Principles of Inheritance and Variation - Part 3

Objectives

After going through this lesson, the learners will be able to understand the following:

- Dihybrid cross.
- Mendel's Third law of inheritance.
- Test cross in two genes inheritance.
- Pleiotropy and polygenic inheritance
- Chromosomal theory of inheritance.
- Linkage and crossing over.

Content Outline

- Introduction
- Inheritance of two genes
- Law of Independent Assortment
- Dihybrid Test Cross
- Pleiotropy
- Polygenic Inheritance
- Chromosomal Theory of Inheritance
- Morgan's Contribution in Genetics
- Linkage and Recombination
- Summary

Introduction

As a result of his experiments, Mendel was able to state three generalizations about the way characters are transmitted from one generation to the next in pea plants.

Mendel's law of independent assortment refers to the fact that a plant contains many different kinds of genes. One gene determines flower colour, second gene determines length of stem, third gene determines shape of pea pods, and so on. Mendel discovered the way in which alleles of different genes segregate and then recombine. That is, suppose that a plant contains genes for type of seed (RR) and for length (TT). Then Mendel's law says that the two genes will segregate independently of each other.

Pleiotropy occurs when one gene influences two or more seemingly unrelated phenotypic traits. Consequently, a mutation in a pleiotropic gene may have an effect on all traits simultaneously.

Polygenic inheritance occurs when one characteristic is controlled by two or more genes. Often the genes are large in quantity but small in effect. Examples of human polygenic inheritance are height, skin colour, eye colour and weight.

Morgan's experimental and theoretical work inaugurated research in genetics and promoted a revolution in biology. He received the Nobel Prize in Physiology or Medicine in 1933. Thomas Hunt Morgan (the father of experimental genetics) selected fruit-fly *Drosophila melanogaster* (the Jackpot of Genetics) as an experimental organism. Thomas Hunt Morgan and his coworkers 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.

Inheritance of Two Genes

In the second series of experiments Mendel studied inheritance of two characters at a time. For this he performed dihybrid cross in which he crossed the pea plants that differed in two characters e. g. pea plant that has seeds with yellow colour and round shape was crossed with the one that had seeds of green colour and wrinkled shape. In his observation Mendel found that the seeds resulting from the crossing of the parents, had yellow coloured and round shaped seeds in F_1. This indicated that yellow colour was dominant over green and round shape dominant over wrinkled. These results were identical to those that he got when he made separate monohybrid crosses between yellow and green seeded plants and between round and wrinkled seeded plants.

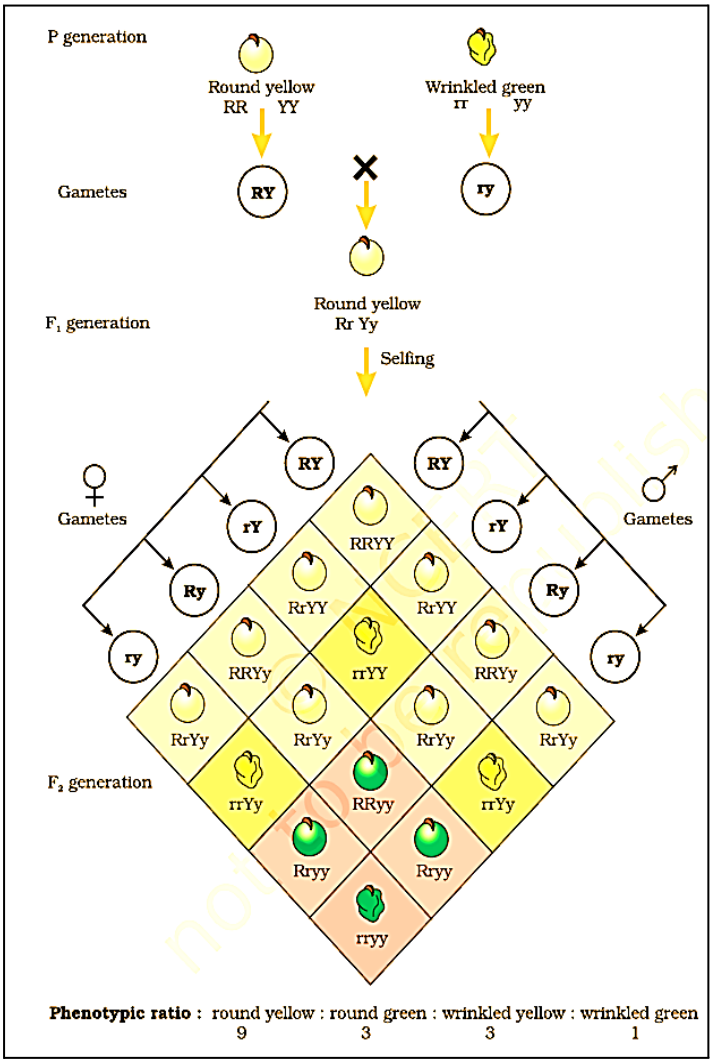
Let us use the genotypic symbols **Y** for dominant yellow seed colour and **y** for recessive green seed colour, **R** for round shaped seeds and **r** for wrinkled seed shape.

The genotype of the parents can then be written as **RRYY for** round and yellow seeds and **rryy for** wrinkled and green seeds. The gametes produced by these plants would be **RY** and **ry** type, which on fertilization unite to produce the F_1 hybrid **RrYy**. When Mendel self-hybridized the F_1 plants he found that 3/4 of F_2 plants had yellow seeds and 1/4 had green. The yellow and green colour segregated in a 3:1 ratio. Similarly round and wrinkled seeds are also segregated in a 3:1 ratio like in a monohybrid cross.

Law of Independent Assortment

The ratio of phenotypes round, yellow; wrinkled, yellow; round, green and wrinkled, green appeared in the F2 generation was 9:3:3:1. Such a ratio was observed for several pairs of characters that Mendel studied. The ratio of 9:3:3:1 can be derived as a combination series of 3 yellow: 1 green, with 3 round: 1 wrinkled. This derivation can be written as follows:

(3 Round : 1 Wrinkled) (3 Yellow : 1 Green) = 9 Round, Yellow : 3 Wrinkled, Yellow : 3 Round, Green : 1 Wrinkled, Green



Based on such observations on dihybrid crosses Mendel proposed the Law of Independent Assortment. The law states that 'when two pairs of traits are combined in a hybrid, segregation of one pair of characters is independent of the other pair of characters.

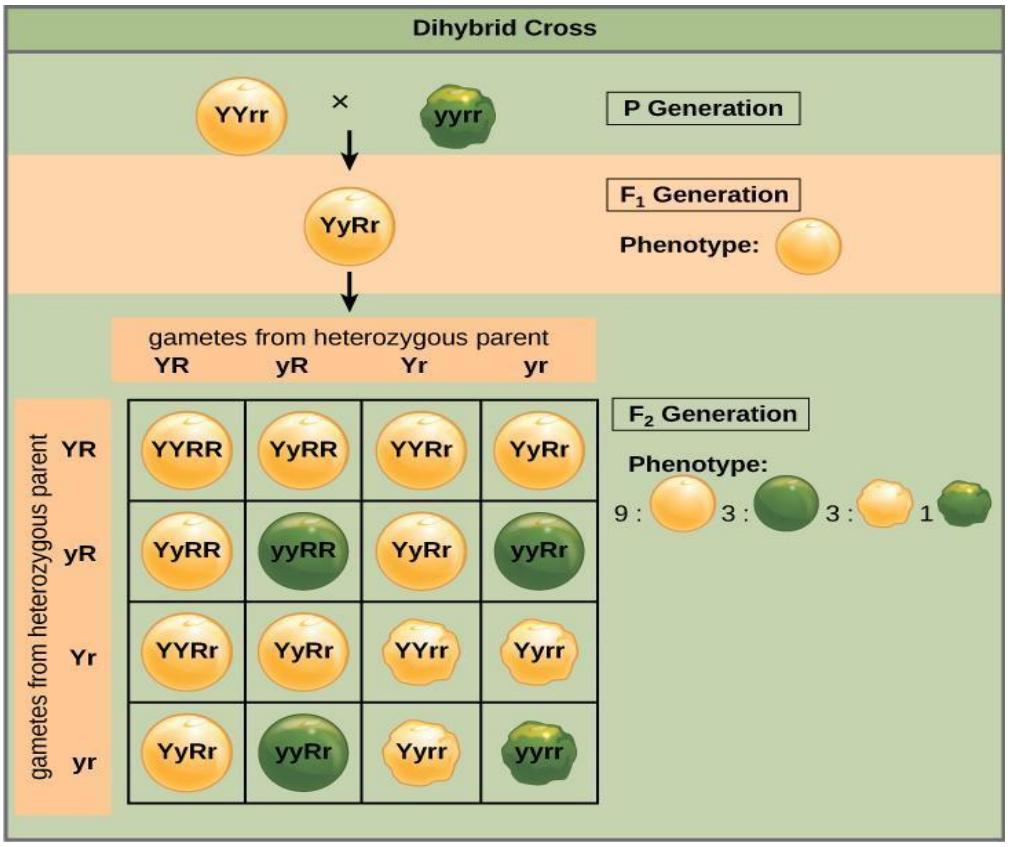
The Punnett square can be effectively used to understand the independent segregation of the two pairs of genes during meiosis and the production of eggs and pollen in the **F_1 RrYy** plant.

F2 Punnett Square

Dihybrid gametes from female \ Dihybrid gametes from male	1/4 RY	1/4 Ry	1/4 rY	1/4 ry
1/4 RY	RRYY	RRYy	RrYY	RrYy
1/4 Ry	RRYy	RRyy	RrYy	Rryy
1/4 rY	RrYY	RrYy	rrYY	rrYy
1/4 ry	RrYy	Rryy	rrYy	rryy

Consider the segregation of one pair of genes R and r. Fifty percent of the gametes have the gene R and the other 50 percent have r. Now besides each gamete having either R or r, it should also have the allele Y or y. The important thing to remember here is that segregation of 50 percent R and 50 percent r is independent from the segregation of 50 percent Y and 50 percent y. Therefore, 50 percent of the r bearing gametes has Y and the other 50 percent has y.

Similarly, 50 percent of the R bearing gametes has Y and the other 50 percent has y. Thus genetically four types of gametes (**Ry RY, rY** and **ry)** each with a frequency of 25 percent would be produced. The four types of eggs and pollen can be written on the two sides of a Punnett square and the composition of F_2 plants can be derived.



Dihybrid Test Cross

Similar to monohybrid cross, by looking at the dominant traits in a dihybrid cross we cannot determine whether it is homozygous or heterozygous.

So in order to find out the genotype, a test cross is performed with an organism that has both recessive characteristics. After the test cross we get a ratio of 1:1:1:1 when the parent is heterozygous. In case of homozygous, all the offspring will show the dominant phenotype for both characteristics.

Example

Genotype	**AaBb**				**aabb**
Gametes	**AB**	**Ab**	**aB**	**ab**	**Ab**

PUNNETT SQUARE

	ab
AB	**AaBb**
Ab	**Aabb**
aB	**aaBb**
ab	**aabb**

Now we have an organism that is homozygous dominant for one trait, but heterozygous for the other, the test cross still works.

In the cross:

For the homozygous dominant characteristic, no recessive trait will show up in the offspring.

For the heterozygous characteristic the recessive trait will show up.

Example

Genotype: **AABb** **x** **aabb**

Gametes: **AB, AB, Ab, Ab,** **ab, ab, ab, ab**

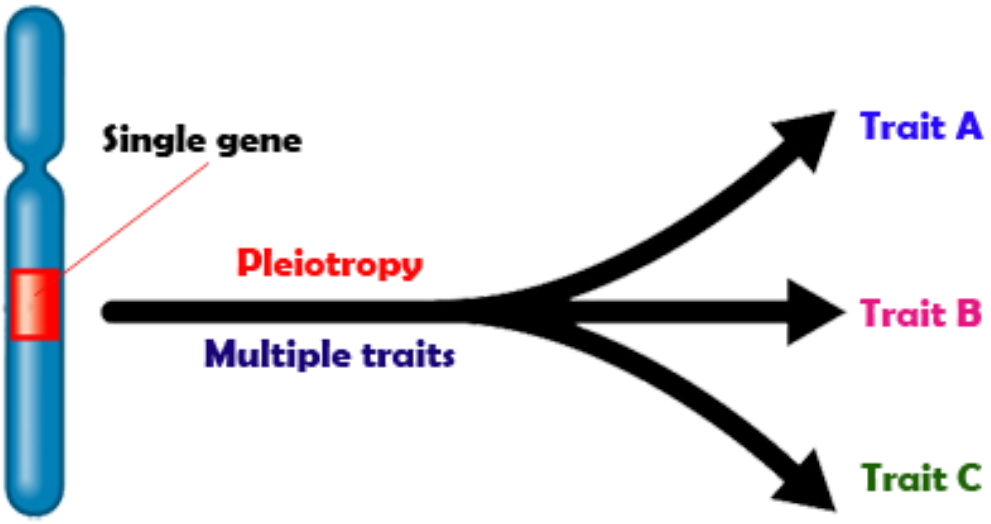
Punnett Square

	ab
AB	**AaBb**
Ab	**Aabb**

All the progeny will show the dominant trait for A and half show the recessive trait for B. From this, you can deduce the genotype as AA for trait A and Bb for trait B

Pleiotropy

A gene that controls multiple traits in an organism is called pleiotropic gene. This phenomenon is called pleiotropy.



Pleiotropy is the phenomenon where one gene has multiple different phenotypes associated with it. For instance, the gene may code for a product that is used in many cells, or for a signaling molecule that has a widespread endocrine effect.

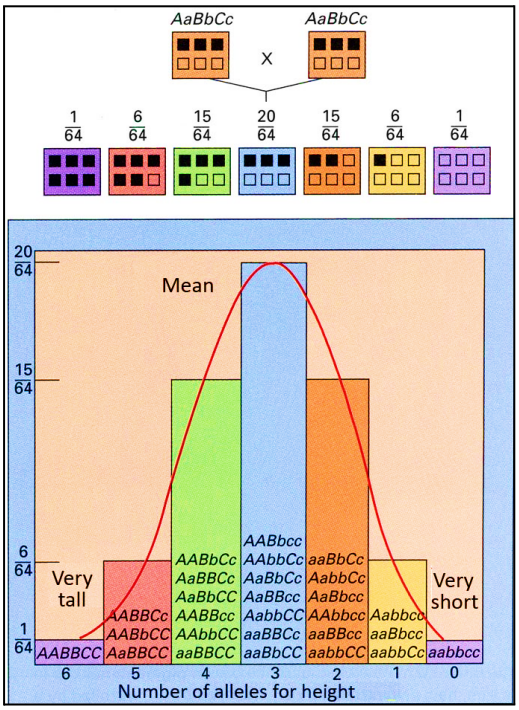
Polygenic Inheritance

Polygenic inheritance occurs when one characteristic is controlled by two or more genes. Often the genes are large in quantity but small in effect. Examples of human polygenic inheritance are **height**, skin colour, eye colour and weight. Polygenic traits show continuous variation; these are quantitative in nature. Polygenes exist in other organisms, as well. *Drosophila* for instance, display phylogeny with traits such as wing morphology, bristle count and many others.

The frequency of the phenotypes of these traits generally follows a normal continuous variation distribution pattern. This results from the many possible allelic combinations. When the values are plotted, a **bell-shaped curve** is obtained. The mode of the distribution represents the optimal, or fittest, phenotype. The more genes are involved, the smoother the estimated curve.

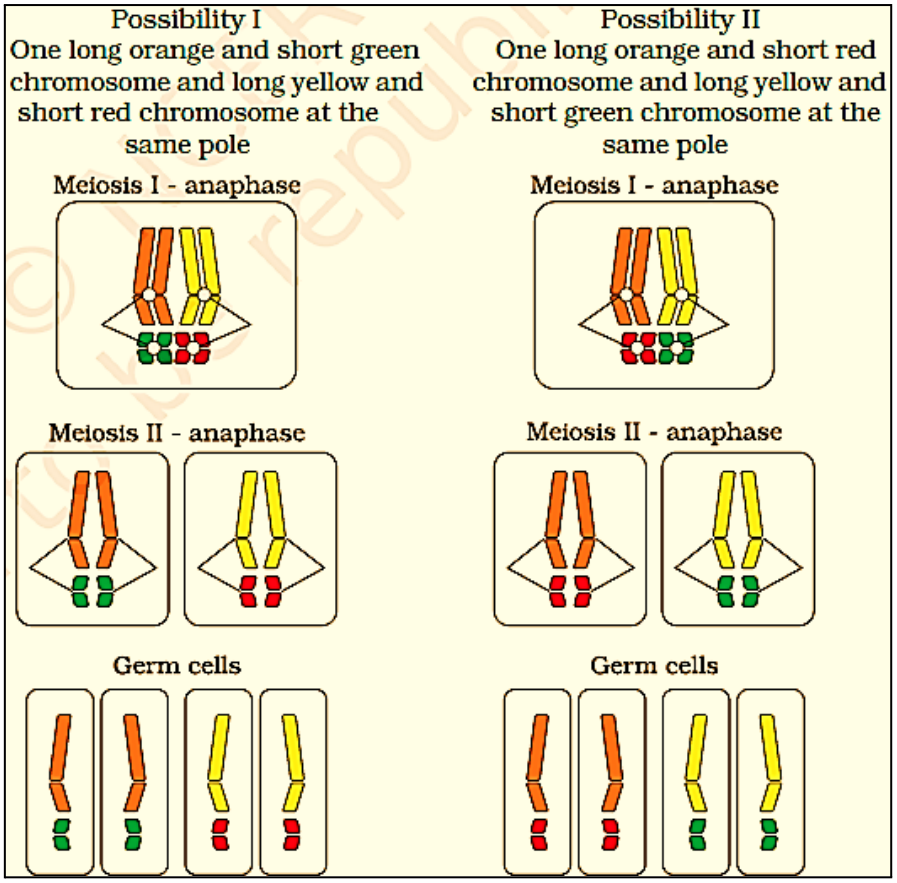
Chromosomal Theory of Inheritance

Mendel published his work on inheritance of characters in 1865 but for several reasons, it remained un-recognized till 1900. Firstly, communication was not easy (as it is now) in those days and his work could not be widely publicized. Secondly, his concept of genes (or factors, in Mendel's words) as stable and discrete units that controlled the expression of traits was not accepted by his contemporaries. This concept could not explain the continuous variation seen in nature. Thirdly, Mendel's approach of using mathematics to explain biological phenomena was totally new and unacceptable to many of the biologists of his time. Finally, though Mendel's work suggested that factors (genes) were discrete units, he could not provide any physical proof for the existence of factors.



In 1900, three Scientists (de Vries, Correns and von Tschermak) independently rediscovered Mendel's results on the inheritance of characters. Also, by this time, scientists were able to carefully observe cell division. This led to the discovery of structures in the nucleus that appeared to double and divide just before each cell division. These were called chromosomes (coloured bodies, as they were visualised by staining). By 1902, the chromosome movement during meiosis had been worked out. Walter Sutton and Theodore Boveri noted that the behavior of chromosomes was parallel to the behavior of genes and used chromosome theory to explain Mendel's laws.

The **Boveri–Sutton chromosome theory** (also known as the **chromosomal theory of inheritance**) is a fundamental theory of genetics which identifies chromosomes as the carriers of genetic material. Sutton and Boveri argued that the pairing and separation of a pair of chromosomes would lead to the segregation of a pair of factors they carried. It correctly explains the mechanism underlying the laws of Mendelian inheritance by identifying chromosomes with the paired factors (particles) required by Mendel's laws. It also states that chromosomes are linear structures with genes located at specific sites called loci along them. It states that the chromosomes, which are seen in all dividing cells and pass from one generation to the next, are the basis for all genetic inheritance.

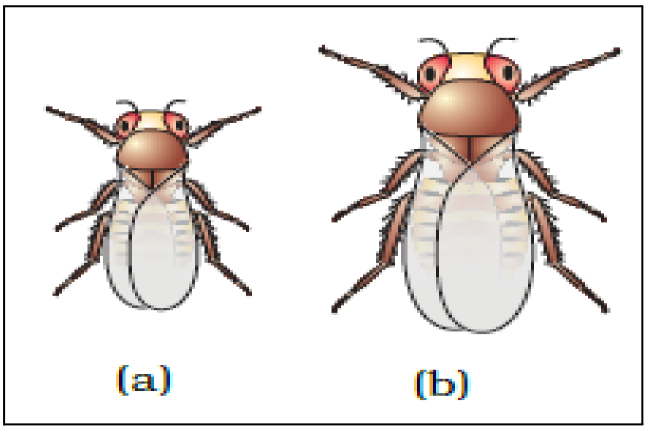


One long orange and short green and other long yellow and short red chromosomes at the same pole. During Anaphase of meiosis I, the two chromosome pairs can align at the metaphase plate independently of each other. To understand this, compare the chromosomes of four different colors in the left and right columns. In the left column (**Possibility I**) orange and green are segregating together. But in the right hand column (**Possibility II**) the orange chromosome is segregating with the red chromosomes.

Morgan's Contribution in Genetics

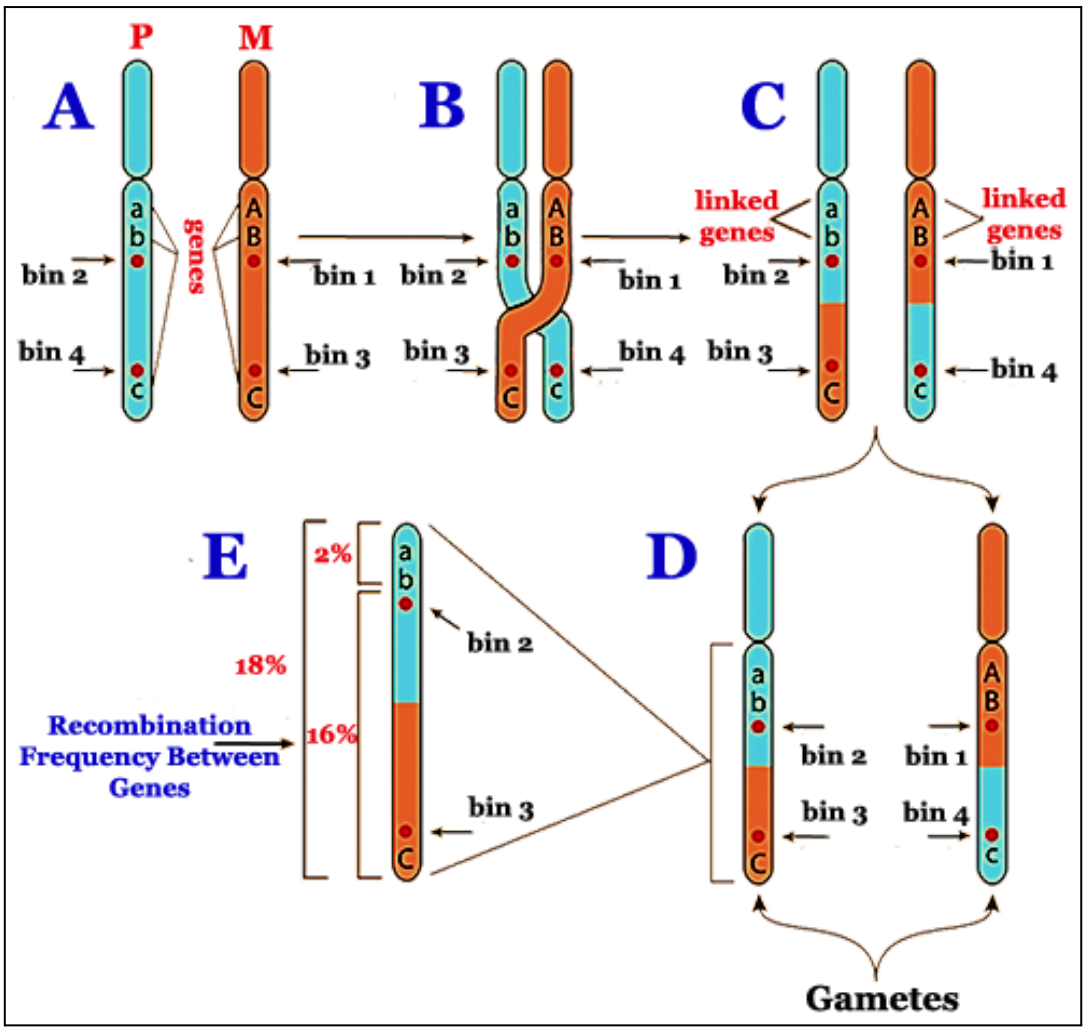
Thomas Hunt Morgan, an American Zoologist and Geneticist, was famous for his experimental research with the fruit fly (*Drosophila*) by which he established the chromosome theory of heredity. He showed that genes are linked in a series on chromosomes and are responsible for identifiable, hereditary traits. He received the Nobel Prize for Physiology or Medicine in 1933.

Drosophila Melanogaster (Fruit fly)



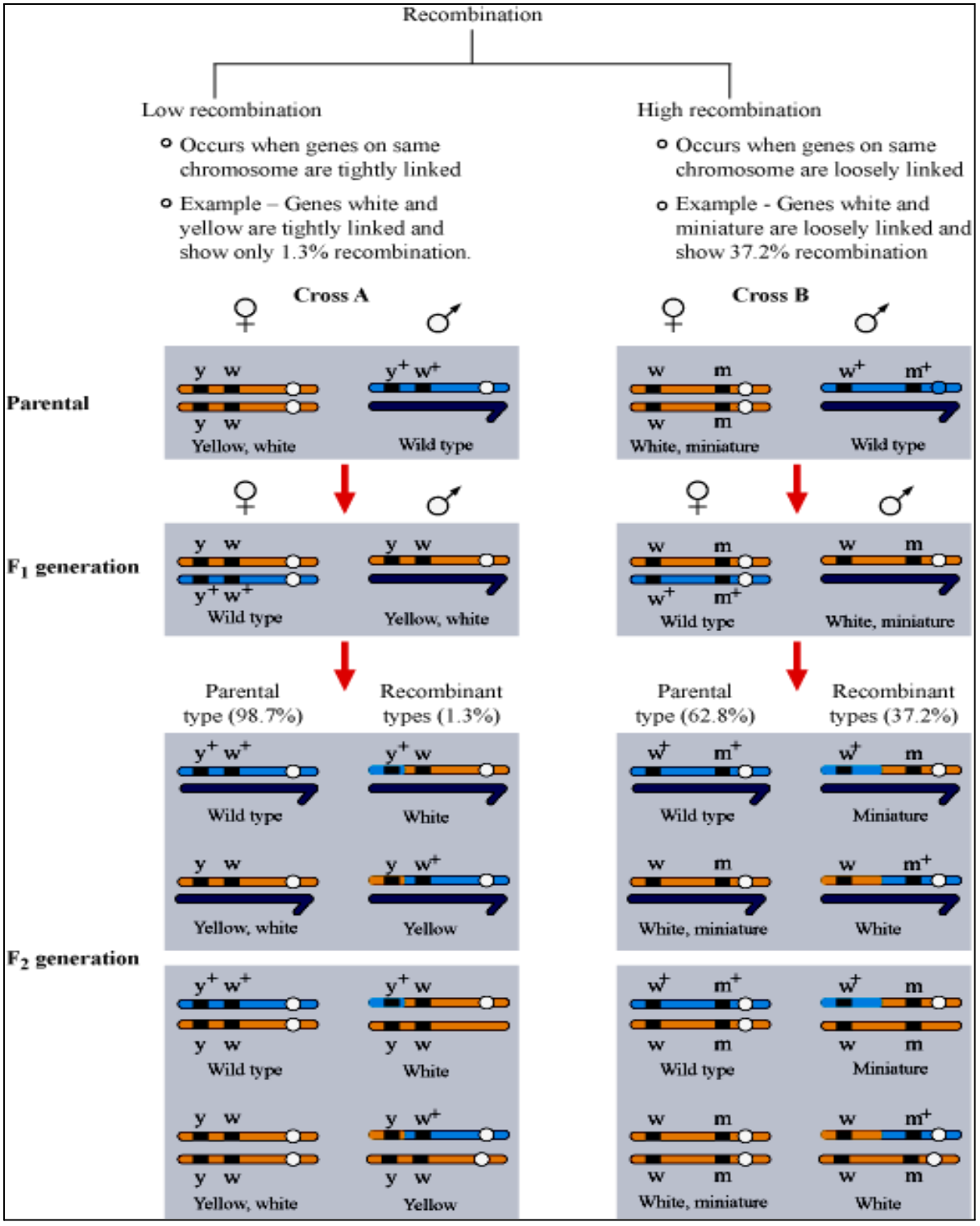
Thomas Hunt Morgan (**the father of experimental genetics**) selected fruit-fly *Drosophila melanogaster* (the Jackpot of Genetics) as experimental materials. It has many advantages over Pea.

- It is easily available hovering over ripe banana fruits where it feeds over yeast cells present on the fruit surface.
- The flies can be reared inside bottles having yeast culture on medium containing cream of wheat, molasses and agar.
- A new generation can be raised within 2 weeks with single mating producing hundreds of individuals.
- The animals can be temporarily inactivated with ether and examined by hand lens/dissection microscope.
- Female is distinguishable from male by its larger size and presence of ovipositor at the rear end.
- The animals possess four pairs of chromosomes of different sizes. The male fly possesses XY sex chromosomes while the female has XX chromosomes. The Y chromosome is hooked and easily distinguished.
- Polytene chromosomes occur in salivary glands of larva which can indicate any type of chromosomal aberration.
- Breeding *Drosophila* is quite easy. Further, it can be done throughout the year.



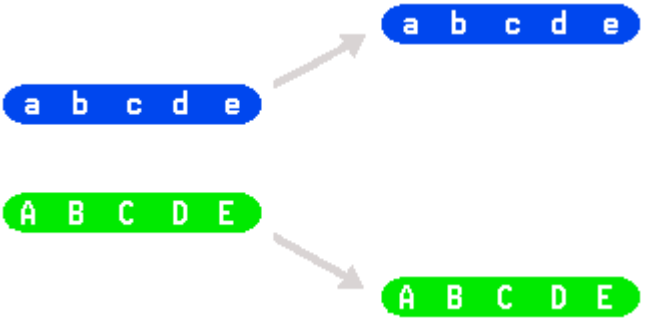
Linkage and Recombination

Thomas Hunt Morgan carried out several dihybrid cross experiments with *Drosophila* to study sex-linked genes. He crossed yellow-bodied, white-eyed females with wild type males. In F_1 generation all the males were yellow-bodied, white-eyed and all the females were wild type. Morgan then crossed the F_1 generation; in F_2 generation he observed that the gene did not assort independently, which was an exception to Mendel's law of independent assortment. Morgan explained this phenomenon by physical association or linkage; which describes the tendency of certain genes to be inherited together and parental combinations of the genes are retained in the progeny. Genes which are located on the same chromosome and that are inherited together are known as linked genes. If an individual inherits one of these traits, he is most likely to inherit the other trait too.



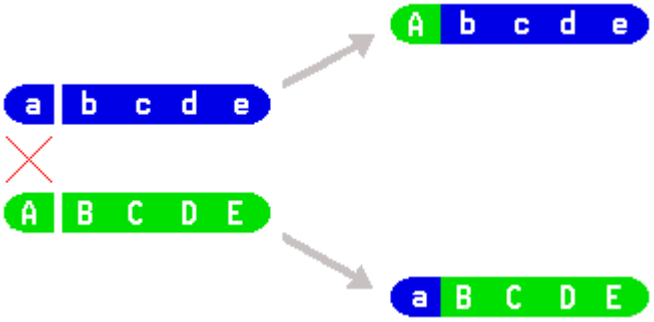
Genes present on the same chromosome tend to inherit together as a unit. Such genes are said to be linked. For example, in the illustration given below "A" and "B" are linked due to their presence on the same chromosome. Therefore either "a" and "b" or "A" and "B" alleles will be inherited as a unit

Linked genes do not segregate at the time of separation of homologous chromosomes at the time of gamete formation.



During the meiosis-I, there is pairing of homologous chromosomes and exchange parts of their chromatids with the other chromosome of their homologous pair. This process of breakage, exchange and reunion of the chromosome segments of homologous chromosomes is called **crossing-over**.

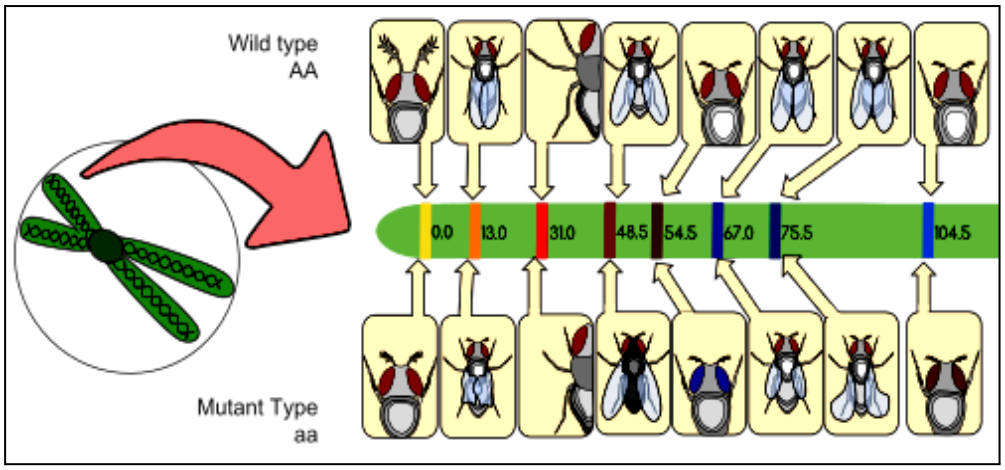
Crossing-over unlinks the linked genes as it involves exchange of genes in the homologous chromosomes.



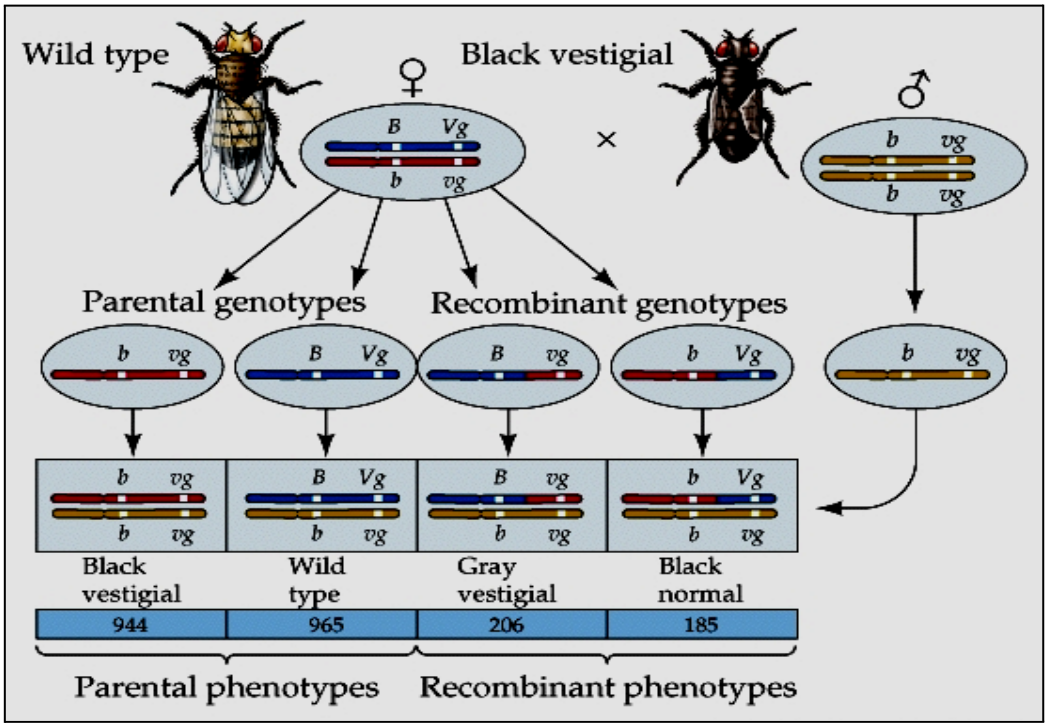
Crossing-over usually results in a partial **recombination**, or creation of combinations of alleles in chromosomes not present in either parent. The further apart the genes are from each other in a chromosome, the greater the likelihood that they will show recombination as a result of crossing-over. Another fact discovered by Morgan and his colleagues was that the likelihood of two genes separating during crossing-over was proportional to the distance between them. In other words, the closer the genes, the more likely they will stay together, and the further they are, the more likely that they will separate.

Recombination frequency, or the crossing over frequency, is the percentage of recombinant gametes produced by the process of crossing over. It always refers to two genes located in the same chromosome. The larger the distance between the loci of two genes on a chromosome, the higher the chances of crossing over and the recombination frequency between these genes. On the contrary, when the genes are closer, they are likely to remain together.

Crossing-over does not produce new alleles. Rather, it only exchanges existing alleles between homologous chromosomes.



Thomas Hunt Morgan's *Drosophila melanogaster* genetic linkage map.



The yellow body colour gene and white eye genes showed recombination of just 1.3% as these genes were tightly linked, while the white and miniature genes showed a recombination of 37.2% as these genes were loosely linked.

At present, genetic maps are a key tool for genome sequencing, discovering the location and identity of genes. Thus, Morgan’s experiments on linkage ruled out the universal nature of Mendel's Law of Independent Assortment.

Summary

When Mendel studied the inheritance of two characters together, it was found that the factors assort independently and combine in all permutations and combinations (Law of Independent Assortment).

Mendel's laws were extended in the form of ‘Chromosomal Theory of Inheritance’. Later, it was found that Mendel’s law of independent assortment does not hold true for the genes that were located on the same chromosomes. These genes were called ‘linked genes’. Closely located genes assort together, and distantly located genes, due to crossing over may show recombination. Frequency of recombination varies according to the distance between the genes on the chromosomes. Hence linkage maps were constructed which correspond to position and distance between genes on a chromosome.