5.1 Mendelian Inheritance

trait a particular version of a characteristic that is inherited, such as hair colour or blood type

You are likely familiar with the notion of resemblance—two siblings who look similar to each other or to their parents. You probably resemble one or more of your family members. This is because you have many genes in common. When we talk about resemblance, we are usually referring to traits. A **trait** is a particular version of an inherited characteristic, such as a person's eye colour or the shape of a leaf. People have always recognized that traits are hereditary, even though they did not understand the mechanism of inheritance. Over the last few centuries, advances in genetics have changed the way we understand inheritance.

We owe much of our understanding of genetics to the extensive experiments conducted by Gregor Mendel in the nineteenth century (**Figure 1**). At that time, some scientists thought that traits from each parent were blended in the offspring, similar to mixing red and white paint to make pink paint. However, offspring sometimes exhibited a trait identical to that of one parent rather than blending those of both parents. To explore patterns of inheritance, Mendel crossbred thousands of plants in his garden and carefully recorded the offsprings' traits.

Figure 1 Gregor Johann Mendel (1822–1884) is known as the "father of genetics."

Mendel's Pea Plants

Mendel conducted experiments with the garden pea, *Pisum sativum*. He chose the garden pea because it reproduces quickly and, more importantly, he could control which parents produced offspring. Pea flowers have both male and female reproductive organs. Garden peas are both self-fertilizing and cross-fertilizing. In other words, the pea flower can self-pollinate (mate with itself) or pollinate others.

true-breeding organism an organism that produces offspring that are genetically identical for one or more traits when self-pollinated or when crossed with another true-breeding organism for the same traits

hybrid the offspring of two different true-breeding plants

Some garden peas are **true-breeding** plants. This means that, when self-pollinated or crossed with a similar true-breeding plant, they will always produce offspring that have the same trait. For example, if a true-breeding pea plant with purple flowers is self-pollinated, or crossed with another true-breeding plant with purple flowers, all offspring plants will have purple flowers. The offspring of two different true-breeding plants is called a **hybrid**. By preventing pea plants from self-pollinating, Mendel was able to cross-breed plants with specific traits. Mendel removed the male reproductive organs, the anthers, from the flowers of true-breeding plants. He then pollinated true-breeding plants with pollen from other true-breeding plants (**Figure 2**). Since the parent plants were true breeding but had different traits, the offsprings' traits would represent the hybrid condition.

LEARNING TIP

Characteristic or Trait
Do not confuse the terms "characteristic" and "trait." Traits represent the variation within a characteristic. For example, height is a characteristic, while short and tall are traits; sight is a characteristic, while normal vision, near-sightedness, and far-sightedness are traits.

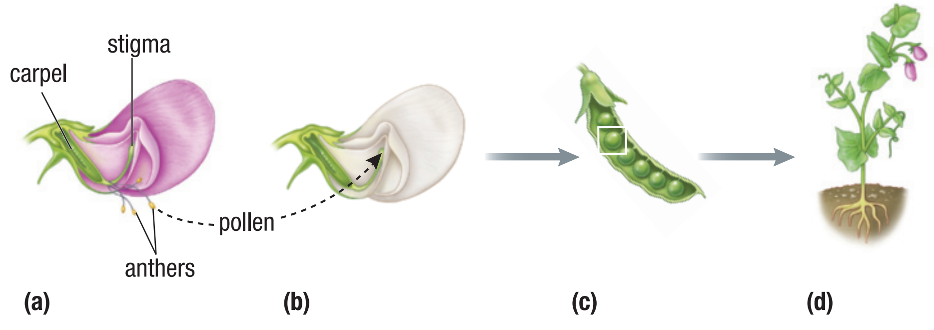

Figure 2 (a) Pollen grains form in the anthers. The egg cell is found in the carpel. (b) Mendel brushed pollen from one plant onto the stigma of a second plant. He had cut the anthers from the second plant so it could not self-pollinate. (c) He then planted the resulting seeds in order to (d) observe the characteristics of the resulting offspring.

Another significant feature of the pea plant is that it has several observable characteristics, each of which is expressed in one of two ways. For example, the shape of the pea may be smooth or wrinkled; the colour of the seeds may be yellow or green. Mendel chose characteristics that always occurred in one of only two ways so that he could distinguish between these traits and thus interpret his data easily.

Mendel performed his experiments on seven hereditary characteristics of the pea plant: flower colour, flower position, stem length, seed shape, seed colour, pod shape, and pod colour (**Table 1**).

Table 1 Characteristics and Traits of Pea Plants

Characteristic	Traits
flower colour	purple/white
flower position	axial (along stems)/terminal (at tips)
stem length	tall/dwarf
seed shape	smooth/wrinkled
seed colour	yellow/green
pod shape	inflated/ constricted
pod colour	green/yellow

Mendel's Experiments

In genetics, the breeding of two organisms with different traits is called a **cross**. In order to track the inheritance of a single trait, Mendel crossed true-breeding plants that differed from each other in only one characteristic, such as flower colour. These plants were his parental generation, or **P generation**. The hybrid offspring of the P-generation cross were the filial generation, or **F_1 generation** (from the Latin word for son, *filius*). The F_1 generation differed from each other in only one characteristic, making them **monohybrids**. This type of cross, which scientists use to study the inheritance of a single trait from two true-breeding parents, is called a **monohybrid cross**.

Figure 3 shows an example of one of Mendel's monohybrid crosses. Mendel crossed a true-breeding pea plant with purple flowers with a true-breeding pea plant with white flowers. He wondered whether the hybrid F_1 generation would have pink (or "blended") flowers, as some scientists might have predicted. Mendel observed, surprisingly, that all the F_1 plants had purple flowers rather than flowers that were a blend of the two traits in the P generation. It was as though the trait for white flowers had disappeared!

cross the successful mating of two organisms from distinct genetic lines

P generation the parent plants used in a cross

F_1 generation the offspring of a P-generation cross

monohybrid the offspring of two different true-breeding plants that differ in only one characteristic

monohybrid cross a cross designed to study the inheritance of only one trait

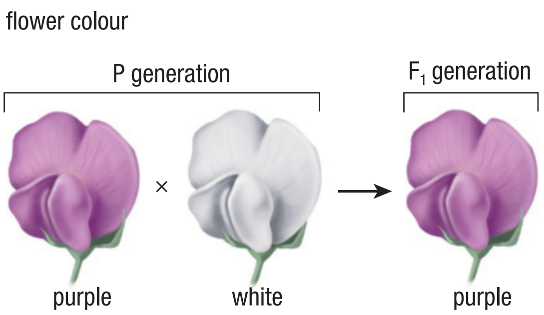

Figure 3 All the offspring of a monohybrid cross between purple true-breeding pea plants and white true-breeding pea plants have purple flowers.

When Mendel allowed the F_1 generation of plants to self-pollinate, the resulting **F_2 generation** consisted of plants with purple flowers and plants with white flowers. This meant that the trait for white flowers had not disappeared but had somehow been masked.

F_2 generation offspring of an F_1-generation cross

What Mendel did next was fundamentally important in his pursuit of scientific knowledge. He recorded the numbers of the F_2 generation plants according to their traits. He then calculated the ratios of the traits for each characteristic.

Mendel found a pattern. In each F_1 generation, only one of the two traits was present. In the F_2 generation, both traits were present—the missing trait had reappeared. This disproved the "blending" theory. The traits in the F_2 generation were repeatedly expressed in a ratio of approximately 3:1.

Mendel differed from other investigators of heredity at the time in some key ways. He kept detailed records and looked for mathematical patterns in his data. Most importantly, he repeated his experiments more than once, crossing thousands of pea plants in the process. He was aware that in order to obtain reliable results he needed to have a large sample size. He knew for example that the ratio of male to female births could not be determined by looking at just a few families. Mendel's conclusions were drawn from a large volume of documented data. In this respect, Mendel was a pioneer in the development of scientific inquiry.

The results of Mendel's careful analysis are summarized in **Figure 4**.

Characteristics	P	F_1	F_2		Ratio
seed shape	round × wrinkled	all round	5474 round	1850 wrinkled	2.96 : 1
seed colour	yellow × green	all yellow	6022 yellow	2001 green	3.01 : 1
pod shape	inflated × constricted	all inflated	882 inflated	299 constricted	2.95 : 1
pod colour	green × yellow	all green	428 green	152 yellow	2.82 : 1
flower colour	purple × white	all purple	705 purple	224 white	3.15 : 1
flower position	axial × terminal	all axial	651 axial	207 terminal	3.14 : 1
stem length	tall × dwarf	all tall	787 tall	277 dwarf	2.84 : 1

Figure 4 Mendel's crosses with seven different characteristics in peas, including his results and the calculated ratios of the offspring

Mendel's Conclusions: The First Law of Mendelian Inheritance

Mendel concluded that traits must be passed on by discrete heredity units, which he called factors. Although these factors might not be expressed in an individual, they can still be passed on. Mendel called the factor that was expressed in all the F_1 generations the "dominant factor." The factor that remained hidden but was expressed in the F_2 generation is the "recessive factor." In addition, once Mendel had compiled all the data and realized that there was a definite pattern, he recognized that the 3 : 1 ratio was an important clue. Why would a trait present in the P generation *not* be expressed in the offspring (F_1) but then reappear in 25 % of the second generation (F_2)? Mendel had noticed a pattern in the data. Now, he had to try to explain it.

Mendel's next two conclusions form the **law of segregation**:

law of segregation a scientific law stating that (1) organisms inherit two copies of genes, one from each parent, and (2) organisms donate only one copy of each gene to their gametes because the genes separate during gamete formation

- For each characteristic (such as flower colour), an organism carries two factors (genes): one from each parent.
- Parent organisms donate only one copy of each gene in their gametes. During meiosis, the two copies of each gene separate, or segregate.

Using his data, Mendel was able to predict the results of meiosis long before the discovery of chromosomes. In addition, Mendel recognized that traits are inherited in distinct units and that an organism inherits two copies of each unit—one from each parent. Today, these distinct units are called *genes*, and we know that they are passed on from one generation to the next. Typically, each gene determines a specific characteristic that will appear in the individual, such as seed colour or pod shape.

Alleles: Alternate Forms of a Gene

Recall from Chapter 4 that each gene has a locus, or position, on a chromosome. Most genes exist in at least two forms. Each form of a gene is called an **allele**. Your cells have two alleles for each gene. One allele for the gene is inherited on a chromosome from one parent, and the other allele is inherited on the homologous chromosome from the other parent.

allele a specific form of a gene

Each parent passes on one copy of each chromosome to the offspring via gametes. Gametes are formed during meiosis. During anaphase of meiosis I (Section 4.3, Figure 6), homologous chromosomes separate. This ensures that each gamete receives only one chromosome from the pair and therefore receives only one allele for each gene. Which of the two alleles will be passed on is random and purely a matter of chance.

The two alleles that an individual inherits from its parents for a particular characteristic may be the same or they may be different. Different allele combinations can result in different traits for that characteristic. If the two alleles for a particular gene are the same, the individual is **homozygous** for that allele. This would be the case, for example, if both flower-colour alleles coded for white flowers. If, however, one allele coded for white flowers while the other coded for purple flowers, the alleles would be heterozygous. The term **heterozygous** describes an organism that has two different alleles for a gene.

The set of alleles that an individual has is its **genotype**. An individual's genotype includes all forms of an individual's genes, even if some of these genes remain "hidden." In contrast, the traits of an individual make up its **phenotype**. The alleles that are expressed determine an individual's phenotype.

homozygous describes an individual that carries two of the same alleles for a given characteristic

heterozygous describes an individual that carries two different alleles for a given characteristic

genotype the genetic makeup of an individual

phenotype an individual's outward appearance with respect to a specific characteristic

Dominant and Recessive Alleles

In heterozygous individuals, which allele is expressed? As Mendel observed in his experiments, some alleles were expressed while others remained hidden. A **dominant allele** is an allele that expresses its phenotypic effect whenever it is present in the individual. A **recessive allele** is expressed only when both alleles are of the recessive form.

In Mendel's experiments, the allele for purple flowers was dominant over the allele for white flowers. This explains why, when Mendel crossed two true-breeding plants with different alleles, all the flowers were the same colour. The resulting F_1 generation expressed only one allele.

Geneticists use letters to represent alleles. Uppercase letters represent dominant alleles; lowercase letters represent recessive alleles. An individual's genotype is expressed with one letter for each allele. As an example, the gene for plant height results in tall plants or dwarf (short) plants. The allele for tall plants is dominant and represented by an uppercase *T*. The allele for dwarf plants is recessive and assigned a lowercase *t*. Possible genotypes for the plant are homozygous dominant (*TT*), homozygous recessive (*tt*), or heterozygous (*Tt*). However, there are only two possible phenotypes: tall and short (**Figure 5**).

dominant allele the allele that, if present, is always expressed

recessive allele the allele that is expressed only if it is not in the presence of the dominant allele, that is, if the individual is homozygous for the recessive allele

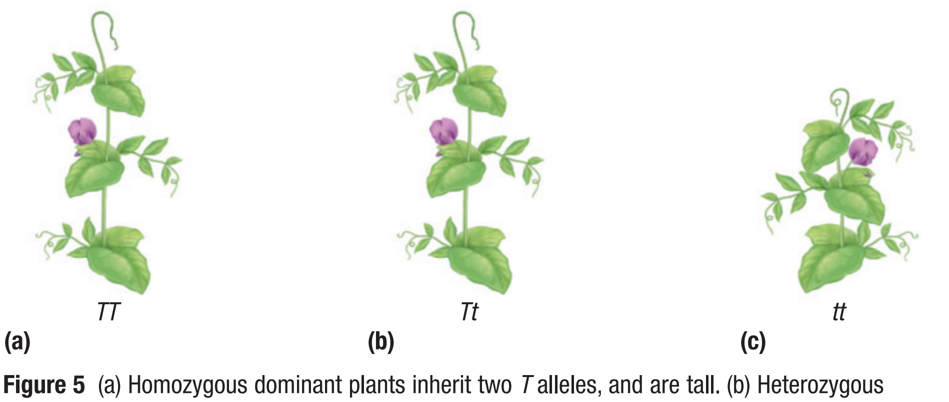

Figure 5 (a) Homozygous dominant plants inherit two *T* alleles, and are tall. (b) Heterozygous plants inherit one *T* allele and one *t* allele, and are tall. (c) Homozygous recessive plants inherit two *t* alleles, and are short.

INFLUENCE OF ALLELES ON PHENOTYPE

It is not possible to determine whether the genotype of a tall pea plant is *TT* or *Tt* just by looking at it. Why do two different genotypes result in the same phenotype? Whenever an individual has at least one copy of the dominant allele, that allele is expressed. All tall plants are either *TT* or *Tt*. It is the *T* allele that makes them tall. Only plants that have no *T* allele—only *tt* plants—show the dwarf phenotype. In heterozygous plants, only the *T* allele is expressed.

What makes an allele dominant or recessive? One common situation occurs when the dominant allele codes for a working protein, while the recessive allele does not. For example, melanin is a pigment responsible for colour in our eyes, skin, and hair. Humans have two forms of the gene for the production of melanin. One form of the gene—call it allele *M*—provides instructions for the production of melanin. The other form—allele *m*—is unable to code for the production of melanin. Only a single copy of the *M* allele (like a single set of instructions) is needed to produce melanin. Individuals who produce melanin have normal eye, skin, and hair colour. An *Mm* individual can make melanin just as easily as an *MM* individual, but *mm* individuals are unable to produce melanin. These individuals have the condition known as albinism (**Figure 6**). In this case the *M* allele is said to be dominant over the *m* allele, because the normal colour phenotype is expressed whenever an *M* allele is present, and the albino phenotype is expressed only in *mm* individuals.

You will learn more about the relationships between alleles and their resulting phenotypes in Section 5.2.

LEARNING **TIP**

Dominance
In genetics, dominance refers only to which gene is expressed in an organism. It does not mean that the allele is stronger, better, or more common than the recessive allele.

Figure 6 People with albinism lack melanin and are extremely susceptible to sun damage.

Predicting the Inheritance of Alleles

Geneticists use monohybrid crosses to study inheritance. They cross two true-breeding parents that differ in a single trait. In other words, the study involves the inheritance of two alleles for a single characteristic. Mendel's experiments consisted of many crosses. As a result of these experiments, he developed a way of mathematically predicting the proportions of phenotypes in the offspring. Biologists now use Punnett squares to copy Mendel's analysis. A **Punnett square** is a diagram used to predict the proportions of genotypes in the offspring resulting from a cross between two individuals (**Figure 7**).

Punnett square a diagram that summarizes every possible combination of each allele from each parent; a tool for determining the probability of a single offspring having a particular genotype

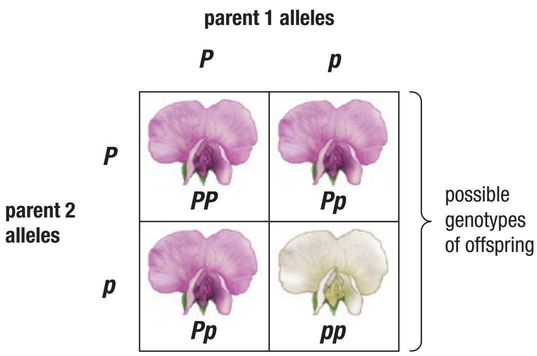

Figure 7 A Punnett square is a grid system for predicting the possible genotypes of offspring

Probability is a measure of the chance that an event will happen. For example, when you flip a coin, there is a 50 % chance (50 : 50) that the coin will land on the side you have selected. However, this does not mean that if you flip the coin 10 times you will get heads 5 times and tails 5 times. Each flip of the coin is an independent event.

probability the likelihood that an outcome will occur if it is a matter of chance

Punnett squares are valuable mathematical tools for geneticists. Punnett squares are used to predict the probability of different genotypes and phenotypes that may result from a given cross. In addition, they are a graphic summary of every possible combination of maternal and paternal alleles. In the following tutorial, you will learn how to set up Punnett squares, execute crosses, and interpret the results.

Tutorial 1 Predicting Single-Characteristic Inheritance

Sample Problem 1: Homozygous Dominant/Homozygous Recessive Cross

In pea plants, the allele for yellow seed colour, *Y*, is dominant over that for green seed colour, *y*. Consider a cross between a pea plant that is homozygous for yellow seeds and a plant that is homozygous for green seeds. Create a Punnett square to determine the possible genotypes and phenotypes of the offspring.

Solution

The plant that is homozygous for yellow seed colour has a genotype of *YY*. The plant that is homozygous for green seed colour has a genotype of *yy*.

Step 1. Draw a Punnett square that shows the genotypes of the two parents and the gametes that they can produce.

Write the symbols for the gametes across the top and along the left side of the square (**Figure 8**). Note that each parent can supply two possible gametes, each containing one of two possible alleles.

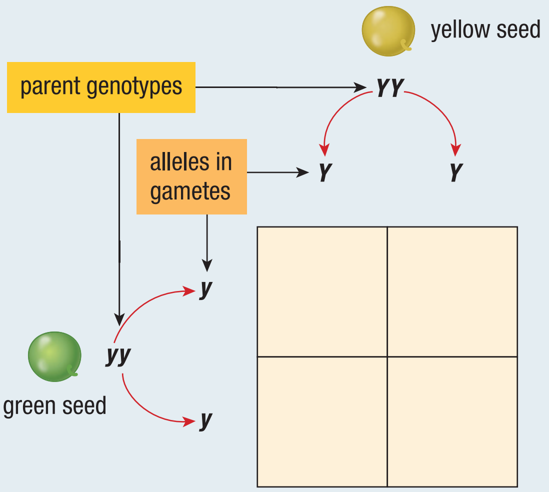

Figure 8 An incomplete Punnett square showing the possible gametes from each parent

Step 2. Fill in the boxes of the Punnett square by combining the gametes corresponding to each row and column.

Each box represents a possible offspring genotype (**Figure 9**).

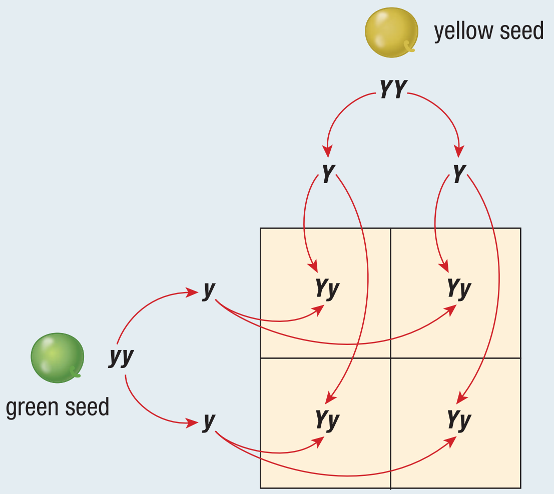

Figure 9 A complete Punnett square showing all the possible genotypes for the offspring.

The four possible genotypes for the cross between a pea plant that is homozygous for yellow seed colour and a pea plant that is homozygous recessive for green seed colour are *Yy*, *Yy*, *Yy*, and *Yy*. The offspring will all have the genotype *Yy*, so all will have the yellow seed phenotype.

Sample Problem 2: Heterozygous/Heterozygous Cross

Two heterozygous yellow seed plants (*Yy*) are crossed. Determine the genotype and phenotype ratios of the F_2 generation offspring.

Solution

Draw a Punnett square and label the parent genotypes. Insert the possible gametes from each parent across the top and down the left-hand side. In this case the two possible gametes from each parent are *Y* and *y*. Proceed to form all the possible offspring.

In the completed Punnett square, there are 1 *YY*, 2 *Yy*, and 1 *yy* genotypes (**Figure 10**). Therefore, the genotype ratio is 1 homozygous dominant plant (*YY*) to 2 heterozygous plants (*Yy*) to 1 homozygous recessive plant (*yy*), or 1:2:1. Both *YY* and *Yy* plants have yellow seeds. The phenotype ratio in the F_2 generation is 3 yellow seed plants (1 *YY* + 2 *Yy*) to 1 green seed plant (1 *yy*), or 3:1.

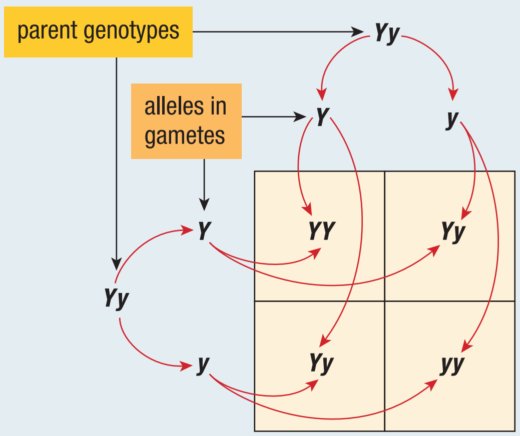

Figure 10

Sample Problem 3: Determining Parent Genotype Using Offspring Phenotype Ratios

In one cross of tomato plants, 1821 red tomato plants and 615 yellow tomato plants were produced. Determine the probable genotype of the parents. Which allele is dominant? Assume that the trait is influenced by only two alleles and follows the laws of Mendelian inheritance. Use the letters *R* and *r* to represent the alleles.

Step 1. Determine the whole number ratio of red tomato plants to yellow tomato plants.

$$\frac{\text{red}}{\text{yellow}} = \frac{1821}{615}$$

$$= \frac{2.97}{1}\text{, or approximately } 3:1$$

Step 2. Since this is a 3 : 1 phenotype ratio, it matches a cross between two heterozygous parents.

Therefore, we predict that red (*R*) is dominant to yellow (*r*), and the parent plants were both *Rr*.

Check Your Answer: Draw a Punnett square to show the cross between two heterozygous red tomato plants (**Figure 11**).

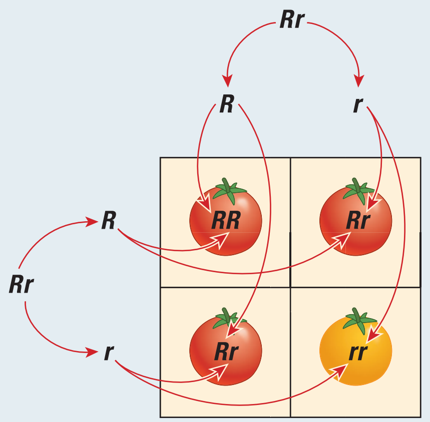

Figure 11

The cross between two heterozygous red tomato plants produces a 3 : 1 phenotype ratio of red to yellow tomato plants. Genotypically, one tomato plant is homozygous dominant (*RR*), two are heterozygous (*Rr*), and one is homozygous recessive (*rr*). In this case many heterozygous tomato plants were crossed, and of 2436 (1821 + 615) tomato plants, about 1821 out of 2436 (about $\frac{3}{4}$) produced red tomatoes and 615 out of 2436 (about $\frac{1}{4}$) produced yellow tomatoes.

Practice

1. A researcher crossed a homozygous yellow seed plant (*YY*) and a heterozygous yellow seed plant (*Yy*). Determine the genotype and phenotype ratios of the offspring.
2. A researcher crossed a heterozygous yellow seed plant (*Yy*) and a recessive green seed plant (*yy*). Determine the genotype and phenotype ratios of the offspring.

Test Crosses

test cross a cross used to determine the genotype of an individual expressing a dominant trait

A **test cross** is used to determine if an individual exhibiting a dominant trait is homozygous or heterozygous for that trait. A test cross is always performed between the unknown genotype and a homozygous recessive genotype. This is done by crossing the individual with the dominant trait with an individual that exhibits the recessive trait. The results reveal the genotype of the parent:

- If all the offspring display the dominant phenotype, then the individual in question is homozygous dominant.
- If the offspring displays both dominant and recessive phenotypes, then the individual is heterozygous.

Test crosses work well with species that reproduce quickly and in large numbers. For example, test crosses can be used on mice because they produce large litters (7 to 12 mice on average) and have a gestation period of only 18 to 21 days. Also, mice can become pregnant again while nursing a litter. Therefore, a large sample size of mice can be studied in a short period of time. Cows, on the other hand, give birth to only one calf each year and the gestation period of a cow is nine months. This makes test-crossing cows difficult. Although farmers often attempt to breed cows with beneficial traits, it takes a long time to improve a herd.

Today, test crosses are rarely performed. Advances in molecular biology techniques allow geneticists to test for specific alleles within the genotype of an organism directly, rather than having to wait for the production of offspring.

Sample Problem 1: Performing a Test Cross

Animal and plant breeders are often interested in whether or not an individual will consistently produce offspring with a desired trait. A breed of rooster has a dominant trait (*S*)—a comb that resembles a series of fingers—while a breed with a recessive trait (*s*) has a flat comb (**Figure 12**).

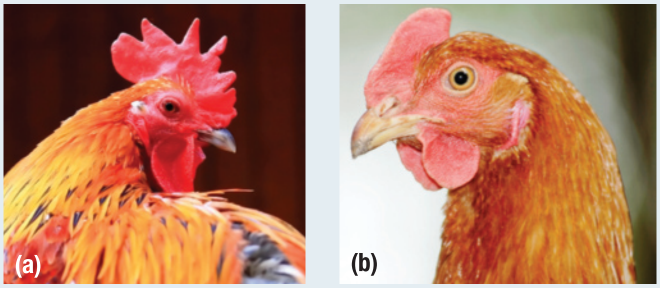

Figure 12 A rooster could have (a) a five-fingered comb or (b) a flat comb

A breeder would like to use a true-breeding, homozygous, five-fingered-comb rooster as a stud in her breeding program. She has many roosters to choose from but does not know if they are heterozygous (*Ss*) or homozygous dominant (*SS*) for the trait.

(a) What type of hen should she cross with the roosters to determine whether a particular rooster is homozygous or heterozygous for the five-fingered comb? Explain your reasoning using Punnett squares.

(b) What are the expected results?

Solution

Step 1. List the possible genotypes of roosters and hens.

The roosters of interest all exhibit the dominant trait, so they must be either homozygous dominant (*SS*) or heterozygous (*Ss*).

There are three possible hen genotypes: homozygous dominant (*SS*), heterozygous (Ss), and homozygous recessive (*ss*).

Step 2. Decide which hen genotype could be used to distinguish homozygous roosters from heterozygous roosters.

No matter which genotype hen is crossed with a homozygous dominant rooster (*SS*), all the offspring will inherit an *S* allele from the rooster and have a five-fingered comb. However, the heterozygous roosters could pass on either an *S* or an *s* allele. Therefore, you can tell them apart if you can detect this *s* allele in the offspring. The only way to tell if an offspring receives an *s* from the rooster is if the offspring also receives an *s* from the hen and is born with a flat comb. Therefore, to ensure that all the offspring receive an *s* allele from the hen, the breeder should choose a homozygous recessive (*ss*) hen.

Step 3. Draw the Punnett squares to determine the expected results (**Figure 13**).

(a) rooster ***Ss***, hen ***ss***

	S	***s***
s	***Ss***	***ss***
s	***Ss***	***ss***

(b) rooster ***SS***, hen ***ss***

	S	***S***
s	***Ss***	***Ss***
s	***Ss***	***Ss***

Figure 13 (a) Homozygous recessive hen and homozygous dominant rooster cross, and (b) homozygous recessive hen and heterozygous rooster cross

Answers:

(a) The breeder should cross the rooster with a hen with a flat comb. Using a homozygous recessive (*ss*) hen ensures that all the eggs will contain a recessive allele from the hen and none will contain a dominant *S* allele that would mask the presence of a recessive *s* allele in the rooster.

(b) If the rooster is homozygous dominant, all the offspring will express the five-fingered comb. If the rooster is heterozygous, we would expect that 50 % of the offspring will have a five-fingered comb while the remaining 50 % will have a flat comb.

Practice

1. The gene for whisker length in seals occurs in two different alleles. The dominant allele (*W*) codes for long whiskers, and the recessive allele (*w*) codes for short whiskers.
   (a) If one parent is heterozygous long-whiskered and the other parent is short-whiskered, what percentage of offspring would you expect to have short whiskers? [ans: 50 %]
   (b) A male long-whiskered seal is mated in captivity with a number of different females. With some females all their offspring are long-whiskered, and with some females there are both long- and short-whiskered offspring.
      (i) What is the genotype of the male? How can you be sure? [ans: *Ww*]
      (ii) Would it be possible to find a female mate that would produce only short-whiskered offspring? Explain.
2. Mendel found that crossing wrinkle-seeded (*rr*) plants with homozygous round-seeded (*RR*) plants produced only round-seeded plants. What genotype ratio and phenotype ratio can be expected from a cross between a wrinkle-seeded plant and a heterozygous plant for this characteristic? [ans: 50 : 50 Rr to rr; 50 : 50 round seeded to wrinkle seeded.]

Mini Investigation

What Are the Chances?

Skills: Performing, Analyzing, Evaluating, Communicating

SKILLS HANDBOOK A2.1, A6.3

When two heterozygous individuals are crossed, the probability of producing each genotype is 25 % homozygous dominant, 50 % heterozygous, and 25 % homozygous recessive. In this investigation you will model a cross between two heterozygous individuals. You will then determine the genotype and phenotype ratios of your model F_1 generation. In addition, you will investigate the role that sample size and probability play in producing a 25:50:25 ratio in the F_1 generation.

Equipment and Materials: two small pouches containing 40 beads each (20 white beads and 20 red beads)

1. Assign the red bead the dominant allele, *R*, and the white bead the recessive allele, *r*. Label the two pouches "P_1" and "P_2." Each pouch therefore contains beads that represent the gametes from one heterozygous individual (20 *R* and 20 *r*). Together, the two pouches represent the parent generation.
2. Without looking, draw one bead from pouch P_1 and one bead from pouch P_2. Place the beads together on a flat surface. This represents the joining of two gametes to form a new individual. The colours represent the alleles and the resulting genotype of the offspring. For example, two red beads would represent a new *RR* member of the F_1 generation. Return each bead to the pouch that you drew it from.
3. Repeat Step 2 another 19 times, producing a total of 20 offspring. Record the genotype of each offspring and then tally the total number of homozygous dominant, heterozygous, and homozygous recessive individuals produced.
4. Pool your data with your classmates' data.

A. What was your ratio of homozygous dominant to heterozygous to homozygous recessive individuals in your 20 F_1 offspring? Calculate each percentage by dividing your genotype counts by the total sample size (20) and multiplying by 100. For example, if you had 4 homozygous dominant individuals, the percentage of homozygous individuals would be $\frac{4}{20} \times 100 = 20$ %. T/I

B. Did your ratio approach a 25:50:25 ratio? T/I

C. Answer A and B with the pooled class data. Remember to use the total class sample size to calculate percentage values. T/I

D. Check with other students. Were the percentages using the pooled data closer to or farther from the theoretical value than the percentages using single-student data? Why is sample size important? T/I

E. What aspect of Mendel's own experimental design suggests he understood the effects of sample size? T/I A

5.1 Summary

- Gregor Mendel studied heredity in pea plants. He was the first person to successfully record and quantify heredity data.
- Genes have alternate forms known as alleles. Individuals have two alleles for each gene.
- The two alleles are found at specific matching locations on homologous chromosomes.
- Each parent passes on to its offspring only one of its two alleles for each gene. This is called the law of segregation.
- Some alleles are dominant, while others are recessive. Dominant alleles are always expressed in the phenotype, but recessive alleles do not show up unless they are the only type of allele present in the genotype.
- A Punnett square is a tool that can be used to illustrate how alleles are distributed from parent to offspring and to predict the frequency of phenotypes and genotypes within a set of offspring.

5.1 Questions

1. Why was the pea plant an excellent choice for Mendel's inquiry into heredity? K/U
2. Why was it important that Mendel experimented with true-breeding plants? K/U
3. What were the phenotype and genotype ratios of Mendel's F_1 crosses? What do these numbers represent? K/U
4. List Mendel's conclusions from his experiments. How do the conclusions relate to what is known today in the field of genetics? K/U A
5. Differentiate between the following: K/U
   (a) dominant and recessive
   (b) gene and allele
   (c) homozygous and heterozygous
6. State the law of segregation. How does the law relate to meiosis? A
7. Explain why it is important that Mendel had a large sample size of offspring to count in his experiments. T/I
8. The round pea seed allele (*R*) is dominant, while the wrinkled pea seed allele (*r*) is recessive. A heterozygous, round-seeded pea plant is crossed with a wrinkle-seeded pea plant. Use a Punnett square to solve the following: T/I C
   (a) Determine the predicted genotype ratio of the offspring.
   (b) Determine the predicted phenotype ratio of the offspring.
   (c) If this cross produced 50 plants, how many plants would you predict would be wrinkle-seeded pea plants?
9. Humans who have an abnormally high level of cholesterol are said to suffer from familial hypercholesterolemia. The gene for this disorder is dominant (*C*). A man who is heterozygous for familial hypercholesterolemia marries a woman who is homozygous for the recessive allele. What is the probability that they will have children that suffer from this disorder? T/I C
10. Holstein dairy cattle normally have black and white spotted coats. On occasion calves with recessive red and white spotted coats are born (**Figure 14**). A dairy farmer purchases a prized black and white spotted bull. To the farmer's dismay the bull produces a red and white spotted calf when mated to one of his cows.
    (a) What is the genotype of the bull? (Use *R* and *r* for the colour alleles.) T/I C
    (b) What phenotype ratio is expected in the offspring if the bull is mated to a red and white spotted cow?

Figure 14

11. At one time, if a farmer wanted to improve his or her cattle herd, he or she would have to buy an expensive bull from another farmer who had a herd proven to show desirable characteristics. Now, semen from bulls with desirable characteristics can be shipped all over the world to help farmers improve their herds. Use the Internet to learn more about the use of artificial insemination (AI) as a cattle-breeding option. K/U T/I A
    (a) What are the primary advantages and disadvantages of using AI to breed cattle?
    (b) How popular is AI as a breeding method for the beef and dairy industry?
12. Plants contain many hormones that determine their characteristics. Mendel was unaware of the hormones that resulted in the different traits in his plants. T/I A
    (a) Using the Internet or other sources, research the role that the hormone gibberellin plays in determining stem length (plant height).
    (b) How could knowledge of gibberellin release in plants help agriculturists?

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