

# *CHAPTER* 11 MENDELIAN PATTERNS OF INHERITANCE

## Chapter Outline

### 11.1 Gregor Mendel

#### A. The Blending Concept of Inheritance

1. This theory stated that offspring would have traits intermediate between those of the parents.
2. Red and white flowers produce pink flowers; any return to red or white offspring was considered instability in the genetic material.
3. Charles Darwin wanted to develop a theory of evolution based on hereditary principles; blending theory was of no help.
  - a. A blending theory did not account for variation (differences) and could not explain species diversity.

#### B. Mendel's Particulate Theory of Inheritance

1. Mendel was an Austrian monk.
2. Mendel formulated two fundamental laws of heredity in the early 1860s.
3. He had previously studied science and mathematics at the University of Vienna.
4. At time of his research, he was a substitute science teacher at a local technical high school.
5. Because Mendel had a mathematical background, he used a statistical basis for his breeding experiments.
6. Mendel's particulate theory is based on the existence of minute particles—now called *genes*.

#### C. Mendel Worked with the Garden Pea

1. Mendel prepared his experiments carefully and conducted preliminary studies.
  - a. He chose the garden pea, *Pisum sativum*, because peas were easy to cultivate, had a short generation time, and could be cross-pollinated by hand.
  - b. From many varieties, Mendel chose 22 true-breeding varieties for his experiments.
  - c. *True-breeding* varieties had all offspring like the parents and like each other.
  - d. Mendel studied simple traits (e.g., seed shape and color, flower color, etc.).
2. He used his understanding of mathematical principles of probability to interpret results.

### 11.2 Mendel's Law

#### A. Law of Segregation

1. Mendel confirmed that his tall plants always had tall offspring, i.e., were *true-breeding*, before crossing two different strains that differed in only one trait—this is called a **monohybrid cross**.
2. A **monohybrid cross** is between two parent organisms true-breeding for two distinct forms of one trait.
3. Mendel tracked each trait through two generations.
  - a. **P generation** is the parental generation in a breeding experiment.
  - b. **F<sub>1</sub> generation** is the first-generation offspring in a breeding experiment.
  - c. **F<sub>2</sub> generation** is the second-generation offspring in a breeding experiment.
4. He performed **reciprocal crosses**, i.e., pollen of tall plant to stigma of short plant and *vice versa*.
5. His results were contrary to those predicted by a blending theory of inheritance.
6. He found that the F<sub>1</sub> plants resembled only one of the parents.
7. Characteristics of other parent reappeared in about 1/4 of F<sub>2</sub> plants; 3/4 of offspring resembled the F<sub>1</sub> plants.
8. Mendel saw that these 3:1 results were possible if:
  - a. F<sub>1</sub> hybrids contained two factors for each trait, one being *dominant* and the other *recessive*;
  - b. factors separated when gametes were formed; a gamete carried one copy of each factor;
  - c. and random fusion of all possible gametes occurred upon fertilization.
9. Results of his experiments led Mendel to develop his first law of inheritance—the **law of segregation**:
  - a. Each organism contains two factors for each trait.
  - b. Factors segregate in the formation of gametes.
  - c. Each gamete contains one factor for each trait.
  - d. Fertilization gives each new individual two factors for each trait.

#### B. Mendel's Cross as Viewed by Classical Genetics

1. The **gene locus** is the specific location of alleles on homologous chromosomes.
2. Alternate versions of a genes are called **alleles**.

3. A **dominant allele** masks or hides expression of a **recessive allele**; it is represented by an uppercase letter.
4. A **recessive allele** is an allele that exerts its effect only in the homozygous state; its expression is masked by a dominant allele; it is represented by a lowercase letter.
5. The process of meiosis explains Mendel's law of segregation.
6. In Mendel's cross, the parents were true-breeding; each parent had two identical alleles for a trait—they were **homozygous**, indicating they possess two identical alleles for a trait.
7. **Homozygous dominant** genotypes possess two dominant alleles for a trait.
8. **Homozygous recessive** genotypes possess two recessive alleles for a trait.
9. After cross-pollination, all individuals of the F<sub>1</sub> generation had one of each type of allele.
10. **Heterozygous** genotypes possess one of each allele for a particular trait.
11. The allele not expressed in a heterozygote is a recessive allele.

#### C. Genotype Versus Phenotype

1. Two organisms with different allele combinations can have the same outward appearance (e.g., TT and Tt pea plants are both tall; therefore, it is necessary to distinguish between alleles present and the appearance of the organism).
2. **Genotype** refers to the alleles an individual receives at fertilization (dominant, recessive).
3. **Phenotype** refers to the physical appearance of the individual (tall, short, etc.).

#### D. Mendel's Law of Independent Assortment

1. This two-trait (**dihybrid**) cross is between two parent organisms that are true-breeding for different forms of *two* traits; it produces offspring *heterozygous* for both traits.
2. Mendel observed that the F<sub>1</sub> individuals were dominant in both traits.
3. He further noted four phenotypes among F<sub>2</sub> offspring; he deduced second law of heredity.
4. **Mendel's law of independent assortment** states that members of one pair of factors assort independently of members of another pair, and that all combinations of factors occur in gametes.
5. The law of independent assortment only applies to alleles on different chromosomes.
6. A phenotypic ratio of 9:3:3:1 is expected when heterozygotes for two traits are crossed and simple dominance is present for both genes.
7. Independent assortment during meiosis explains these results.

#### E. Mendel's Laws and Meiosis (*Science Focus* box)

1. Scientists now know that Mendel's laws hold true because of meiosis.
2. For example, a parent cell will have two pairs of homologous chromosomes.
3. During metaphase I, all alignments of homologous chromosomes can occur, following the lines of Mendel's law of independent assortment.
4. During metaphase II, there is only one member of each homologous pair, following the lines of Mendel's law of segregation.
5. All possible gametes result since one daughter cell has both dominant alleles (AB), one daughter cell has both recessive alleles (ab), and two daughter cells have one dominant and one recessive allele (Ab and aB), following Mendel's two laws.

#### F. Mendel's Law of Probability

1. A **Punnett square** is used for two-trait crosses.
2. **Probability** is the likely outcome a given event will occur from random chance.
  - a. For example, with every coin flip there is a 50% chance of heads and 50% chance of tails.
3. The *product rule of probability* states that the chance of two or more independent events occurring together is the product of the probability of the events occurring separately.
  - a. The chance of inheriting a specific allele from one parent and a specific allele from another is  $\frac{1}{2} \times \frac{1}{2}$  or 1/4.
  - b. Possible combinations for the alleles Ee of heterozygous parents are the following:  

$$EE = \frac{1}{2} \times \frac{1}{2} = 1/4$$

$$eE = \frac{1}{2} \times \frac{1}{2} = 1/4$$

$$Ee = \frac{1}{2} \times \frac{1}{2} = 1/4$$

$$ee = \frac{1}{2} \times \frac{1}{2} = 1/4$$
4. The sum *law of probability* calculates the probability of an event that occurs in two or more independent ways; it is the sum of individual probabilities of each way an event can occur; in the above example where unattached earlobes are dominant (EE, Ee, and eE), the chance for unattached earlobes is  $1/4 + 1/4 + 1/4 = 3/4$ .

#### G. Testcrosses

1. A **testcross** is used to determine if an individual with the dominant phenotype is homozygous dominant or heterozygous for a particular trait.
2. By Mendel performing a testcross, the law of segregation was supported.
3. A **one-trait testcross** is used between an individual with dominant phenotype and an individual with a

- recessive phenotype to see if the individual with dominant phenotype is homozygous or heterozygous.
4. A *two-trait testcross* tests if individuals showing two dominant characteristics are homozygous for both or for one trait only, or heterozygous for both.
    - a. If an organism heterozygous for two traits is crossed with another recessive for both traits, the expected phenotypic ratio is 1:1:1:1.
    - b. In dihybrid genetics problems, the individual has four alleles, two for each trait.
- H. Mendel's Laws and Human Genetic Disorders
1. Genetic disorders are medical conditions caused by alleles inherited from parents.
  2. An **autosome** is any chromosome other than a sex (X or Y) chromosome.
  3. In a pedigree chart, males are designated by squares, females by circles; shaded circles and squares are affected individuals; line between square and circle represents a union; vertical line leads to offspring.
  4. A **carrier** is a heterozygous individual with no apparent abnormality but able to pass on an allele for a recessively-inherited genetic disorder.
  5. Autosomal dominant and autosomal recessive alleles have different patterns of inheritance.
    - a. Characteristics of autosomal dominant disorders
      - 1) Affected children usually have an affected parent.
      - 2) Heterozygotes are affected.: two affected parents can produce unaffected child; two unaffected parents will not have affected children.
    - b. Characteristics of autosomal recessive disorders
      - 1) Most affected children have normal parents since heterozygotes have a normal phenotype.
      - 2) Two affected parents always produce an affected child.
      - 3) Close relatives who reproduce together are more likely to have affected children.
- I. Autosomal Recessive Disorders
1. **Methemoglobinemia**
    - a. Relatively harmless disorder resulting from an accumulation of methemoglobin in the blood.
    - b. Cause and genetic link still remain a mystery.
    - c. Symptoms include bluish-purple skin due to inability to clear abnormal blue protein from blood.
    - d. People with methemoglobinemia lack the enzyme diaphorase, which is coded for by a gene on chromosome 22.
  2. **Cystic Fibrosis**
    - a. This is the most common lethal genetic disease in Caucasians in the U.S.
    - b. About 1 in 20 Caucasians is a carrier, and about 1 in 3,000 newborns has this disorder.
    - c. An increased production of a viscous form of mucus in the lungs and pancreatic ducts is seen.
      - 1) The resultant accumulation of mucus in the respiratory tract interferes with gas exchange.
      - 2) Digestive enzymes must be mixed with food to supplant the pancreatic juices.
    - d. New treatments have raised the average life expectancy to up to 35 years.
    - e. Chloride ions ( $\text{Cl}^-$ ) fail to pass plasma membrane proteins.
    - f. Since water normally follows  $\text{Cl}^-$ , lack of water in the lungs causes thick mucus.
    - g. The cause is a gene on chromosome 7; attempts to insert the gene into nasal epithelium has had little success.
    - h. Genetic testing for adult carriers and fetuses is possible.
  3. **Niemann-Pick Disease**
    - a. Infant symptoms include jaundice, difficulty feeding, enlarged abdomen, and pronounced mental retardation.
    - b. Type A and B forms of Niemann-Pick disease are caused by defective versions of the same gene located on chromosome 11.
    - c. This disease is marked by the inability to break down lipids. Lipid droplets accumulate in liver, lymph nodes, and spleen, and in severe cases, the brain.
- J. Autosomal Dominant Disorders
1. **Osteogenesis Imperfecta**
    - a. This is an autosomal dominant disorder that affects one in 5,000 newborns and is distributed equally around the world.
    - b. Affected individuals have weakened, brittle bones. Additional symptoms include unusual blue tinge in the sclera of the eye, reduced skin elasticity, weakened teeth, and sometimes heart valve abnormalities.
    - c. The disease may be treated by long-term medicine.
  2. **Heredity Spherocytosis**

- a. This genetic blood disorder results from a defective copy of a gene found on chromosome 8.
  - b. Symptoms include: spherical shape of red blood cells, and enlarged spleen.
  - c. Hereditary spherocytosis affects 1 in 5,000 people and is one of the most common hereditary blood disorders.
- H. Testing for Genetic Disorders (*Science Focus* box)
1. Two genetic disorders resulting from faulty genes are Huntington disease and cystic fibrosis.
  2. Researchers are tests that can detect particular DNA base sequencing that may be able to identify individuals who may either have a genetic disease or if they are carriers to a particular genetic disease.
    - a. A **carrier** is a person who does not exhibit traits of the disease, but who has the potential of passing the recessive allele of a genetic disorder.
  3. In order to develop a test for a particular genetic disorder, scientists must first obtain family pedigrees.
    - a. **Family pedigrees** trace particular genes through many family generations.
    - b. In the example of Huntington disease, the family pedigree illustrated that the offspring of an affected individual has a 50% of having the disease.
    - c. When blood testing can be conducted, DNA base sequencing is determined and compared to see if there are similarities in base sequencing with people who have the disease.
    - d. However, this gene is only linked to the disease and not the disease itself.
    - e. More than one allele can occur on the same chromosome, meaning the alleles are linked.
    - f. **Linked alleles** are found together on the same gamete. However, even though they are considered to be linked, crossing over and unlinking can occur.
  4. **Association studies** are another method to discover potential base sequencing to identify if an individual has a genetic disorder.
    - a. DNA of the general population is tested to identify similar base sequences.
    - b. The exploration of the human genome project has made it possible to identify genes that may be linked to particular genetic disorders.
  5. Base sequencing identification can be used for prenatal testing and carrier testing.

### 11.3 Extending the Range of Mendelian Genetics

- A. Multiple Allelic Traits
1. This occurs when a gene has many allelic forms or alternative expressions.
  2. ABO Blood Types
    - a. The ABO system of human blood types is a multiple allele system.
    - b. Two dominant alleles ( $I^A$  and  $I^B$ ) code for presence of A and B glycoproteins on red blood cells.
    - c. This also includes a recessive allele ( $i^0$ ) coding for no A or B glycoproteins on red blood cells.
    - d. As a result, there are four possible phenotypes (blood types): A, B, AB, and O.
    - e. This is a case of **codominance**, where both alleles are fully expressed.
  3. The Rh factor is inherited independently from the ABO system; the  $Rh^+$  allele is dominant.
- B. Incomplete Dominance and Incomplete Penetrance
1. **Incomplete dominance:** offspring show traits intermediate between two parental phenotypes.
    - a. True-breeding red and white-flowered four-o'clocks produce pink-flowered offspring.
    - b. Incomplete dominance has a biochemical basis; the level of gene-directed protein production may be between that of the two homozygotes.
    - c. One allele of a heterozygous pair only partially dominates expression of its partner.
    - d. This does not support a blending theory; parental phenotypes reappear in  $F_2$  generation.
  2. Human Examples of Incomplete Dominance
    - a. Curly versus Straight Hair
      - 1) A curly-haired Caucasian and a straight-haired Caucasian will have wavy-haired offspring.
      - 2) Two wavy-haired parents will produce a 1:2:1 ratio of curly-wavy-straight hair children.
    - b. Cystic fibrosis is considered an example of incomplete dominance.
  3. **Incomplete penetrance:** offspring does not always show dominant allele.
    - a. Polydactyly is an example of incomplete penetrance.
- C. Pleiotropic Effects
1. **Pleiotropy** describes a gene that affects more than one characteristic of an individual.
  2. Examples include Marfan syndrome, porphyria, and sickle-cell anemia.
  3. **Marfan syndrome**
    - a. The gene is on chromosome 15.
    - b. Symptoms include disproportionately long arms, legs, hands, and feet; weakened aorta; poor eyesight.
  4. **Porphyria**

- a. This disease is caused by a chemical insufficiency in the production of hemoglobin.
- b. Symptoms include photosensitivity, strong abdominal pain, port-wine-colored urine, paralysis in arms and legs.

5. **Sickle-cell anemia**

- a. This disease is the most common inherited disorder in blacks, affecting about 1 in 500 African Americans.
- b. The gene is on chromosome 11.
- c. In affected individuals, the red blood cells are shaped like sickles—an abnormal hemoglobin molecule, Hb<sup>s</sup>, causes the defect.
  - 1) Normal hemoglobin, Hb<sup>A</sup>, differs from Hb<sup>s</sup> by one amino acid in the protein *globin*.
- d. Sickling of the red blood cells occurs when the oxygen content of the person's blood is low, thereby slowing down blood flow and clogging small vessels.
- e. Signs and symptoms include anemia, weakness, fever, pain, rheumatism, low resistance to disease, kidney and heart failure.
- f. Treatment includes pain management, blood transfusions, and bone marrow transplants.
- g. The disease can be diagnosed prenatally.
- h. Individuals with the sickle cell trait (carriers), who normally do not have any sickle-shaped cells unless they experience dehydration or mild oxygen deprivation, are resistant to the disease malaria.

D. Polygenic Inheritance

- 1. **Polygenic inheritance** occurs when one trait is governed by two or more sets of alleles.
- 2. Dominant alleles have a quantitative effect on the phenotype; each adds to the effect.
- 3. The more genes involved, the more continuous is the variation in phenotypes, resulting in a bell-shaped curve.
- 4. **Multifactorial traits** are controlled by polygenes subject to environmental influences.
  - a. The coats of Siamese cats and Himalayan rabbits have darker tipped ears, nose, paws, etc., due to the enzyme encoded by an allele which is only active at the extremities at low temperatures.
- 5. Human Examples of Polygenic Inheritance
  - a. A hybrid cross for skin color provides a range of intermediates.
  - b. Parents with intermediate skin color can produce children with the full range of skin colors.
  - c. Other examples include cleft lip, clubfoot, congenital dislocations of the hip, hypertension, diabetes, schizophrenia, allergies, and cancers.
  - d. Behavioral traits including suicide, phobias, alcoholism, and homosexuality may be associated with particular genes but are not likely completely predetermined.
  - e. All behavioral traits are partly heritable, and genes work together and are susceptible to environmental influences.

E. X-Linked Inheritance

- 1. Sex chromosomes in the human female are XX; those of the male are XY.
- 2. Males produce X-containing and Y-containing gametes; therefore males determine the sex of offspring.
- 3. Besides genes that determine sex, sex chromosomes carry many genes for traits unrelated to sex.
- 4. An **X-linked gene** is any gene located on X chromosome; used to describe genes on X chromosome that are missing on the Y chromosome.
- 5. Work with fruit flies (*Drosophila*) by Thomas Hunt Morgan (early 1900s) confirmed genes were on chromosomes.
  - a. Fruit flies are easily and inexpensively raised in common laboratory glassware.
  - b. Females only mate once and lay hundreds of eggs.
  - c. The fruit fly generation time is short, allowing rapid experiments.
- 6. Fruit flies have an XY sex chromosome system similar to the human system; experiments can be correlated to the human situation.
  - a. Newly discovered mutant male fruit flies had white eyes.
  - b. Cross of the hybrids from the white-eyed male crossed with a dominant red-eyed female yielded the expected 3:1 red-to-white ratio; however, all of the white-eyed flies were males.
  - c. An allele for eye color on the X but not on the Y chromosome supports the results of this cross.
  - d. Behavior of this allele corresponds to the behavior of the chromosome; this confirmed the chromosomal theory of inheritance.
- 7. Solving X-Linked Genetic Problems
  - a. X-linked alleles are designated as superscripts to the X chromosome.
  - b. Heterozygous females are carriers; they do not show the trait but can transmit it.

- c. Males are never carriers but express the one allele on the X chromosome; the allele could be dominant or recessive.
  - d. One form of color-blindness is X-linked recessive.
- F. Human X-Linked Disorders
- 1. More males have X-linked traits because recessive alleles on the X chromosome in males are expressed in males.
  - 2. Color Blindness
    - a. Color blindness can be an X-linked recessive disorder involving mutations of genes coding for green or red sensitive cone cells, resulting in the inability to perceive green or red, respectively; the pigment for blue-sensitive protein is autosomal.
    - b. About 8% of Caucasian men have red-green color blindness.
  - 3. Menkes Syndrome (kinky hair syndrome)
    - a. Caused by a defective allele on the X chromosome.
    - b. Symptoms include: poor muscle tone, seizures, low body temperature, skeletal abnormalities, and brittle, steely hair.
    - c. Treatments include copper injections, but prognosis is poor and many individuals die within the first few years of life.
  - 4. Muscular Dystrophy
    - a. Duchenne muscular dystrophy is the most common form and is characterized by wasting away of muscles, eventually leading to death; it affects one out of every 3,600 male births.
    - b. This X-linked recessive disease involves a mutant gene that fails to produce the protein *dystrophin*.
    - c. Signs and symptoms (e.g., waddling gait, toe walking, frequent falls, difficulty in rising) soon appear.
    - d. Muscles weaken until the individual is confined to a wheelchair; death usually occurs by age 20.
    - e. Affected males are rarely fathers; the gene passes from carrier mother to carrier daughter.
    - f. Lack of dystrophin protein causes calcium ions to leak into muscle cells; this promotes action of an enzyme that dissolves muscle fibers.
    - g. As the body attempts to repair tissue, fibrous tissue forms and cuts off blood supply to the affected muscles.
    - h. A test now detects carriers of Duchenne muscular dystrophy; treatments are being attempted.
  - 5. Adrenoleukodystrophy (ADL)
    - a. This disease is an X-linked recessive disorder.
    - b. Fatty acids are not broken down and severe nervous system damage occurs.
    - c. Symptoms include failure to properly develop after the age of five, loss of adrenal gland function, exhibit poor coordination, and show progressive loss of hearing, speech, vision.
  - 6. Hemophilia
    - a. About one in 10,000 males is a hemophiliac with impaired ability of blood to clot.
    - b. The two common types: *Hemophilia A*, due to the absence of clotting factor IX; *Hemophilia B*, due to the absence of clotting factor VIII.
    - c. Hemophiliacs bleed externally after an injury and also suffer internal bleeding around joints.
    - d. Hemorrhages stop with transfusions of blood (or plasma) or concentrates of clotting protein.
    - e. Factor VIII is now available as a genetically-engineered product.
    - f. Of Queen Victoria's 26 offspring, five grandsons had hemophilia and four granddaughters were carriers.