Chapter 15

Optimizing Food Production

THE MAIN IDEA

Agriculture employs much chemistry.

Λ Genetically engineered golden rice provides nutrients that help prevent blindness.

Each year, about 500,000 children in developing countries become irreversibly blind because of a deficiency of vitamin A. In an effort to stop this tragedy, scientists created a new strain of rice genetically engineered to produce the orange pigment beta-carotene, which the body uses to make vitamin A. The amount of beta-carotene in this rice gives the rice a golden hue. Developing a new strain of a crop to meet our nutritional needs is nothing new. Most of our major crops are the result of centuries, if not millennia, of *selective breeding*, a process whereby organisms that offer more value are selectively bred over ones of less value. What is different about golden rice is that it was created over a single generation by inserting genes from a daffodil and a bacterium into the DNA of a strain of rice.

Provided here is a showcase of the chemistry involved in the production of food, primarily the food derived from plants, which feeds both us and livestock. Along the way, you will be introduced to many of the fundamental concepts of agriculture, such as soil composition, fertilizers, pesticides, and transgenic crops such as golden rice.

15.1 Humans Eat at All Trophic Levels

The formation of food begins with *photosynthesis*, the biochemical process used by plants to create carbohydrates and oxygen from solar energy, water, and atmospheric carbon dioxide:

$$\underset{\text{Carbon dioxide}}{6\,CO_2} + \underset{\text{Water}}{6\,H_2O} \xrightarrow{\text{Sunlight}} \underset{\text{Carbohydrate}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\,O_2}$$

Each day, only about 1 percent of the solar energy reaching the Earth's surface is used in photosynthesis. On a global scale, this is enough to produce 170 billion tons of organic material per year. The energy content in this amount of organic matter is the total annual energy budget for virtually all living organisms.

The route food energy takes through a community of organisms is determined by the community's **trophic structure**, which is the pattern of feeding relationships in the community. Trophic structures, also known as

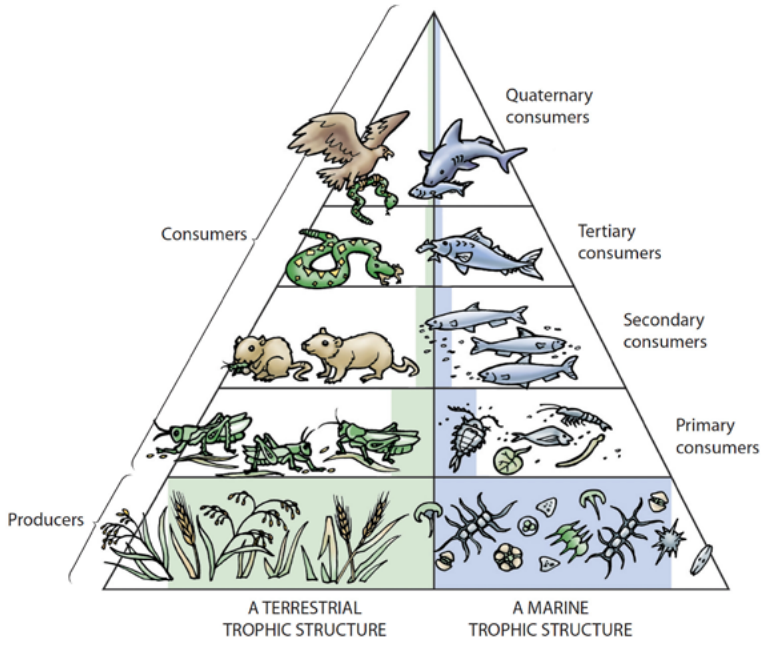

Figure 15.1 >

Terrestrial and marine trophic structures. Energy and nutrients pass through the trophic levels when one organism feeds on another. The shaded blocks represent the amount of energy transferred from one trophic level to the next.

food chains, consist of a number of hierarchical levels, shown in **Figure 15.1**. The first trophic level is producers, most of which are photosynthetic organisms that use light energy to power the synthesis of organic compounds. Plants are the main producers on land. In water the main producers are photosynthetic organisms known as *phytoplankton* (*phyto-* means "plant").

Producers support all other trophic levels, collectively called **consumers**. Organisms that consume producers are *primary* consumers. In terrestrial environments, these are *herbivores* ("grass-eaters"), such as grazing mammals, most insects, and most birds. The primary consumers in aquatic environments are the many microscopic organisms collectively known as *zooplankton*. Above the primary consumers, the trophic levels are made of *carnivores* ("meat-eaters"), each level eating consumers from lower levels. Secondary consumers eat primary consumers, tertiary consumers eat secondary consumers, and quaternary consumers eat tertiary consumers. Any organism that dies before being eaten becomes subject to the action of **decomposers**, organisms that break down organic material into simpler substances that then act as soil nutrients. Common decomposers are earthworms, insects, fungi, and microorganisms.

READING CHECK

What happens to an organism that dies and is not eaten?

With each transfer of energy from one trophic level to the next, there is a significant loss of energy. Typically, not more than10 percent of the energy contained in the organic material of one trophic level is incorporated into the next higher level. The availability of food energy is therefore greatest for the organisms lowest on the food chain. A grasshopper for example, will find many more blades of grass to feed on than a field mouse will find grasshoppers. And the field mouse will find more grasshoppers than a snake will find field mice. This dwindling supply of food resources quickly limits the number of trophic levels, which rarely exceeds the quaternary level. Accordingly, the higher the trophic level, the smaller the possible population of organisms.

We humans eat at all trophic levels. When we eat such things as fruits, vegetables, or the grains shown in **Figure 15.2**, we are primary consumers; when we eat beef or other meat from herbivores, we are secondary consumers. When we eat fish such as trout or salmon, which eat insects and other small animals, we are tertiary or quaternary consumers. Our great and growing numbers, however, are possible only because of our ability to eat as primary consumers.

Eating meat is a luxury. For the people who will eat the chickens shown in **Figure 15.3**, for instance, the amount of biochemical energy they will obtain from eating the chickens is minuscule compared with the amount of biochemical energy used in raising the chickens. In the United States, more than 70 percent of grain production is fed to livestock. Producing meat therefore requires that more land be cultivated, more water be used for irrigation, and more fertilizers and pesticides be applied to croplands. If people in the United States ate 10 percent less meat, the savings in resources could feed 100 million people. As the human population expands, meat consumption will likely become even more of a luxury than it is today.

Λ Figure 15.2

Most people are primary consumers, with a diet consisting primarily of grains.

Λ Figure 15.3

In affluent countries, eating meat is quite common. In the United States, for example, chickens outnumber people almost 2 to 1.

CONCEPT **CHECK**

The orca (killer whale) eats both sharks and phytoplankton-feeding gray whales. In which case is the orca eating at a higher trophic level?

CHECK YOUR ANSWER Sharks feed on fish and marine mammals, which make them secondary, tertiary, or quaternary consumers. Phytoplankton-feeding gray whales, however, are primary consumers. When an orca feeds on a shark, it is eating at a higher trophic level than when it feeds on a gray whale.