Chapter 2

FOOD, WATERBORNE, AND AGRICULTURAL DISEASES

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INTRODUCTION

Food and waterborne pathogens cause a considerable amount of disease in the United States. A decade ago, the US Department of Agriculture (USDA) estimated that medical costs and productivity losses for diseases caused by the five leading foodborne pathogens are as much as $6.7 billion per year.[1] Many of the common foodborne pathogens, whether bacteria, viruses, parasites, or toxins, can cause disease if purposefully introduced into water or food sources. These pathogens characteristically have the potential to cause significant morbidity or mortality, have low infective dose and high virulence, are universally available, and are stable in food products or potable water. These agents include (*a*) *Clostridium botulinum* toxin, (*b*) the hepatitis A virus, (*c*) *Salmonella*, (*d*) *Shigella*, (*e*) enterohemorrhagic *Escherichia coli* species, (*f*) *Cryptosporidium parvum, (g) Campylobacter jejuni*, (*h*) *Listeria monocytogenes*, and (*i*) *Vibrio cholerae*, among others. Pathogens in the Centers for Disease Control and Prevention (CDC) list of biological threat agents that also may cause food or waterborne disease are *Bacillus anthracis*, *Brucella* species, staphylococcal enterotoxin B, and ricin. The potential for nonlisted biological agents such as mycotoxins and parasites (eg, *Taenia* sp) to be used in a bioterrorist event also should be considered.

This chapter provides an introduction to the far-reaching subjects of food and waterborne diseases, the potential for terrorist attacks on the food and water supply, and terrorism directed at the nation's food-to-farm continuum (agricultural terrorism). For a more extensive review of these topics, readers may consult more specialized texts on food[2] and waterborne[3] diseases and agricultural terrorism.[4,5]

FOODBORNE AND WATERBORNE PATHOGENS AND DISEASES

B anthracis is the causative agent of two forms of foodborne anthrax: (1) oropharyngeal and (2) gastrointestinal. Although *B anthracis* would cause the most potential harm via an aerosol release, anthrax is not normally perceived as having bioterrorism potential as a foodborne bacterial contaminant because the infective dose required for such an attack would be high.[6] However, given that the early diagnosis of gastrointestinal anthrax is difficult and problematic for clinicians who have never treated cases of this disease, a higher mortality rate than expected may result from a natural or purposeful outbreak. Anthrax spores are resistant to disinfection by contact chlorination as used by water treatment facilities, although higher levels of chlorination (≥ 100 ppm) for longer contact times (5 minutes) will kill *Bacillus* spores.[7]

C botulinum is the causative agent of botulism intoxication, of which there are three natural manifestations: (1) classic, (2) wound, and (3) infant botulism. A bioterrorism use of botulinum toxin would possibly occur through inhalational intoxication, as was considered by the Aum Shinrikyo cult in Japan.[8] *C botulinum* produces the most potent natural toxin known; the human lethal dose of type A toxin is approximately 1.0 µg/kg.[9] There are seven antigenic types of botulinum toxin, denoted by the letters A through G. Most human disease is caused by types A, B, and E. Botulinum toxins A and B are often associated with home food preparation[10] and home canning[11] and pickling.[12] Botulism-contaminated food cannot be distinguished by visual examination, and the cook is often the first to show the toxin's effects (via sampling the food during cooking). A 12- to 36-hour incubation period is common. The incubation period is followed by blurred vision, speech and swallowing difficulties, and descending flaccid paralysis.[13]

The current mortality rate associated with botulism intoxication is less than 10%. Foodborne botulism mortality during the 1950s (before the advent of modern clinical therapies) was approximately 25%.[14] Little evidence of acquired immunity from botulinum intoxication exists, even after a severe infection. Successful treatment consists of aggressive trivalent (A, B, E) botulinum antitoxin therapy and ventilatory support. Early diagnosis is critical for patient survival. Toxin can be found in food, stool, and serum samples, which may all be used in the standard mouse model assay to test for the presence of botulism toxin.[15]

A recent controversial paper[16] explored the potential for botulinum toxin contamination of the milk supply. A 9-stage cows-to-consumer supply chain was examined, which accurately reflected a single milk-processing facility. The release of botulinum toxin was assumed to have occurred either at a holding tank at the dairy farm, in a tanker truck transporting milk from the farm to the processing plant, or at a raw milk silo at the plant. By the use of this model, it was predicted that 100,000 individuals could be poisoned with >1 gram of toxin, and 10 grams would affect about 568,000 milk consumers.[16] The National Academy of Sciences published this information to foster further discussion and alert authorities to the dangers to the milk supply from purposeful contamination.[17] The paper describes interventions that the government and the dairy industry could take to prevent this scenario. Officials at the US Department of Health and Human Services requested that this paper not be published. Regardless, publication ensued because the The National Academy of Sciences was convinced that this information would not enable bioterrorists to conduct an attack, and that the paper itself would stimulate biodefense efforts. However, whether this information presents a "roadmap for terrorists" by exposing vulnerabilities in food processing remains to be determined.[18]

Campylobacter, *Salmonella*, *Listeria*, and *E coli* O157:H7 can be transmitted zoonotically from contaminated animal food sources. These bacteria species are ubiquitous and cannot be restricted. *C jejuni* is the most commonly reported bacterial cause of foodborne infection in the United States. Chronic sequelae associated with *C jejuni* infections include Guillain-Barre syndrome[19] and arthritis.[20] Infants have the highest age-specific isolation rate for this pathogen in the United States, which is attributed to a greater susceptibility upon initial exposure and a lower threshold of seeking medical treatment for infants.[21] Reservoirs for *C jejuni* include wild fowl and rodents.[22] The intestines of poultry are easily colonized with *C jejuni*,[23] and it is a commensal inhabitant of the intestinal tract of cattle.[24] Antibiotic resistance of *Campylobacter* is a growing concern for poultry.[25] *Campylobacter* has a 100 to 1,000 cell infective dose, with poultry being the primary source of infection in the United States.[26] Insect transmission by several fly species has also been documented.[27] There is a 3- to 5-day illness onset for campylobacteriosis and a 1-week recovery time. Immunity is conferred upon recovery, which accounts for a significantly higher incidence rate among individuals younger than 2 years of age in developing countries.[28]

Salmonellosis is the second most common foodborne illness,[29] and contaminated food is the principal route of disease transmission.[30] There are over 2,400 *Salmonella* serotypes, many of which can cause gastroenteritis, manifested as diarrhea, abdominal pain, vomiting, fever, chills, headache, and dehydration. Other diseases from *Salmonella* infections include enteric fever, septicemia, and localized infections. Poultry is a principal reservoir of the salmonellae. Water, shellfish, raw salads, and milk also are commonly implicated as vehicles for this pathogen. In humans, the most highly pathogenic *Salmonella* species is *S typhi*. This bacterium is the causative agent of typhoid fever, which comprises about 2.5% of salmonellosis in the United States. The symptoms of typhoid include septicemia, high fever, headache, and gastrointestinal illness.

An immense outbreak of milk-borne salmonellosis from *Salmonella enteritica* serovar *typhimurium* occurred in northern Illinois in 1985, with more than 14,000 people reported ill and five deaths.[31,32] A nonpurposeful outbreak of this magnitude demonstrates what could be initiated by bioterrorism. Cases also were reported in the neighboring states of Indiana, Iowa, and Michigan because the contaminated milk was distributed via supermarket distribution systems.[33] Medical treatment was complicated because the strain of *S typhimurium* was found to be resistant to antibiotics. The cause of the outbreak was the accidental comingling of raw milk into the pasteurized product in the milk plant.[34]

The earliest use of biological weapons by the Japanese during World War II was the intentional poisoning of wells with *S typhimurium* along the Russian border of Mongolia in 1942.[35] In September and October 1984, two large groups of salmonellosis cases occurred in The Dalles, Oregon. Case interviews by health officials associated patronage of two restaurants in The Dalles with illness, especially with food items eaten from salad bars. *S typhimurium* isolates were then obtained from clinical specimens.[36] The size and nature of this outbreak helped to initiate a criminal investigation, which previously was almost never done in conjunction with a foodborne disease outbreak. The cause of the epidemic became known when the Federal Bureau of Investigation investigated a nearby cult (the Rajneeshees) for additional criminal violations.[37] In October 1985 authorities found an opened vial holding the original culture type of *S typhimurium* in the Rajneeshee clinic laboratory.

Listeria monocytogenes is often found in silage, water, and the environs of animal fodder.[38] Soft cheeses,[39] raw or contaminated milk,[40] and contaminated refrigerated foods[41] are often sources of this organism. Listeriosis can result in meningo-encephalitis and septicemia in neonates and adults, and fever and abortion in pregnant women.[42] Fetuses, the newborn,[43] the elderly,[44] and those immunocompromised[45] are at greatest risk for serious illness. Listeriosis case investigations can be problematic because of the variable incubation period for illness (3 to > 90 days). Large outbreaks of foodborne listeriosis have occurred, including a 1983 Massachusetts epidemic where improperly pasteurized milk was the source of the infection.[46] The milk originated from a group of farms at which listeriosis occurred in dairy cows. Of the 49 infections associated with this outbreak, 14 patients died.

E coli O157:H7 produces two verotoxins and has emerged as a major cause of serious pediatric illness. It can result in bloody diarrhea and hemolytic uremic syndrome, which is defined as the demonstration of three clinical conditions: (1) microangiopathic hemolytic anemia, (2) acute renal failure, and (3) thrombocytopenia.[47] Children younger than 5 years of age are at greatest risk for hemolytic uremic syndrome when infected with *E coli* O157:H7 or other enterohemorrhagic *E coli* species, and deaths from these infections occur most often in the age ranges of 1 to 4 years and 61 to 91 years.[48]

A major source of EHEC exposure is from consumption of and contact with beef cattle.[49] About 20% of the ground beef consumed in the United States is derived from cull dairy cattle, which may be an important contributor to this bacterial contamination of the food supply.[50] For example, during July 2002, the Colorado Department of Public Health and Environment identified an outbreak of *E coli* O157:H7 infections, which linked 28 illnesses in Colorado and six other states to the consumption of contaminated ground beef products. Seven patients were hospitalized; five developed hemolytic uremic syndrome.[51] *E coli* contaminated food items commonly result from use of cattle waste for fertilizer, or coming into contact with cattle products. Outbreaks have occurred from exposure to various *E coli*-tainted food items, including alfafa[52] and radish[53] sprouts, parsley,[54] lettuce,[55] apple cider,[56] unpasteurized gouda cheese,[57] raw milk,[58] recontaminated pasteurized milk,[59] and salami,[60] as well as through petting zoos[61] and environmental transmission.[62,63] Waterborne outbreaks with *E coli* O157:H7 also occur, thereby demonstrating the potential for such contamination from a purposeful effort. From mid-December 1989 to mid-January 1990, 243 cases of gastrointestinal illness from antibiotic-resistant *E coli* O157:H7 occurred in a rural Missouri township as a result of an unchlorinated water supply.[64] Swimming water-associated outbreaks of *E coli* O157:H7 also have occurred.[65,66]

Humans are the major reservoir for *Shigella* and the primary source of subsequent infections. It is thought that worldwide *Shigella*-associated illness causes about 165 million cases per year, of which fewer than 1% occur in industrialized nations.[67] *Shigella dysenteriae* produces severe disease, may be associated with life-threatening complications, and causes about 25,000 cases of illness each year in the United States. Four serogroups (A through D) cause approximately 80% of shigellosis cases in the United States. Immunity is serotype-specific,[68] vaccine development has been problematic,[69] and the species can easily become resistant to antibiotics.[70] Infants and young children are most susceptible to shigellosis, attributable in part to toiletry behaviors and child care practices. Although not an environmentally hardy organism, *Shigella* is highly infectious and can be very persistent in a close community environment.[71] The infectious dose for *Shigella* is from 10 to 100 organisms, and *Shigella* contamination can cause outbreaks associated with food, water, and milk. Shigellosis also has been associated with recreational swimming.[72] Shigellosis is readily transferred from person-to-person contact and through fomites;[73] it can also be transmitted by insect vectors (primarily flies).[74] There is a 1- to 3-day incubation period for shigellosis. *Shigella* organisms are shed for 3 to 5 weeks after symptoms cease, ultimately contributing to a greater person-to-person spread than in other enteric pathogens such as *Salmonella* and *V cholerae*.

Cryptosporidium, a protozoan and an obligate intracellular parasite, can cause food and waterborne illness and can also be acquired from exposure to contaminated recreational water.[75-79] Seroprevalence surveys indicate that about 20% of the US population have been infected with *Cryptosporidium* by adulthood.[80] The severity and course of infection can vary considerably, dependent upon the immune status of the individual. Intestinal cryptosporidiosis is often characterized by severe watery diarrhea but may, alternatively, be asymptomatic. Pulmonary and tracheal cryptosporidiosis in humans is associated with coughing and low-grade fever; these symptoms are often accompanied by severe intestinal distress. The duration of illness in one study of 50 healthy individuals varied from 2 to 26 days, with a mean of 12 days.[81] The precise infectious dose is unknown; research indicates that a range of 9 to 1,024 oocysts will initiate infection.[82] The pathobiology is not completely known; however, the intracellular stages of the parasite can cause severe tissue alteration. Infected food handlers are a major contributor to disease transmission. Consequently, cryptosporidiosis incidence is higher in facilities that serve uncooked foods, such as restaurants with salad bars. Child care centers can be a problematic source of cryptosporidium infection because diarrhea in children in diapers can be difficult to contain.[83] A significant reservoir worldwide for *Cryptosporidium parvum* is domestic livestock, predominately cattle.[84] Drinking-water outbreaks have affected as many as 403,000 individuals in a 1993 outbreak in Milwaukee.[85] The water in the Milwaukee system was both filtered and chlorinated.[86] This organism's resistance to chlorine treatment ensures that it will remain a concern in treated potable water,[87] and therefore a risk to immunocompromised individuals for whom this organism causes severe and chronic life-threatening gastroenteritis.[88]

Humans are the source of the *Hepatovirus* hepatitis A virus. Illness caused by hepatitis A is characterized by sudden onset of fever, malaise, nausea, anorexia, and abdominal discomfort, followed by jaundice. The infectious dose is not precisely known but is thought to be 10 to 100 virus particles. The virus is hardy, and it survives on hands and fomites. Because viral particles are excreted in the feces during clinical illness, stringent personal hygiene is crucial to prevent disease transmission. Hepatitis A is commonly transmitted via personal contact, and fewer than 5% of all hepatitis A cases are demonstrated to have been caused by food or waterborne transmission.[89] Permanent immunity to hepatitis A is assumed subsequent to infection[90] or immunization completion.[91] The advent of nationwide hepatitis A vaccination programs is gradually causing a decrease in disease incidence and susceptible population.[92] As a result of these successful immunization programs, hepatitis A may in time cease to be a public health concern.[93]

The potential for hepatitis A virus transmission in drinking water was demonstrated in the hepatitis A outbreak among members of the varsity football team at the College of the Holy Cross in Worcester, Massachusetts, in 1969. Although 90 of 97 players and coaches on the team became ill (93% attack rate), serologic testing performed years later revealed that only 33 had IgM anti-hepatitis A virus in serum (34% attack rate).[94] Because of this discrepancy, the illness may have been caused by another pathogen present in the water. The same water supply was used for both irrigation and potable water. Water used by firefighters to battle a blaze nearby caused a drop in water pressure, and back-siphonage brought groundwater into the football practice field's irrigation system. The groundwater had been contaminated by children infected with hepatitis A in a building immediately adjacent to the playing field. The football team members became ill after consuming the water from a faucet hooked up to this contaminated water source.[95,96]

Fungi are plant pathogens that can cause both mycoses (infections) and mycotoxicoses (exposures to toxic fungal metabolites that may be dietary, dermal, or respiratory). Mycotoxins are ubiquitous worldwide toxic fungal metabolites and contaminants of stored cereal grains.[97,98] Although they are not on the CDC threat list, mycotoxins (including aflatoxin B1, ochratoxin, T-2 toxin, deoxynivalenol [DON], and nivalenol [NIV], and others), often have oncogenic properties from chronic exposure, and may also have potential for use as small-scale biological weapons. The fact that these toxins are found naturally in commercially available cereal-based foods, including bread and related products, noodles, breakfast cereals, baby and infant foods, and rice, indicates that a ready substrate for growth is available and purposeful contamination of these foodstuffs is possible. Mycotoxicoses are often undiagnosed and hence unrecognized by public health authorities, except when large numbers of people are affected.[99] The symptoms of mycotoxicosis depend on the type of mycotoxin; the amount and duration of exposure; the age, health, and sex of the exposed individual; and many unknown synergistic effects including genetics, dietary status, and interactions with other toxic insults.[100]

Large naturally occurring outbreaks of trichothecene intoxications have occurred, including an outbreak affecting 130,000 people in the Anhui province in China in 1991 caused by moldy wheat and barley. Fusarium mycotoxins including DON and NIV have also been discovered in corn samples in Linxian, China, in positive correlation with the incidence of esophageal cancer.[101,102] A large exposure of trichothecene mycotoxin from moldy grain and bread in Orenburg, Russia, in 1944 caused alimentary toxic aleukia and subsequent mortality in at least 10% of the population.[103] Although outbreaks of mycotoxicoses have decreased greatly as a result of increases in hygiene measures, they still occur in developing countries,[104] are considered a serious international health problem,[105] and are also a risk for domestic animals.[105-107]

The history of mycotoxin use as a biological weapon includes efforts by Iraq's biological weapon program to develop and use aflatoxins during the 1980s. Strains of *Aspergillus flavus* and *A parasiticus* were cultured, and 2,300 liters of concentrated toxin were extracted. This aflatoxin was used mostly to fill missile warheads, and the remainder was kept stockpiled.[108,109] The Soviet Union is suspected of deploying trichothecene toxins (NIV, DON, and T-2) in the "yellow rain" incidents in Laos and Cambodia during the 1980s. Whether the toxin exposures that occurred at that time were the result of purposeful[110] or natural[111] events has never been completely resolved. These events indicate the potential for mycotoxin use as a biological weapon or bioterrorism agent.

Parasites such as tapeworms (eg, *Taenia* sp) may have the potential for use as agents of bioterrorism. It is conceivable that, for example, a culture of *Taenia solium* eggs be poured onto a salad bar or into water, and be ingested and cause illness. Symptoms of *taeniasis* from ingestion of the eggs would include cysticercosis, which would not appear for weeks to years following infection. However, this infection timeline should not eliminate parasites from consideration as having the potential for bioterrorist use. In their novel *The Eleventh Plague*, Marr and Baldwin present just such a scenario, with devastating effects.[112] *T solium* has the potential to be transmitted from person-to-person through food handlers with poor personal hygiene, adding to the spread of the outbreak.[113] Such an outbreak may go undiagnosed for an additional period, during which ill persons are seen by healthcare providers unfamiliar with tapeworm infections. A purposeful outbreak of giardiasis that occurred in Edinburgh, Scotland, in 1990 demonstrates that parasites can be used for bioterrorism. Nine individuals living in the same apartment complex developed giardiasis subsequent to the purposeful fecal contamination of an unsecured water supply.[114]

TABLE 2-1

FOOD AND WATERBORNE DISEASE PATHOGENS

Pathogen	Incubation Period	Infective or Toxic Dose*	Mortality in United States	Bloody Diarrhea
Enterohemorrhagic *Escherichia coli*	3–4 d	$10–10^2$	rare	yes
Salmonella typhi	8–14 d	$10–10^2$	low	yes
Salmonella sp	6–72 h	$10^2–10^3$	low	yes
Shigella dysenteriae	1–7 d	$10–10^2$	rare	yes
Campylobacter jejuni	2–5 d	$\geq 5 \times 10^2$	rare	yes
Clostridium botulinum toxin	12–72 h	70 µg†	5%–10%	no
Vibrio cholera	2–3 d	10^6	rare	no
Cryptosporidium sp	7 d	9–1,024	rare	no
Listeria monocytogenes	3 - > 90 d	unknown	high	no
Hepatovirus hepatitis A	30 d	$10–10^2$	low	no
Norovirus	1–2 d	$< 10^2$	rare	no
Mycotoxins	mins–mos‡	4 mg/kg§	rare	yes

*The number of organisms unless otherwise noted.
†Oral lactate dehydrogenase$_{50}$ for a 70 kilogram human
‡Dose-dependent
§Oral lactate dehydrogenase$_{50}$ for laboratory rat

PATHOGEN SUMMARY

Table 2-1 categorizes various pathogens according to their threat potential as purposeful food contaminants. Both bacterial and viral enteric pathogens were considered for this compilation. This taxonomic approach may prove useful in stimulating further discussion of pathogenicity and potential for misuse. For example, *Salmonella* was not considered a threat agent before its use in the salad bar contamination in 1984. A high dose of *Salmonella* is required to cause illness. If the infectious or toxic dose required for illness from an organism is sole consideration for its classification as a bioweapon, then salmonellae should not even be considered as a threat agent. However, the use of *S typhimurium* to sicken many hundreds of people demonstrated a reality concerning biological agents: those that can be cultured and dispersed to cause illness will prove effective. Although no deaths occurred, the incident involved a rapid-onset illness with gastrointestinal effects that spread through 10 restaurants, causing widespread fear of food poisoning and long-lasting economic consequences in the community.[115] Given suitable circumstances, almost any pathogen could be used to make a target population ill. The severity of illness, including symptoms such as bloody diarrhea, also should be considered. For example, an outbreak of bloody diarrhea could have strong psychological effects upon those directly affected and perhaps lead to widespread psychological effects in the general public[116] if exacerbated by media coverage of the epidemic.[117]

WATER SUPPLY CONCERNS

Poisoning water supplies is one of the oldest methods of warfare. The earliest documentation of poisoned drinking water occurred in Greece in 590 BCE, when the Amphictyonic League used hellebore to poison the city of Kirrha's water source, causing the inhabitants to become "violently sick to their stomachs and all lay unable to move."[118] It is more difficult for a terrorist to contaminate water because of the large volumes of water and the extensive purification processes used in modern water treatment facilities. The modern water facility contains various treatment processes, including aeration, coagulation and flocculation, clarification, filtration, and chlorination.[119] All of these methods remove contaminants and pathogens in the water, whether purposefully added or not.

However, the risk to the US water supply has been known for some time. Federal Bureau of Investigation Director J Edgar Hoover noted in 1941, "It has long been recognized that among public utilities, water supply facilities offer a particularly vulnerable point of attack to the foreign agent…"[120] A terrorist might bypass the purification process and introduce a pathogen later in the distribution system. A private well water supply system may be more vulnerable because it may have a smaller volume of water and a less extensive purification system. Another potential avenue for purposeful waterborne contamination is the addition of a pathogen to a building's water supply, which would present an enclosed system, with likely little or no subsequent water treatment processes and a precise target community.

Waterborne pathogens included on the CDC threat list are *Vibrio cholerae* and *C parvum.* The Milwaukee outbreak with *C parvum* previously mentioned demonstrates the potential to affect great numbers of people with public water supply contamination. Another example of an extensive waterborne disease outbreak resulting from contaminated well water was the 1999 *E coli* O157:H7 and *Campylobacter* outbreak involving more than 900 illnesses and 2 deaths among attendees of a New York state county fair.[121] According to a comprehensive review of potable water threats by Burrows and Renner, potential water threat agents may also include *B anthracis, Brucella, V cholera, Clostridium perfringens, Yersinia pestis, Chlamydia psittaci, Coxiella burnetii, Salmonella, Shigella, Francisella tularensis*, enteric viruses, smallpox virus, aflatoxin, *C botulinum* toxin, microcystins, ricin, saxitoxin, staphylococcal enterotoxins, T-2 mycotoxin, and tetradotoxin.[122] The hepatitis A outbreak that occurred at the College of the Holy Cross in 1969 demonstrates the potential for this pathogen to cause illness when distributed in a water supply.

Communitywide outbreaks of gastroenteritis, caused by *Giardia lamblia*, *Cryptosporidium*, various *E coli* serotypes, *Torovirus*, and other infectious agents, have occurred from recreational water use, including swimming pools, water slides, and wave pools. Nongastroenteritis recreational water outbreaks often include those caused by *Pseudomonas aeruginosa*, *Naegleria fowleri*, and *Legionella*.[123] A recent naturally occurring outbreak of gastroenteritis associated with a contaminated recreational water fountain at a Florida beachside park demonstrates the potential for disease transmission.[124] In this incident, 44% of the interviewed park visitors who used an interactive water fountain became ill. Both *C parvum* and *Shigella sonnei* were subsequently isolated from clinical specimens obtained from those ill persons. The median age of the ill persons was 8 years old. One can imagine the effect of a powerful biological agent such as *C botulinum* toxin covertly added to a recreational public water fountain in similar circumstances.[125]

The water utility industry and federal public health agencies have carried out plans to improve the ability to prevent as well as detect deliberate contamination of water systems.[126] An example of a new program to detect purposeful contamination of the water supply is the WaterSentinel program.[127] However, much work remains to attain full biosecurity of the US water supply.[128,129]

AGRICULTURAL TERRORISM

Agricultural terrorism (agroterrorism) may be directed at stored or processed food, but some of the greatest vulnerabilities may exist close to the farm end of the farm-to-food continuum (Figure 2-1). Many of the potential bioterrorist agents are endemic, and therefore cannot easily be controlled. As with processed food and water terrorism, agroterrorism concerns are not recent developments.

From 1952 to 1960, a tribal insurgency in British-controlled Kenya was known as the Mau-Mau, which is a Swahili acronym for "Let the white man go back abroad so the African can get his independence."[130] In 1952 the Mau-Mau used the indigenous poisonous African milk bush (*Synadenium compactum*) to kill 33 cows at a mission station.[131]

Anticrop terrorism has been claimed on numerous occasions. The Colorado potato beetle (*Leptinotarsa decemlineata*) is a crop pest of plants of the genus *Solanum,* which includes potatoes, tomatoes, and eggplants. During World War II outbreaks of the Colorado potato beetle occurred in England and the United States, and Germany was suspected of releasing the insects. Germany conducted large-scale breeding and field trial dispersals of the insects in Germany, which may have backfired by initiating local crop infestations.[132,133] An offensive research program was conducted at the Kruft Potato Beetle Research Station near Koblenz by Dr Martin Schwartz.[134] In 1950 Soviet-occupied East Germany accused the United States of releasing the Colorado potato beetle.[135] Other insect pests can wreak economic havoc upon crops. In 1989 a group known as "the Breeders" announced that it had released Mediterranean fruit flies in southern California to protest the use of pesticides in that region.[136] Herbicides have also been used for wartime missions, such as the large-scale use of the defoliant Agent Orange by the United States to both defoliate and destroy crops used by North Vietnamese forces.[137]

In the United States, livestock may be more susceptible to agroterrorism than crops (Figure 2-2). Because US disease eradication efforts among livestock herds have been so successful, much of the nation's livestock is either unvaccinated or unmonitored for disease by farmers and veterinarians. Upon infection, livestock may become a vector[138] or reservoir[139] for disease transmission. This potential was plainly demonstrated with the outbreak of foot and mouth disease (FMD) in the United Kingdom in 2001.[140] This outbreak was the single largest FMD epidemic experienced in the world.[141] Agricultural and food losses to the United Kingdom exceeded $4.6 billion,[142] and psychological effects in residents of the worst-affected areas were extensive and long-lasting.[143] The United States has not had an outbreak of this disease since 1929.[144] The USDA has developed national protective measures to prevent a reintroduction.[145] The relevance of FMD as a biological weapon has been known for some time, and it is perhaps the greatest agroterrorism threat for livestock. Field trials of FMD virus dissemination were conducted in Nazi Germany's offensive biological warfare program. Consideration was given to aerial dissemination and dispersal of the FMD virus through contaminated hay and grass.[146] FMD is thought to inherently spread through airborne virus transmission, a problematic issue for outbreak containment.[147]

Perhaps the greatest national risks from agroterrorism involve the potential for widespread economic consequences. Not only would immediate loss to a crop occur from such an event, but also incidental costs would result from lost production, the destruction of potentially diseased products, and containment (including quarantine, drugs, and diagnostic and veterinary services). Much of the costs of these programs would be borne by the federal and state governments.[148] Export markets would be rapidly lost. As an example, a single case of mad cow disease (bovine spongiform encephalopathy) was found in Washington state on December 23, 2003; by December 26, Japan had banned all US beef imports, and beef prices dropped by as much as 20% in the following week.[149] Additionally, multiplier economic effects would occur from decreased sales by agriculturally dependent businesses and tourism. Other animal pathogens besides FMD and bovine spongiform encephalopathy that could have severe economic consequences if uncontrolled include highly pathogenic avian influenza,[150] rinderpest,[151] and African[152] and classical swine fever.[153]

The USDA's Animal and Plant Health Inspection Service has developed a select agent and toxin list of pathogens and toxins that endanger agriculture in the United States[154] (some of these zoonotic pathogens also endanger humans and appear on the CDC Category A list)[155]; these pathogens are listed separately by the USDA as overlap agents and toxins. Another USDA list enumerates harmful plant pathogens.[156]

Fig. 2-1. Some of the greatest vulnerabilities from agricultural terrorism may exist at the farm end of the farm-to-food continuum.
Photograph: Courtesy of US Department of Agriculture, Washington, DC.

Fig. 2-2. Livestock may be more susceptible to agroterrorism than crops.
Photograph: Courtesy of US Department of Agriculture, Washington, DC.

FOOD AND WATER SECURITY

On December 3, 2004, the former Secretary of the Department of Health and Human Services, Tommy Thompson, warned of a possible terrorist attack on the nation's food supply: "For the life of me, I cannot understand why the terrorists have not attacked our food supply, because it is so easy to do…We are importing a lot of food from the Middle East, and it would be easy to tamper with that."[157] In American society, the farm-to-fork continuum, which includes production, processing, distribution, and preparation, has myriad potential vulnerabilities for natural and intentional contamination.[158] Centralized food production and widened product distribution systems present increased opportunities for the intentional contamination of food.[159]

There are many opportunities along the food and water production continuum to accidentally or intentionally introduce various pathogens, many of which are not categorized as threat agents.[160] Strategies to counter these threats should focus on enhancing knowledge of all raw material inputs to the system; identifying and addressing the most likely points of vulnerability; disposing of end products after they leave the systems; and accounting for employees, visitors, computers, and physical security throughout the continuum.

Studying incidents of nonpurposeful foodborne pathogen contamination may reveal potential avenues for purposeful outbreak scenarios. A 1985 Minnesota outbreak affecting more than 16,000 persons with antimicrobial-resistant salmonellosis was eventually thought to have been caused by cross-contamination of raw milk into a pasteurized milk product sold to the public.[161] The potential for bioterrorist contamination of the milk supply is obvious. This outbreak and many others demonstrate that foodborne bioterrorism might have greater chances of success when pathogens are introduced after processing and as close to consumption as possible, thus circumventing opportunities for dilution and destruction by cooking or pasteurization.

Knowledge of the various processes involved in food production will help to determine potential vulnerabilities for agricultural terrorism. The typical food distribution system includes agricultural production and harvesting, storage and transport of raw commodities, processing and manufacture, storage and transport of processed and manufactured products, wholesale and retail distribution, and the food service sector.[162] The responsibility for food safety and security throughout this network is shared by the producers and suppliers as well as many different state and federal agencies. Typically, a state's health and agricultural agencies ensure that the food comes from safe sources and is served with safeguards to prevent foodborne disease transmission. Equivalent federal agencies similarly share these responsibilities, including the Food and Drug Administration, the USDA, the Department of Health and Human Services, the US Public Health Service, the CDC, and other partner agencies now part of the Department of Homeland Security, including the Federal Bureau of Investigation and the US Customs Service.

One prevention strategy is to anticipate intentions or motivations that could result in an attack using a particular product or organization. These motivations could include religion or ideology; personal grievances (real or perceived); and contentious issues such as animal rights, environmental protection, and abortion. Research facilities, food processors, and food retailers have been recent targets of terrorism and should take extra preventive measures. Knowledge of terrorism trends can be an indicator for the need to change security measures to meet the threat. However, because the US food industry is highly competitive on a price basis, additional preventive measures may only be an option if they are government subsidized.

From an attacker's standpoint, the choice of methods and weapons is determined by the target and the delivery medium. It is rare that someone wants to cause harm without consideration of whom or how many people are affected. The target population may then define the vulnerabilities.

Strategies also should be implemented to address specific vulnerabilities. The first task is to define production processes in terms of the inputs and outputs at all potential nodes of vulnerability. For example, foods that are either eaten uncooked or that can be contaminated after cooking should receive special quality control attention. Also, knowledge of where raw materials including water are obtained can help identify needs for enhanced security and accountability.

Although many production processes can receive much attention, a targeted focus is often on the inputs to food, water, or agricultural production. When a product leaves the plant, that attention may be discontinued. The time and route of delivery, as well as the security of the transportation, may be the most important with reference to vulnerability and should not be overlooked when security planning.

Implementing rational employee hiring and accountability procedures also may effectively mitigate food, water, or agricultural vulnerabilities. Additional strategic components include implementing procedures for laboratory testing and monitoring, reporting and investigating inspection discrepancies, and ensuring computer and information security.

SUMMARY

Any biological pathogen, whether bacteria, virus, toxin, or parasite, has the potential to be used in a terrorism context. Historical examination of both purposeful and inadvertent food and waterborne disease outbreaks can greatly assist in understanding how such events occur and how they may be prevented. A comprehensive understanding of animal production and crop farming, as well as food production and distribution, is required to ensure protection for the agricultural industry from terrorism events. Absolute safety of the food supply is perhaps an unattainable goal, but should be the benchmark for which all food protection and agricultural efforts are directed.

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