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Agriculture, Biological Weapons and Agrobioterrorism: A Review

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Abstract

This paper reviews biological weapons attacks on agriculture as well as acts of agrobioterrorism. The paper explores reasons for biological attacks on agricultural targets as well as the history of the development of biological weapons by nation states as well as examples of non-state actors (terrorists) and lone individuals committing acts of agrobioterrorism. The routes of food from farm to consumer and the modes of attack (e.g. crops, livestock animals) are described as a means to achieve agrobioterrorism. Vulnerability factors of agricultural targets to biological weapon attacks are discussed in detail as are nonstandard models of biological weapons attack (examples biocruise, biofuel crops, and use of introduced species). Furthermore, a clear set of indicators is described to differentiate whether an outbreak is accidental or deliberate and hence a potential biological weapons attack. Counterstrategies to deal with agricultural biological weapons attacks are discussed and include improvements in detection technologies; enhanced communication between producers, agricultural agencies, and military; and use of genetic engineering and advanced agricultural techniques.

Keywords: *Agriculture; Agrobioterrorism; Agroterrorism; Anti-animal weapons; Anti-crop weapons; Aphis; Biocruise; Biodefense; Biofuels; Biological Weapon; Biosecurity; Bioterrorism; BWTC; Commodities; Counterstrategies; Detection; Food; Economic effects; Introduced Species; USDA*

Introduction

The importance of food and agriculture to mankind can be traced back over 10,000 years ago. Yet, in this modern age of biological weapons, agriculture and agricultural products have been targeted by various nation states as viable strategic targets as well as targeted by terrorists (aka non-state actors) for acts of bioterrorism [1,2]. This paper will examine the reasons for biological weapons (BW) to be targeted at food and agricultural systems as well as the history of the development of agricultural BW. The term "Agrobioterrorism" (also referred to as "agricultural bioterrorism") can be defined as the use of bioterrorism tactics (pathogens, toxins, etc.) against agricultural products or facilities usually with the resultant effects of causing casualties or fatalities from contaminated agricultural resources or foodstuffs. Chalk defines Agroterrorism "as the deliberate introduction of a disease agent, either against livestock or into the food chain, for purposes of undermining socioeconomic stability and/or generating fear." Chalk also notes that Agroterrorism can be used "either to cause mass socioeconomic disruption or as a form of direct human aggression" [3].

This paper will also discuss the economic and national security concerns over the use of BW on food supplies or agricultural production. Finally, this paper will examine some of the technologies and strategies regarding the development, detection, and containment of terrorist or national BW attacks against food or agricultural resources as well as briefly mention some counterstrategies.

Reasons for Biological Weapons Attack

Horn and Breeze [4] briefly describe how agriculture is one of the pre-eminent foundations for the United States' (US) wealth in the global marketplace as well as a key element for national security as part of US critical infrastructure. The US food and fiber system accounts for 13% of gross domestic product (GDP) and for 16.9% of total employment [4]. Agricultural exports alone account for $140 billion and for 860,000 jobs. The United States has been known to have one of the most safe, secure, and reliable supply of food at a reasonable price that the world has ever known. Finally, the authors note that only about 2% of the population is involved in agriculture with the remaining population available to engage in business, commerce, and other wealth creating endeavors [4].

Yet, as Brown points out [5], much of the success in agricultural productivity and trade is dependent on freedom from disease. If a disease enters the food production arena, both the consumer and the export markets are adversely affected. The spreading disease would affect the consumer with increasing food prices (especially as contaminated food stocks were recalled from shelves or culled from infected farms), while a simultaneous drop in export-market transactions would occur as nations refuse to import food stocks to prevent the spread of the disease to their own farms or morbidity or mortality of their own populace. Two brief examples warrant mention here.

Brown notes that the last major foreign animal disease outbreak in the US was avian influenza (1983-1984) in Pennsylvania and several neighboring states. After the expensive eradication of infected chickens and decontamination of chicken facilities was completed, the cost of the process was $63 million which was paid out by the US federal government; yet, during the six months period of the outbreak, the US consumer suffered poultry price increases to the total of $349 million [5]. Yet, the impact on Great Britain due to bovine spongiform encephalopathy (BSE) was even more stunning. The emerging disease in cattle (prion based) required a mandated destruction of approximately 1.35 million cattle with all carcasses disposed of by incineration. This resulted in an estimated cost of over US$4.2 billion. Yet, as Brown notes, the cost in allowing prions into the food supply would have been devastatingly negative to the beef and dairy industries as a whole [5].

Parker [6] describes the "economic multiplier effect" of farm commodities as a measure of total economic activity of that commodity (e.g. eggs, grain, meat, milk). This multiplier effect starts at the farm gate value of the commodity and accrues value from transportation, marketing, and processing of the commodity. Parker states that the US Department of Commerce has concluded that the economic multiplier effect of exported farm commodities is 20 to 1 as compared to less than 2 to 1 for domestic crop sales and less than 3 to 1 for domestic livestock sales [6]. It is this multiplier effect which helps to account for US agricultural product exports constituting 15 % of all global agricultural exports and (as noted above in US dollars export sales) making the farm component of the economy the largest positive contributor to the US trade balance [6].

The reasons for a BW attack on agriculture can be summarized by Chalk [3] who writes that three major outcomes would result from a bioterrorism attack on agriculture. First, economic disruption would occur creating at least three levels of costs. Initially these costs come from eradication and containment measures. For example, during the 1997 outbreak of Foot and Mouth Disease (FMD) in Taiwan, the vaccination costs were $10 million, but the surveillance, cleaning, disinfection and related viral eradication costs were $4 billion. The next costs are the indirect multiplier effects that would accumulate from both compensations paid to farmers for destruction of agricultural commodities as well as the revenue losses by direct and indirectly related industries (e.g. dairy processors, bakeries, abattoirs, etc.). Finally, international trade costs would occur due to protective embargoes imposed by major export partners. One example is the 1989 Chilean grape scare caused by anti-Pinochet extremists that laced fruit bound for the US with sodium cyanide. While only a small handful of grapes were contaminated, the resultant imports suspensions (imposed by such nations as Canada, United States, Denmark, Germany, and Hong Kong) cost Chile over US$200 million in lost earnings [3].

Another possible outcome from a BW attack on agriculture would be the loss of political support and confidence in the government. Chalk [3] details how sociopolitical events, if not carefully controlled (including the media), would undermine the public's trust and cooperation in state and federal governance during the crisis. It is possible that euthanizing large numbers of animals to control the outbreak would result in such public distain that public protests could result to save infected animals or generate active resistance by farmers striving to protect infected herds from eradication [3]. These public reactions could leave politicians with little strength to follow the necessary protocols to contain the epidemic lest they are voted out by an angry albeit poorly educated populace. Chalk provides an example of the 2001 FMD outbreak in Great Britain that triggered a massive public resistance to the livestock eradication and thereby resulted in a tremendous loss of public support for the Blair government and the Labor party in general.

The next outcome of a BW attack on agriculture is based on the motive of all terrorist attacks; to elicit fear and anxiety among the public. Chalk [3] mentions the effects could include socially disruptive migrations from rural to urban to escape the possibility of a zoonotic epidemic "jumping" species and becoming a human epidemic. This could be further complicated if the disease did in fact, jump the species barrier, or if it was genetically engineered to jump the barrier and infect humans as well as livestock. Chalk describes the example of the 1999 Nipah virus outbreak in Malaysia which not only destroyed the swine population of the Negri Sembilan province, but also killed 117 villagers. During the height of the outbreak, thousands of people deserted their homes and abandoned livestock while becoming refugees in shanty towns outside of Kuala Lampur [3]. It must also be mentioned that a highly organized terrorist group could use social anarchists to help incite further social chaos by following the food attacks with riots over food shortages or price spikes. The scenario could be seen as step one: attack food stocks; step two: the attacks incite fear and terror in the populace; step three: orchestrate protests and riots against the government that the public does not trust; step four: cause violence during the riots to galvanize further mistrust of the government and cultivate further social chaos.

Chalk finally discusses another outcome of a BW attack on agriculture: raising financial capital or blackmail. One possible route for a BW terrorist to raise financial capital would be to direct attacks which create and exploit fluctuations in the commodity futures markets. These attacks could be directed at crops or livestock or -even with the rise of biofuels- be directed against crops used for biofuels (e.g. corn or sorghum for ethanol production and soybeans or palm oils for biodiesel production). Either under direct support by other parties (e.g. organized crime, terrorists, foreign cartels) or acting independently, the BW terrorist would be able to take advantage of market reactions to the attack (as Chalk eloquently states "allowing the 'natural' economic laws of supply and demand to take effect") and harvest maximum dividends from the commodity futures sales [3].

Chalk [3] also observes that this form of BW terrorism could make it easier for state and federal government officials to negotiate with the terrorists (extortion and blackmail) to avoid the immediate and latent effects of the attacks. These forms of attacks would not garner the same public outcry over dead farm animals as they would have had over an anthrax or smallpox attack with numerous human causalities.

Finally, Hickson [12] discusses the use of BW against "soft targets" as a form of Fabian strategy of indirect warfare. In essence, Hickson describes the Fabian strategy (named after the Roman general Quintus Fabius Maximus, who defeated Hannibal by avoiding direct conflict) as a strategy of indirect actions used to weaken the resistance of an opposing force. If an aggressor wished to defeat an enemy, but avoid the "after effects" of prolonged direct warfare that would leave deep scars on the civilization or the subsequent peace; the aggressor must develop ways to weaken the enemy beyond their capacity to fight or beyond the capacity to sustain a prolonged fight. This strategy could include BW directed at agricultural targets with the resultant effects of reduced export trade of agricultural commodities, food shortages, reduced employment for workers in agricultural and food related industries, reduced biofuels productivity (if the targets include biofuels crops), and due to the multiplier effects, overall decreased economic vigor of the nation. This could result in a subsequent cascade of socio-economic effects, including as discussed above, distrust and resistance to state or federal government authority; greater social dissent exemplified by public protests over food or fuel shortages and spiking food prices; riots over unemployment or food shortages. These final actions could indicate to an aggressor that the enemy is now weakened sufficiently so that a quick invasion and defeat is possible.

History of Biological Weapons Development or Attacks against Agricultural Targets

Whether it is a nation sponsored or non-state sponsored (e.g. terrorist) BW attack against agriculture, it is important to understand the historical development of this weapons technology. Although this paper cannot cover all historical aspects of the topic, it is important to mention various nations that did research or made advances in the use of BW against agriculture as well as mention the use by terrorists against livestock, crops, or food.

In World War I, early uses of BW on agricultural targets involved German spies using of anthrax and glanders against pack animals (horses and mules) being shipped out for use in war. Anton Dilger, a German-American physician, cultured anthrax and glanders bacteria and had German agents or sympathizers infect the animals in stockyards prior to export to Europe [2,7,45]. Dilger's agents either injected the pathogens into the horses or added the pathogens into animal feed and/or the water supplies [2,7,45].

During World War II, Nazi Germany began extensive work on BW for livestock using Rinderpest and FMD as well as an array of anti-crop pathogens and pests [4,8,9]. Although twice during the war, Hitler forbade offensive BW development, research continued with German development of anti-crop weapons such as Colorado potato beetles, Turnip weevils, Pine leaf wasps, Wheat blight, Wheat rust, Turnip fungus, Potato stalk rot, Potato blight (*Phytophthora infestans*), and smothering weeds [8,9]. Some research demonstrated a successful means to disseminate fungal spores mixed in combination with talcum powder [4,8,11]. It must be noted that upon the defeat of France by Nazi Germany in 1940, Germany obtained a great deal of BW information from debriefing French BW researchers [8,9].

France anti-crop program was mostly directed at Germany [4]. In 1939, French researchers explored methods to breed potato beetles and undertook release trials of the insects. Also, the French researched Rinderpest (aka bovine plague) and anthrax against livestock as well as performed research on Potato blight [4,8].

Japan, well known for the brutal use of BW against civilians and prisoners in China, was also actively researching and developing anti-crop and livestock BW [4,8,10]. Harris discusses the Japanese camp, Unit 100 (aka the Hippo-epizootic Unit of the Kwantung Army), which focused on animal and crop BW research [10]. The camp contained several farms, some of which grew poisonous plants thought to kill humans and animals or both. Other research done at these farms included development of herbicides used to kill plants or poison food. Also, the Japanese researched a variety of fungi, bacteria, and nematodes on most grains and vegetables grown in the regions of Manchuria and Siberia [4,8]. Japanese researchers had limited success in the aerial dissemination of anthrax and glanders [10].

During World War II, the United States, Britain, and Canada were actively engaged in research and development of BW and eagerly exchanged technical information and research results [11]. The US gained much from Britain's research, especially from British researcher, Paul Fildes. Fildes and associates established the inhalation doses required to achieve infection in laboratory animals. Fildes and his colleagues also developed the means of using a high explosive chemical warfare munitions to create an aerosolized bacterial cloud of particles capable of remaining in the lung (e.g. anthrax). With research done at Porton Down, Britain developed a retaliatory BW capability that included the production of 5,000,000 anthrax-laced cattle cakes. These cakes were intended to undermine the agricultural sector of the German economy [11].

Biological weapons research in the United States during World War II included the development of anti-crop chemicals which were defoliants: 2,4-dicholorophenoxy acetic acid (2,4,-D) and 2,4,5-tricholorophenoxy acetic acid (2,4,5-T) [8,11]. Further research in anti-crop agents was directed at the fungal pathogens: *P. infestans* (Potato blight), *Sclerotium rolfsii sacc* (Sclerotium Rot of sugar beets), *Piricularia oryzae Br. and Cav*. (Rice blast), and *Helminthosporium oryzae van Brede de Haan* (Brown Spot of rice). The research was also directed at the use of resistant fungi and the development of more virulent fungal strains to enhance success of an attack even during adverse conditions of warfare [11].

During the 1950's and 1960's, the US directed the anti-crop research, conducted at the Crop Division at Fort Detrick, to mass production and storage of anti-crop agents. The research also included the development of delivery vehicles including a "feather bomb" consisting of a modified propaganda bomb loaded with feathers dusted with fungal spores. Upon release, the bomb was found to create 100,000 foci of infection over a 50 square mile area. Other anti-crop dispersal devices included large volume spray tanks to disperse dry anti-crop BW agents which could with one aircraft disperse a plant disease epidemic over an area in excess of 1,000 square kilometers. Another dispersal device was a balloon gondola unit which could under the proper weather conditions would carry five containers of feather/fungal spore payloads deep into enemy territory. During this time period, various studies targeted the "grain belt" of Russia and the rice production regions of Communist China [8,11].

The former Soviet Union was known to have one of the most innovative and broad anti-crop and anti-livestock programs [4]. According to Alibek [13], the anti-crop program only began in the late 1940's or early 1950's. The anti-crop agents developed included wheat rust, rice blast, tobacco mosaic virus, brown leaf rust, and rye blast [4]. The anti-animal (anti-livestock) agents included African swine fever, Rinderpest, FMD, vesicular stomatitis virus, avian influenza, and a combined class of anti-personnel/anti-animal agents which included anthrax and psittacosis [11]. Mostly the anti-crop agents were targeted at US and Western European crops. Alibek states that the Soviets used Glanders BW against the mujaheddin in Afghanistan; the effect would kill their horses and sicken (incapacitate) the mujaheddin. The primary goal was to kill off the primary mode of transportation in the mountainous terrain-the horses [13].

Furthermore, the Soviets were successful in lyophilization and vacuum storage of maize rust and other stabilization techniques for Newcastle Disease virus [4]. The Soviets had claimed to have perfected insect rearing techniques and had built an automated mass-rearing facility which would produce millions of parasitic insects per day [4]. The release patterns and dissemination of insect attractants were studied to influence the migration patterns of natural and deliberately introduced insects [4]. It must further be noted that despite signing the Biological Toxins and Weapons Convention (BTWC) treaty in 1975 as well as publicly renouncing BW research and development, the Soviets cheated on the treaty and continued weapons development and research well into the early 1990's [14].

After the fall of the Soviet Union, concern has been raised over the end of research into BW agents, including anti-crop weapons [13,14]. Also, there has been anxiety that former Soviet BW scientists may transfer their knowledge or skills to rouge nations or terrorists [11,13,14]. As such, concern grows that the BTWC may need further updates in the area of plant pathogens to clarify and monitor "peaceful" applications as opposed to BW applications [8].

In Iraq, research was pursued prior to the Persian Gulf War and focused mostly on wheat stem rust, camel pox, and anthrax [4]. In 1988 near Mosul, large field tests demonstrated that wheat fields could be infected with a fungal plant pathogen (*Tiletia* which causes wheat bunt, aka Karnal Bunt). It must be noted that wheat bunt leaves the wheat seeds replaced by black teliospores as well as the teliospore produces a gas (trimethylamine) which can cause explosions in wheat harvesters [15]. According to the United Nations Special Commission on Iraq (UNSCOM), this contaminated wheat crop was harvested and stored to be used as an "economic" weapon against Iran to cause food shortages [11] during the Iraq-Iran war of attrition (1980-1988).

Kolavic et al [58] and Carus [50] report that in late 1996, Diane Thompson, a medical laboratory technician deliberately contaminated pastries with Shigella dysenteriae Type 2 bacteria and arranged to have them consumed in a break room by fellow laboratory workers. This act resulted in 12 laboratory workers becoming ill and one family member of one lab worker, who consumed the shared pastry at their home, also became ill. Although there were no fatalities, four victims required hospitalization and five others required emergency room treatment. The strain of bacteria was obtained from the medical laboratory's stock culture freezer where Thompson had ready access. Thompson was eventually arrested and sentenced to 20 years for intentional food tampering.

In 1989, a group calling itself "The Breeders" announced that they had bred and released Mediterranean fruit flies to protest the use of pesticides in the southern California area [4,17]. Later a US Department of Agriculture (USDA) study identified peculiar patterns of Mediterranean fruit fly (Medfly) infestations especially in new and strange places where the fruit fly would not likely appear. A review panel which included USDA scientists, concluded that someone or group was in fact breeding and releasing Medfly larvae. Later follow up attempts to communicate with the group yielded no criminal leads and no one to date has come forth or been apprehended over the incident [17].

Finally, Neher describes an experience in the state of Wisconsin in late 1996, where an unknown person or persons notified the local police chief that animal feed products leaving a rendering plant were contaminated with a pesticide and to expect large-scale animal deaths [18]. Neher, then an administrator in the Wisconsin Department of Agriculture, Trade, and Consumer Protection, discusses how a Toxic Response Team was mobilized, analyzed records and samples, and determined within two days that the feed and liquid fat were contaminated with chlordane (an organochlorine pesticide). Due to excellent feed industry and government agency cooperation, all potentially contaminated feed was removed from major customers and the contaminated feed was replaced within two days. The recall of the feed and liquid fat resulted in the disposal of 4,000 tons of feed and 500,000 pounds of fat with an estimated value of about $4 million dollars. Although the terrorist was never caught, no livestock animals were found to have serious contamination, and no human causalities occurred [18].

Routes of Food

The movement of food and agricultural products into the food chain of US consumers (or most other nations) starts at the farm. Yet, the simplistic view of farmer's produce to consumer table has become quite complex in the later part of the 20th and now 21st Century. Schwab [21] describes how the US food system has gone away from the local farm to massive cooperate farms as well as that fact that the US food system is tied into the global food supply. The route for plant based foods may include farm to warehouse/distribution center to grocer-produce section, to consumer table; yet, if any modifications of the food product occur (e.g. milling, dehydration, packaging), then the farm delivers the product to a factory for that food processing. For livestock based foods, processing includes the farm, abattoir (slaughterhouse), packing facility for additional processing (usually a factory department within the slaughterhouse), warehouse distributor, grocer, then to the consumer. Parker notes that each level of processing is a level of vulnerability in food BW attacks [6]. Cameron and Pate describe how the US cultivation of certain crops are concentrated in certain areas of the country (example: in 1997, 75.5% of strawberries, 92.2% of grapes, 47% of tomatoes 33.8% of oranges for the US were grown in California) and as such, these areas would be more vulnerable to BW attacks [19].

Chalk also mentions that developments in the farm-to-table continuum have greatly increased the points of entry for BW agents (for example: bacterial, viral, or toxin based agents) [3]. Many of these processing and packing plants lack security and surveillance and Chalk notes that these factors augment the ease for a food-borne attack [3].

Schwab notes that food-borne diseases could be introduced into the food chain as another form of agricultural BW [26]. Food-borne or waterborne pathogens could be introduced in the market place (e.g. grocery store or restaurant) or during food processing. Because many food-borne pathogens can be found locally in soils, water, plants, and animals; a deliberate BW attack using these organisms might be overlooked as a BW attack and merely attributed to food contamination of one type or another. The BW attack using food or water is a preferred method as dispersal of a pathogen in food or water allows for the increased likelihood of affecting a greater number of people [26]. Schwab notes that the Centers for Disease Control's (CDC) classification of Bioagents that are food-borne or waterborne include: Category A-Botulinum toxin; Category B-Salmonella species, *Shigella dysenteriae, Escherichia coli* O157:H7, *Vibrio Cholerae, Cryptosporidium,* and Noroviruses [26]. Finally, it must be noted that food and water borne pathogens have selective characteristics that favor their use as a BW agent including: low inoculation dose, ease of secondary transmission, and moderate to high persistence in the environment [26].

Wein and Liu in a study, that was controversial over its public release, used a mathematical model that covered cows to consumers and analyzed a hypothetical bioterrorist attack using botulinum toxin deliberately released into a milk supply chain with a single milk-processing facility [20]. (**SEE TABLE 1- CONCLUSIONS FROM A HYPOTHETICAL BIOTERRORIST ATTACK USING BOTULINUM TOXIN**) The authors study concluded that: 1- due to dilution factors along the milk supply chain, a minimum amount of the toxin would be required to ensure consumer causalities; 2- if terrorists obtained the proper amount, the rapid distribution and consumption would result in several hundred thousand causalities (NOTE: causalities of children due to their greater consumption of milk and greater toxin sensitivity would be significant); 3- the higher the initial dose of toxin introduced could mean a shorter time span for detection of poisoned milk as casualties began to appear more rapidly in the population; 4- current processing methods for milk-pasteurization-using either radiation or heat treatment are inadequate to inactivate the botulinum toxin, although Ultrahigh-Temperature (UHT) pasteurization (which has not been embraced by US consumers) will inactivate botulinum toxin in milk; 5- an ELISA test for the toxin is available and if implemented would cost less than one cent per gallon of milk; 6- more security measures for transport trucks, tanks, and silos as well as security background checks for farm laborers, plant personnel, and truck drivers are warranted as the present Food and Drug Administration (FDA) security guidelines are purely voluntary [20].

Modes of Attack

Parker describes five potential targets of agricultural bioterrorism: field crops; farm animals; food items in the processing or distribution chain; market-ready foods at the wholesale or retail level; and agricultural facilities that include processing plants, storage facilities, and components of the transportation sector as well as research laboratories [6]. Parker notes that most concerns over agricultural bioterrorism (or biological warfare attacks from nation states) have focused on mostly on field crops and farm animals. Yet, Parker notes that it is critical to be aware that BW attacks against foods in the food chain and also notes that research facilities engaged in investigations or analysis of foods could also be targets of attack [6]. Von Bredow., *et al*. [22] notes that compared to human food, one of the most vulnerable (i.e. least guarded) sources of the food supply is animal feed. Von Bredow., *et al*. notes that considering the vast amount of feed required by poultry and livestock, it would be next to impossible to secure all of this food [22]. Yet, it is possible that by contamination of the animal feed, the contamination could easily end up in the human food chain (as exemplified by the Wisconsin bioterrorism case described by Neher [18] above).

Kosal and Anderson [46] describe an incident where an antibiotic feed additive, salinomycin, a lipid soluble ionophore, contraindicated for camelids (such as alpacas); was unknowingly added at the commercial feed production facility. The feed was distributed to 6 to 8 alpaca farms resulting in over 1000 alpacas exposed and 135 deaths. After confirmation of the salinomycin contamination by the Ohio Department of Agriculture, a recall of the contaminated feed was issued. This is an example of how a contaminant at a nexus point of manufacture can have far reaching effects in the agricultural food chain.

A brief review of various agents of attack, based in part on previous BW weapons researched or developed for agricultural targets, as well as discussion of bioterrorism will be described below.

Crops

Most crop pathogens in BW research have been chosen due to their ease of culture, stability in storage, ease of dissemination, and capacity to cause significant damage over a rapid period of time [8]. From a phytopathologist's view, the variety of pathogens for any plant includes viruses, nematodes, bacteria, fungus, mycoplasmas, as well as insects either acting as vectors or as crop pests. Furthermore, even with the successful dispersal of pathogens, other environmental conditions can affect the chances of the pathogen causing an epidemic in the crops. These variables include: light, humidity, changes in temperature, as well as wind shifts causing the aerosolized agent to be re-directed away from the target crop field [11].

Key agents for BW attacks against crops focus on the high calorie (i.e. carbohydrate) crops such as wheat, rice, corn, and potatoes [8]. Watson [23] and Whitby [8] describe some of these anti-crop agents: Black stem rust (*Puccinia graminis tritici*), Karnal bunt of wheat (*Tilletia*), Stripe rust (*Puccinia glumarum*) for wheat; Rice blast (*Piricularia oryzae*), Brown spot (*Helminthosporium oryzae*), Rice blight (*Xanthomonas oryzae*) for rice; Maize rust (*Puccinia Sorghi*), Leaf blight (*Helminthosporium maydis*), Streak (*virus spread by Cicadulina mblia-the South African leafhopper*), and Corn blight (*Pseudomonas alboprecipitans*) for corn; Late blight (*Phytophthora infestants*), Brown rot (*Pseudomonas solanacearum*), Common scab (*Streptomyces scabies*) for potato. Other crops for BW attack were chosen due to their international economic significance, such as coffee, bananas, citrus fruits, and sugar cane [8]. Some anti-crop agents for these crops include [8, 23, 49]: Leaf spot of bananas (*Cercospora musae*), Wilt of bananas (*Fusarium oxysporum F. cubense*), Tristeza of citrus (*citrus tristeza* virus), Downy mildew of sugar cane (*Sclerospora sacchari*), Sugar cane smut (*Ustilago scitaminea*), Anthracnose of coffee (*Colletotrichum coffeanum*), Citrus greening (*aka Huanglongbing*) of citrus fruits (*Candidatus Liberibacter asiaticus*) and Coffee rust (*Hemileia vastatrix*).

Livestock Animals

Several aspects of anti-animal agents need to be discussed. The successful BW agents (like the anti-crop) agents need to be pathogens that can be easily cultured, easily stored until needed, easily disseminated, and have a high degree of virulence to the targeted population. Watson [23] describes some of these agents: Foot and Mouth Disease (FMD virus) and Rinderpest (Rinderpest virus) for cattle; Newcastle disease (Newcastle disease virus) for poultry, Heart water for sheep and goats (a rickettsial organism formerly referred to as *Cowdria ruminantium*, now called *Erlichia ruminatum*), yet in the field this organism requires a tick vector (Tropical Bont Tick-*Amblyomma variegatum*)[60]; and Aspergillosis of poultry (*Aspergillus fumigatus*).

Brown and Slenning discuss anti-animal diseases as a serious threat that could be introduced via smuggling infected animals into the country [24]. This would be one mode of attack that would not require aerial spraying of the pathogen, but could nonetheless introduce the pathogen in a coordinated BW attack or an act of bioterrorism. Furthermore, the authors note that if the anti-animal disease was introduced, it could remain endemic in the country as the pathogen could infect wildlife. One example of such an anti-animal disease is Rinderpest which can infect both livestock animals but also wild hoofed stock that exist in North America [24].

Gordon and Beck-Nielsen state that foreign animal diseases (FAD) could be key tools for a future bioterrorism attack against the livestock industry [25]. Besides the anti-animal pathogens mentioned above, the authors also include for FAD candidates Avian influenza and African Swine Fever (ASF). ASF could be a devastating anti-animal agent as this hemorrhagic viral disease can result in 100% mortality during the initial onset and no vaccine against the disease is available [25].

Bioterrorism Non-State Actors

Although other parts of this paper discuss the topic with consideration of motives and methods to a bioterrorism attack, it must be discussed here as well. Bioterrorists (aka non-state actors) might use agricultural BW in the following methods: multiple attacks with the pathogen at sites of high concentration of crops or livestock using contaminated animals (e.g. animals smuggled into the country with Avian influenza); pathogen aerosols (Karnal bunt teliospores for wheat crops or FMD in an aerosol for cattle); vectors carrying the pathogen (such as ticks with Heart water) [25]; or fruit bats or pigs (domesticated or feral) infected with Nipah virus [43,47].

Jonathan Ban [2] discusses some of the reasons that BW against agricultural targets might be favored by bioterrorist. First, many of the pathogens are zoonotic and many do not affect humans, so without the risk of human fatalities, the moral restrains to using BW would be removed. Second, since the disease is agricultural, it may be very difficult to distinguish the attack from a natural outbreak of the disease. This is an important point, since many BW attacks (human or agricultural) would still require an incubation period from the time of exposure to the onset of disease. If the bioterrorist wants to avoid taking credit, the attack might be mistaken for a natural outbreak. Third, agricultural facilities and resources are largely exposed and not protected, hence very vulnerable to BW attacks. Finally, the biotechnical (e.g. culturing a fungal plant pathogen) and operational barriers related to agricultural BW are relatively lower compared to human targeted BW weapons. Most agricultural BW will not infect humans (e.g. Karnal bunt, Late blight in potatoes, or FMD for cattle) and many will require a simple infection of a single animal or dispersal of a fungal pathogen over unprotected wheat or corn field [2,48,49,51,52].

O'Hara reports one unusual bioattack in 1997 was initiated by pastoral farmers in South Island of New Zealand [50-52]. The farmers introduced Rabbit Haemorrhagic Disease (RHD)-a calicivirus-on rabbit infested farms to control the invasive rabbit population on the island. The farmers captured infected wild rabbits in Australia, homogenized rabbit tissues (liver and spleen) and applied the homogenated tissues to rabbit baits consisting of grain, carrots, and parsnips [51]. The farmers acted as the local bureaucrats did not act quickly in response to the farmers' demands for effective rabbit biocontrol. The RHD is now endemic in New Zealand.

Genetic Engineering

This paper must not ignore a topic of great concern-the risk of genetically engineered BW agents (aka Black Biology). Horn and Breeze [4] discuss this concern as a topic of growing potential weapons relevance. It is possible using genetic engineering techniques to enhance the toxicity or pathogenicity of organisms or toxins. It is also possible to engineer new organisms with enhanced capabilities to be resistant to antibiotics, vaccines, or to display a new series of symptoms. The resultant BW agent directed at agricultural targets would create a greater vulnerability for any nation. Since without appropriate countermeasures (e.g. antibiotics, vaccines) or an extensive delay in disease identification (due to a new array of symptoms for the pathogen), any attack by a genetically engineered pathogen could potentially ruin the agricultural productivity of a nation.

Modes of Detection

The present strategy of detection of BW agents includes diagnostic tools such as Electrochemiluminescence, Polymerase Chain Reaction (PCR) tied with Enzyme Immunoassay, and Fluorogenic probe based PCR [27]. Higgins et al describe the feasibility of technical laboratory detection tools to be used in field based labs. The development of rapid diagnostics in a field laboratory was demonstrated by the 520th Theater Area Medical Laboratory (TAML) of the US Army. Higgins and colleagues state that the use of such rapid testing could provide rapid and accurate diagnosis of food borne or water borne BW agents. The authors also stress that rapid testing techniques would not be used alone, but would be used in conjunction with more traditional techniques to verify the pathogen and route to treatment [27].

Von Bredow., et al. [22] describes several technologies developed for the detection of bacteria or contamination in food. One rapid method is a luminometer using a luciferin-lucifera reagent to detect live bacteria. The detection method has been found effective in detecting bacteria in either animal carcasses or in animal feed, even in samples of whole oats! Another rapid method of analysis and detection is the SMART (Sensitive Membrane Antigen Rapid Test) system developed by New Horizons Diagnostic Corporation. This test is an antigen-antibody two step process that uses colloidal gold particles attached with the primary antibody to attach to the antigen (i.e. target BW agent). The system has been used to identify different BW agents, including Anthrax, Brucella, Botulism toxin, Tularemia, and Ricin. The authors state that the test can be modified for detection of other biological agents as soon as the appropriate antibody is developed [22].

Ron Sequeria of the USDA Animal and Plant Health Inspection Service (APHIS) notes that APHIS has expanded its capability to monitor BW attacks on agricultural facilities [27]. These strategies include use of geographic informational systems (GIS), Global Positioning Systems (GPS), satellite image analysis, remote sensing, and training an elite staff within an emergency response framework capable of managing the information processing and analysis. The APHIS framework can monitor the movement of epidemics and make necessary recommendations based on weather, geographic, and phytopathological data to halt or eradicate the epidemic. The author also notes that the APHIS activities will also be in close cooperation with other emergency management agencies as well as include cooperation from industry groups, state organizations, and academic institutions [27].

Vulnerability Factors of Agricultural Targets

Chalk [3] discusses the vulnerabilities of US agriculture to BW attacks and notes six primary vulnerabilities. (**SEE TABLE 2- VULNERABILITY FACTORS OF AGRICULTURAL TARGETS**) First, the contemporary farming practices of concentrated and intensive farming practices. Ban [4] notes that 84% of the US cattle population is concentrated in the southwest, 60% of the swine population is located in the Midwest, and 78% of the chicken population is located in the southeast Atlantic region. Cattle are raised in feedlots holding as many as 150,000 to 300,000 head of beef, whereas chicken farms will pen 100,000 birds together [4]. This tight living arrangement allows for rapid spread of pathogens among livestock, especially if the pathogen is transmitted as an aerosol.

Second, the increased susceptibility of livestock to disease. Parker notes that intensive farming practices have stressed livestock weakening their resistance to disease. This results in an increased need for antibiotic use in feed stock and an increased risk of the development of antibiotic resistance strains of pathogens [6].

Third, a general lack of farm/food related security and surveillance [3]. Although this has been discussed previously, one example of the poor security is the cavalier attitudes of farm workers entering and leaving chicken pens. Bruce Stewart-Brown [29] reported a survey done at one large chicken farm where personnel freely entered and exited chicken pens. Many did not sign in or sign out, while few if any monitored what was tracked into the pens via shoes or clothing. Stewart-Brown notes that the lack of security practices and failure to prevent contamination via shoes or clothing could result in an easy and rapid transfer of pathogens from one large chicken pen (holding 100,000 or more chickens) to another. Furthermore, Stewart-Brown notes that outsiders entering the pens were not required to clean off shoes nor were required to provide any identification. Thus outsiders visiting the farms could easily transfer pathogens from soil off of their shoes to various chicken pens as well as be active BW terrorists [29].

Fourth, Chalk mentions that an inefficient and passive disease-reporting system exist that is further hampered by a lack of trust between regulators and producers. Chalk notes that the communication lines with state regulatory personnel are crude and in many cases confusing. Furthermore, farmers are reluctant to report disease outbreaks for fear of undergoing livestock "depopulation" (without compensation) in an effort to stop the outbreak of the disease [3]. This resistance to report and poor reporting communication systems engenders the conditions for rapid outbreaks and poor evidence chains to track back the disease to the source of the epidemic.

Fifth, Chalk discuses the problem that most veterinarian training does not include foreign animal diseases (or Biological Warfare diseases) as well as large scale husbandry [3]. Since large scale husbandry is the prevalent method of modern farming, most veterinarians fail in diagnosing diseases unique to large scale husbandry or are able to detect conditions that are conducive for an epidemic. Also, since most veterinarians have not had training in foreign animal diseases (or biological weapon-based diseases); the opportunity to rapidly detect and stop an outbreak will be lost. This is not unusual since many younger physicians have not been trained in recognition of human directed (anti-personnel) BW, such as smallpox, anthrax, or Ebola [3].

The sixth vulnerability factor identified by Chalk [3] was a prevailing focus on aggregate, rather than individual, livestock statistics. Chalk describes this factor as a result of large livestock populations. As farmers have such large populations of livestock, they tend to miss problems with individual animals and rather focus only on large scale results (e.g. total milk output). This large scale data tends to miss individual animals that could be the incubator of a major outbreak of disease that would quickly spread throughout the crowded herd of livestock.

Two other factors have to be mentioned as vulnerability factors. Monoculture is the farming practice where only one crop is raised in a field (e.g. wheat, corn, tomatoes, barley, etc.). As a result, the monoculture becomes a large scale susceptible host to the pathogen infection and spread of the pathogen within the monoculture field [6,8,11]. If the pathogen can spread beyond that field by airborne particles (such as fungal spores), then the pathogen can successfully spread to other fields or across the country or even across the continent. The spread by aerial dispersal of plant disease pathogens on a global or continental scale was described in great detail by Brown and Hovmeller [30]. The authors note that long distance dispersals of fungal pathogen spores by the wind can spread plant diseases across or between continents. Furthermore, the irregular nature of these long-distance dispersals of fungal pathogens can create epidemics in new territories or create outbreaks in previously resistant plant cultivars [30]. This last observation could be a warning to those that consider using agricultural BW as the pathogens released in an enemy nation could blow back to the aggressor nation eventually with epidemic results.

The other vulnerability factor is the low genetic variation (genetic uniformity) within agricultural crops and animals [11,34]. Modern agricultural husbandry and plant genetics has resulted in reduced genetic variation within farm crops and livestock. With reduced genetic variation within livestock or crops, the potential for resistance to the pathogen is reduced. Furthermore, with low genetic variation within livestock and crops, the potential for finding genes for resistance is reduced as well [34].

Nonstandard Models of Attack

The following section will briefly discuss several possible routes of agricultural BW attack based on recent technological, economic, and scientific developments. These "nonstandard" models may become future attack models for agricultural BW in the 21st Century.

Biocruise

Biocruise is defined as the combining of BW technology with cruise missile delivery systems. A cruise missile is defined as "an unmanned self-propelled guided vehicle that sustains flight through aerodynamic life for most of its flight path and whose primary mission is to place an ordnance or special payload on a target."[31]. this definition today includes unmanned air vehicles (UAVs) and remotely piloted helicopters or aircraft (RPVs). Cruise missiles are easier to obtain, maintain, weaponries, and employ than ballistic missiles. Cruise missiles have the advantage that a properly sized aerosol dispersal system (such as fungal spores or bacteria) could be installed within the missile. Once installed, the cruise missile could deliver a BW aerosol over a large swath area such as crop fields or livestock pastures or feedlots [31].

Some cruise missiles have extremely accurate navigation systems, using terrain contour matching (TERCOM) guidance systems, whereas others have guidance systems using US Global Positioning System (GPS) or the Differential GPS (DGPS) systems. With these systems, the accuracy of targeting by cruise missiles is far superior to ballistic missiles [31].

Kiziah [32] discusses the biocruise threat from the perspective that a biocruise attack could provide "plausible deniability" from a rouge nation. If the attack was done at night, a long range land attack cruise missile (LACM) could be directed to disperse the BW agent while programmed to fly a circuitous route to the target. After dispersal, the missile could be programmed to crash in the ocean or self destruct. Since cruise missiles fly low, (some below radar detection level) as well as have a small Infrared (IR) and radar signature; this makes detection of cruise missiles difficult. Further, it must be noted that cruise missiles can be launched from sea (even launched covertly from a cargo or tanker ship), from the air, as well as from a submarine.

With biocruise technology, any nation or terrorist group could direct a cruise missile to navigate and disperse BW agents over agricultural targets; especially at night when notice by farmers or farm security is at the lowest level. With GPS navigation, the missile could disperse anti-crop or anti-animal agents over a number of targets, self-destruct in the ocean, and hence hide any evidence of a deliberate BW attack on agricultural resources.

Although it has not been described in detail; the application of drone (remotely controlled aerial vehicles) technology for shorter range delivery of Agroterrorism agents, could evoke a Agroterrorism attack of serious magnitude even if the bioterrorist was a "lone wolf".

Attacks against Biofuel Crops

With the rise in demand for liquid fuels, ethanol and biodiesel, biofuels crops like corn or sorghum for ethanol production and soybeans or palm oils for biodiesel production will be prime targets for BW. Either a competing nation or a bioterrorist using BW to attack the crops could achieve a multiplier effect with an attack on corn, soybeans, or sorghum: an epidemic on the crops; a resulting shortage of raw materials for biofuel production; and a subsequent shortage of biofuel.

Use of Introduced Species

An introduced species (aka exotic species) is a foreign organism introduced into an ecosystem and causing damage to that ecosystem [33,43,44]. Some organisms have been introduced and caused damage to agriculture (e.g. Kudzu and Gypsy Moth in US, Rinderpest in Africa, Rabbits in Australia). Barnaby [34] discusses that the biodiversity of the planet is decreasing and this includes the genetic diversity of crop plants such as wheat and rice. One of the problems of emerging plant diseases is that some pathogens are "exotic" species until they have achieved establishment within new territories. Bandyopadhyay and Frederiksen [35] discuss the rise of some of these plant diseases as merely exotic species introduced into new habitats. These diseases include Sorghum ergot, Karnal bunt of wheat, Potato late blight, and Citrus tristeza. The authors further assert that these introductions can occur naturally or via trade practices [35].

If a nation or bioterrorist were to introduce a non-native pathogen to a susceptible agricultural target, it could have a devastating effect [43]. Hence, it would be possible to use the knowledge of the ecological success of introduced species to apply it as an agricultural BW weapon. One candidate for such application is Striga (aka witch weed) [43]. Striga is a parasitic plant that consists of several species; all of them can grow underground and invade plant roots, robbing the host plant of water and nutrients [36]. The target host plants (depending on the species of Striga) are corn, rice, and sorghum. Originally from Africa where the parasitic plant is a menace, the plant was accidently introduced into the Carolinas, where plant quarantine was set up to contain the infestation [36]. At present, no complete eradication of Striga from the Carolinas has occurred.

Counterstrategies

This section will focus on the various counterstrategies that can be used or are recommended to deal with agricultural BW attacks. Casagrande [48] has stated that biological attacks against agriculture should be regarded as a "high-consequence, high probability" event as a well as a grave “national security risk” [48]. Hence, counterstrategies should be given high priority in any discussion of agricultural BW.

Detection

Although the detection technologies presently have been described above, one key aspect in the detection is how to determine if the outbreak or epidemic was caused by natural means or by a BW attack [54].

Sequeira [28] describes the following points to help in determining that the outbreak is intentional. (**SEE TABLE 3- INDICATORS IN THE DETERMINATION THAT AN AGRICULTURAL OUTBREAK WAS INTENTIONAL**). This criterion is used for pathogens or for other “introduced species”. Sequeira notes that intentional introductions will differ from accidental introductions in the following ways: 1-use of non-traditional pathways; 2- increase of the probability of survival of the pest in transit; 3- widespread dissemination of the disease from disparate foci; 4- use of highly virulent strains; 5- high rates of inoculum; 6- introduction into remote areas; 7- targeting of susceptible production areas; 8- targeting of susceptible natural environments; 9- release of multiple species simultaneously; 10- precise timing of releases to coincide with maximal colonization potential. Sequeira also notes that the globalization of the economy has already taxed the existing USDA structures and resources [28].

Rogers [37] notes that anti-crop BW has potential in nations where crop strains are susceptible to a pathogen. This risk is further enhanced if by genetic modification, a strain (or strains) of the pathogen are intended to affect the specific varieties of a crop grown in a target state. Rogers further notes that a state that is vulnerable to anti-crop BW, is a state with a system of arable agriculture which uses extensive monoculture of important crops, but lacks a well developed research and extension service. The lack of monitoring, education, and research means that the state lacks the infrastructure necessary to rapidly fend off an agricultural BW attack (or a bioterrorist BW attack on agriculture) [37].

With regard to anti-animal BW attacks, Hugh-Jones [38] describes some of the indicators as follows: the event has: unusual time and/or place of occurrence; unexpected strain of agent or multiple strains; a noted reversal of an otherwise steady progress in disease control or freedom; an epidemiologically “weird” event or occurrence that does not match normal experience or knowledge. Hugh-Jones notes that these events lead to the following results: marked economic or political costs with benefits going to a competitor; removal of the target country from international trade (quarantine); the target country must still continue imports from the competitor; there is marked social unrest in a significant part of the population due in part to the loss of livestock or crops and jobs [38]. From these indicators, Hugh-Jones recommends steps to prepare for future incidents, assessing data to determine the suspicious outbreaks (including identification of the spread of the disease and the strain of the pathogen), analysis of economic and trade effects, determination of people movements of possible suspects involved in the incident; and finally publicity with reports properly detailing the known data for review by the scientific community as well as the public at large [38].

Furthermore, detection can be bolstered further by advanced training and tools for the farms and first responders [61] on plant and animal pathogens, such as introducing farmers [53], veterinarians [55,57], and customs and border agents [55,57] to enhanced training in exotic pathogens, phytopathology, and early detection systems for animal diseases. For example, Chomel and Marand [57] discussed the need for expanding coursework for veterinary students in wildlife zoonotic diseases, emerging diseases, and training in the reporting pathways for notifiable diseases in their country and state.

Knutsson., et al. [59] describes how biotraceability can enhance the response phase during a bioterrorism attack to feed or the food chain. The authors define biotraceability as the ability to use downstream information to indicate the process or the specific food chain where the source of an agent (e.g. microbiological agent) was introduced. Thus, regardless of an accidental or deliberate pathogen or toxin entering the food chain; biotraceability techniques, biomarker tracer discovery, tracking tools, and communication reduce the response phase and enhance the tracing of the origin of the biological agent contamination [59].

Recommendations for Increased Cooperation and Communication between Agricultural agencies, other Federal Agencies, and the Military

From the tools developed by the USDA, Sequeira reports that the USDA has accessed existing emergency response structures (including APHIS, Plant Protection and Quarantine (PPQ), and Veterinary Services (VS) of APHIS) as well as developed the formal organization, Regional Emergency Animal Disease Eradication Organization (READO). All of these organizations are directed to assist in the containment and eradication of pathogenic or introduced organisms resulting from a BW attack [28]. Casagrande [48] recommended that funding to APHIS should be increased to create Early Response Teams consisting of three member teams that can respond to an animal or plant outbreak in 24 hours.

In 1998, agricultural bioterrorism was not given proper attention under the Presidential Decision Directive 63 (PDD-63) which dealt with “Critical Infrastructure Protection”. PDD-63 did not list food and agriculture was one of the eight critical infrastructures that needed to be protected from Weapons of Mass Destruction (WMD). Although President Clinton did issue both PDD-63 and PDD-62 (PDD-62 dealt with “Combating Terrorism”) at the same time, agriculture was given a subcommittee under PDD-62 [6]. Parker describes how the USDA should be in the front of leadership in dealing with agricultural bioterrorism or BW attacks directed at agricultural resources. The USDA should lead in the bioterrorism strategy since its federal role is food safety and food security.

Parker concludes his book [6] with a series of recommendations, including: taking the lead in agricultural bioterrorism from the federal level; secure intelligence from the various intelligence agencies and maintain contacts with them; continue to cultivate a relationship with the military and use them where necessary in securing eradication efforts and maintaining order; expand contacts with state and local government agencies and academic institutions; develop partnerships with the private sector, especially with Farm Bureau Federation, national commodity organizations, and agribusiness organizations (e.g. American Poultry Association, National Cattlemen’s Beef Association, National Corn Growers Association, etc.) as well as major agribusiness companies, feed companies, food wholesalers, slaughterhouses, seed companies, and other agribusiness related firms-large and small [6].

Martensson., *et al*. [56] describes a similar strategy of building networks of intelligence, police, forensics, customs agencies, along with the public and animal health and environmental organizations to share information to prevent an Agroterrorism incident. AniBioThreat is a European Union project with a strategy of early warning and workshops to identify and build a collaborative culture to prepare and confront bioterrorism or Agroterrorism threats [56].

In essence, communication with the public will help maintain order and help engender trust when an agricultural BW attack does surface.

Finally, Yeh., *et al*. [53] discussed control and preventing acquisition of anti-livestock agents from laboratories and cell banks. Furthermore, the authors recommend that paperwork requirements for obtaining livestock pathogens be as stringent as obtaining human pathogens. Also, Yeh., *et al*. [53] recommend that any request for livestock pathogens that seem unusual or suspicious be reported to government authorities with the case forwarded to a national investigative agency for possible review of bioterrorist activity.

Genetic Engineering

One tool that can be very useful for defense against agricultural BW is the exploration of genetic engineering. Genetic engineering of plants has led to major improvements in food quality and composition [39], but it has also provided new opportunities to improve insect resistance of the plants [40]. Dixon., *et al*. [41] report success in enhancing the natural defense responses of plants by boosting phytoalexin responses which can play a critical role in resistance to viral, fungal and bacterial pathogens. If this work expands and continues to be successful, it is possible that anti-crop pathogens could have their outbreaks blunted or blocked by crops with genetically engineered enhanced natural defenses. Finally, Gressel., *et al*. reported success in the development of herbicide resistant plants which would allow use of herbicides to stop plant parasites like Striga and Broomrape, yet allow the target crop to flourish [42]. These techniques would offer opportunities for the developing world to deal with parasitic plants, but could also provide tools to counteract parasitic plants that would be used as anti-crop BW.

Advanced Agricultural Techniques

Finally, advanced agricultural techniques will be required to break away from the modern agricultural methods that make present day agriculture so vulnerable to BW.

First, monoculture as a practice increases the vulnerability of the field crops to a BW attack. Intercropping with two different crops (e.g. rows of beans between rows of corn) would decrease the vulnerability of the whole field to a rapid spread of a pathogen. Next, many monoculture crops use an asexual means to propagate the plants (e.g., strawberry plants from stolons) which would reduce genetic diversity in the field. If all of the plants are genetically the same (asexually they are cloned from the "mother" plant), then this process would also contribute to increased vulnerability to a BW attack. Genetic variation within a crop field must be encouraged to reduce this risk.

Barnaby [34] comments that the genetic diversity of wheat and rice are becoming impoverished. Yet, it is the primitive cultivars that contribute to new genetic traits being bred into the germ lines of various food crops [34]. Barnaby recommends more intercropping practices, expanded work on integrated pest control and biological control agents, as well as development of resistant cultivars. With these improvements, crops would be more resistant to anti-crop BW attacks.

Summary

Agricultural products are a key part of US infrastructure, a major part of the US Gross Domestic Product, and a vital part of the US export trade. Agriculture and food has been taken for granted in the US due to the relative low cost, abundant productivity, and enhanced modern techniques for raising crops and livestock. Unfortunately, with these modern techniques, agriculture has become quite vulnerable to anti-crop and anti-animal BW. The reasons for the use of agricultural BW range from nations attacking overtly or covertly to destroy an enemy nation's food resources; to terrorist motivations for blackmail and extortion; evoking public fear; or profiting from commodity market turmoil following a BW attack on agricultural commodities.

History has demonstrated that many nations have explored or fully developed anti-crop and anti-animal BW. Although banned by the Biological Toxins and Weapons Convention (BTWC) treaty, agricultural BW may still exist in some nations as well as in the plans of bioterrorists (whether as a group or a lone disgruntled individual). As the food chain and food production techniques have become more complex, the vulnerability for agricultural BW has increased, both on the farm and in the food processing plant. Furthermore, food and water borne pathogens could be used as BW agents to obtain the greatest number of victims through contaminated food or water.

Agricultural BW agent detection methods exist as well as federal and state agencies have developed the necessary testing tools and protocols to contain, decontaminate, identify, and eradicate any agricultural BW agent. Improvements are necessary to improve the response timing to an attack (i.e. response phase) as well as enhance the cooperation of farmers, food producers, and the public in general. These improvements include having the USDA lead the response and communication with federal, state and local organizations in the event of an agricultural BW attack as well as provide the USDA with Federal recognition that agriculture is one of the critical infrastructures that must be protected from terrorist attack.

Conflict of interest

The author declares no conflicts of interest.

1- Due to dilution factors along the milk supply chain, a minimum amount of the toxin would be required to ensure consumer causalities
2- If terrorists obtained the proper amount, the rapid distribution and consumption would result in several hundred thousand causalities (NOTE: causalities of children due to their greater consumption of milk and greater toxin sensitivity would be significant)
3- The higher the initial dose of toxin introduced could mean a shorter time span for detection of poisoned milk as casualties began to appear more rapidly in the population
4- Current processing methods for milk-pasteurization-using either radiation or heat treatment are inadequate to inactivate the botulinum toxin, although UltraHigh-Temperature (UHT) pasteurization (which has not been embraced by US consumers) will inactivate botulinum toxin in milk
5- An ELISA test for the toxin is available and if implemented would cost less than one cent per gallon of milk
6- More security measures for transport trucks, tanks, and silos as well as security background checks for farm laborers, plant personnel, and truck drivers are warranted as the present Food and Drug Administration (FDA) security guidelines are purely voluntary

Table 1: *CONCLUSIONS FROM A HYPOTHETICAL BIOTERRORIST ATTACK USING BOTULINUM TOXIN DELIBERATELY RELEASED INTO A MILK SUPPLY CHAIN WITH A SINGLE MILK-PROCESSING FACILITY [20].*

1. Contemporary farming practices of concentrated and intensive farming practices.
2. Increased susceptibility of livestock to disease.
3. General lack of farm/food related security and surveillance.
4. Inefficient and passive disease-reporting system exists that is further hampered by a lack of trust between regulators and producers.
5. Most veterinarian's training does not include foreign animal diseases (or Biological Warfare diseases) as well as large scale husbandry.
6. Prevailing focus on aggregate, rather than individual, livestock health statistics.
7. Monoculture as a farming practice becomes a large scale susceptible host to the pathogen infection and spread of the pathogen within the monoculture field
8. Low genetic variation (genetic uniformity) within agricultural crops and animals

Table 2: *VULNERABILITY FACTORS OF AGRICULTURAL TARGETS [3,8,11,34].*

1- Use of non-traditional pathways
2- Increase of the probability of survival of the pest in transit
3- Widespread dissemination of the disease from disparate foci
4- Use of highly virulent strains;
5- High rates of inoculum
6- Introduction into remote areas
7- Targeting of susceptible production areas
8- Targeting of susceptible natural environments
9- Release of multiple species simultaneously
10- Precise timing of releases to coincide with maximal colonization potential.

Table 3: *INDICATORS IN THE DETERMINATION THAT AN AGRICULTURAL OUTBREAK WAS INTENTIONAL.*
NOTE: intentional introductions differ from accidental introductions in the following means: Based on Sequeira [28].

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