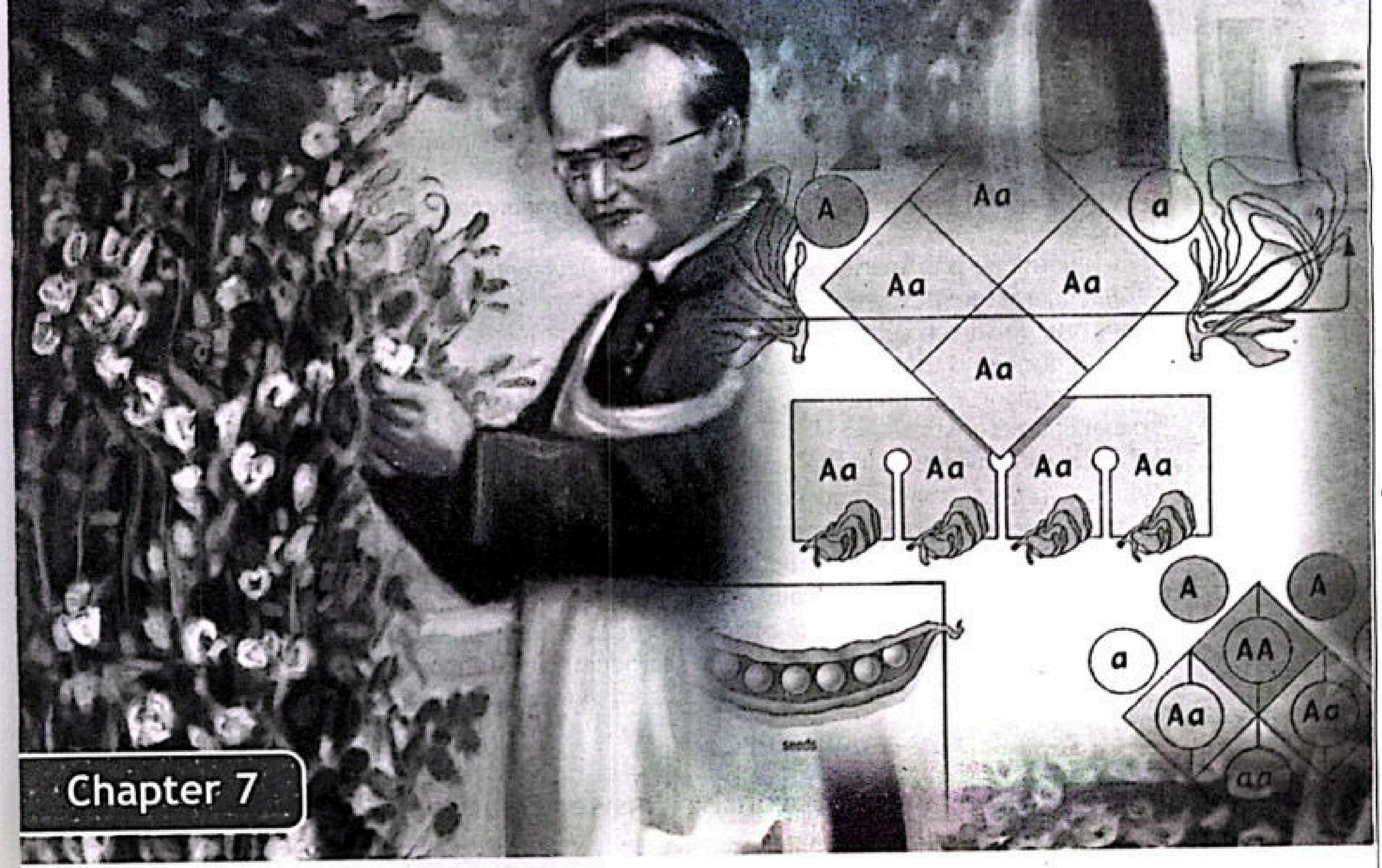


INHERITANCE

SLOs: After completing this lesson, the student will be able to:

1. [B-10-H-05] Sketch the structure of chromosomes.
2. [B-10-H-06] Define genotype and phenotype, allele homozygous, heterozygous, dominant, recessive
3. [B-10-H-07] Illustrate Mendelian inheritance laws through monohybrid and dihybrid cross.

Inheritance is the process by which traits are passed from parents to offspring. These traits may base on the similarities between parent and their offspring (**heredity**) or difference between them (**variation**). The study of heredity and variation is called **genetics**. Gregor Mendel's pioneering work with pea plants established key principles of inheritance, now known as **Mendelian genetics.** He identified that traits are controlled by genes, which can be dominant or recessive, and are inherited in predictable patterns. This chapter will explore how traits are passed through generations, the role of chromosomes, and Mendel's laws of inheritance, providing insight into the genetic mechanisms that drive biological diversity.

7.1 STRUCTURE OF CHROMOSOME

Chromosomes are thread-like structures found in the nucleus of cells, made up of DNA (Deoxyribonucleic Acid) and proteins. During interphase, the chromosomes are present in the form of a thin fibrous network called **chromatin.** The DNA in chromosomes carries the genetic information necessary for the development, functioning, and reproduction of organisms.

7.1.1 Parts of a chromosomes

A chromosome consists of three main parts: chromatids, centromere and telomeres.

i) Chromatid: A single chromosome, before S-phase (DNA replication), consists of one thread-like structure called chromatid. After S-phase, a chromosome consists of two identical chromatids called sister chromatids that are attached together at centromere. These chromatids are the duplicated copies of the chromosome.

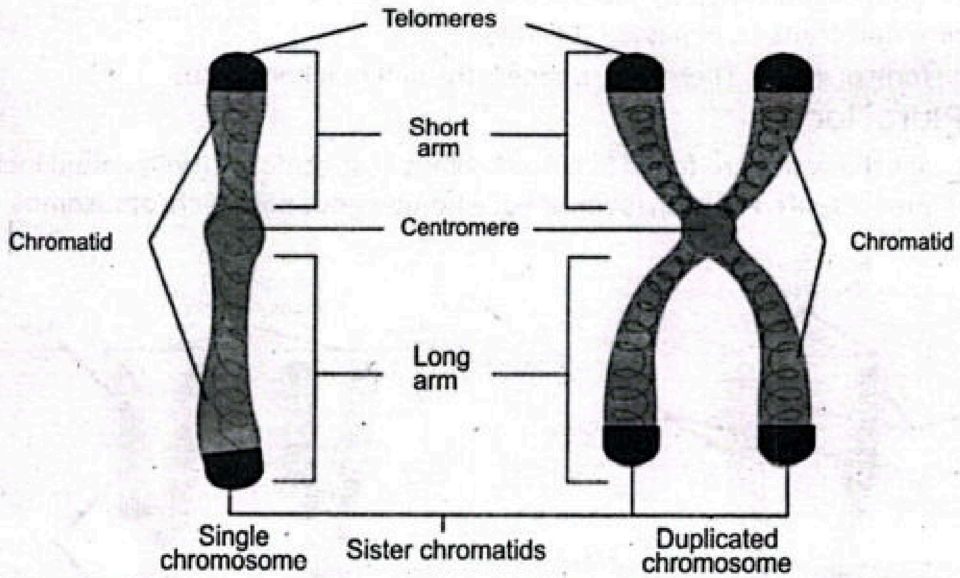


Fig. 7.1: Parts of a chromosome

ii) Centromere: The centromere is the constricted region of a chromosome where the two chromatids are attached. The kinetochore is a protein complex in the centromere which serves as the attachment site for spindle fibers (microtubules) during mitosis and meiosis. The centromeres ensure that chromosomes are evenly distributed between the daughter cells.

iii) Telomeres: These are repetitive nucleotide sequences at the ends of chromosomes, protecting them from degradation and preventing the loss of important genetic information during cell division.

7.2 GENOTYPES AND PHENOTYPES

A discussion of Mendelian genetics usually requires an understanding of some basic genetic terms, such as gene, allele, genotype (homozygous or heterozygous), phenotype (dominant or recessive), genome, and gene pool. These terms help explain how traits are inherited and expressed in living organisms.

7.2.1 Genes, Alleles and Loci

i) Genes

Each characteristic and function of the body is controlled by factor called gene. The parental traits are passed to their offspring in the form of genes. Therefore, a gene is the unit of inheritance. Basically, **a gene is a specific segment of DNA, comprising a unique sequence of nucleotides that encodes the sequence of amino acid in a particular polypeptide.** Mendel was the first person who proposed the idea of gene, he called them "factors" or "elementens" and used to represent the genes of different characteristics with alphabetical symbols. Each characteristic and function of the body is controlled by factor called gene. The parental traits are passed to their offspring in the form of genes. Therefore, a gene is the unit of inheritance.

> **For your information**
>
> The complete set of an individual's genes is called the **genome.** The number of chromosomes that carry the entire genome is referred to as a **set of chromosomes**, represented by "n" or **monoploid.** A cell with two sets of chromosomes is called **diploid** or 2n. In humans, the full genome is spread across 23 chromosomes, which make up one set. The term haploid is used to represent a cell that contains half than the number of chromosomes of somatic cells (body cells other than gametes).

ii) Locus (Plural loci)

Now we know that the genes are found in chromosomes at specific positions called loci (**singular locus**). A locus is represented on both members of a **homologous pair of chromosomes**

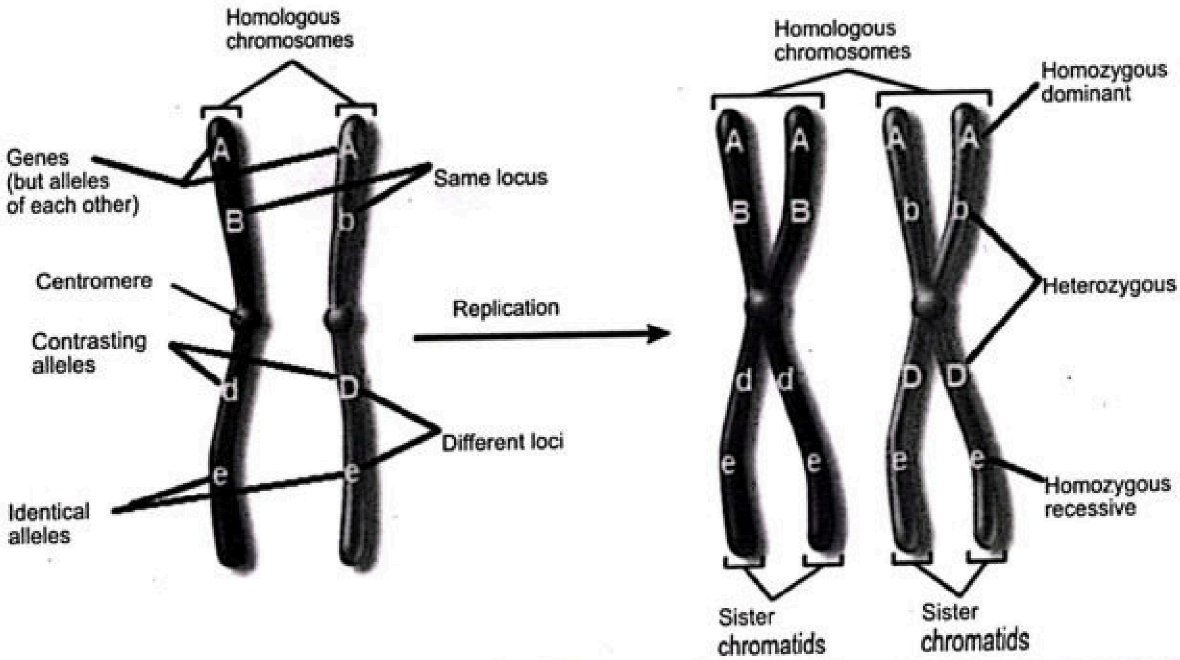


Fig. 7.2: Arrangement of genes in homologous chromosomes

iii) Allele

At each locus on a chromosome, a gene can exist in two or more forms. These different forms or variations of a gene are called **alleles.** Alleles are versions of the same gene that occupy the same position on a chromosome. For example, in humans, earlobes can either be free or attached. The gene for free earlobes is represented by "E" and the gene for attached earlobes is "e". Both "E" and "e" are located at the same locus and are alleles of each other. Although "E" and "e" are different alleles, they are both considered genes as well.

7.2.2 Genotype and Phenotypes

i) Genotype

The genetic makeup of a trait at each locus is called the **genotype.** A genotype usually consists of a pair of genes or alleles. For example, the genotype for free earlobes can be represented as "**EE**" or "**Ee**," while the genotype for attached earlobes is "**ee**." If the genotype has two identical alleles (like "**EE**" or "**ee**"), it is called **homozygous.** If it has two different alleles (like "**Ee**"), it is called **heterozygous.** An individual with a homozygous genotype is considered a "**true breed,**" as it always produces offspring with the same trait when self-fertilized. In contrast, a heterozygous individual is "**non-true breed**" because it can produce offspring with either form of the trait when self-fertilized. For example, a true bree round seeded pea plant (RR) always produces round seeded offspring upon self-fertilization. Similarly, a non-true breed round seeded plant (Rr) can produce both round seeded and wrinkled seeded plants upon self-fertilization.

> **For your information**
>
> Self-fertilization is a type of reproduction where an organism's own sperm fertilizes its own eggs. This process commonly occurs in plants and some hermaphroditic animals. In self-fertilization, the offspring usually inherit genes from a single parent, leading to less genetic variation compared to cross-fertilization.

ii) Phenotype

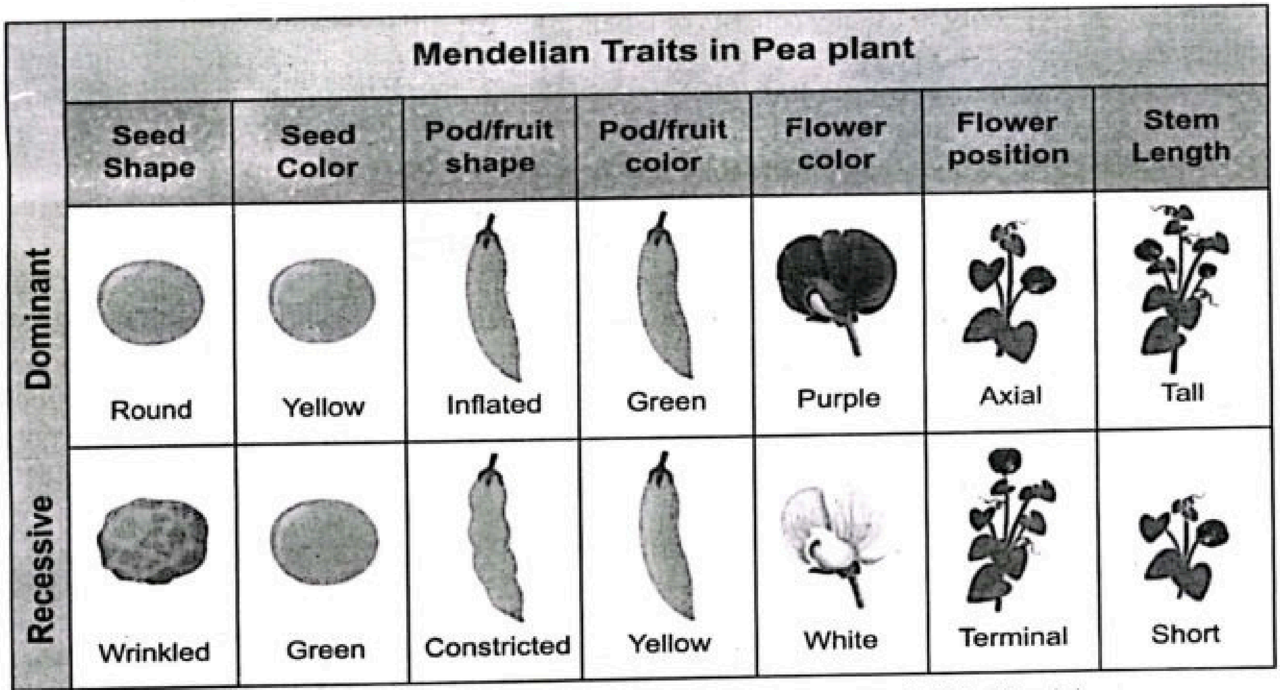
The physical appearance of a trait is called the phenotype, which is determined by the genotype. For example, when **"EE"** or **"Ee"** genotypes are expressed, they produce free ear lobes and when **"ee"** is expressed, it produces attached earlobe. A phenotype that is visible even in the heterozygous state is called a **dominant phenotype,** while a phenotype that only appears in the homozygous state is called a **recessive phenotype.** The gene for a dominant phenotype is usually represented by a **capital letter,** while the gene for a recessive phenotype is represented by a **lowercase letter.**

> **For your information**
>
> A **gene pool** is the complete set of all the genes and their different alleles on specific locus present in all the individuals of a population. For example. Total number of earlobe genes or alleles ("E" and "e") in a population of 500 individuals, is the gene pool of earlobe. **Gene frequency,** also known as **allele frequency,** refers to how often a particular allele appears in the gene pool. For example, total number of free earlobe genes (E) in the population is the **dominant gene frequency** and total number of attached earlobe genes (e) in the population is the **recessive gene frequency.** These frequencies reflect the genetic diversity of a population and can change over time due to factors like natural selection or mutation.

7.3 MENDELIAN INHERITANCE

The field of genetics began in 1900 with the rediscovery of a paper published in 1866 by **Gregor Johann Mendel**, an Augustinian monk. Mendel was the first person who successfully explained *mode of inheritance of traits* from one generation to the next through his experiments on pea plants. The mode of inheritance according to the principle proposed by Mendel is kanown as **Mendelian inheritance.** Mendel's work laid the foundation for the science of inheritance, which is why he has been titled as the **"Father of Genetics"**.

First, he developed **true-breeding plants**, which consistently produced offspring with the same traits after self-fertilization. This was achieved by repeated self-fertilization over successive generations. Mendel worked with seven pairs of contrasting traits, creating true-breeding plants for each.



Mendelian Traits in Pea plant	Seed Shape	Seed Color	Pod/fruit shape	Pod/fruit color	Flower color	Flower position	Stem Length
Dominant	Round	Yellow	Inflated	Green	Purple	Axial	Tall
Recessive	Wrinkled	Green	Constricted	Yellow	White	Terminal	Short

Fig. 7.3: Seven pairs of contrasting traits of pea plant studied by Mendel

Mendel then carried out **hybridization,** where he cross-fertilized plants with different traits. For example, he crossed a round-seed plant with a wrinkled-seed plant to study a single trait (monohybrid cross) and a round, yellow-seed plant with a wrinkled, green-seed plant to study two traits (dihybrid cross).

A **monohybrid cross** involves parents differing in one trait, while a **dihybrid cross** involves parents differing in two traits. Mendel ensured specific matings of different pea plants by removing the stamen of one plant and transferring pollen using a paintbrush.

By analyzing the inheritance of one, two, or three traits at a time, Mendel formulated what are now known as **Mendel's laws of inheritance.**

7.3.1 Inheritance of Single Trait by Monohybrid Cross

Mendel's study of inheritance for a single trait, known as a monohybrid cross, involved crossing two plants that differed in one trait, such as seed shape.

Mendel's Procedure and observations

He crossed a true-breeding round-seed plant with a true-breeding wrinkled-seed plant. In the first filial generation (F_1), all offspring displayed the round seed trait (he designated this phenotype as dominant while other as recessive). However, when these F_1 plants self-fertilized, their offspring (F_2) exhibited both round and wrinkled seeds in a 3:1 ratio. Further investigation revealed that 25% F_2 generation were true breed round, 50% were non-true breed round and 25% were true breed wrinkled. So the genotypic ratio in F_2 generation was 1:2:1. Similar results were obtained when he studied other pairs of contrasting traits.

Conclusion/Interpretation of the results

Mendel concluded that:

(i) The traits are controlled by factors or elementens (now called genes) passed from parents to offspring through gametes.

(ii) Each plant carries two factors (alleles) for each trait—one from each parent.

(iii) Dominant alleles, like "R" for round seeds, are expressed, while recessive alleles, like "r" for wrinkled seeds, are not expressed in F_1 but reappear in F_2 generation.

(iv) During gamete formation both alleles of a gene pair segregate from each other and pass into different gamete.

(v) The gene pair is restored when gametes are fertilized to make the next generation.

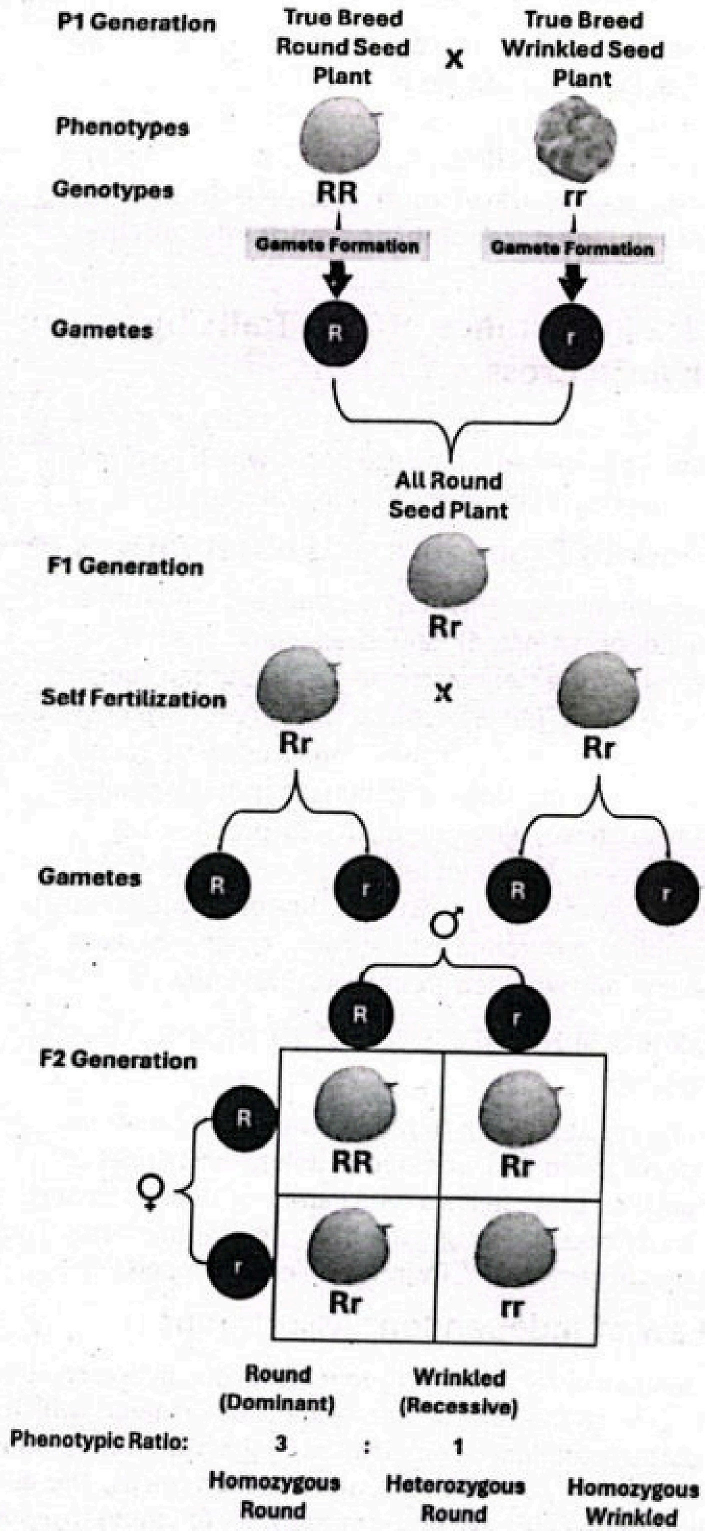


Fig. 7.4: Outcome of F1 and F2 Generation in Monohybrid cross

Law of segregation

Mendel's analysis in monohybrid cross while studying the inheritance of single trait led to the formulation of the law of segregation which states that co-existing alleles (occupy the same locus) segregate (separate) during gamete formation (Meiosis) and recombine randomly during fertilization.

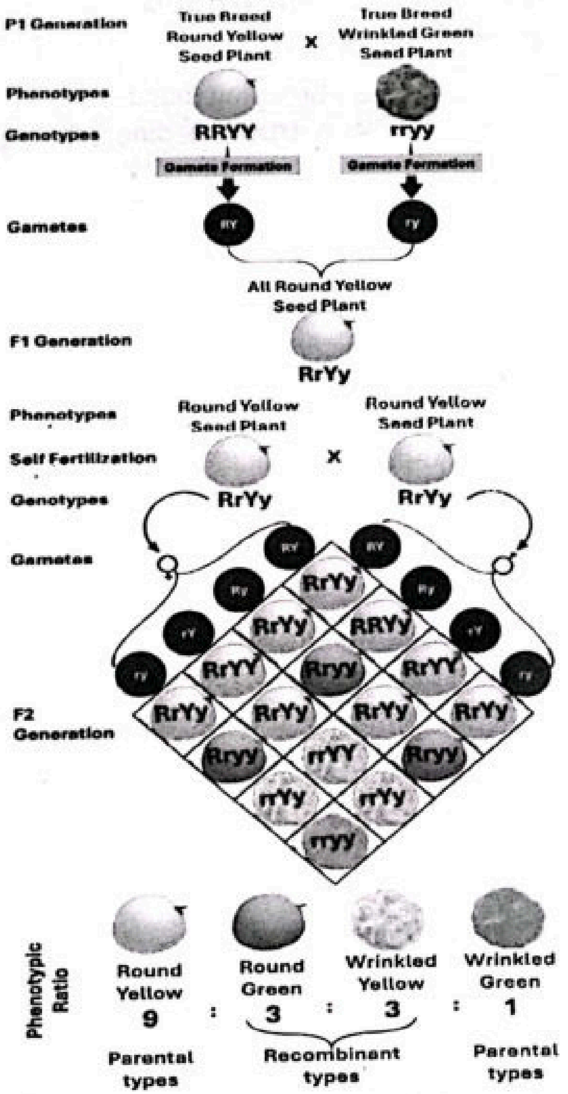


Fig. 7.5: Outcome of F1 and F2 Generation in Dihybrid cross

7.3.2 Inheritance of Two Traits by Dihybrid Cross

In studying the inheritance of two traits at once, Mendel performed a dihybrid cross, which involves crossing individuals that differ in two traits.

Mendel's Procedure and observations

In one of his experiments, he examined seed shape (round or wrinkled) and seed color (yellow or green). When Mendel crossed a true breed round yellow plant (RRYY) with a true breed wrinkled green plant (rryy), all the F_1 offspring were round and yellow, showing the dominant traits. When he self-fertilized these F1 plants to produce the F_2 generation, he expected a 3:1 ratio like in his monohybrid cross. Instead, he observed four combinations: round yellow, round green, wrinkled yellow, and wrinkled green in a 9:3:3:1 ratio.

Conclusion/Interpretation of the results

This result, which included new combinations (round green and wrinkled yellow), led Mendel to conclude that alleles of one gene pair (R and r) assort independently to the alleles of other gene pair (Y and y) during gamete formation (meiosis). Therefore, the F1 individuals produced four kinds of gamete (RY, Ry, rY, ry) in equal proportions.

Law of Independent Assortment

Mendel's observation in F_2 generation of dihybrid cross became known as the law of independent assortment, which states that the alleles for one trait are inherited independently of the alleles for another trait. In other words, the alleles of one gene pair have equal probability (chance) to assort with the alleles of other gene pair during gamete formation (meiosis). However, in case of linked genes (whose loci are present on the same chromosome), the independent assortment of alleles is conditional to the occurrence of crossing over between those two kinked genes during meiosis.

Do you know?

Mendel performed test crosses to confirm the genotype of his F_1 plants and to validate his ideas about how traits are inherited. This helped him conclude whether the traits were homozygous or heterozygous, thus supporting his laws of segregation and independent assortment.

STEAM ACTIVITY 7.1 EXPLORING MENDEL'S LAWS THROUGH A GENETIC SIMULATION

Objective

To understand and apply Mendel's **Law of Segregation** and **Law of Independent Assortment** using a hands-on simulation with colored beads.

Materials Needed

- Two sets of colored beads (e.g., red and blue for one gene, yellow and green for another gene)
- Two small bowls or cups labeled Parent 1 and Parent 2
- A dice or coin (optional for independent assortment simulation)
- A data sheet for recording results
- Ziploc bags for storing beads
- Chart paper and markers (for visualizing results)
- Calculator (optional, for calculating probabilities)

Procedure

PART 1: LAW OF SEGREGATION

1. Setup

Assign colors to represent alleles for a single trait (e.g., **R = Red, r = Blue**). Alternatively, you can use circular plastic or cardboard discs and write gene symbols on them. Each parent (bowl) contains two alleles for the trait (e.g., Rr = one red bead and one blue bead or two cardboard discs labelled with gene symbols).

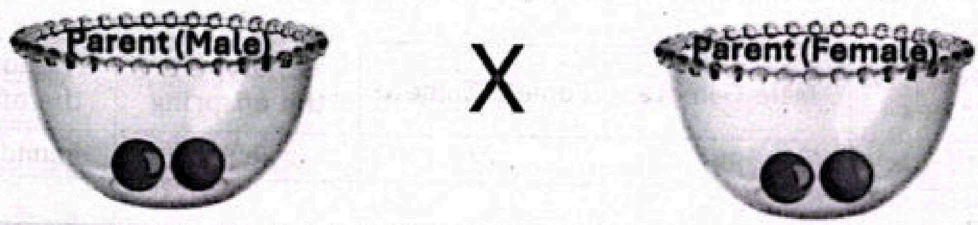


Fig. 7.6: Monohybrid cross (Inheritance of seed shape)

2. Simulation

Students randomly draw one bead from each parent to simulate gamete formation. Combine the beads from both parents to form an offspring genotype (e.g., RR, Rr, or rr).

3. Repeat/ replication

Perform the draw 50 times to simulate multiple offspring. Record the genotypes and phenotypes on a data sheet (sample is given below).

Repeats / Replicates	Male Gamete	Female Gamete	Genotype of the offspring	Phenotype of the offspring
1	R	r	Rr	Round
2				
3				
And so, on up to 50				

4. Analysis
Tally the frequency of each genotype and phenotype. Compare the results to the expected 1:2:1 genotypic ratio and 3:1 phenotypic ratio.

PART 2: LAW OF INDEPENDENT ASSORTMENT

1. Setup
Add another trait to the simulation. Assign yellow and green beads to represent another gene (**Y = Yellow, y = Green**). Alternatively, you can use circular plastic or cardboard discs and write gene symbols on them. Each parent now contains four beads (e.g., RrYy = one red, one blue, one yellow, one green or four plastic or four cardboard discs labelled with gene symbols).

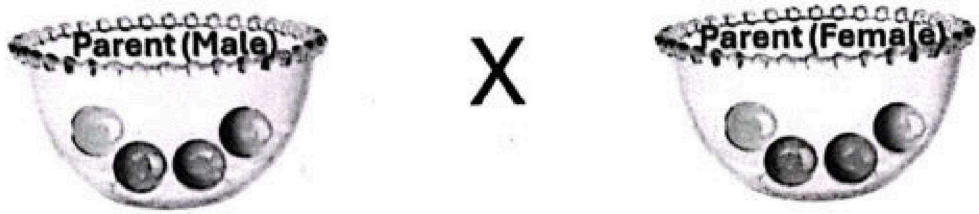


Fig. 7.7: Dihybrid cross (Inheritance of seed shape and seed color)

2. Simulation
Students randomly draw one bead for each gene (one for R/r and one for Y/y) from each parent. Combine the beads to determine the offspring's genotype (e.g., RrYy, rrYy, etc.).

3. Repeat/ Replicates
Conduct 50 trials and record the offspring genotypes and phenotypes in datasheet (sample is given below).

Repeats / Replicates	Male Gamete	Female Gamete	Genotype of the offspring	Phenotype of the offspring
1	RY	ry	RrYy	Round Yellow
2				
3				
And so, on up to 50				

4. Analysis
Tally the frequency of each genotype (e.g., RrYy, RRyy, etc.). Verify the 9:3:3:1 phenotypic ratio for dihybrid crosses.

Integration of STEAM
- Science involves understanding of Mendel's principles of heredity and exploring genetic variation and probability.
- Technology involves the use of spreadsheet software (e.g., Excel) to tabulate and analysis of data.
- Engineering involves the designing an efficient way to simulate large sample sizes using beads and tools.
- Art involves the creation of visual Punnett squares and frequency graphs to illustrate results.
- Mathematics involves the calculation of observed ratios and comparing them with theoretical ratios. It also involves the use of percentages and probabilities for analysis.

Follow-Up Discussion Questions

1. How do your results compare to the expected ratios? Were there any deviations? Why might that occur?
2. How does the random drawing of beads mimic Mendel's experiments with pea plants?
3. Why is it important to have a large sample size in genetic studies?
4. How can the laws of segregation and independent assortment explain genetic variation in offspring?

SUMMARY

1. Inheritance is the process through which traits are passed from parents to offspring, involving heredity (similarities) and variation (differences). The study of inheritance, or genetics, was pioneered by Gregor Mendel, whose experiments with pea plants laid the foundation for modern genetics. Mendel discovered that traits are controlled by genes, which can be dominant or recessive, and are inherited in predictable patterns across generations.
2. Chromosomes are thread-like structures in the cell nucleus made of DNA and proteins. They contain genetic information essential for development and reproduction. Each chromosome consists of chromatids, a centromere (the point where chromatids are joined), and telomeres (protective ends). DNA is coiled around histone proteins to form chromatin, which condenses during cell division to create chromosomes.
3. Chromosomes carry genes that direct the production of proteins, which determine traits and carry out essential cellular functions. The DNA in chromosomes is transcribed into mRNA, which is then translated into proteins. These proteins serve various functions, such as acting as enzymes, hormones, or structural components of the body.
4. A genotype refers to the genetic makeup of an organism, including the alleles inherited from both parents. Alleles are variations of a gene located at specific positions (loci) on chromosomes. A phenotype is the physical expression of a trait, determined by the genotype. Dominant traits are expressed even if only one dominant allele is present, while recessive traits require two recessive alleles to be expressed.
5. Mendel's experiments revealed that traits are passed from one generation to the next through predictable patterns. His Law of Segregation states that alleles for a trait separate during gamete formation, ensuring offspring inherit one allele from each parent. His Law of Independent Assortment states that alleles for different traits are inherited independently of one another, explaining genetic variation in offspring.
6. Mendel used test crosses to determine the genotype of individuals expressing dominant traits by crossing them with recessive individuals. This allowed him to distinguish between homozygous and heterozygous individuals. His experiments confirmed his laws of segregation and independent assortment.

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

1. Which of the following terms refers to the similarities between parents and their offspring?

   A) Variation B) Evolution C) Heredity D) Mutation

2. Which part of the chromosome is responsible for protecting it from degradation?
   A) Centromere B) Telomere C) Chromatid D) Histone
3. What does each nucleosome consist of?
   A) RNA molecules B) DNA wrapped around eight histone proteins
   C) Chromatids and centromeres D) Telomeres and kinetochores
4. What is the function of chromosomes in protein synthesis?
   A) They produce energy for cells
   B) They protect the cell from external damage
   C) They carry genes that encode proteins
   D) They replicate during cell division
5. Which of the following best defines a gene?
   A) A segment of RNA that produces proteins
   B) A sequence of amino acids
   C) A unit of inheritance found in DNA
   D) A type of chromosome
6. Alleles are:
   A) Different forms of a gene located at the same locus
   B) Different species of organisms
   C) Mutated chromosomes
   D) Copies of RNA molecules
7. What is a genotype?
   A) The visible traits of an organism
   B) The genetic makeup of an organism
   C) The protein synthesis process in an organism
   D) The evolutionary history of a species
8. In Mendelian genetics, a dominant allele:
   A) Is always expressed when present
   B) Is never expressed
   C) Is only expressed in the presence of a recessive allele
   D) Is the same as a recessive allele
9. Mendel's conclusion that each parent contributes one factor (allele) for each trait is known as:
   A) Law of Mutation B) Law of Independent Assortment
   C) Law of Segregation D) Law of Evolution
10. In a dihybrid cross, what was the phenotypic ratio Mendel observed in the F2 generation?
    A) 3:1 B) 9:3:3:1 C) 1:1 D) 2:1
11. Mendel's Law of Independent Assortment states that:
    A) Alleles of different genes are inherited independently
    B) Genes do not change over time
    C) Dominant alleles are inherited together
    D) All traits are linked to one another

12. In a test cross, if all offspring display the dominant trait, the parent with the dominant phenotype is:
    A) Heterozygous
    B) Homozygous
    C) Mutated
    D) Recessive
13. What is the purpose of a test cross?
    A) To determine the phenotype of an individual
    B) To determine the genotype of an individual showing a dominant trait
    C) To identify new mutations
    D) To observe the effects of environmental factors on inheritance
14. Which of the following is true of a homozygous genotype?
    A) It contains two different alleles
    B) It contains two identical alleles
    C) It contains no alleles
    D) It contains only one allele
15. What ratio did Mendel observe in the F2 generation of a monohybrid cross?
    A) 1:1
    B) 2:1
    C) 3:1
    D) 9:3:3:1

Section II: Short Answer Questions

1. Why do chromosomes need to compact into thick chromatids during cell division?
2. How does the structure of telomeres help protect genetic information during cell division?
3. How do Mendel's experiments with pea plants support the idea of dominant and recessive traits?
4. Why did Mendel use true-breeding plants in his experiments?
5. How can two parents with free earlobes have a child with attached earlobes?
6. How does the law of segregation ensure genetic diversity in offspring?
7. Why did Mendel's dihybrid cross results differ from his monohybrid cross results?
8. In pea plants, the allele for round seeds (R) is dominant over the allele for wrinkled seeds (r). If a heterozygous round-seed plant (Rr) is crossed with a homozygous wrinkled-seed plant (rr), what will be the genotypic and phenotypic ratios of their offspring?
9. If a true-breeding tall pea plant (TT) is crossed with a short pea plant (tt), what will be the genotype and phenotype of the F1 generation? What will be the genotypic and phenotypic ratios of the F2 generation if two F1 plants are crossed?
10. In humans, free earlobes (E) are dominant over attached earlobes (e). A person with free earlobes has a child with attached earlobes. What is the genotype of the parent with free earlobes, and what are the possible genotypes of the offspring?
11. Two pea plants, one with yellow round seeds (YYRR) and another with green wrinkled seeds (yyrr), are crossed. What are the phenotypic ratios in the F2 generation if the F1 generation self-fertilizes?
12. In a dihybrid cross, two pea plants with the genotype RrYy are crossed. What is the probability (chance) that an offspring will have round, yellow seeds (RRYY) in the F2 generation?

Section III: Extensive Answer Questions

1. Describe the different parts of a chromosome, including chromatids, centromeres, and telomeres.
2. Explain how DNA is organized within the chromosome, including the role of histone proteins and nucleosomes.
3. Describe Mendel's procedure of crossing a true-breeding round-seeded pea plant with a *wrinkled*-seeded plant. Also draw the diagram of the cross.
4. Explain the results of the F1 and F2 generations in monohybrid cross and describe the conclusions he drew regarding dominant and recessive traits.
5. Define genotype and phenotype, providing examples to illustrate how different genotypes (homozygous and heterozygous) can lead to different phenotypes.
6. Explain what a test cross is and how it can be used to determine whether an organism displaying a dominant trait is homozygous or heterozygous.