

# 2

## Food Safety and Agricultural Medicine

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Food safety and security are important public health issues for agriculture and other food production sectors. As the global population continues to grow past 6 billion, food safety, food insecurity, and hunger remain major problems in the world. Hunger and malnutrition are the primary risk to global health, killing more people than AIDS, malaria, and tuberculosis combined by claiming 10 million lives each year, 25,000 lives each day, and one life every 5 seconds (1–3).

Sustaining the growing world population with adequate and safe food and water supplies is the major global nutritional and public health priority for the 21st century. To meet this challenge, the 53rd World Health Assembly, the governing body of the World Health Organization (WHO), adopted a resolution in May 2000 calling upon WHO and its member nations to recognize food safety as an essential public health function. In addition, WHO has made food safety one of its top 11 priorities and calls for more systematic and aggressive steps to significantly reduce the risk of microbial foodborne illnesses. This will require major redirections of food microbiology efforts and cooperation on a global scale (2,3).

To decrease the risk of microbial foodborne illnesses, the main methods of increasing food safety use pesticides and chemicals, food irradiation, and combined nonthermal technologies. Newer agricultural methods of genetically modified foods and organic farming have been advanced as ways of increasing global food supply while reducing the use of chemicals and pesticides. Organic farming has been popular over the past decade but may pose some risks for food safety.

Although these technological advances help increase food safety and supply, they may have potential occupational effects on agricultural workers and on the environment. This chapter briefly reviews the history of food safety, discusses the sources of risk for food safety, reviews the main methods currently used for ensuring food safety, and highlights potential occupational consequences of these methods for agricultural workers. Evolving potential threats to food safety from bioterrorism and agroterrorism are also discussed.

## Brief History of Food Safety and Agriculture

Agriculture has evolved since humans first domesticated plants such as corn more than 6000 years ago. Although current agricultural practices vary worldwide, in the United States and developed countries agriculture has become increasingly industrialized since the 1940s and 1950s, resulting in more efficiency and production on the farm. Mechanical inventions such as the self-propelled combine reduced the need for manual labor and encouraged the production of grain commodities, which led to the practice of monocropping or monoculture, as farmers began to focus on growing the most profitable crops such as corn, soy, and wheat. Though profitable, monocropping reduced the previous soil-enriching practices of crop rotation and livestock grazing, making agriculture more dependent on synthetic or petroleum-based fertilizers in place of natural manure for amending the soil. Furthermore, although arsenic and lead-based pesticides had been used widely since the late 1800s, new pesticide formulations came on the market during the agricultural boom of the mid-20th century. These included methylbromide, a fumigant once widely applied to soil and crops to kill insects and weeds that was approved for use in 1947, atrazine, a herbicide approved in 1959, and chlorpyrifos, an organophosphate pesticide approved for use in 1965. Since the 1960s, pesticide use in the United States has more than tripled. Despite the ban on several toxic pesticides, like the organochlorines in the United States over the past several years, currently more than 1 billion pounds of agricultural pesticides are still purchased each year in the United States. Globally, pesticide use also has increased, and the type used, amount, and regulations vary regionally (4–6).

Since 1962, the Codex Alimentarius Commission (CAC) of the Food and Agricultural Organization of WHO has been responsible for developing standards, guidelines, and other recommendations on the quality and safety of food to protect the health of consumers and to ensure fair practices in food trade. In the United States, various regulations exist to enhance food safety. Early actions of the U.S. Department of Agriculture (USDA) culminated in the passage of the 1906 Food and Drug Act that helped increase food safety for the public. In 1910, the Insecticide Act established product-labeling provisions. The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947 required registration of pesticide products with the USDA prior to domestic or foreign sales. The Federal Food, Drug, and Cosmetics Act that evolved from the 1906 statute was expanded in 1954 by the Miller Amendment that established pesticide tolerances in or on agricultural commodities based primarily on good agricultural practices. The Delaney Clause of 1958 prohibited use of any carcinogenic food additive in processed foods. Subsequently, regulatory authority was enhanced by creation of the U.S. Environmental Protection Agency (EPA) in 1970 and an additional 1972 FIFRA amendment that required manufacturers to demonstrate that use of a product “would not cause adverse effects on human health or the environment” (7–9).

Recurrent outbreaks of food and water diseases have highlighted the importance of sustaining safe food and water supplies. In response to threats to food safety, the United States government and other entities have made several changes in the United States food safety regulatory structure. These include implementation by USDA of the Pathogen Reduction: Hazard Analysis Critical Control Point (HAACP) in 1995, Final Rule for Meat and Poultry (from USDA's Food Safety and Inspection Service (FSIS), creation of FoodNet (a sentinel surveillance system for active collection of foodborne disease surveillance data), creation of PulseNet (a national molecular subtyping network for foodborne bacterial disease surveillance), and revisions to the Food Code and the National Primary Drinking Water Regulations (10–12).

## Threats to Food Safety

Despite regulations and increasing awareness, food supplies continue to be at risk from contamination by microbial pathogens and chemicals used to control pests. Food handlers are another potential source of foodborne illness if they do not practice good hygiene when handling food items.

### *Microbial Contamination of Food*

Foodborne illnesses remain a major risk globally. Each year, unsafe food makes at least 2 billion people ill worldwide, which is about one third of the global population. Furthermore, food- and waterborne diarrheal diseases are leading causes of illness and death in less developed countries, killing approximately 1.8 million people annually, most of whom are children. Obtaining accurate estimates of the incidence of specific microbial foodborne illnesses is often difficult in many areas of the world. A population-based study in the Netherlands estimated a total annual incidence of gastroenteritis to be 28%, without attributing the degree of foodborne or microbiological etiology. In the United States, it has been estimated that 76 million cases of foodborne diseases may occur each year, resulting in 325,000 hospitalizations and 5000 deaths. Important sources of foodborne pathogens include contaminated produce and improperly cooked, handled, or stored meat and poultry products. Major pathogens in foodborne diseases worldwide include salmonella, campylobacter, *Escherichia coli* 0157, cholera, and listeriosis. Furthermore, microbial and chemical sources can pose significant health risks for certain vulnerable populations such as the elderly, children, pregnant women, those in institutionalized settings, and the immunocompromised (13–21).

Milk and meat obtained from infected animals is another threat to food safety. Important zoonotic foodborne illnesses worldwide are tuberculosis due to *Mycobacterium bovis*, *Campylobacter* spp., verotoxigenic *E. coli*, and *Brucella abortis* from ingestion of contaminated, raw unpasteurized milk.

Farmers, farm families, and visitors to farms should be advised about the risks associated with the consumption of unpasteurized milk from any animal species. *M. bovis* infection in humans has also been reported to occur after consumption of contaminated meat (22).

To reduce the global burden of foodborne illnesses, the WHO and the Food and Agricultural Organization of the United Nations released the Five Keys Strategy on October 13, 2004, in Bangkok, Thailand at the second Global Forum of Food Safety Regulators. The five simple measures consist of:

1. Keeping hands and cooking surfaces clean.
2. Separating raw and cooked food.
3. Cooking food thoroughly.
4. Keeping food stored at safe temperatures.
5. Using safe water and raw ingredient(s) (13).

Other methods recommended by WHO in the past include eating cooked food immediately, reheating cooked food thoroughly, keeping all kitchen surfaces meticulously clean, and protecting food from insects, rodents, and other animals (23).

### *Agricultural Workers as Vectors for Foodborne Illness*

Occupational health and hygiene during the course of handling food items should be a top priority for food safety. However, agricultural workers and food handlers are potential vectors of foodborne illnesses when handling food items in the course of customary work practices. Many agricultural practices, such as harvesting, are labor-intensive operations involving direct human contact with fresh produce. In fact, humans and animals are major sources of pathogens in our food supply. Major pathogens such as *E. coli* 0157.H7, *Salmonella* spp., *Shigella* spp., *Staphylococcus aureus*, *Giardia lamblia*, and *Cryptosporidium parvum* can often be traced back to human or animal sources. Hepatitis A outbreaks have also occurred via food contaminated by infected food handlers in several areas worldwide (24–28).

Prevention is the mainstay to decrease morbidity from spread of transmissible diseases by food handlers. In the United States, food preparation and service regulations are issued by state health departments and may vary from state to state. For instance, routine hepatitis A vaccination of all food handlers is not recommended because their profession does not put them at higher risk for infection. However, local regulations mandating proof of vaccination for food handlers or offering tax credits for food service operators who provide hepatitis A vaccine to employees has been implemented in some areas. One economic analysis concluded that routine vaccination of all food handlers would not be economical from a societal or restaurant owner's perspective. However, the Centers for Disease Control and

Prevention (CDC) in the United States have supported use of the hepatitis A vaccine among dietary workers who may be at risk for contracting or spreading the disease (29–31).

The CDC has also supported screening for tuberculosis (TB) in high-risk groups such as foreign-born or recent immigrants from outside the United States. Screening of food handlers for TB has been found to be cost-effective in high-risk populations. However, this recommendation is to identify high-risk individuals who may be candidates for preventive treatment for latent TB and not to protect the public from contaminated food as *Mycobacterium tuberculosis* is not transmitted through food (32–35).

The WHO does not recommend routine medical and microbial screening of agricultural workers and food handlers. However, workers suffering from an illness that includes symptoms such as jaundice, diarrhea, vomiting, fever, sore throat, skin rash, or skin lesions such as boils or cuts should report this to their supervisor prior to starting work and should be temporarily excluded from activities requiring food handling (23,36).

Good worker hygiene practices during production, harvest, and food-handling activities can help prevent or minimize microbial contamination of food. Simple preventive practices such as teaching employees how to effectively wash their hands (i.e., wet the hands, use soap, rub hands together for at least 20 seconds to develop a lather, clean under fingernails, rinse, and dry with a paper towel) and when to wash hands (i.e., before starting to pack or process, after each break, after handling unsanitary items such as decayed produce, and after using the toilet facilities) are recommended. Other useful strategies include prohibiting workers from smoking or eating in the fields, where saliva could accidentally be sprayed on produce, and encouraging use of impermeable, nonlatex gloves when handling fresh produce. Multilingual signs and direct communication between supervisor and employee are also important (24).

### *Food Contamination from Pesticides and Chemicals*

Pesticides, herbicides, fungicides, and other chemicals have been used globally for decades to increase food supply and eliminate pests. Data on worldwide pesticide sales and use are remarkably difficult to find, and survey results from countries are often not reliable. The EPA estimates that each year domestic users in the United States spend \$8.5 billion for 1.1 billion pounds of pesticides active ingredients. Many of the banned or withdrawn pesticides from developed countries are still produced and sold in developing countries or by some multinationals acting through subsidiaries or joint ventures. These include DDT and other persistent organochlorine (OC) insecticides, which represent about 15% of the sales in regions outside the United States, Western Europe, and Japan. Estimates indicate that 70,000 to 80,000 tons of these compounds were applied in 1995 in developing and formerly socialist countries (Table 2.1) (37–39).

TABLE 2.1. Regulatory status of some organochlorine pesticides in different countries.

	U.S.	China	India	Mexico	U. K.	Canada
DDT	B	R	R	R	B	Not registered
Aldrin	B	Not banned	Not banned	B	B	Not registered
Dieldrin	B	Not banned	R	B	B	Not registered
Endrin	B	Not banned	Not registered	B	B	Not registered
Heptachlor	(R)	Not banned	Not banned	Not registered	B	Not registered
Hexachloro- benzene	B				B	Not registered
Mirex	B	R		R		Banned
Toxaphene	B	Not banned	B	B	B	Not registered

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Note: Blank spaces above indicate no available data.

R, registered; B, banned; (R), restricted.

Banned pesticides have recently been reintroduced into certain environments such as DDT sprayed in several areas of Africa as a preventive measure against malaria. Older and more toxic organophosphate (OP) and carbamate insecticides and herbicides also have very significant sales in the Third World (e.g., alachlor, aldicarb, benomyl, captan, carbofuran, chlor-dane, cyanazine, dimethoate, endosulfan, EPN, mancozeb, lindane, monocrotophos, paraquat, parathion, toxaphene, zineb, carbaryl, atrazine, glyphosate, 2-4-D, dichlorovos, phorate, and many others). In developing countries, these pesticides are still preferred by the small farmers because they are less costly, easily available, and display a wide spectrum of bioactivity. Globally, OPs account for nearly 40% of total insecticide sales by volume, followed by carbamates (20.4%), pyrethroids (18.4%), and others (6.1%) (5,6,40).

Persistent pesticides travel through the air, soil, and water into living tissues where they can bioaccumulate up the food chain into human diets. In fact, it has been estimated that approximately 85% to 90% of pesticides applied agriculturally never reaches the target pest organisms but disperses through the air, soil, and water. As an example, the half-life of toxaphene in soil is up to 29 years (5,41,42).

Humans bioaccumulate organochlorine and metal-containing pesticides in their body fat, where they tend to stay unless the fat is metabolized for energy, such as during an illness. For example, in Latin American countries, the pattern of residues found in human body tissues consisted of high levels of DDT and its metabolites, followed by benzene hexachloride (BHC), dieldrin, heptachlor epoxide, and hexachlorobenzene (HCB). Interestingly, these organochlorines were also found in people's body tissues in 22 Third World and formerly socialist countries. Furthermore, food standards in developing countries are typically not as well regulated as those in industrialized

countries, and pesticide residues are frequently found on agricultural products. For instance, in Brazil, pesticide residues in 13.6% of fruits and 3.7% of vegetables exceeded tolerance limits (5,43,44).

Although less is known of the toxicological consequences of chemical contamination of food items, the WHO has identified acrylamide and semicarbazide as emerging contaminants that may have potential health consequences for humans, although more investigation is needed. Acrylamide is a chemical that has several uses including manufacture of polyacrylamide materials, treatment of drinking water and wastewater to remove particles and other impurities, and the construction of dam foundations and tunnels. Interestingly, acrylamide also appears to be produced in some foods at high temperatures (45).

Acrylamide is known to cause cancer in animals; certain doses are toxic to the nervous system of both humans and animals. In humans, studies of workers exposed to acrylamide through air and skin contact found no evidence of cancer. However, the International Agency for Research on Cancer (IARC) has classified acrylamide as “probably carcinogenic to humans” on the basis of the evidence from research studies on animals (45).

There is currently little information about, and poor understanding of, how acrylamide forms in foods. It appears to be produced naturally in some foods that have been cooked or processed at high temperature, and the levels appear to increase with the duration of heating. Acrylamide has also been found in home-cooked foods as well as precooked, packaged, and processed food and seems to arise when different food components react together. Although the exact temperature at which acrylamide forms in food is not currently known, acrylamide has not been found in food prepared at temperatures below 120°C. Thus far, the highest levels have been in starchy foods such as potato and cereal products (45,46).

The WHO has also highlighted public health concerns of semicarbazide (SEM) in food at the request of several member states and based on information provided by the European Food Safety Authority. Semicarbazide is found in food products packaged in glass jars with metal lids that have formed plastic seals. Semicarbazide has been detected at low levels in a number of such food products, including baby foods. The origin of SEM is not clear but has been linked to the permitted use of azodicarbonamide in the plastic seals. The presence of SEM has raised concerns since it has weak carcinogenic activity when fed to laboratory animals at high doses. Based on levels reported in food, the health risk, if any, to consumers, including infants, seems quite small. However, since the relatively high consumption of products in glass jars by infants can result in higher exposure as compared to other consumers, the presence of SEM in baby foods is considered particularly undesirable. The WHO has recommended that alternative materials be evaluated for their suitability, including their microbial and chemical safety, and introduced as rapidly as possible for baby foods and subsequently other foods (47).



Other examples of chemical contaminants in food include polychlorinated biphenyls (PCBs), dioxins, and mercury contamination in seafood. Some aquatic organisms can convert inorganic mercury into organic methylmercury, with resulting bioaccumulation in large carnivorous fish such as swordfish. Soils and water used for agriculture may also contain regional environmental hazards such as the widespread arsenic contamination of ground water in Bangladesh (48–50).

### *Organic Farming and Food Safety*

Conventional and organic farming are two major forms of agricultural practices today. Although organic farming can be traced back to England in the 1920s, it has been embraced over the last several years due to concerns over use of pesticides and genetically modified organisms in large-scale conventional agriculture. Organic farming avoids use of synthetic chemicals and genetically modified organisms (GMOs) and follows the principles of naturally sustainable agriculture (51).

Despite many favorable characteristics of organic farming, one of several criticisms about organic farming is the increased potential for microbial food contamination. A French study in 1999 to 2000 warned that biological toxins in certain organic products (i.e., apples and wheat) should be closely monitored. Another major concern is the use of manure as a fertilizer in organic farming. Manure can carry human pathogens and mycotoxins from molds. It is well known that *E. coli* 0157:H7 originates primarily from ruminants such as cattle, sheep, and deer, which shed it through their feces. In addition, growers must also be alert to the potential contamination of produce growing and handling environments by human or animal fecal material, which is known to harbor *Salmonella*, *Cryptosporidium*, and other pathogens. However, properly treated manure (and other biosolids) can be an effective and safe fertilizer. Other sources of contamination related to organic farming may arise from nearby composting or manure storage areas, livestock, or poultry operations, nearby municipal wastewater or biosolids storage, treatment or disposal area, and high concentrations of wildlife in the growing and harvesting environment, such as nesting birds in a packing shed, or heavy concentrations of migratory birds, bats or deer in fields (51,52).

## Occupational Risk from Methods to Increase Food Safety

### *Use of Pesticides and Chemicals*

Although it is well established in the medical literature that acute and subacute exposure to pesticides and other chemicals poses major health issues, less is currently known about low-level chronic occupational or environmental exposures to residues of pesticides and chemicals. However, evidence



exists for potential chronic health effects of exposure to several pesticide classes at chronic low levels such as the association of chronic neurological effects with exposure to several pesticide classes. Examples include the association of increased vibration sense, motor-sensory neuropathy, and cognitive and affective deficits after exposure to organophosphates; the association of olfactory, cognitive, and behavioral deficits after exposure to methylbromide; and the association of symptoms of Parkinson's disease after paraquat exposure. Another example is association of oligospermia and azoospermia after exposure to dibromochloropropane (DBCP), which is now banned in the United States. There is also evidence of associations of chronic low-level exposure to pesticide residues and cancer (5,6,53–56).

A major area of interest in relation to pesticides and cancer has concentrated on pesticides acting as endocrine disrupters, mostly organochlorinated insecticides, and on hormone-related cancers. Research has largely focused on the association of breast cancer and exposure to DDT and its metabolites, although a causal inference has not been established. A recent study carried out in India, a country in which exposure to organochlorinated pesticides is expected to be higher and more recent than in populations from developed countries, found significantly higher levels of organochlorinated pesticides (DDT and its metabolites and others) in the blood of women with breast cancer as compared to reference women. In a Danish study, a modifying effect of p53 mutations on the breast cancer risk associated with exposures to organochlorines was observed, suggesting a potential for gene-environment interactions as an important factor in pesticide-related carcinogenicity (56–58).

Other pesticides have also been linked to cancer. For example, an Italian study observed a significantly increased risk for ovarian cancer in women exposed to triazines, a class of herbicides including the frequently used atrazine, simazine, and others (56,59).

Workplace factors and work practices influence the magnitude and amount of exposure. In addition, workers are often exposed to mixtures of pesticides and chemicals in the occupational setting. Other relevant factors contributing to the significance of the occupational exposure to pesticides and chemicals in the agricultural setting are the nature of the pesticide, shorter versus longer duration pesticide, type of work activity (e.g., pesticide operators versus reentry workers), and length of exposure. For example, a study in California determined that certain organophosphate application variables were significantly related to systemic illness. These included application to fleshy fruit, vegetables, and melons; air application drift; and specific OPs such as mevinphos, demeton, oxydemeton-methyl, methamidophos, and azinphos-methyl. California's unique pesticide mandatory reporting requirements make it the only state in which data are available on both pesticide use and suspected pesticide-related illnesses (59,60).

Studies evaluating the health effects of pesticides have mainly addressed the oral route of exposure after consumption. However, exposure to pesticide

and chemical residues primarily involves the dermal route and, to a lesser extent, the inhalation route and typically occurs intermittently. However, despite the relatively high dermal exposure in occupational settings, existing regulations such as the FIFRA in the United States have primarily evolved from concerns about the oral route of exposure. Therefore, to accurately estimate occupational exposures to residues in agricultural work, more dermal toxicodynamic studies focusing on intermittent exposures are needed. Furthermore, the bioavailability of bound skin residues of pesticides and chemicals and the effects of the parent compound or relevant metabolite(s) in the context of various agricultural practices and work activities are other areas that need to be researched (9,59,61–63).

Gender-specific research is also needed. There are a number of major gender-related variables in agriculture that may lead to occupational exposure in females to pesticides. For example, compared to men, women working in agriculture may be found in lower-paid and lower-status jobs, with less access to promotion, information, and safety measures. In a survey of over 500 farmers in Thailand, in which all male and female farmers applied pesticides, 53% of the women were not able to read, compared to 29% of men, decreasing their ability to heed the safety warnings written on the labels of pesticides. Another occupational group that has often been overlooked is children. Child labor persists globally. The International Labor Organization estimates that approximately 250 million children between the ages of 5 and 14 work part-time or full-time around the world. Although they engage in various jobs, by far the largest number work in agriculture where they may be exposed to various hazards, including toxic chemicals (see Chapter 12) (56,64–67).

### *Food Irradiation*

Irradiation of food has the potential to decrease the incidence of foodborne disease and makes possible the replacement of toxic and environmentally harmful chemical fumigants such as methylbromide, ethylene oxide, and propylene oxide. Irradiation can also increase the shelf life of certain food items and decrease losses from spoilage and pests. Decreasing losses is important in the context of global storage of food supplies. Although it remains controversial, food irradiation is widely supported by various international and national medical, scientific, and public health organizations, as well as groups involved with food processing and food services. Many countries have started to irradiate food, including France, the Netherlands, Portugal, Israel, Thailand, Russia, China, and South Africa. However, in the United States, only 10% of herbs and spices and less than 0.002% of fruits, vegetables, meats, and poultry are currently irradiated (18,68–70).

The technology of food irradiation involves use of high-energy radiation in any of three approved forms: gamma rays, electron beams, or x-rays. Gamma rays can be generated by either of two approved radionuclide

sources, cobalt-60 or cesium-137, which give off high-energy photons, called gamma rays, that can penetrate foods to a depth of several feet. The radioactive substances emit gamma rays all the time, and massive concrete walls are needed to contain them. Foods to be irradiated are brought into a chamber on conveyor systems and are exposed to the rays for a defined time period. Although some fear that foods become radioactive, since gamma irradiation does not emit neutrons, foods are not made radioactive by the procedure (71,72).

Electron beam (e-beam) technology uses a stream of high-energy electrons propelled from an electron gun. No radioactivity is involved, but shielding is needed to protect workers from the electron beam (72).

The newest technology is x-ray irradiation, an outgrowth of e-beam technology, and is still being developed. The x-ray machine is a more powerful version of the machines used in many hospitals to take radiographs. To produce the x-rays, a beam of electrons is directed at a thin plate of gold, producing a stream of x-rays coming out on the other side. Like gamma rays, x-rays can pass through thick foods and require shielding for worker safety. Four commercial x-ray units have been built in the world since 1996 (73).

The absorption of gamma rays, x-ray photons, or electrons produces ionization. Water is the principal target for the radiation since it is the largest component of most foods and microorganisms. Normally, approximately 70% of the radiation-induced ionization occurs in cellular water, and the target organisms are inactivated because of secondary reactions, not because of a direct effect on bacterial DNA. However, others have proposed that DNA damage is the mechanism by which irradiation acts (68,74–76).

Radiation doses used in the irradiation process are measured in units of grays (Gy) or kilograys (kGy), with 1 Gy equal to 100 rads. Doses can be divided into three groups: low dose (less than 1 kGy); pasteurizing dose (1 to 10 kGy) used for pasteurization of meats, poultry, and other foods; and high dose (more than 10 kGy) for sterilization or for reduction of the number of microbes in spices. Some bacterial spores may be more resistant to irradiation than vegetative cells and require doses substantially higher than those used in pasteurization. In general, inactivation of viruses also requires higher doses of radiation than doses used to sterilize pests in plants or for pasteurization (18,77–79).

In the United States, the Nuclear Regulatory Commission (NRC) regulates facilities that utilize radioactive sources. To be licensed, the facility must have been designed with multiple fail-safe measures, and must establish extensive and well-documented safety procedures and worker training. The occupational risk in working in areas where food irradiation takes place is minimal if safe work practice guidelines are followed. Outside the United States, a small number of fatal incidents have been documented in which a worker bypassed multiple safety steps to enter the chamber while the radioactive source was exposed, resulting in a severe or even lethal radiation injury (73).

### *Alternative Nonthermal Methods*

Nonthermal technologies that appear promising include high hydrostatic pressure (HHP), pulsed electric fields (PEF), and high-intensity ultrasound combined with pressure, or combinations of these methods, or with irradiation. As with food irradiation, occupational health and safety guidelines and worker education and training would prevent injuries or accidents (74).

## **Influence of Biotechnology on Food Safety**

The influence of biotechnology on agriculture has already led to profound and revolutionary developments through genomics and transgenics and continues to transform agriculture. Whereas genomics seeks to understand and modify the chromosomal traits of a species, transgenics focuses on changing traits of an organism by transferring individual genes from one species to another. Estimates indicate that the world market for genetically modified (GM) plants will be \$8 billion in 2005 and \$25 billion by 2010. The number of countries growing transgenic crops commercially has increased from 1 in 1992 to 13 in 1999. Furthermore, between 1996 and 2000, the global area of agriculture devoted to growing transgenic crops increased by more than 25-fold, from 1.7 million hectares in 1996 to 44.2 million hectares in 2000. The United States, Canada, and Argentina grew approximately 98% of the total amount. Within transgenic plants, herbicide tolerance is the most common trait, accounting for 74% of all transgenic crops in 2000 (80).

Genetically modified crops can directly benefit the farmer by altering the inputs needed to produce a crop, such as herbicides or fertilizer. Other plants are designed to benefit the consumer when the end product expresses a desirable outcome, such as improved quality, nutritional content, or storability (81,82).

Examples of genetic engineering to benefit the farmer/grower include the following:

1. Glyphosate or round-up tolerant soybeans: A gene from another plant is introduced into the soybean plant, allowing farmers to spray the glyphosate herbicide and kill weeds without harming the genetically engineered (GE)-soybean plant.
2. Bt crops: *Bacillus thuringiensis* (Bt) is an aerobic, motile, gram-positive endospore-forming bacillus initially isolated in Japan and described by Berlinger in 1915 (80).

Bt has insecticidal activity from endotoxins included in crystals formed during sporulation, but vegetative insecticidal proteins (VIPs) from before sporulation are also being developed. The crystals of different strains of most Bts contain varying combinations of insecticidal crystal proteins (ICPs), and

different ICPs are toxic to different groups of insects. To confer resistance to insects in specific plants, a gene from the Bt bacteria is introduced into corn, cotton, or other plant types. The plants then produce the same protein crystal that the bacteria produce that is toxic to many types of insects that would normally harm the plant, such as the European corn borer (80).

Two examples of genetic engineering to benefit the consumer include the following:

1. High-oleic soybeans: These contain less saturated fat than conventional soybeans, leading to consumer health benefits, lower processing costs, and longer shelf life for oil.
2. High-lauric canola: An inserted gene allows the plant to produce an oil composed of 40% lauric acid, a key ingredient in many soaps, detergents, lubricants, and cosmetics.

Similar applications are occurring in animal agriculture. These include the creation of a synthetic version of a naturally occurring hormone to boost milk production in dairy cows and development of low-phytate corn and other types of animal feeds that lead to the decrease of phosphorus in animal waste, leading to less pollution and lower cost of animal feeds (81).

### *Potential Occupational Risk*

Regulatory frameworks exist to address vital issues related to food safety and environmental protection in regard to GMO applications. However, little research or regulatory oversight currently exists addressing the potential impact of genetically modified/engineered crops on the health and safety of agricultural workers. Some studies have evaluated the health effects of Bt in agricultural workers. In a public health survey, a large number of individuals were exposed to a massive Bt pesticide spraying program. Some of the symptoms reported included rash and angioedema. One of the spray workers developed dermatitis, pruritus, swelling, and erythema with conjunctival injection. Bt was cultured from the conjunctiva in this case. In 1992 the use of Bt as part of an Asian gypsy moth control program was associated with symptoms of allergic rhinitis, exacerbations of asthma, and skin reactions among individuals exposed to the spraying operations. However, no follow-up was performed to determine if these events were a result of hypersensitivity to Bt or possible toxic reactions, or were secondary to common aeroallergens coincidental to the season when the spraying was performed. Similar results were produced during another spraying of Bt in 1994 (82–88).

Given that approximately 75% of asthma cases are triggered by allergens, the potential allergenicity of Bt is important to investigate further. A study by Bernstein et al. (83) measured immune responses in seasonal migrant farm workers exposed to Bt pesticides in the muck crops region of Northern Ohio in the United States in October 1995. This study included questionnaires, nasal and mouth lavages, ventilatory function assessment, and skin tests to

indigenous aeroallergens and to a variety of Bt spores and vegetative preparations. The exposure group consisted of farmers who picked vegetables (celery, parsley, cabbage, kale, spinach, and strawberries) that required Bt pesticide spraying soon after the first crops were planted and continuing until the harvesting of the last crop in early October. Positive skin-prick tests to several Bt spore extracts were seen chiefly in exposed workers. Specifically, there was a significant ( $p < .05$ ) increase in the number of positive skin tests to spore extracts at 1 and 4 months after exposure to Bt spray. The number of positive skin test responses was significantly higher in high-versus low-to-moderately exposed workers. The majority of nasal lavage cultures from exposed workers were positive for the commercial Bt organism, as demonstrated by specific molecular genetic probes. Specific immunoglobulin E (IgE) antibodies were also more present in workers exposed to high Bt spray levels, and specific IgG and IgE levels were present in all groups of exposed workers. However, there was no evidence found of occupationally related respiratory symptoms. Another study by Pearce et al. (87) studied the effects of aerial spraying with the *Kurstaki* species of Bt on children with asthma within the Bt spray area in Victoria, British Columbia, in 1999. The study found no difference in asthma symptom scores between exposed and gender and age-matched controls either before or after the spray. No significant changes were found for the peak expiratory flow rates for subjects after the spray period.

From a consumer standpoint, concerns have been raised about the allergenic potential of GM foods. For example, the CDC investigated 51 reports of possible adverse reactions to corn that occurred after Starlink, a corn variety modified to produce a Bt endotoxin, Cry9C, was allowed for animal feed and was found in the human food supply. However, allergic reactions were apparently not confirmed. More research is needed to better comprehend the health effects of Bt and other biological sources such as novel proteins found in genetically modified foods from an occupational, environmental, and consumer perspective (88,89).

## Terrorism and Food Safety

Given the reality of the geopolitical terrorism threats facing the world today, agriculture can also be a potential target for terrorism. For instance, agroterrorism, the use of microbes and poisons to shake the confidence in the food supply, could cripple the \$201 billion agricultural economy in the United States. Diseases such as swine fever and citrus greening can potentially spread across the land silently. The impact of a single case of foot-and-mouth disease could require the destruction of millions of cows and result in a worldwide ban on United States cattle export for years. Furthermore, unlike the most feared bioterrorism threats, such as anthrax or smallpox, some virulent agricultural diseases are harmless to humans and can be trans-



ported from great distances from infected crops and animals worldwide. To defend against this threat in the United States, the USDA is building or modernizing laboratories to quickly screen disease samples from around the country. Some have advocated greater use of vaccines, but this is problematic due to high cost and logistical complexity. With increasing global trade, another concern is that many nations cannot readily distinguish between infected and vaccinated animals and may reject either at their border. Some private companies have developed a suitcase-size device that can detect DNA from the air to determine the presence of a deadly microbe within about half an hour. Such devices may help localize and map outbreaks (90).

## Global Issues Related to Food Safety

Cooperation between nations will help achieve food safety on a global scale. The concept of good agricultural practices (GAP) has evolved in recent years to meet the needs of a rapidly changing and globalizing food economy and to address concerns of a wide range of stakeholders about food production and security, food safety and quality, and the environmental sustainability of agriculture. The Committee on Agriculture (COAG) of the Food and Agricultural Organization (FAO) of the United Nations in 2003 adopted a holistic food chain (sometimes called “farm to table” or “farm to fork”) approach that encompasses the whole food chain to maximize food safety and quality worldwide. The FAO defines the food chain approach as recognition that the responsibility for the supply of food that is safe, healthy, and nutritious is shared along the entire food chain by all involved with the production, processing, and trade of food on a global scale (91–93).

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24 R.B.J. Pandya

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