7 INHERITANCE

Students Learning Outcomes

After studying this chapter, students will be able to:

- Sketch the structure of chromosomes.
- Define genotype and phenotype, allele, homozygous, heterozygous, dominant, recessive
- Illustrate Mendelian inheritance laws through monohybrid and dihybrid cross.
- Outline function of DNA as carrier of hereditary information
- Describe briefly the structure of RNA as single stranded macromolecule made of nucleotides with nitrogenous base overhangs.
- Outline the function of RNA as aid in converting hereditary information into useful proteins.
- Outline how information in the DNA is converted to information on RNA and then into proteins.

An organism is made up of many structural and behavioural characteristics. Organisms are able to pass these characteristics to their offspring. Offspring get some characteristics from each parent. The process by which characteristics are transferred from parents to offspring is called **inheritance** or **heredity**.

Every cell in the body contains the instructions for making characteristics. Inside the cells, this information is present in long molecules of Deoxyribonucleic acid (DNA). The cells use the information in their DNA to produce particular proteins. The proteins made by a cell determine its characteristics.

7.1 STRUCTURE OF CHROMOSOME

Chromosome is made up of **chromatin** material. In eukaryotes, chromatin consists of **DNA** and special proteins called **histones**. Chromatin is a thread-like material. In chromatin, a long molecule of DNA is wrapped around the bundles

Recalling:

- All the cells of the organisms of a species have a constant number of chromosomes.
- The body cells are diploid (2n). It means that the chromosomes are in pairs (homologous chromosomes).
- Before cell division, the DNA makes a copy of itself. In this way, chromatids are formed. When the cell divides, each daughter cell receives one chromatid from each chromosome.

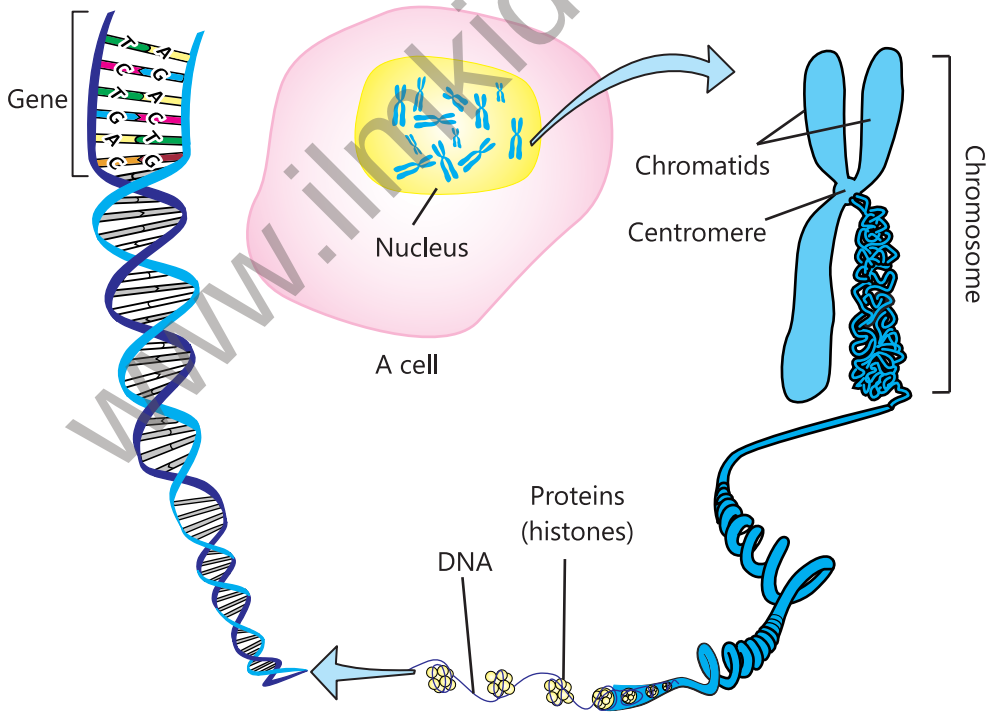


FIGURE 7.1: Chemical composition of chromosome

of **histones**. When a cell is not dividing its chromatin is in the form of fine thread, scattered in the nucleus. During cell division, chromatin coils and makes compact structures of chromosomes.

A **chromosome** is rod-shaped and consists of two identical halves. Each half of chromosome is called a **chromatid.** The two chromatids of a chromosome are attached at a point called **centromere.** The centromere holds the two chromatids together until they separate during cell division.

The prokaryotes have only one chromosome which is made of a circular DNA molecule. It is not bound by a nuclear envelop and is present in cytoplasm.

7.2 DNA AND RNA

DNA (Deoxyribonucleic Acid): DNA is a double-stranded, helical molecule. It is made of nucleotides. Each nucleotide of DNA is made of a deoxyribose sugar, a phosphate group, and a nitrogenous base (adenine, thymine, cytosine, or guanine). The two strands are held together by base pairing (A with T, and C with G).

RNA (Ribonucleic Acid): RNA is single-stranded chain of nucleotides. Its nucleotides have a sugar called ribose, a phosphate group, and nitrogenous bases (adenine, uracil, cytosine, and guanine).

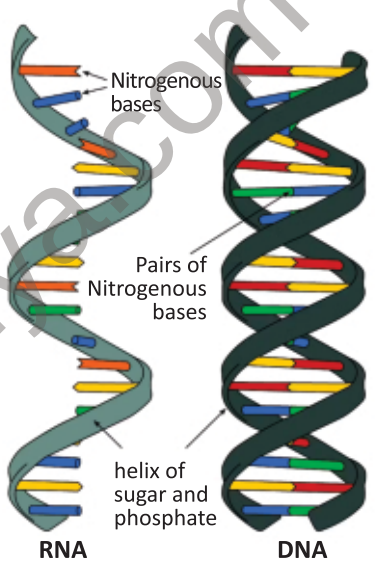


FIGURE 7.2: RNA and DNA

Functioning of DNA and RNA

A gene is a segment of DNA that has the information for making a particular protein. The following processes occur for making a protein according to the information present in a gene:

1. The segment of DNA (gene) acts as a template. A type of RNA, called messenger RNA (mRNA), is synthesised according to this template. In this way, DNA transfers the information to mRNA. This process is called **transcription**. mRNA acts as aid in converting information into proteins.
2. The mRNA moves out into the cytoplasm. Here, ribosome attaches with mRNA. The ribosome joins amino acids according to the information present on mRNA. In this way, a protein is produced. This process is called **translation**.

This concept of the working of a gene is called **central dogma** and is

symbolized as;

DNA ⟶ **mRNA** ⟶ **Protein**

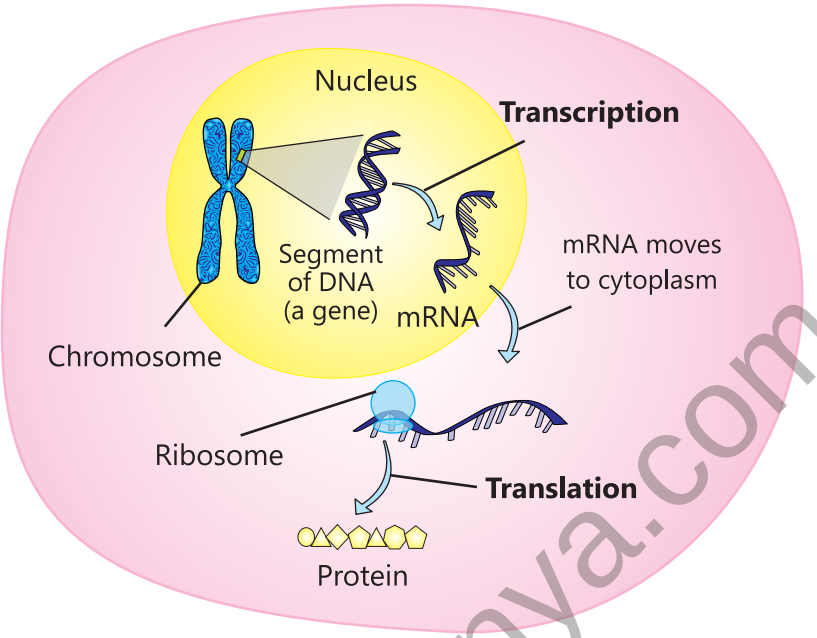


FIGURE 7.3: Working of a gene (central dogma)

Gene and Allele

A **gene** is a segment of DNA that contains the information for a hereditary character. For example, the gene for eye colour, gene for earlobe shape, and gene for the hair texture. Genes are located on chromosomes. The locations or positions of genes on chromosomes are known as **loci** (singular locus). Like chromosomes, genes are also in pairs.

The pair of genes on homologous chromosomes may not contain identical genes. The homologous chromosomes may have different forms of the same gene. These alternate (different) forms of a gene are called its **alleles**. For example, the gene of hair colour can have two alleles. One allele makes hair pigments while the other does not make pigments.

Genotype

The combination of the alleles is called **genotype**. When both alleles are the same, the genotype is **homozygous**. The genotype, in which both alleles are different, is called **heterozygous**. For example, in Fig. 7.4, a cell has genes for eye colour, hair shape and ear shape. All genes are in pairs.

- Both alleles of the eye colour gene are similar. It means that the genotype for eye colour is homozygous. Similarly, both alleles of the hair shape gene are similar. It means that its genotype is also homozygous.

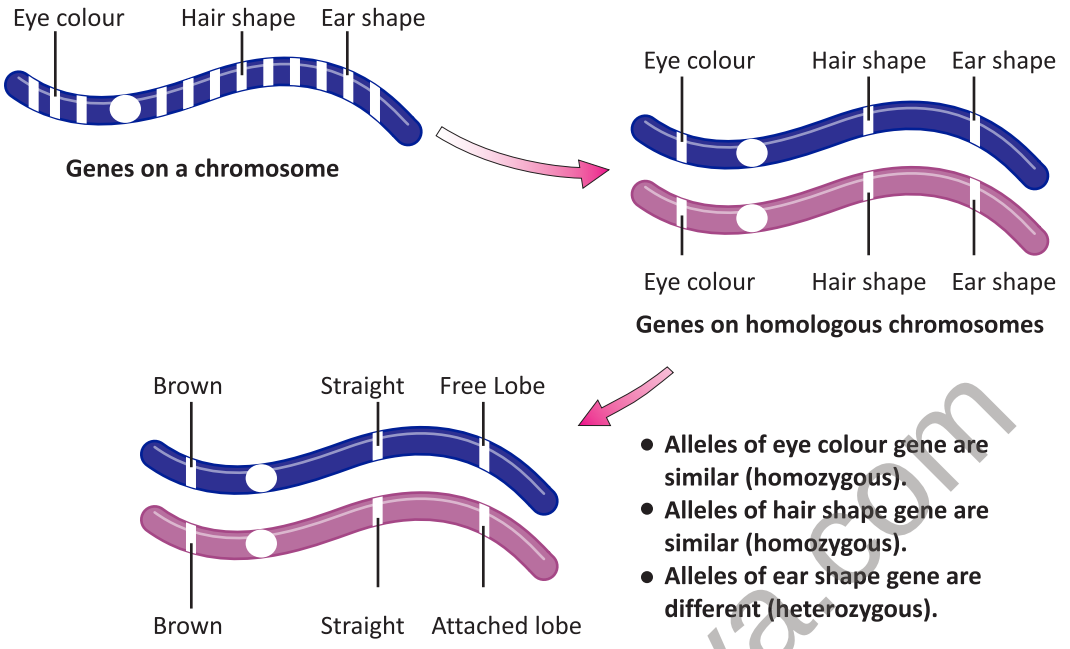


FIGURE 7.4: Alleles and genotypes

- The alleles of the ear shape gene make different characteristics. One allele makes free earlobe while the other allele makes attached earlobe. It means that the genotype for ear shape is heterozygous.

In the heterozygous genotype one allele may mask the working of the other allele. Such an allele is called the **dominant allele**. The allele which is masked (not expressed) is called **recessive allele**. Dominant alleles are expressed by capital letters while the recessive alleles are expressed by lowercase letters. For example, in the pair Tt, the dominant alleles T is responsible for tall plant while the recessive allele t is for dwarf plant. So, if a plant has genotype Tt, it will be a tall plant. The observable outcome of genotype, in the form of characteristic, is called **phenotype**.

7.3 MENDEL'S LAWS OF INHERITANCE

Gregor Mendel was an Austrian monk, working in a monastery. From 1856 to 1863, he performed experiments on garden pea. The results of these experiments cleared the views of heredity.

FIGURE 7.5: Gregor Mendel

Selection of garden pea for experiments

Mendel selected the garden pea for his experiments. His choice was a good one for several

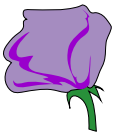
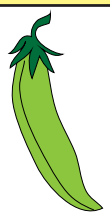
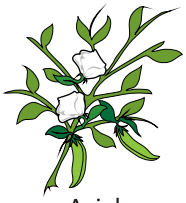
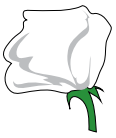
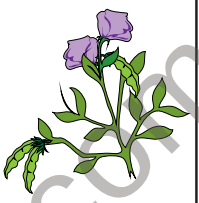
	Flower colour	Seed colour	Seed shape	Pod colour	Pod shape	Flower position	Plant height
Character 1	 Purple	 Yellow	 Round	 Green	 Flat	 Axial	 Tall
Character 2	 White	 Green	 Wrinkled	 Yellow	 Constricted	 Terminal	 Short (dwarf)

FIGURE 7.6: Distinguishing characters in plant, studied by Mendel

reasons.

1. Pea plants have a relatively short generation time.
2. Pea plant has seven easily distinguishable characteristics, such as round versus wrinkled seeds and purple versus white flowers.
3. Normally, self-pollination occurs in pea flowers. But cross-pollination can also be performed. For this purpose, the stamens of a flower are removed and its pollen grains are transferred to the flower of another plant.

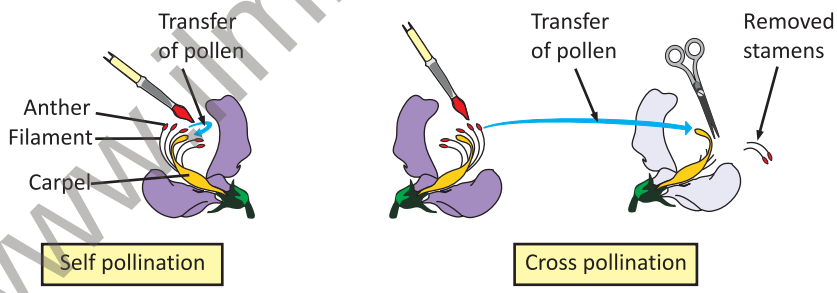


FIGURE 7.7: Self and Cross-pollination in pea plants

Mendel's Experiments

Mendel got the true-breeding plants for each characteristic. If a plant with a characteristic produces offspring with the same characteristic on self-pollination; it means that the plant is **true-breeding** for that characteristic. For example, when a true-breeding tall plant self-pollinates, it will always produce tall plants. After choosing the true-breeding varieties, Mendel performed **monohybrid crosses**. It is a cross in which only one characteristic is studied.

Experiment 1

Mendel crossed a true-breeding tall plant with a true-breeding short plant. He called these true-breeding parents as **P generation.** The offspring of this cross were called the first filial generation, or **F1 generation**. All offspring of F1 were all tall.

During Mendel's time, most people believed that characteristics of both parents are mixed together and are passed to offsprings. For example, if a short plant is crossed with a tall plant, the offsprings will be medium sized.

Next, Mendel allowed the tall plants of F1 generation to self-pollinate. He called the next generation as F2 generation. He found that 75% of F2 offspring were tall, while 25% were short.

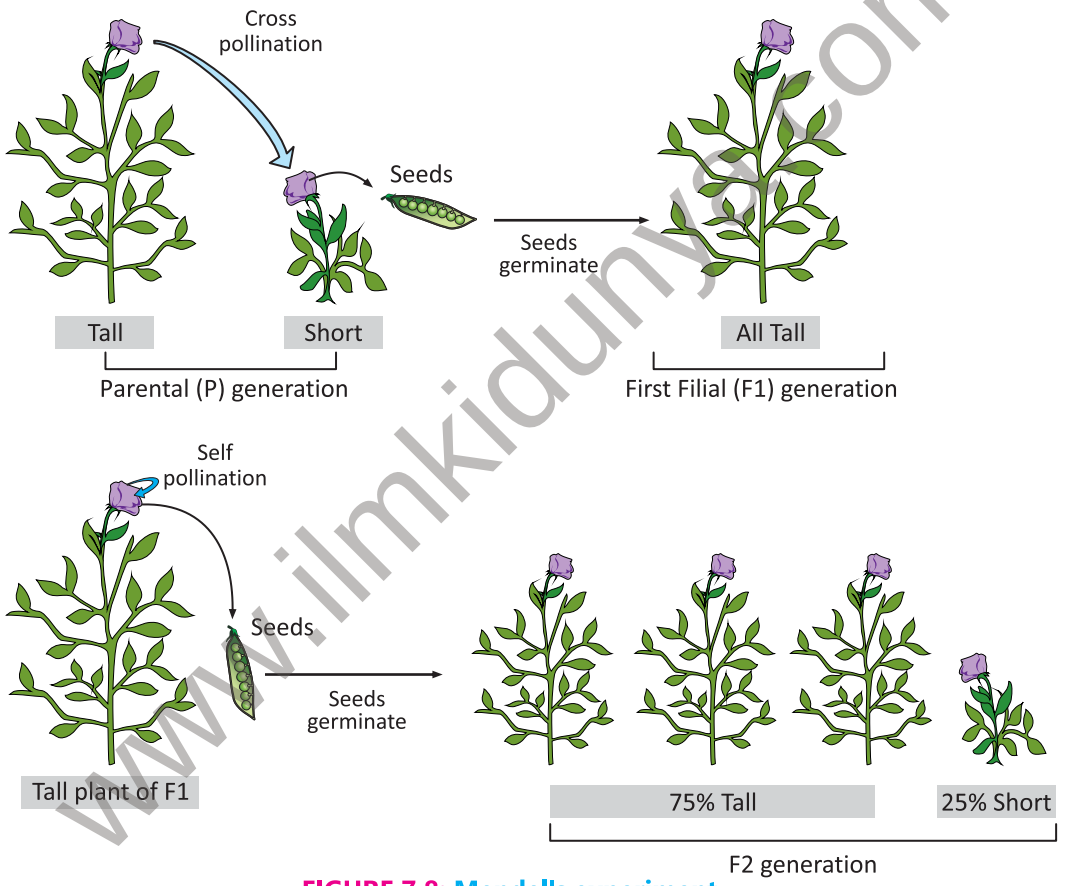


FIGURE 7.8: Mendel's experiment

Mendel found the same results over and over again with all the characteristics.

Conclusions

Concept of Dominance: Mendel explained his results and proposed that there were two forms (alleles) of the gene of plant height. When two different alleles

are together in an organism, one allele may mask the expression of the other. The allele that shows its effect is called dominant, while the one that is hidden is called recessive. This is called as the concept of **dominance**.

Law of Segregation: Mendel explained that each parent has two alleles of a gene. But a parent can only pass one allele to the offspring. During gamete formation, the alleles separate and there is only one allele in each gamete. When fertilization occurs, the offspring has the two alleles again. It is called the **law of segregation**. It states that "the alleles are separated during gamete formation and each gamete receives one or the other allele, but not both".

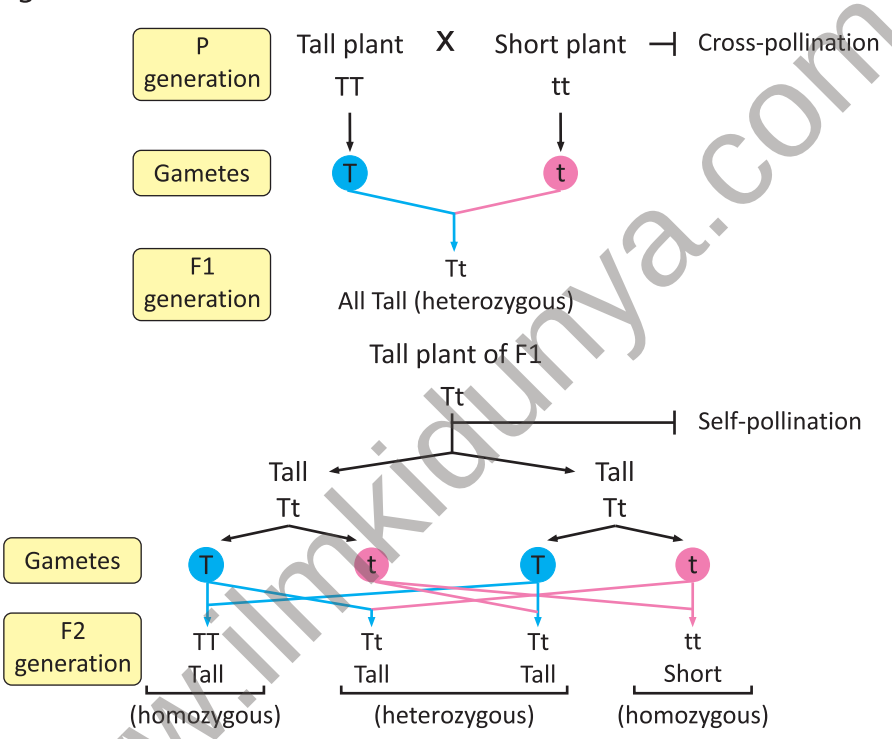


FIGURE 7.9: Segregation of alleles

In pea plant, the allele for tallness is dominant. In parent (P) generation, one parent had alleles TT. Each of its gametes received a single T allele. The second parent had alleles tt. Each of its gametes had a single t allele. When these gametes (T and t) joined, the new plants in F1 plant received the pair as Tt. So, all F1 plants were tall. When self-pollination was allowed in F1 tall plant, the results were:

- 25% of the F2 generation received both alleles of shortness i.e., tt. So, they were short.
- 50% plants of F2 received one T allele and one t. So, they were tall (Tt).
- 25% plants of F2 received both alleles of tallness i.e., TT. So, they were also tall.

Experiment 2

In his next experiments, Mendel did **dihybrid crosses**. In a dihybrid cross, the inheritance of two characteristics was studied at the same time. In such experiments, studied the characteristics of seed shape (round or wrinkled) and seed colour (yellow or green). He first grew true-breeding varieties of pea plants. One plant had round yellow seeds and the other had wrinkled green seeds.

Mendel crossed these true-breeding plants. All F1 plants produced round

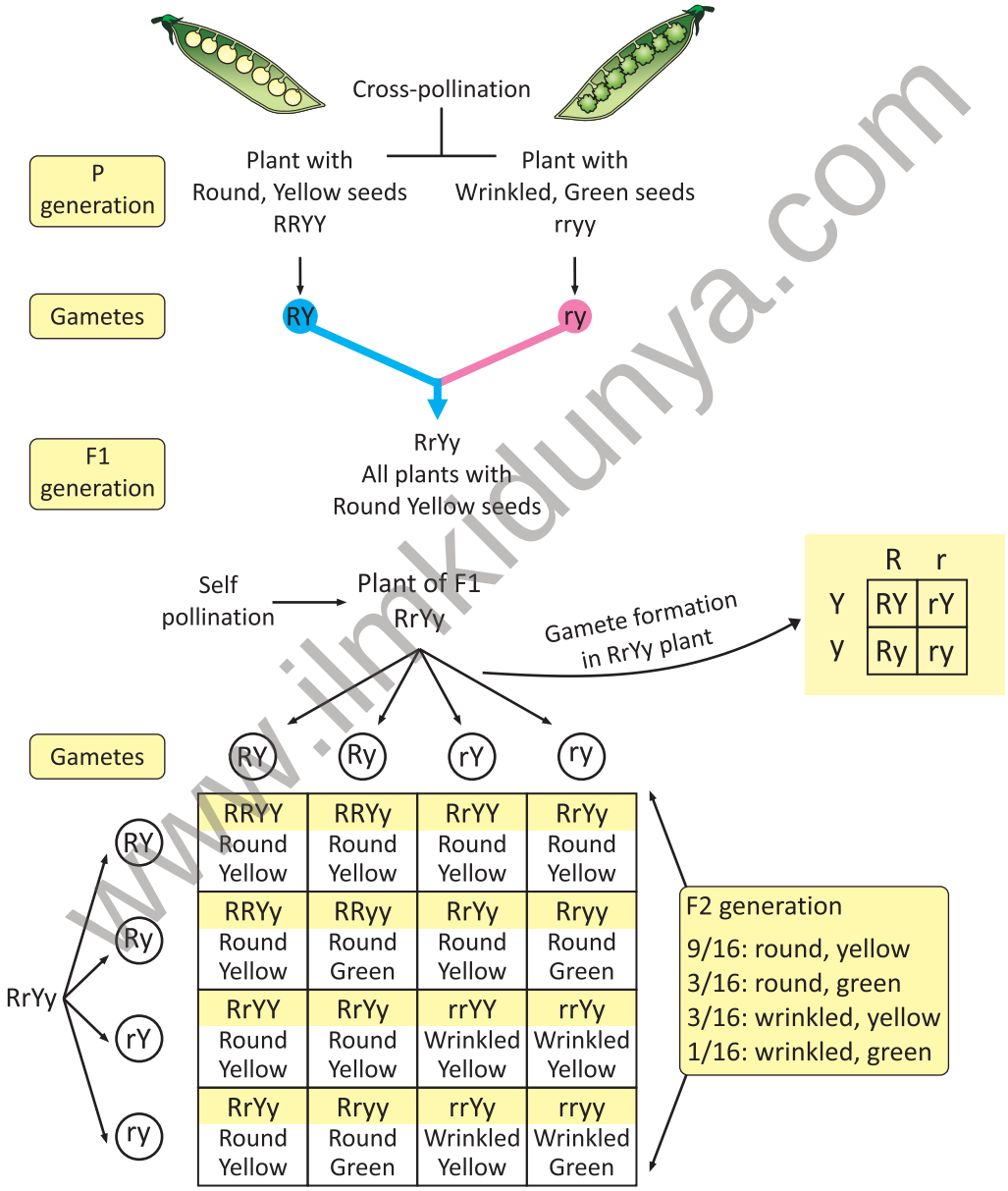


FIGURE 7.10: Independent assortment of alleles

yellow seeds. It proved that the allele for round seeds (R) is dominant over the allele for wrinkled seeds (r). Similarly, the allele for yellow seeds (Y) is dominant over the allele for green seeds (y). All the F1 plants were heterozygous for both seed shape and seed colour (genotype: RrYy).

He allowed self-pollination in the F1 plants and got the F2 generation. The F2 generation had the following four phenotypes:

- 9/16 that have round, yellow seeds (genotypes: RRYY, RRYy, RrYY, and RrYy)
- 3/16 that have round, green seeds (genotypes: RRyy and Rryy)
- 3/16 that have wrinkled, yellow seeds (genotypes: rrYY and rrYy)
- 1/16 that have wrinkled, green seeds (genotype: rryy)

Conclusions:

Law of Independent Assortment

The F1 plants (RrYy), produced four types of gametes i.e., RY, Ry, rY, and ry. When these plants were allowed to self-pollinate, there were 16 combinations of alleles in F2 generation. It means that alleles R and r segregated independently of the alleles Y and y. Mendel's discovery is referred to as the **law of independent assortment**. It states that "alleles separate independently of one another during the formation of gametes".

EXERCISE

A. Select the correct answers for the following questions.

1. Chromosomes of eukaryotes are made of;
   a) Lipids and proteins
   b) Lipids and DNA
   c) RNA and proteins
   d) DNA and proteins
2. What is the relationship between a gene and an allele?
   a) Alleles are alternative forms of a gene
   b) Genes are alternative forms of an allele
   c) Genes mask the effects of genes
   d) Alleles and genes are unrelated
3. Which molecule is formed during transcription?
   a) DNA b) Protein c) mRNA d) Ribosome

4. The central dogma of molecular biology is best represented by;

a) DNA + RNA = Protein
b) DNA -----> RNA + Protein
c) DNA -----> RNA -----> Protein
d) Protein -----> RNA -----> DNA

5. What happens during transcription?

a) A new polypeptide is created
b) RNA is scanned by a ribosome.
c) A new copy of DNA is produced
d) A copy of RNA is made

6. What is the role of DNA in protein synthesis?

a) Produces amino acids
b) Provides the template for mRNA formation
c) Transports proteins
d) Stores proteins

7. The allele that is expressed, when two separate alleles are inherited;

a) Dominant
b) Recessive
c) Homozygous
d) Heterozygous

8. Which of these is a reason why pea plants were suitable for Mendel's experiments?

a) Long life cycle
b) Easy to cross-pollinate
c) Few seeds produced per plant
d) No variation in traits

9. What does Mendel's Law of Segregation state?

a) Genes are linked together
b) Each allele separates during gamete formation
c) Dominant traits appear in all generations
d) Alleles blend together

10. In peas, allele for purple flower (P) is dominant over the allele for white flower (p). If a white flower is crossed with a heterozygous purple flower (Pp), what will be the ratio of offspring?

a) 100% purple
b) 75% purple & 25% white
c) 50% purple & 50% white
d) 100% white

B. Write short answers.

1. Write down the combination of alleles in the gametes of a plant, which has genotype Rryy.
2. State Mendel's law of segregation.
3. State Mendel's law of independent assortment.
4. Define monohybrid cross and a dihybrid cross and give an example of

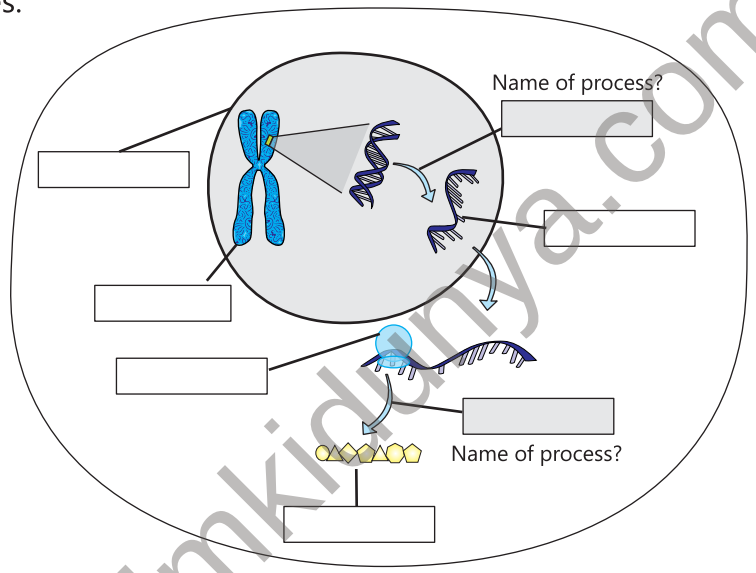
each.

5. Draw a cross between two pea plants. One of them has round green seeds (RRyy) while the other has wrinkled yellow seeds (rrYY).

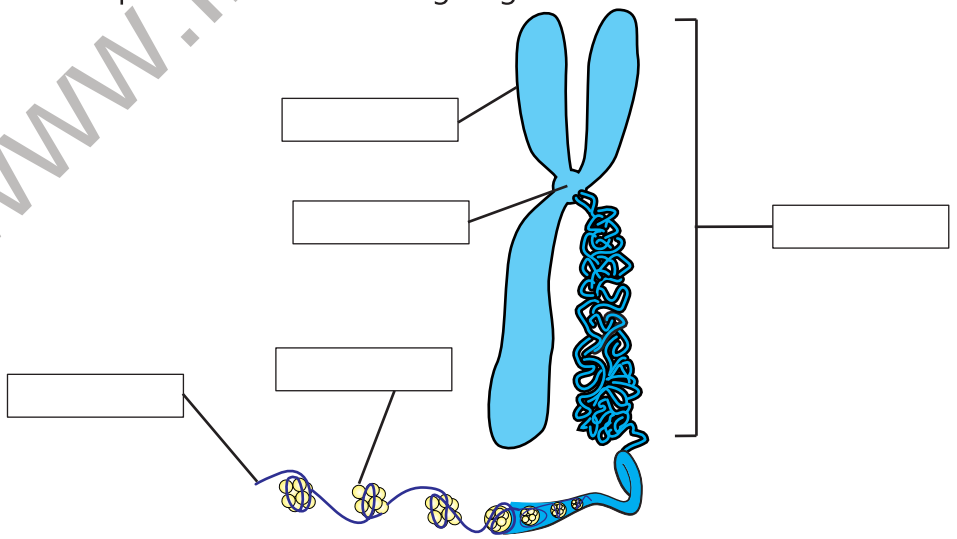
6. Differentiate between:

- Gene and allele
- Dominant and recessive
- Genotype and phenotype
- F1 and F2 generations
- Homozygous and heterozygous

7. In the following diagram of a cell, label the components and the processes.



8. Label the components in the following diagram.



C. Write answers in detail.

1. Write a note on the structure and composition of chromosome.
2. Why did Mendel choose pea plants for his genetic experiments?
3. Describe Mendel's experiment on two-character inheritance and state the law he proposed.
4. Describe Mendel's Law of Segregation? Give an example.
5. Describe how DNA and RNA take part in the synthesis of a protein.

D. Inquisitive questions

1. How do genes control the traits and characteristics of an organism?
2. Why can different alleles of the same gene lead to different physical traits?