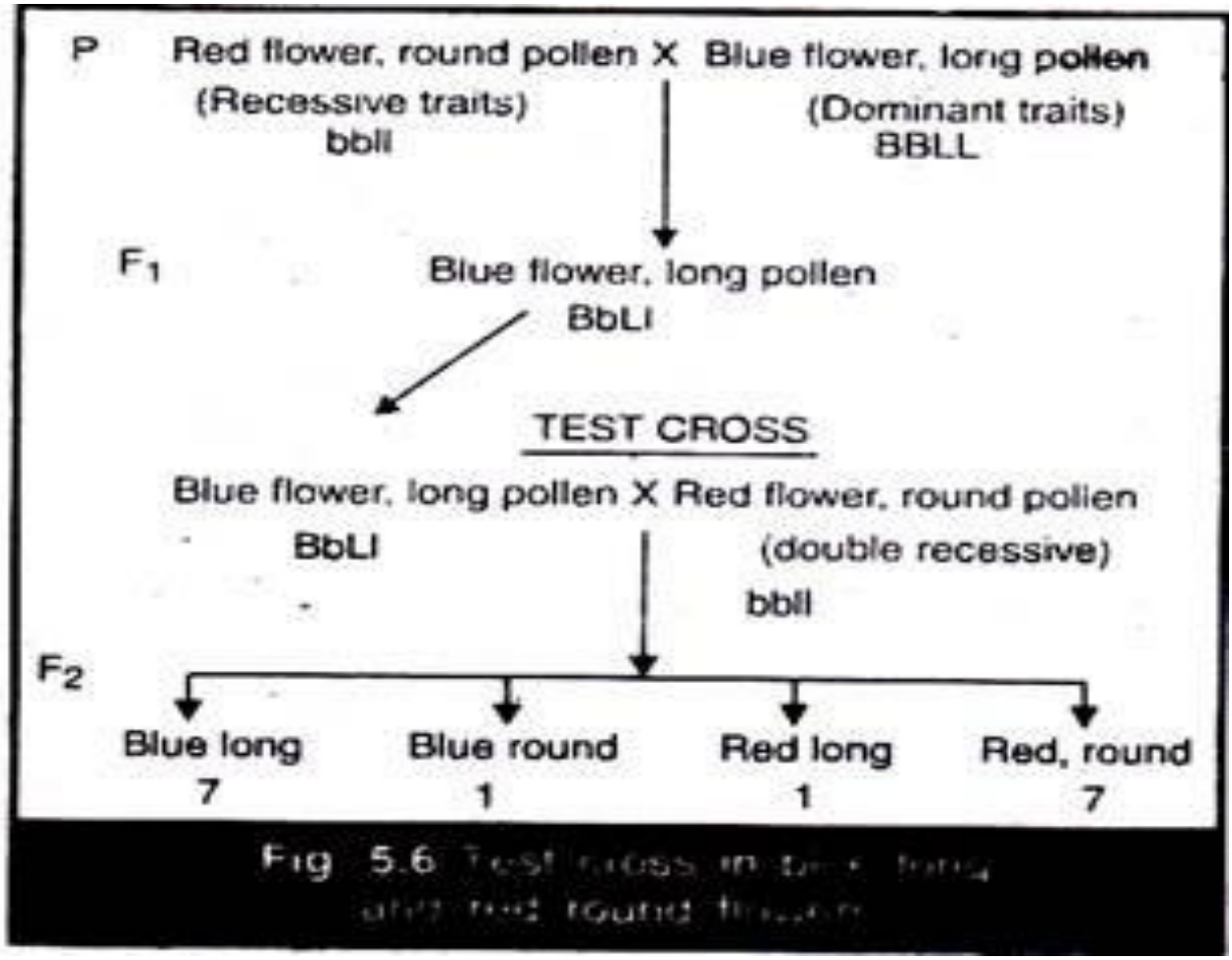

Fig 5.6

The above result of the test cross clearly indicates that the parental combinations (blue, long and red, round) are seven times more numerous than the non-parental combinations. Bateson and Punnet suggested that the genes (such as B and L) coming from the same parent (BBLL × bbll) tend to enter the same gamete and to be inherited together (coupling). Similarly, the genes (B and 1) coming from two different parents (such as BBLL x bbll), tend to enter different gametes and to be inherited separately and independently (repulsion).

Linkage Significance

The phenomenon of linkage has one of the great significance for the living organisms in that it reduces the possibility of variability in gametes unless crossing over occurs.

- Due to the linkage between genes, desired characters cannot be brought together by breeders. This would be possible only if the genes would sort independently.
- The characters that are linked remain so as there is no chance of recombination of the linked genes.