11.2 The Hardy-Weinberg Principle

EXPECTATIONS

- **Solve problems related to evolution using the Hardy-Weinberg equation.**
- **Develop and use appropriate sampling procedures to conduct investigations into questions related to evolution.**

For a population to undergo change there must be genetic variation. If all members of a population were genetically identical, all of their offspring would be identical and the population would not change over time. One way to determine how a real population *does* change over time is to develop a model of a population that *does not* change genetically from one generation to the next. Then, actual populations can be compared with this hypothetical model. Such a model was developed independently and published almost simultaneously in 1908 by English mathematician G.H. Hardy and German physician G. Weinberg. These men noted that in a large population in which there is random mating, and in the absence of forces that change the proportions of the alleles at a given locus, the original genotype proportions will remain constant from generation to generation. Their theory is referred to as the **Hardy-Weinberg principle**. In the example shown in Figure 11.7 on page 369, this principle says that the genotypes of 0.49 AA, 0.42 Aa, and 0.09 aa would persist in the mouse population from generation to generation. Because their proportions do not change, the genotypes are said to be in **Hardy-Weinberg equilibrium**.

The Hardy-Weinberg principle is written as an equation. For a gene with two alternative alleles, say A and a, the frequency of allele A (the dominant and, usually, more common allele) is expressed as p, and the alternative allele a (the recessive and, usually, more rare allele) is expressed as q. Because there are only two alleles, $p + q$ must always equal one. The Hardy-Weinberg equation is:

$$\mathbf{p^2 + 2pq + q^2 = 1}$$

where:

p = frequency of dominant allele

q = frequency of recessive allele

p^2 = frequency of individuals homozygous for allele A

$2pq$ = frequency of individuals heterozygous for alleles A and a

q^2 = frequency of individuals homozygous for allele a

Let's apply the Hardy-Weinberg principle to the population of field mice introduced in Figure 11.7. In this population, 70 percent (0.7) of the fur-colour loci in the gene pool have the A allele and 30 percent (0.3) have the a allele. The equation can be applied to see how genetic recombination during sexual reproduction will affect the frequencies of the two alleles in the next generation of field mice. The Hardy-Weinberg principle assumes that mating is completely random and that all embryos will survive. The gametes — sperm and ova — each have one allele for fur colour, and the allele frequencies of the gametes will be the same as the allele frequencies in the parent. Every time a gamete is drawn from the pool at random, the chance that the gamete will bear an A allele is 0.7, and the chance that the gamete will have an a allele is 0.3 (see Figure 11.8). Using the Hardy-Weinberg equation, $p = 0.7$ and $q = 0.3$ ($p + q$ must equal 1).

Figure 11.8 shows the possible scenarios that can result when gametes combine their alleles to form zygotes. The Hardy-Weinberg equation states that the probability of generating an AA genotype is p^2. So, in our population of field mice, the probability of an A sperm fertilizing an A ovum to produce an AA zygote is 0.49 (which is 0.7×0.7).

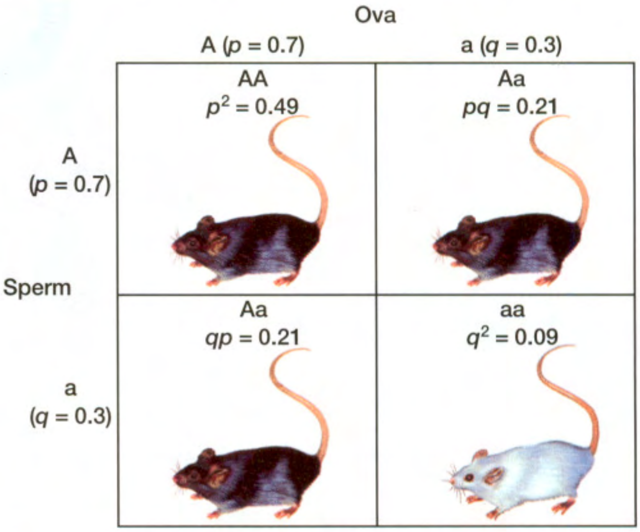

Figure 11.8 The genetic structure of the second generation of field mice

The frequency of individuals homozygous for the other allele (aa) is q^2, or $0.3 \times 0.3 = 0.09$. The genotype Aa can arise in two ways, depending on which parent contributes the dominant allele. Therefore, the frequency of heterozygous individuals in the population is $2pq$ ($2 \times 0.7 \times 0.3 = 0.42$ in our example). All of these possible genotypes add up to 1 ($0.49 + 0.09 + 0.42 = 1$).

The Hardy-Weinberg principle predicts the expected allele and genotype frequencies in idealized populations that are not subjected to selective pressure. Deviations from the frequencies that are expected by the principle indicate that natural selection is occurring. The five conditions required to maintain the Hardy-Weinberg equilibrium are:

- Random mating — Mating must be random with respect to genotype. For example, females cannot select males with a particular genotype or phenotype when they mate.

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Biotechnology and Evolution

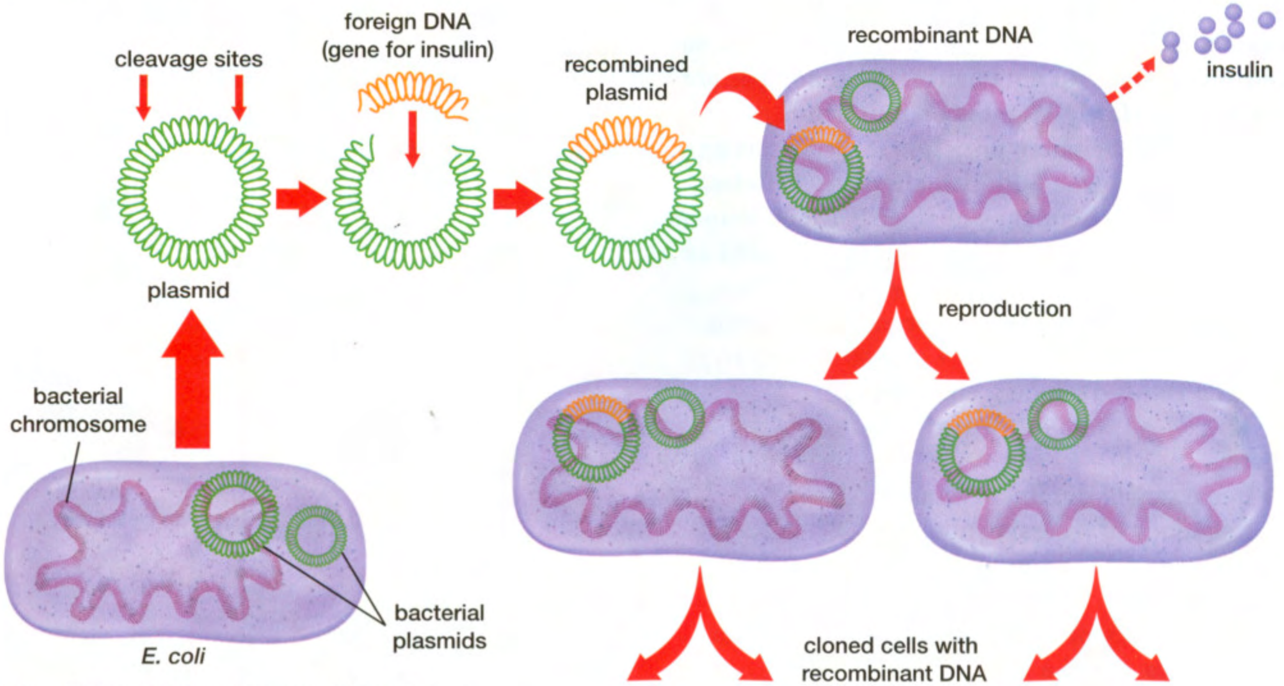
Can technology create new species? This question might bring to mind a scientist putting together bits and pieces from various organisms, like a child making new designs from the parts of a construction toy. Modern biotechnology includes techniques that do make novel combinations of species possible. In many ways, humans have been producing new animals, plants, and micro-organisms for thousands of years.

Charles Darwin himself explained the process of evolution by first describing how livestock, crops, ornamental plants, and pets are developed by artificial selection — breeding only those organisms that have certain desirable inherited characteristics. This early form of reproductive technology gave us cows, chickens, apples, roses, dogs, and many other types of animals and plants previously unknown in nature.

In the twentieth century, other technologies led to the unexpected evolution of new organisms with less desirable characteristics. As farmers added more pesticides to their fields, new forms of resistant weeds and insect pests appeared on farms. As physicians prescribed more antibiotics for their patients, new varieties of antibiotic-resistant bacteria sprang up in hospitals. By adding toxins to the environment, humans unintentionally selected organisms able to survive exposure to the chemicals meant to kill them.

Playing with Genes

The tools of genetic engineering now make it possible to bypass the selection of individual organisms and directly select particular genes with useful characteristics. For example, biotech companies add genes to organisms to give them new traits, such as the ability to produce beneficial enzymes or resist certain herbicides. Unlike



Recombinant DNA can be cloned to produce many copies of a specific segment of DNA.

- No mutations — Alleles must not mutate. In other words, allele choices in the gene pool (as defined in section 10.1) must remain unaltered.
- Isolation — There must be no exchange of genes among populations, since this would alter the gene pool.
- Large population size — The population must be very large.
- No natural selection — No genotype can have a reproductive advantage over another.

These conditions will be explored further in the next section.

In most natural populations, the allele and genotype frequencies *do* change from generation to generation — they are not in Hardy-Weinberg equilibrium since natural populations cannot meet all of the criteria listed above. Therefore, most natural populations are changing. You will explore what causes gene frequencies to deviate from Hardy-Weinberg equilibrium in the next section.

earlier forms of artificial selection, genes from one species can be introduced into other species. For example, one of the earliest applications of genetic engineering created populations of bacteria containing human genes that code for the production of the human insulin molecule. These transgenic bacteria are now the main source of insulin for diabetics.

Many people are concerned that the transfer of genes from one species to another is unnatural. However, gene swapping between species is not entirely a human invention. Different bacteria routinely exchange genetic material by the processes of transformation and conjugation, producing recombinant cells. Viruses also carry genetic material from species to species, even among widely different groups of organisms such as insects and mammals. Because of this ability, viruses are commonly used by molecular biologists.

Another misconception is that transgenic organisms are a type of hybrid, like the result of crossing a lion with a tiger (which has been done in zoos). The offspring of a lion and a tiger have equal genetic contributions from both parents. In contrast, the genetic contribution added to a transgenic organism by genetic engineering is only a tiny fraction of the organism's genome — far less than 1 percent. It is no more of a change in the genome than might be produced by normal random mutation. Even though the change is very small, a directed change can have large impacts on the phenotypes of organisms (for example, the changes made to the genes of people who have certain genetic disorders).

Directed Evolution

The characteristics of each species are determined by their genes. The genes that are of most interest to genetic engineers are those that code for the production of useful molecules such as enzymes and other proteins. These biological molecules have evolved within living organisms over billions of years to perform specific functions. But some of the properties we want enzymes to have for industrial or medical use are not found in any organisms we know of — perhaps because they would clash with the needs of the organism, or because they were never required. For decades, scientists have been applying the principles of evolution to explore a vast universe of novel protein designs that never evolved in nature.

Directed evolution can produce proteins that have capabilities not found in naturally occurring organisms. By speeding up rates of mutation and selection, researchers have created completely new enzymes from purely random pools of DNA sequences in only a few days. For example, one lab increased the catalytic efficiency of an enzyme more than 100-fold by applying random mutagenesis, gene recombination, and screening over a sequence of generations.

As we learn more about the relationships that genes, proteins, and organisms have with their environments, it may be possible to artificially evolve entire organisms. A study of the history of life on Earth shows us that millions of strange and remarkable species have evolved and disappeared. The future will bring new species and new diversity, some of it deliberately introduced by humans but most of it produced by the never-ending process of natural selection.

Follow-up

1. Biotechnology analyzes and manipulates genomes. This makes it seem like each type of organism is simply the product of various molecules working together in a co-ordinated way. Are organisms more than their genes? If so, what else helps define and separate one species from another?
2. The numbers of some rare and endangered animals have been increased by techniques such as cloning and implanting embryos in surrogate mothers of a different species. It is also possible that recently extinct species could be revived by using genetic material from well-preserved specimens. Do you think these techniques might affect the course of evolution?

Practice Problems

1. An investigator has determined that 16 percent of a certain human population *cannot* roll their tongue. The ability to roll the tongue is controlled by a dominant allele. Calculate the genotype and allele frequencies for the population.
2. In a certain population, 30 percent are homozygous dominant, 49 percent are heterozygous, and 21 percent are homozygous recessive. What percentage of the next generation is predicted to be homozygous recessive, assuming a Hardy-Weinberg equilibrium?
3. In a population of pea plants, 1 percent are short, which means they are homozygous recessive. What are the frequencies of the recessive allele t and the dominant allele T? What are the genotypic frequencies in this population?

WEB LINK

www.mcgrawhill.ca/links/biology12

One application of the Hardy-Weinberg equation is to predict how many people in one generation of a human population are carriers of a particular recessive allele. If the number of babies born annually with a particular disease (such as phenylketonuria [PKU] or cystic fibrosis) are known, the number of adults that carry the allele can be predicted. This information can be used to track trends in the conditions, help medical researchers garner support for their work, and help public-health workers allocate their time and resources effectively. To learn more about these diseases and the frequency of these recessive alleles in our population, go to the web site above, and click on **Web Links**. Determine the frequency of the recessive traits for PKU and cystic fibrosis using the Hardy-Weinberg equation.

UNIT PROJECT PREP

For your Unit Project on Searching for a Common Ancestor, consider how new techniques in DNA analysis can help determine relatedness among fossils. How would evolving populations of possible ancestral fossils differ from the Hardy-Weinberg principle?

SECTION REVIEW

1. K/U The Hardy-Weinberg principle is a model that uses a hypothetical situation that would rarely, if ever, be replicated in nature. Explain why it is useful to use the Hardy-Weinberg principle to help understand population genetics.
2. K/U A biologist has found that 10 percent of a population of bats are hairless, which is a recessive trait. Assuming that the population is in Hardy-Weinberg equilibrium, determine the genetic structure (genotype and allele frequencies) of the population.
3. K/U List the conditions necessary to maintain the Hardy-Weinberg equilibrium.
4. K/U Select one condition that is necessary for the Hardy-Weinberg equation to work, and explain why this condition must be met for no change to occur.
5. C A population of flowers are in Hardy-Weinberg equilibrium with 32 white flowers and 168 yellow flowers. The white flowers are bb and the yellow flowers are Bb or BB, where b is recessive and B is dominant. Draw a table showing the phenotypes, genotypes, frequency of the genotypes in the population, and frequency of alleles B and b. Create a Punnett square that shows the potential crosses for this population of flowers.
6. K/U If a plant breeder started selecting either the white or the yellow flowers from Question 5 above, would the population be in Hardy-Weinberg equilibrium?
7. MC Is the human population of North America in Hardy-Weinberg equilibrium? Explain your answer.
8. MC Why would you expect the whooping crane population of North America to not be in Hardy-Weinberg equilibrium?