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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 environmental impacts of the “green revolution”
- Categorize the strategies of pest management
- Discuss the importance of pollination
- Describe the science behind genetically modified food
- Evaluate controversies and the debate over genetically modified food
- Ascertain approaches for preserving crop diversity
- Assess feedlot agriculture for livestock and poultry
- Weigh approaches in aquaculture
- Evaluate sustainable agriculture

Lecture Outline

I. Central Case: Possible Transgenic Maize in Oaxaca, Mexico

- A. Corn is a staple grain of the world’s food supply, and today Oaxaca, Mexico, is a world center of biodiversity for maize, with many native varieties, or *cultivars*.
- 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 genetically modified crops may affect people and the environment.

II. The Race to Feed the World

- A. Agricultural production has outpaced population increase so far.
 1. 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.
 2. Starting in the 1960s, a number of doomsayers predicted widespread starvation and catastrophic failure of agricultural systems.
 3. Instead, we have achieved dramatic increases in our carrying capacity, in part by increasing our ability to produce food.
 4. This has occurred because we have devoted more energy (especially fossil fuel energy) to agriculture; increased the use of irrigation, fertilizer, and pesticides; increased the amount of cultivated land; and developed (through crossbreeding and genetic engineering) more productive crop and livestock varieties.
- B. We face undernourishment, overnutrition, and malnourishment.
 1. While some people do not have access to enough food to stay healthy, others are affluent enough to consume far more than is healthy.
 - a. Those who are **undernourished** receive less than 90% of their daily caloric needs.
 - b. Those who suffer from **overnutrition** receive too many calories each day.
 2. The quantity of food a person eats is important for health, but 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.
 3. One-fifth of the world's people live on less than \$1 per day, and over half live on less than \$2 per day, according to the World Bank.
 4. *Kwashiorkor* results from a high-starch diet with little protein.
 5. *Marasmus* is caused by a combination of protein deficiency and lack of calories.
- C. The "**green revolution**" led to dramatic increases in agricultural production.
 1. Farmers in the United States had been dramatically increasing their yields using new methods and technology, and many people saw this as a way to end starvation in developing nations.

2. The transfer of technology to the developing world began in 1940 when a specially bred wheat species was introduced to Mexico.
 3. Some varieties of crops yielded three or four times as much per acre as did the older varieties.
- D. The green revolution has caused the environment both benefit and harm.
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. From 1900 to 2000, humans expanded the world's total cultivated area by 33%, yet increased energy inputs into agriculture by 80 times.
 4. The 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 caused increased susceptibility of an entire crop to disease, pathogens, or insect pests. This brings the risk of catastrophic failure.
 6. Monocultures have also contributed to a narrowing of the human diet. This has nutritional dangers as well as biodiversity dangers.

III. Pests and Pollinators

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, and a *weed* is any plant that competes with our crops. These are subjective categories defined entirely by our own economic interests.
- A. Many thousands of chemical **pesticides** have been developed and applied.
1. 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.
- 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 may become pests.
1. Scientists argue over the relative benefits and risks of biocontrol measures.

2. A widespread modern biocontrol effort has been the use of ***Bacillus thuringiensis (Bt)***, a naturally occurring soil bacterium that produces a protein that kills many caterpillars and the larvae of some flies and beetles.
- 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 many of our 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.
- G. Conservation of pollinators is vital.
1. North American farmers today are dependent on European honeybees for much of their pollination. Parasitic mites have been devastating the hives of these bees in recent years.
 2. Native pollinators are often more effective than European honeybees, but they are kept from plants by the more aggressive honeybees.
 3. All insect pollinators are vulnerable to the vast arsenal of insecticides that are applied to crops in modern agriculture.
 4. There are ways that everyone can help to maintain populations of pollinating insects. Planting flowering plants that nourish pollinating insects and providing nesting sites for native bees can help to maintain a diverse community of insects.

IV. Genetic Modification of Food

- A. Genetic modification of organisms depends on **recombinant DNA**.
1. **Genetic engineering** is any process whereby scientists directly manipulate an organism's genetic material in the lab by adding, deleting, or changing segments of DNA.
 2. **Genetically modified (GM) organisms** are organisms that have been genetically engineered using recombinant DNA technology, developed in the 1970s by scientists studying the *Escherichia coli* bacterium.
 3. When scientists use recombinant DNA technology to develop new varieties of crops, they often can introduce the recombinant DNA directly into a plant cell and then regenerate an entire plant.
 4. The creation of transgenic organisms is one type of **biotechnology**, the material application of biological science to create products derived from organisms.
- B. Genetic engineering is like, and unlike, traditional agricultural breeding.
1. The genetic modification of organisms 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.
- C. Biotechnology is transforming the products around us.
- D. What are the impacts of GM crops?
1. Some feared the new foods might be dangerous. Others were concerned that transgenes might escape and pollute ecosystems and damage nontarget organisms. Others worried 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 races of crops.
 2. We still don’t know the answers to these questions, and some say that we should adopt the **precautionary principle** and not undertake a new action until the ramifications of that action are well understood.
 3. 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 the domination of the global food supply by a few large businesses.
 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 less 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. Some countries are approving GM crops, with China aggressively expanding the use of transgenic crops, while other nations refuse to allow any GM foods or seeds within their borders. Zambia refused United States food aid during a drought in 2002, worried that farmers would plant some of the GM corn seed rather than eat it and that GM corn would then establish itself within the country.

V. Preserving Crop Diversity

- A. Crop diversity provides insurance against failure.

1. Monoculture cropping places food systems at risk should one catastrophic event wipe out the entire crop variety.
2. Wild and domestic relatives of crop plants contain genes that can reinvigorate crops by conferring disease, pest, or drought resistance.
3. Because accidental interbreeding can decrease the diversity of local variants, scientists argue that we need to protect areas like Oaxaca.
4. Many fruit and vegetable crops in the United States have decreased in diversity by 90% in less than a century.
5. A primary cause of this loss of biodiversity is that market forces have discouraged diversity in the appearance of fruits and vegetables.

B. Seed banks are living museums for seeds.

1. In seed banks, or **gene banks**, institutions store seeds from crop varieties, keeping them in cold, dry conditions to encourage long-term viability.
2. Large seed banks include the U.S. National Seed Storage Laboratory, the Royal Botanic Garden's Millennium Seed Bank in Britain, Seed Savers Exchange in Iowa, and the Wheat and Maize Improvement Center (CIMMYT) in Mexico.

VI. Feedlot Agriculture: Livestock and Poultry

A. Consumption of animal products is growing.

1. The world population of domesticated animals raised for food tripled between 1961 and 2000. Most of these animals are chickens.
2. Per capita meat consumption around the world nearly doubled between 1950 and 2000.

B. 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 living at 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 impacts can be minimized when properly managed.

C. Our food choices are also energy choices.

1. The lower in the food chain our food sources are, the greater the proportion of the sun's energy we put to use as food, and the more people Earth can support.
2. Producing eggs and chicken meat requires the least space and water, while 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.

VII. Aquaculture

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.

- A. Aquaculture brings a number of 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.
- B. Aquaculture has negative environmental 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 including spreading disease, outcompeting native species, and introducing new genetic material to a native population.

VIII. 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 use no synthetic fertilizers or pesticides are often termed **organic agriculture**.
- A. Organic agriculture is on the increase.
 - 1. In 1990, the U.S. Congress passed the Organic Food Production Act that established national standards for organic products and facilitated the sale of organic food.
 - 2. Long viewed as a small niche market, the market for organic foods is on the rise, although it accounts for only 1% of food expenditures.
 - 3. Production is increasing along with demand, although organic agriculture takes up less than 1% of cultivated land worldwide.
 - 4. These trends have been fueled by the desire of many consumers to reduce health risks in their diets and to support improving environmental quality.
 - 5. Government initiatives have also spurred the growth of organic farming.
 - B. Locally supported agriculture is growing.
 - 1. Farmers' markets are more numerous as consumers rediscover the joys of fresh, locally grown produce.

2. 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.
- C. Cuba has embraced organic agriculture.
1. Cuba suffered economic and agricultural upheaval upon the dissolution of the Soviet Union because it lost 75% of its imports.
 2. With far less oil available, farmers began growing food closer to cities and even within them.
 3. In addition, Cuban farmers are now using oxen and integrated pest management.
- D. Organic and sustainable agriculture will likely need to play a large role in our future.

IX. Conclusion

- A. Many of the intensive agricultural practices discussed have substantial negative environmental impacts, but have positive impacts as well.
- B. It is certain that if we are to support nine billion people we must make a shift to more sustainable agriculture.
- C. The extent to which individuals, governments, and corporations will be able to put their own interests and agendas in perspective to work together toward a sustainable future remains to be seen.