Before You Read

Think about what you have learned about the scientific method. On the lines below, list some of the steps Mendel might have used to learn about the natural world. In this section, you will learn about Gregor Mendel’s experiments.

What You’ll Learn

- the law of segregation and the law of independent assortment
- how to use a Punnett square

Read to Learn

How Genetics Began

Gregor Mendel, an Austrian Monk, lived in the 1800s. He experimented with pea plants in the monastery gardens. Pea plants usually reproduce by self-fertilization. This means that the female gamete is fertilized by a male gamete in the same flower. Mendel discovered a way to cross-pollinate peas by hand. He removed the male gametes from a flower. He then fertilized the flower with the male gamete from a different flower.

Through these experiments, Mendel made several hypotheses about how traits are inherited. In 1866, he published his findings. That year marks the beginning of the science of genetics, the science of heredity. Mendel is called the father of genetics.

The Inheritance of Traits

Mendel used true-breeding pea plants—plants whose traits stayed the same from generation to generation. Mendel studied seven traits—flower color, seed color, seed pod color, seed shape, seed pod shape, stem length, and flower position.
What did Mendel find when he crossed pea plants with different traits?

Mendel called the original plants the parent, or P, generation. The offspring were called the F₁ generation. The offspring of the F₁ plants were called the F₂ generation.

In one experiment, Mendel crossed yellow-seeded and green-seeded plants. All the F₁ offspring had yellow seeds. The green-seed trait seemed to disappear.

Mendel allowed the F₁ plants to self-fertilize. He planted thousands of seeds from these plants. He saw that in these offspring, the F₂ generation, three-fourths of the plants had yellow seeds and one-fourth had green seeds, a 3:1 ratio.

Mendel performed similar experiments for other traits. Each time, he observed the same 3:1 ratio.

How did Mendel explain his results?

Mendel proposed that there were two forms of each trait, and each form was controlled by a factor, which is now called an allele. An allele (uh LEEL) is a different form of a gene passed from generation to generation. Yellow-seed plants have a different allele than green-seed plants.

Mendel proposed that each trait was controlled by two alleles. The dominant form is the version of the trait that appears in the F₁ generation. The recessive form is the version that is hidden in the F₁ generation.
How does dominance work?
When written, the dominant allele is represented by a capital letter. The recessive allele is represented by a lowercase letter.

An organism is homozygous (hoh muh ZI gus) if both alleles for a trait are the same. The organism is heterozygous (heh tuh roh ZY gus) if the alleles for a trait are different. In heterozygous organisms, only the dominant trait can be seen. Dominant alleles mask recessive alleles.

How do genotype and phenotype differ?
It is not always possible to know what alleles are present just by looking at an organism. A yellow-seed plant could be homozygous (YY) or heterozygous (Yy). An organism’s allele pairs are called its genotype (JEE nuh tipe). The expression of an allele pair, or the way an organism looks or behaves, is called its phenotype (FEE nuh tipe).

What is the law of segregation?
Recall that the chromosome number is divided in half during meiosis. The gametes contain only one of the alleles. Mendel’s law of segregation states that the two alleles for each trait separate from each other during meiosis and then unite during fertilization. When parents with different forms of a trait are crossed, the offspring are heterozygous organisms known as hybrids (HI brudz).

A cross which involves hybrids for a single trait is called a monohybrid cross. Mono means one. The offspring of the cross have a phenotypic ratio of 3:1.

How are two or more traits inherited?
Mendel also performed dihybrid crosses, crossing plants that expressed two different traits. Mendel crossed yellow, round-seed plants with green, wrinkle-seed plants. Round seeds are dominant to wrinkled, just as yellow color is dominant to green. He wondered whether the two traits would be inherited together or separately. Members of the F₁ generation are dihybrids because they are heterozygous for both traits.

Mendel found that the traits were inherited independently. Members of the F₂ generation had the phenotypic ratio of 9:3:3:1—9 yellow round seeds, 3 green round, 3 yellow wrinkled, and 1 green wrinkled. From experiments with dihybrid crosses, Mendel developed the law of independent assortment, which states that alleles distribute randomly when gametes are made.
Punnett Squares

In the early 1900s, Dr. Reginald Punnett developed a square to predict possible offspring of a cross between two known genotypes. Punnett squares are useful for keeping track of genotypes in a cross.

What information does a Punnett square contain?

A Punnett square can help you predict the genotype and phenotype of the offspring. The genotype of one parent is written vertically, on the left side of the Punnett square. The genotype of the other parent is written horizontally, across the top. A Punnett square for a monohybrid cross contains four small squares. Each small square represents a possible combination of alleles in the children.

The Punnett square below shows the results of Mendel’s experiment with seed color. The Punnett square shows that four different genotypes are possible—one YY, two Yy, and one yy. The genotypic ratio is 1:2:1.

How is a Punnett square used for two traits?

Punnett squares also can be used to predict the results of a dihybrid cross. A Punnett square for a dihybrid cross is larger. It has 16 boxes to represent 16 allele combinations.

Probability

Genetics follows the rules of probability, or chance. It is like flipping a coin. The probability of flipping heads is one out of two. Because of chance, if you flip a coin 100 times, it might not land heads exactly 50 times, but it will be close.

It is the same in genetics. A cross might not give a perfect 3:1 or 9:3:3:1 ratio. The larger the number of offspring, the more closely the results will match the ratio predicted by the Punnett square.
Genetics is like a game of cards. In meiosis, chromosomes are shuffled and sorted. On the lines below, explain the chances of a player getting the same cards two games in a row. In this section, you will learn about the independent assortment of chromosomes that occurs during meiosis.

Genetic Recombination

During meiosis, genes are combined in new ways. Genetic recombination occurs when crossing over and independent assortment produce new combinations of genes.

Recall that independent assortment occurs in meiosis when chromosomes separate randomly. The number of possible gene combinations due to independent assortment can be calculated using the formula $2^n$, where $n$ equals the number of chromosome pairs.

Pea plants have 7 pairs of chromosomes. The possible combinations of these chromosomes would be 27, or 128. Fertilization further increases the number of combinations. During fertilization, any possible male gamete can fertilize any possible female gamete. The number of combinations after fertilization would be $2^n \times 2^n$. For peas, this number is 16,384, or $128 \times 128$.

In people, the possible combinations of chromosomes are $2^{23} \times 2^{23}$—over 70 trillion. Crossing over increases genetic recombination even more.

1. Calculate The fruit fly has four chromosome pairs. How many possible combinations of chromosomes can be produced by meiosis and fertilization?
Gene Linkage

Chromosomes contain many genes. Genes that are located close together on the same chromosome are said to be linked. This means they usually travel together during gamete formation. Linked genes do not segregate independently. They are an exception to Mendel’s law of independent assortment.

Occasionally, linked genes separate due to crossing over. Crossing over occurs more frequently between genes that are far apart than between genes that are close together.

What does a chromosome map show?

The relationship between crossing over and chromosome distance is very useful. The distance between two genes can be estimated by the frequency of crossing over that occurs between them. Scientists use cross-over data to create a drawing of genes along a chromosome. The drawing, called a chromosome map, shows the order of genes on a chromosome. The first chromosome maps were published in 1913 for fruit-fly crosses. One is shown in the figure below.

Polyploidy

Most organisms have diploid cells—cells with two chromosomes in each cell. Some species have polyploid cells. Polyploidy (PA lih ploy dee) means the cells have one or more extra sets of all chromosomes. For instance, a triploid organism has three complete sets of chromosomes in each cell. It is designated 3n.

Polyploidy occurs in only a few animals, such as earthworms and goldfish. It is always lethal in humans. Polyploidy is common in flowering plants. Polyploid plants are often bigger and more vigorous. Many food plants, such as wheat (6n), oats (6n), and sugarcane (8n), are polyploid.
Before You Read

A family tree shows how people in a family are related. On the lines below, list people who might appear in a family tree. Then read the section to learn how scientists trace inheritance through several generations of a family.

Read to Learn

Recessive Genetic Disorders

During the early 1900s, Gregor Mendel’s work on heredity was rediscovered. Archibald Garrod, an English doctor, was studying a disorder that results in black urine and affects bones and joints. Dr. Garrod, with the help of other scientists, discovered that the disorder was a recessive genetic disorder. This finding began the study of human genetics.

Review the table below and recall that a recessive trait is expressed when the person is homozygous recessive for that trait. A person with at least one dominant allele will not express the recessive trait. A person who is heterozygous for a recessive disorder is called a carrier.

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homozygous</td>
<td>An organism with two of the same alleles for a particular trait is said to be homozygous for that trait.</td>
</tr>
<tr>
<td>Heterozygous</td>
<td>An organism with two different alleles for a particular trait is said to be heterozygous for that trait. When alleles are present in the heterozygous state, the dominant trait will be observed.</td>
</tr>
</tbody>
</table>

Create a Quiz

After you read this section, create a quiz based on what you have learned. Then be sure to answer the quiz questions.

Picture This

1. Identify Circle the term that describes the genotype of a person who expresses a recessive trait.
What is cystic fibrosis?

Cystic fibrosis is a recessive genetic trait. Chloride ions are not absorbed into cells but are excreted in sweat. Without the chloride ions in cells, water does not diffuse from cells. This causes the secretion of a thick mucus that affects many areas of the body. The mucus interferes with digestion, clogs ducts in the pancreas, and blocks air pathways in the lungs. Patients with cystic fibrosis often get infections because of excess mucus in their lungs.

Treatment includes physical therapy, medicine, special diets, and replacement digestive enzymes. Genetic tests are used to determine if the recessive gene is present.

What causes albinism?

Albinism is a recessive disorder found in people and animals. In humans, it is caused by the absence of the skin pigment melanin in hair and eyes. People with albinism have white hair, pale skin, and pink eyes. They need to protect their skin from the Sun’s ultraviolet rays.

What is Tay-Sachs disease?

Tay-Sachs (TAY saks) disease is a recessive genetic disorder. Tay-Sachs disease (TSD) is more common among Jews whose ancestors are from eastern Europe.

People with TSD are missing an enzyme needed to break down fatty acids called gangliosides. Normally, gangliosides are made and then destroyed as the brain develops. In people with TSD, gangliosides build up in the brain, causing mental deterioration. Children born with TSD usually die by age five. Currently, there is no cure.

What causes galactosemia?

Galactosemia (guh lak tuh SEE mee uh) is a recessive genetic disorder. It causes intolerance of the sugar galactose. Milk contains the sugar lactose. During digestion, lactose breaks down into galactose and glucose, the sugar used by the body for energy. People with galactosemia lack the enzyme needed to break down galactose.

Dominant Genetic Disorders

Not all genetic disorders are recessive. Some are caused by dominant alleles. People who do not have the disorder are always homozygous recessive, meaning they carry two recessive genes for the trait.
What happens in Huntington’s disease?

Huntington’s disease is a dominant genetic disorder that affects the nervous system. It is rare. Symptoms occur when the person is between 30 and 50 years old. Symptoms are gradual loss of brain function, uncontrollable movements, and emotional disturbances. Genetic tests can tell people whether they have the gene for Huntington’s disease, but there is currently no treatment or cure.

What is achondroplasia?

Achondroplasia (a kahn droh PLAY zhee uh) is a dominant genetic disorder that is also known as dwarfism. People with this disorder have a small body size and short limbs. They grow to an adult height of about 1.2 m.

About 75 percent of people with achondroplasia have parents of average size. Because the gene is dominant, parents who are average size do not have the gene. Therefore, when average-sized parents have a child with achondroplasia, the condition occurs because of a new mutation.

Pedigrees

Scientists use a diagram called a pedigree to trace inheritance of a trait through several generations. A pedigree uses symbols to illustrate inheritance of the trait.

A sample pedigree is shown in the figure below. In the top row, the two symbols connected by a horizontal line are the parents. Their children are listed below them, oldest to youngest from left to right.

Roman numerals are used to represent generations—I for the parents, II for the children, and so on. Arabic numbers are used to represent the individuals within a generation.

Key to Symbols

- Normal female
- Female who expresses the trait being studied
- Female who is a carrier for the particular trait

- Normal male
- Male who expresses the trait being studied
- Male who is a carrier for the particular trait

Generation
Parents
Siblings

Example Pedigree

Roman numerals — Generations
Arabic numerals — Individuals in a certain generation

3. Explain How can scientists determine if achondroplasia developed from a new mutation?

4. Evaluate Circle the carriers in the second generation.
Analyzing Pedigrees

The figure below is a pedigree showing the inheritance of Tay-Sachs disease, a recessive disorder. The pedigree shows that two parents who do not have Tay-Sachs disease can have a child who has the disorder.

How is the inheritance of a dominant disorder shown on a pedigree?

The pedigree below shows the inheritance of the dominant disorder, polydactyly (pah lee DAK tuh lee). People who have polydactyly have extra fingers and toes. A person who has polydactyly could be homozygous or heterozygous for the trait. A person who does not have polydactyly would be homozygous recessive for the trait.

How are genotypes deduced?

A pedigree can be used to learn the genotype of a person. The genotype is determined by observing the phenotypes, or physical traits, of a person.

Genetic counselors use pedigrees to determine if an inherited trait is dominant or recessive. Dominant traits are easy to recognize. Recessive traits are more difficult because people who carry the allele do not always show the trait.

Can genetic disorders be predicted?

Scientists can use pedigrees to predict whether a person in a family will get a genetic disorder. Scientists have to follow several people for many generations to accurately study a disorder. Good record keeping within a family can help scientists predict the inheritance of a disorder.
Complex Inheritance and Human Heredity

Before You Read

Cats can look different from one another because of differences in their coats. Think about the different kinds of cats you have seen. On the lines below, describe differences you have seen in the coats of cats. Then read the section to learn more about complex inheritance patterns.

Read to Learn

Incomplete Dominance

Not all traits follow Mendel’s rules. Some traits are not dominant or recessive. Sometimes, the heterozygous organism has a mixed phenotype. **Incomplete dominance** occurs when the heterozygous phenotype is an intermediate phenotype between the two homozygous phenotypes.

An example of incomplete dominance occurs in snapdragon flowers. Red-flowered snapdragons \((RR)\) can be crossed with white-flowered snapdragons \((rr)\) to produce offspring with pink flowers \((Rr)\). When heterozygous \(F_1\) generation snapdragon plants \((Rr)\) self-fertilize, the offspring have a 1:2:1 ratio of red, pink, and white flowers.

Codominance

In Mendel’s experiments with pea plants, heterozygous pea plants expressed only the dominant allele. **Codominance** occurs when a heterozygous organism expresses both alleles. Sickle-cell anemia is an example of codominance.

What You’ll Learn

- the difference between sex-linked and sex-limited inheritance
- how environment can influence a trait

Main Idea

Complex inheritance of traits does not follow the inheritance patterns described by Mendel.

Highlight each question head. Then highlight the answer to the question.

1. Define What is codominance?
What happens in sickle-cell anemia?

Sickle-cell anemia is common in people of African descent. Sickle-cell anemia affects red blood cells and their ability to transport oxygen. Changes in the protein in red blood cells cause those red blood cells to change from a normal disc shape to a sickle or C shape.

Sickle-cell anemia is a codominant trait. People who are heterozygous for the trait make both normal and sickle-shaped cells. The normal cells compensate for the sickle-shaped cells.

Where does sickle-cell anemia occur?

Sickle-cell anemia is found in areas of Africa where malaria occurs. Scientists have discovered that people who are heterozygous for the sickle-cell trait are resistant to malaria. Because the sickle-cell gene helps people resist malaria, they are more likely to pass the sickle-cell trait on to their offspring.

Multiple Alleles

So far you have learned about traits that result from a gene with two alleles. Some traits are controlled by a gene that has multiple alleles. Blood groups in humans is an example of a multiple allele trait.

How are blood types produced?

There are four blood types in people: A, AB, B, or O. The four types result from the interaction of three different alleles, as shown below. The allele \( I^A \) produces blood type A. \( I^B \) produces blood type B. The allele \( i \) is recessive and produces blood type O. Type O is the absence of AB alleles. People with one \( I^A \) and one \( I^B \) allele have blood type AB. Blood types are examples of multiple alleles and codominance.

Rh factors are also in blood. One factor is inherited from each parent. Rh factors are either positive or negative (Rh+ or Rh−); the Rh+ is dominant.
What genes control coat color in rabbits?

The fur color of rabbits is another trait controlled by multiple alleles. In rabbits, four alleles control coat color: \(C\), \(c\), \(c^h\), and \(c^{h} \). The alleles are dominant in varying degrees. The hierarchy can be written as \( C > c^h > c^{h} > c \).

Allele \( C \) is dominant to all other alleles and results in a dark gray coat color. Allele \( c^h \) is dominant to \( c^{h} \), and \( c^{h} \) is dominant to \( c \). Allele \( c \) is recessive and results in an albino when the genotype is homozygous recessive.

Multiple alleles increase the possible number of genotypes and phenotypes. Two alleles have three possible genotypes and two possible phenotypes. Four alleles have ten possible genotypes and can have five or more phenotypes.

Epistasis

Epistasis (ih PIHS tuh sus) occurs when one allele hides the effects of another allele. Coat color in Labrador retrievers is a trait controlled by epistasis. Labrador coats vary from yellow to black. Two different genes control coat color. The dominant allele \( E \) determines whether the coat will have dark pigment. A dog with genotype \( ee \) will not have any pigment. The dominant allele \( B \) determines how dark the pigment will be. If the genotype is \( EEbb \) or \( Eebb \) the coat will be chocolate. If the genotype is \( eebb, eeBb, \) or \( eeBB \) the coat will be yellow because the \( e \) allele hides the effects of the dominant \( B \) allele.

Sex Determination

Each cell in your body contains 23 pairs of chromosomes. One pair, the sex chromosomes, determines gender. The other 22 pairs of chromosomes are called autosomes.

There are two types of sex chromosomes—\( X \) and \( Y \). A person’s gender is determined by the sex chromosomes present in the egg and sperm cell. Females inherit two \( X \) chromosomes. Males inherit one \( X \) and one \( Y \) chromosome.

Dosage Compensation

In humans, the \( X \) chromosome carries genes needed by males and females. The \( Y \) chromosome mainly carries genes needed to develop male characteristics. Because females have two \( X \) chromosomes and males have only one, body cells randomly turn off one of the \( X \) chromosomes. This is called dosage compensation or \( X \)-inactivation.
How is coat color determined in calico cats?
The coat color of calico cats is controlled by the random inactivation of X chromosomes. Orange patches are formed when an X chromosome carrying the allele for black coat color is turned off. Black patches are formed when an X chromosome carrying the allele for orange coat color is turned off.

What are Barr bodies?
Canadian scientist Murray Barr first observed inactivated X chromosomes, now known as Barr bodies. Barr bodies appear as dark objects in the cell nuclei of female mammals.

Sex-Linked Traits
Traits controlled by genes on the X chromosome are called sex-linked traits or X-linked traits. Males who have only one X chromosome are affected more than females by recessive sex-linked traits. Females would not likely express a recessive sex-linked trait because one X chromosome will mask the effect of the recessive trait on the other X chromosome.

How is red-green color blindness inherited?
The trait for red-green color blindness is a recessive sex-linked trait. People who are color blind cannot see the colors red and green. About 8 percent of males in the United States are red-green color blind. Examine the Punnett square below to see how red-green color blindness is inherited.

<table>
<thead>
<tr>
<th></th>
<th>X&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>X&lt;sup&gt;b&lt;/sup&gt;</td>
<td>X&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;sup&gt;b&lt;/sup&gt;Y</td>
</tr>
<tr>
<td>X&lt;sup&gt;b&lt;/sup&gt;</td>
<td>X&lt;sup&gt;b&lt;/sup&gt;</td>
<td>X&lt;sup&gt;b&lt;/sup&gt;Y</td>
</tr>
<tr>
<td>X&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

How is hemophilia inherited?
Normally, when a person is cut, the bleeding stops quickly. Hemophilia is a recessive sex-linked disorder that slows blood clotting. Hemophilia is more common in males. Until the discovery of clotting factors in the twentieth century, most men with hemophilia died at an early age. Safe methods of treating the disorder now allow for a normal life span.
Polygenic Traits

So far you have learned about traits that are controlled by one gene with different alleles. Polygenic traits develop from the interaction of multiple pairs of genes. Many traits in humans are polygenic, including skin color, height, eye color, and fingerprint pattern.

Environmental Influences

The environment influences many traits. Factors such as sunlight, temperature, and water can affect an organism’s phenotype. For example, the gene that codes for the production of color pigment in Siamese cats functions only under cooler conditions. Cooler parts of the cat’s body, such as the ears, nose, feet, and tail, are darker. The warmer parts of the body, where pigment production is inhibited, are lighter.

Environmental factors also include an organism’s actions. Heart disease can be inherited, but diet and exercise also strongly influence the disease. An organism’s actions are considered part of the environment because they do not come from genes.

Twin Studies

Scientists can learn about inheritance patterns by studying twins. Twin studies often reveal how genes and the environment affect phenotype.

Identical twins have identical genes. If a trait is inherited, both identical twins will have the trait. Scientists presume that traits that are different in identical twins are strongly influenced by the environment. The percentage of identical twins who both have the same trait is called a concordance rate, as shown in the graph below. The higher the concordance rate, the stronger the genetic influence.

8. List an example of a polygenic trait.

9. Evaluate Circle the trait that shows the strongest genetic influence.
Before You Read

Think about the traits that people in a family might share. On the lines below, list the ways that people in families resemble each other. Then read to learn more about how scientists study genetic material.

Read to Learn

Karyotype Studies

Genetics not only is the study of genes, it is also the study of chromosomes. Images of chromosomes that have been stained during metaphase are studied. The staining bands mark identical places on homologous chromosomes. The homologous chromosomes are arranged, from biggest to smallest, to produce a micrograph called a karyotype (KER ee uh tipe). A karyotype is shown in the figure below.

Chromosomes of a human cell

1. Apply Examine the karyotype. Are these chromosomes from a male or female?

_____ (No. of chromosome pairs) \times 2 = _____ (No. of chromosomes)
Telomeres

Telomeres are protective caps at the ends of chromosomes. They are made of DNA and proteins. Scientists have discovered that telomeres might be involved in both aging and cancer.

Nondisjunction

During cell division, the chromosomes separate and move to opposite poles of the cell. This ensures that each new cell has the correct number of chromosomes.

Cell division during which sister chromatids do not separate properly is called **nondisjunction**. Nondisjunction does not often occur.

Nondisjunction during meiosis results in gametes that do not have the correct number of chromosomes. When one of these gametes undergoes fertilization, the offspring will not have the correct number of chromosomes. The figure below shows nondisjunction during meiosis. Trisomy (TRI so me) means having a set of three chromosomes. Monosomy (MAH nuh so me) means having only one copy of a chromosome.

2. **Define** What happens during nondisjunction?

3. **Evaluate** Does nondisjunction during meiosis produce any normal gametes? Explain.

---

**Picture This**

3. **Evaluate** Does nondisjunction during meiosis produce any normal gametes? Explain.
How does nondisjunction lead to Down syndrome?

Down syndrome is usually the result of an extra copy of chromosome 21. People with Down syndrome have distinctive facial features, are short, and have heart defects and mental disability. Approximately one out of 800 children born in the United States has Down syndrome. Older women have a greater chance of having a child with Down syndrome.

Does nondisjunction occur with sex chromosomes?

People can inherit incorrect numbers of both autosomes and sex chromosomes. The results of nondisjunction in sex chromosomes are shown in the figure below. A female with Turner’s syndrome has only one sex chromosome. A male with Klinefelter’s syndrome has two X chromosomes and one Y chromosome.

Fetal Testing

A couple with a genetic disorder in the family might want to know if the developing baby, known as a fetus, has the disorder. Older couples might want to know the chromosome number of the fetus. Many fetal tests are available for observation of both the mother and the fetus. Fetal tests can provide important information to the parents and the physician.

Some risk is present in any test or procedure. The physician needs to consider health problems of the mother and the health of the fetus. The physician would not want to perform any tests that might harm the mother or the fetus. Physicians closely monitor the health of the mother and the fetus during testing.

Picture This

4. Label Circle the pictures that show a trisomy in the sex chromosomes.

5. State the purpose of fetal testing.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>XX</th>
<th>XO</th>
<th>XXX</th>
<th>XY</th>
<th>XXY</th>
<th>XY</th>
<th>OY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td><img src="image" alt="XX" /></td>
<td><img src="image" alt="XO" /></td>
<td><img src="image" alt="XXX" /></td>
<td><img src="image" alt="XY" /></td>
<td><img src="image" alt="XXY" /></td>
<td><img src="image" alt="XY" /></td>
<td><img src="image" alt="OY" /></td>
</tr>
<tr>
<td>Phenotype</td>
<td>Normal female</td>
<td>Female with Turner’s syndrome</td>
<td>Nearly normal female</td>
<td>Normal male</td>
<td>Male with Klinefelter’s syndrome</td>
<td>Normal or nearly normal male</td>
<td>Results in death</td>
</tr>
</tbody>
</table>
Before You Read

Imagine that you could design the perfect dog. What color would it be? Would it be big or small? On the lines below, describe the traits your dog would have. In this section, you will learn how selective breeding produces certain traits.

Read to Learn

Selective Breeding

For thousands of years, people have been breeding animals and plants to have certain traits. For instance, some dogs, such as huskies, have been bred to be strong runners. Other dogs, such as Saint Bernards, have been bred to have a good sense of smell.

People have also bred plants, such as tomatoes, apples, and roses, to taste better, resist disease, or produce fragrant flowers. Selective breeding is the process used to breed animals and plants to have desired traits. As a result of selective breeding, desired traits become more common.

What is hybridization?

A hybrid is an organism whose parents each have different forms of a trait. For instance, a disease-resistant tomato plant can be crossed with a fast-growing tomato plant. The offspring of the cross would be a tomato plant that has both traits. The hybrid is disease resistant and grows quickly.

Hybridization is the process of making a hybrid organism. Hybridization is expensive and takes a long time, but it is a good way to breed animals and plants with the right combination of traits.

Create a Quiz

After you read this section, create a five-question quiz from what you have learned. Then, exchange quizzes with another student. After taking the quizzes, review your answers together.

What You’ll Learn

- how inbreeding differs from hybridization
- how to use test crosses and a Punnett square to find the genotypes of organisms

Selecting breeding is used to create animals or plants with certain traits.

Reading Check

1. Name an advantage of hybridization.
   ____________________________________________
   ____________________________________________
   ____________________________________________
How is inbreeding used?

Inbreeding is another example of selective breeding. **Inbreeding** occurs when two closely related organisms that both display the desired trait are bred. Inbreeding can be used to ensure that the desired trait is passed on. Inbreeding can also eliminate traits that are not desired.

Purebred animals are created by inbreeding. Clydesdale horses are an example of a purebred animal. Clydesdale horses were first bred in Scotland hundreds of years ago. They were bred for use as farm horses that could pull heavy loads. All Clydesdales have the traits of strength, agility, and obedience.

A disadvantage of inbreeding is that harmful traits can be passed on. Harmful traits are usually carried on recessive genes. Both parents must pass on the recessive genes for the harmful traits to appear in the offspring. Inbreeding increases the chance that both parents carry the harmful traits.

Test Cross

Breeders need a way to determine the genotype of the organisms they want to cross before creating a hybrid. They use test crosses to find out the genotype of an organism. In a **test cross**, an organism whose genotype for a desired trait is unknown is crossed with an organism that has two recessive genes for the trait.

When are test crosses performed?

An orchard owner might use a test cross to find out the genotype of a white-grapefruit tree. In grapefruits, white color is a dominant trait and red color is a recessive trait. A red-grapefruit tree has two recessive genes (ww). A white-grapefruit tree might have two dominant genes (WW), or it might have one dominant gene and one recessive gene (Ww).

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homozygous dominant (WW)</td>
<td></td>
</tr>
<tr>
<td>Homozygous recessive (ww)</td>
<td></td>
</tr>
<tr>
<td>Heterozygous (Ww)</td>
<td></td>
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How does a test cross reveal the genotype?

The orchard owner decides to do a test cross to find out the genotype of a white-grapefruit tree. The white-grapefruit tree is crossed with a red-grapefruit tree. The orchard owner uses a Punnett square to understand the results of the cross.

The figure below shows a Punnett square for the test cross if the white-grapefruit tree is homozygous, meaning it has two dominant genes (WW). All the offspring from the test cross will be heterozygous, meaning they will have one dominant and one recessive gene (Ww). All the offspring of the test cross are white-grapefruit trees.

What if the test cross involved the heterozygous tree?

The figure below shows a Punnett square for the test cross if the white-grapefruit tree is heterozygous (Ww). Half the offspring from the test cross will be white (Ww). Half the offspring from the test cross will be red (ww).

Picture This

4. **Evaluate** If you planted 100 seeds from this test cross, about how many would be white? How many would be red?

5. **Calculate** If you planted 100 seeds from this test cross, about how many would be white? How many would be red?