10

Agriculture, Biotechnology, and the Future of Food

Chapter Objectives

This chapter will help students:

Explain the challenge of feeding a growing human population

Identify the goals, methods, and consequences of the Green

Revolution Describe approaches for preserving crop diversity

Categorize strategies for pest management

Discuss the importance of pollination

Describe the science behind genetically modified food

Evaluate the debate over genetically modified food

Assess feedlot agriculture for livestock and poultry

Weigh approaches in aquaculture

Evaluate sustainable agriculture

Lecture Outline

I. Central Case: Possible Transgenic Maize in Southern Mexico

A. Corn is a staple grain of the world's food supply. Southern Mexico is a world center of biodiversity for maize, with many locally adapted domesticated varieties, called **landraces**.

B. In 2001, Mexican scientists found DNA in Oaxacan farmers' maize that seemed to match genes from genetically modified corn.

1. To genetically engineer crops, scientists extract genes from the DNA of one organism and transfer them into the DNA of another organism of a different species.

2. The genes are called **transgenes,** and the new organisms are **transgenic** plants.

C. Two researchers collected samples of wild maize and their lab analyses revealed traces of DNA from genetically engineered corn.

D. Their findings were published in *Nature*, but the findings were

disputed and, bowing to criticism, *Nature* stated that the study should never have been published.

E. Further research has confirmed their findings.

F. The question is how (positively and negatively) genetically modified crops may affect people and the environment.

II. The Race to Feed the World

A. We are producing more food per person.

1. We have increased food production by devoting more fossil fuel energy to agriculture; intensifying our use of irrigation, fertilizers, and pesticides; planting and harvesting more frequently; cultivating more land; and developing (through crossbreeding and genetic engineering) more productive crop and livestock varieties.

B. We face undernutrition, overnutrition, and malnutrition.

1. People suffer from **undernutrition**, receiving fewer calories than the minimum dietary energy requirement. Most people who are undernourished live in the developing world.

2. Agricultural scientists and policymakers pursue a goal of **food security**, the guarantee of an adequate, reliable, and available food supply to all people at all times.

3. Those who suffer from **overnutrition** receive too many calories each day.

4. The quality of food is important as well. **Malnutrition** is a shortage of nutrients the body needs, and it can occur in both undernourished and overnourished individuals.

C. The Green Revolution boosted agricultural production.

1. Realizing that farmers could not go on forever cultivating additional land to increase crop output, agricultural scientists devised methods and technologies to increase crop output per unit area of existing cultivated land, called the **Green Revolution.**

2. Many people saw such growth in production and efficiency as key to ending starvation in developing nations.

3. The transfer of technology to the developing world began in 1940 when a specially bred wheat species was introduced to Mexico.

4. Soon many developing countries were doubling, tripling, or quadrupling their yields using selectively bred strains of wheat, rice, corn, and other crops from industrialized nations.

D. The Green Revolution brought mixed consequences.

1. Developing countries imported the methods of industrialized agriculture such as the use of synthetic fertilizers, chemical

pesticides, irrigation, and heavy equipment.

2. This high-input agriculture was dramatically successful at allowing farmers to harvest more corn, wheat, rice, and soybeans from each hectare of land.
3. Between 1961 and 2008, food production rose 150% and population rose 100%, while area converted for agriculture increased only 10%.
4. Green revolution techniques have had negative consequences for biodiversity and mixed consequences for crop yields. The intensive use of water, fossil fuels, and chemical fertilizers and pesticides has had extensive negative impacts in terms of pollution, salinization, and desertification.
5. The planting of **monocultures**, large expanses of single-crop types, has made planting and harvesting more efficient, but has reduced biodiversity and increased the susceptibility of entire crops to disease, pathogens, and insect pests. This brings the risk of catastrophic failure.
6. Monocultures have also contributed to a narrowing of the human diet. This has nutritional and biodiversity dangers.

E. Biofuels affect food supplies.

1. **Biofuels** are fuels derived from organic materials. They are used in internal combustion engines as replacements for petroleum.
    a. In the United States, **ethanol** made from corn is the primary biofuel.
2. The world realized belatedly that growing crops for biofuels could compete directly with growing food for people to eat.

III. Preserving Crop Diversity

A. Crop diversity insures against failure.

1. Because accidental interbreeding can diminish the diversity of local variants, many scientists argue that we need to protect landraces in areas that remain important repositories of crop biodiversity, as in southern Mexico.
2. Over the past century, we have already lost a great deal of genetic diversity in crops worldwide.

B. Seed banks are living museums.

1. The most renowned **seed bank** is the so-called "doomsday seed vault" that opened in 2008 on the island of Spitsbergen in Arctic Norway. The internationally funded Svalbard Global Seed Vault is storing millions of seeds from around the world (spare sets from other seed banks) as a safeguard against global agricultural calamity——an insurance policy for the world's food supply.

IV. Pests and Pollinators

A. We have developed thousands of chemical pesticides.

1. Throughout the history of agriculture, pests have taken advantage of our clustering of food plants into agricultural fields.
2. A *pest* is any organism that damages crops that are valuable to us. A *weed* is any plant that competes with our crops. These are subjective categories defined entirely by our own economic interests.
3. Poisons that target pest organisms are called **pesticides**. Over 900 million pounds of the active ingredients of pesticides are applied in the United States each year.

B. Pests evolve resistance to pesticides.

1. Industrial chemists are caught up in an evolutionary arms race with the pests they battle, racing to increase or retarget the toxicity of their chemicals while the armies of pests evolve ever-stronger resistance to their efforts.
2. Pesticides often kill non-target organisms, including the predators and parasites of the pests. When these valuable natural enemies are eliminated, pest populations become that much harder to control.

C. **Biological control** pits one organism against another.

1. Biological control, or **biocontrol**, operates on the principle that "the enemy of one's enemy is one's friend." We find natural enemies, or predators, of a species we consider a pest and introduce them to an area where the pests are a problem.

D. Biological control agents themselves can become pests.

1. Scientists argue over the relative benefits and risks of biocontrol measures.

E. Integrated pest management combines biocontrol and chemical methods.

1. **Integrated pest management (IPM)** uses numerous techniques, including biocontrol, chemicals, population monitoring, habitat alteration, crop rotation, transgenic crops, alternative tillage methods, and mechanical pest removal.

F. We depend on insects to pollinate crops.

1. **Pollination** is the process by which male sex cells of a plant (pollen) fertilize female sex cells of the same species of plant; it is the botanical version of sexual intercourse.
2. While our staple grain crops are grasses that are wind-pollinated, many of our other crops depend on insects for pollination.
3. Populations of native pollinators have declined precipitously.

G. Conservation of pollinators is vital.

1. Preserving the biodiversity of native pollinators is especially important today because the domesticated workhorse of pollination, the honeybee *(Apis mellifera)*, is also declining.
2. Parasitic mites have been devastating the hives of these bees in recent years. In each of the last several years, up to one-third of all honeybees in the United States have vanished from what is being called *colony collapse disorder*.
3. Farmers and homeowners can help maintain populations of pollinators by reducing or eliminating pesticide use.

V. Genetically Modified Food

A. Genetic modification of organisms depends on **recombinant DNA.**

1. **Genetic engineering** is any process in which scientists directly manipulate an organism's genetic material in the lab by adding, deleting, or changing segments of DNA.
2. **Genetically modified (GM) organisms** have been genetically engineered using recombinant DNA technology, developed in the 1970s by scientists studying the *Escherichia coli* bacterium.
3. The creation of transgenic organisms is one type of **biotechnology**, which is the material application of biological science to create products derived from organisms.

B. Genetic engineering is like, and unlike, traditional breeding.

1. The genetic alteration of plants and animals by humans is nothing new.
2. However, the new techniques mix genes of different species in the lab, involving experiments with genetic material apart from the organism, creating novel combinations never to be found in nature.

C. Biotechnology is transforming the products around us.

D. What are the benefits and impacts of GM crops?

1. Some fear the new foods might be dangerous. Others are concerned that transgenes might escape and pollute ecosystems and damage nontarget organisms. Still others worry that pests would evolve resistance to the supercrops and become "superpests," or that transgenes would be transferred from crops to other plants, ruining the integrity of native crops.
2. Supporters of GM crops maintain that transgenic crops are beneficial for the environment. Reasons include using less pesticide, no ill health effects to humans, and encouraging no-till

farming.

3. Some say that we should adopt the **precautionary principle** and not undertake a new action until the ramifications of that action are well understood.
4. Studies thus far have shown no clear answers to questions about the impacts of GM crops.

E. Debate over GM foods involves more than science.

1. Ethical issues have played a large role in the debate over GM foods because the idea of "tinkering" with the food supply seems dangerous or morally wrong.
2. The perceived lack of control over one's own food has caused concern about a few large businesses dominating the global food supply.
3. So far, GM crops have not lived up to their promise of feeding the world's hungry.
    a. Most crops have been engineered to express pesticidal properties or herbicide tolerance—the herbicides are often manufactured and sold by the same companies.
    b. Crops with traits that might benefit poor farmers in developing countries have not been developed, perhaps because corporations have little economic incentive to do so.
4. Public relations has played a role.
    a. In Canada, Monsanto has been engaged in a high-publicity battle with a third-generation Saskatchewan farmer, Percy Schmeiser.
    b. European consumers have expressed widespread unease about possible risks of GM technologies.
    c. Transnational spats between Europe and the United States will surely affect the future direction of agriculture.
    d. Brazil, India, and China are now aggressively pursuing GM crops, even as ethical, economic, and political debates over the costs and benefits of these foods continue.

VI. Raising Animals for Food, Livestock, Poultry, and Aquaculture

A. Consumption of animal products is growing.

1. The world population of domesticated animals raised for food rose from 7.2 billion animals to 24.9 billion animals between 1961 and 2008. Most of these animals are chickens.
2. Global meat production has increased fivefold since 1950, and per- capita meat consumption has doubled.

B. Our food choices are also energy choices.

   1. Eating meat is far less energy-efficient than relying on a vegetarian diet, and it leaves a far greater ecological footprint.
   2. Producing eggs and chicken requires the least space and water, whereas producing beef requires the most.
   3. Such differences make clear that when we choose what to eat, we are also indirectly choosing how to make use of resources such as land and water.

C. High consumption has led to feedlot agriculture.

   1. **Feedlots**, or factory farms, are operations in which animals are housed in huge warehouses or pens where energy-rich food is provided to the animals that are living in extremely high densities.
   2. Animals that are densely concentrated in feedlots will not contribute to overgrazing and soil degradation.
   3. Waste from feedlots can emit strong odors, and can pollute surface water and groundwater.
   4. Feedlot impact can be minimized when properly managed.

D. Livestock agriculture pollutes water and air.

   1. Localized concentrations of pollution is the most noticeable environmental impact of feedlots.
   2. Livestock produce prodigious amounts of manure and urine, and their waste can pollute surface water and groundwater.
   3. Moreover, the crowded and dirty conditions under which animals are often kept necessitate heavy use of antibiotics to control disease.
   4. Feedlot impacts can be minimized when properly managed, and both the EPA and the states regulate U.S. feedlots.
   5. Raising animals for food also results in air pollution.

E. We also raise fish on "farms."

   1. Raising fish and shellfish on "fish farms" in controlled environments is **aquaculture**; it may be the only way to meet the demand for these foods because most fisheries are overharvested.

F. Aquaculture brings benefits.

   1. Aquaculture provides a reliable source of protein for developing countries.
   2. On a small scale, aquaculture is sustainable and is compatible with other activities.
   3. On a large scale, aquaculture helps improve a nation's food security.
   4. Aquaculture reduces fishing pressures on wild stocks.

5. Aquaculture relies far less on fossil fuels than do fishing vessels, and is very energy-efficient.
6. Aquaculture provides a safer work environment than does commercial fishing.

G. Aquaculture has negative impacts.

1. The dense concentrations of farmed animals can increase the incidence of disease and necessitates the use of antibiotics.
2. Aquaculture can also produce large amounts of waste, both from the organisms being farmed and from uneaten feed.
3. The escape of farmed animals into the environment can have negative consequences such as spreading disease, outcompeting native species, and introducing new genetic material to a native population.

VII. Sustainable Agriculture

A. We are moving toward sustainable agriculture.

1. **Sustainable agriculture** is farming that does not deplete soils faster than they form and does not reduce the amount of healthy soil, clean water, and genetic diversity essential to long-term crop and livestock production.
2. *Low-input agriculture* is farming that uses smaller amounts of pesticides, fertilizers, growth hormones, water, and fossil fuel energy than is used in industrial agriculture.
3. Food growth practices that do not use synthetic fertilizers or pesticides are often termed **organic agriculture**.

B. Organic approaches reduce inputs and pollution.

1. In 1990, the U.S. Congress passed the Organic Food Production Act, which established national standards for organic products and facilitated the sale of organic food.
2. For farmers, organic farming can bring the benefits of lower input costs, enhanced income from higher-value produce, and reduced chemical pollution and soil degradation.
3. Farmers face obstacles to adopting organic methods. There are the risks and costs of shifting to new methods, particularly during the transition period, as U.S. farmers need to meet standards for three years before they can be certified.
4. Many consumers favor organic food out of concern that the pesticides, hormones, and antibiotics used in conventional agriculture pose health risks.

5. The main obstacle to adopting organic food for consumers is price.

C. Organic agriculture is booming.

1. Government initiatives have spurred the growth of organic farming.

D. Locally supported agriculture is growing.

1. The average food product sold in U.S. supermarkets travels at least 1,400 miles between the farm and the shelf, and is often chemically treated to preserve freshness and color.
2. At **farmers' markets**, consumers buy meat, fresh fruit, and vegetables in season from local producers.
3. Some consumers are even partnering with local farmers in a phenomenon called **community-supported agriculture (CSA)**. In a CSA program, consumers pay farmers in advance for a share of their yield, usually a weekly delivery of produce.

E. Sustainable agriculture mimics natural ecosystems.

1. Treating agricultural systems as ecosystems is a key aspect of sustainable agriculture, and this general lesson applies regardless of location, scale, or the crop involved.

VIII. Conclusion

A. Many of the intensive agricultural practices discussed have substantial negative environmental impacts, but have positive impacts as well.

B. If we are to support 9 billion people, we must make a shift to more sustainable agriculture.

Key Terms for Chapter 10

aquaculture
bacillus thuringiensis (Bt)
biofuels
biological control (biocontrol)
biotechnology
Borlaug, Norman
community supported agriculture (CSA)
ethanol
farmers' markets
feedlots
food security
genetic engineering
genetically modified (GM) organisms
Green Revolution
integrated pest management (IPM)
landraces
malnutrition
monocultures
organic agriculture
overnutrition
pesticides
pollination
precautionary principle
recombinant DNA
seed banks
sustainable agriculture
transgenes
transgenic
undernutrition