Chapter 10
Bioterrorism: A Threat to Plant Biosecurity?

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10.1 Plant Biosecurity: The Foundation for Food Security

10.1.1 What Is Plant Biosecurity?

There are many definitions of biosecurity ranging from very broad to very narrow in nature and scope. Much of the variation can be attributed to the scale of the systems under consideration and the attributes being analyzed. For the purpose of this paper, biosecurity will be used as previously defined (Stack 2008). Security is a state of existence that assures safety and provides protection from harm; real or perceived. Biosecurity is in specific reference to protection from harm caused by biological agents. Biosecurity at the laboratory scale is focused on physical and behavioral measures that ensure specific organisms cannot accidentally escape or be deliberately taken from the laboratory. Geographic biosecurity is focused on exclusion and containment; it is about ensuring that exotic organisms are not introduced into a given area and that potentially harmful organisms cannot escape from that area. Plant biosecurity is concerned with the protection of natural and managed plant systems from the introduction of exotic organisms or from the emergence of indigenous organisms that would negatively impact the productivity, sustainability,

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or diversity of plant systems. Plant biosecurity is a state of preparedness that ensures productive and sustainable plant ecosystems. In agricultural systems, plant biosecurity is a state of preparedness that ensures a safe and constant supply of food, feed, fiber, timber and fuels. Crop biosecurity has also been defined as protecting a state from invasive plant pathogens (Brasier 2008).

10.1.2 The Food Security – Plant Biosecurity Linkage

The food systems that provide the caloric requirements for most of the world's population are plant-based, including, rice, wheat and maize. We either consume those plants directly or we provide them as feed, forage, or grazing to the animals that we consume. The health and productivity of plant systems are prerequisites for food security and human health. At present, many nations lack the food production capacity to feed their existing and projected populations. They are dependent upon international aid programs and trade of plants and plant products to compensate for food deficits. Consequently, global food security is, in part, dependent upon effective plant biosecurity strategies and appropriate infrastructure at the national and international levels (Stack and Fletcher 2007). In food production systems, plant biosecurity is a state of preparedness that ensures a safe, affordable, and available supply of food and feed. Food protests and riots in at least 30 nations over the last 18 months are evidence of the significant linkage between food security and national security (Shelburne 2008). Without effective plant biosecurity programs to protect the world's staple crops, food safety and security will decline in developing nations and weak governments will fail (Shelburne 2008). This will further compromise global economic development and international programs to reduce hunger and improve health. Without effective plant biosecurity programs to protect the world's natural plant systems, the ecosystem services that they provide to support humans will decline, thus compromising the development of sustainable societies.

10.2 Threats to Plant Biosecurity

10.2.1 General Threats to Plant Biosecurity

There are many general threats to plant systems that put plant biosecurity at risk, including global trade of plants and plant products, climate change, population growth and landscape exploitation (Stack 2008; Gullino et al. 2008; Brasier 2008). One of the significant difficulties associated with addressing the threats of bioterrorism and biocrime targeting plant systems is the inability to determine that an outbreak was intentionally caused (Fletcher 2008). There is a lack of specific criteria by which to distinguish intentional from accidental or natural introductions (Nutter and Madden 2005; Fletcher et al. 2006). This is made much more difficult by the increasing frequency of accidental introductions associated with global plant trade (Palm 1999; Rossman 2001; Brasier 2008). Natural dispersal of plants via ocean currents or air systems is insignificant compared to the intentional movement of plants for the purpose of global trade (Mack and Lonsdale 2001). The deliberate trade of ornamental and landscape plants began and continues without adequate regard for the consequences of those introductions to the new environments (Britton 2004; Brasier 2008). Plant pathogens can be readily dispersed within plants and plant products in a latent, asymptomatic phase. The number of plant pathogens introduced into the United States increased approximately 300% from 1900 to 2000 (Windle 2004). Whether the increasing numbers are due solely to new introductions or a combination of new introductions and better detection protocols and diagnostic technologies is difficult to determine. However, a recent United States Department of Agriculture (USDA) estimate indicates that a new exotic species is detected in the U.S. every 8–12 days. This large-scale influx of exotic species has been termed biological pollution (Britton 2004). With that as the norm, determining a specific introduction to be intentional will be challenging. Further complicating efforts to assign attribution, global trade in plants has facilitated the evolution of new pathogen species with novel properties that would not be predicted from the parental phenotypes (Man in't Veldt et al., 1998; Brasier 2001). Newly described species have been detected in nurseries where plants from geographically distinct areas of the world were placed in close proximity to each other. This arrangement allowed for the mixing and eventual hybridization of distinct species that were normally separated geographically. Unless a perpetrator claims responsibility, it may be very difficult to determine whether outbreaks of new diseases by previously undescribed pathogens were caused by the trade-facilitated evolution of new pathogen species or the deliberate introduction of novel pathogens created in a laboratory.

In addition to masking acts of bioterrorism and biocrime in the backdrop of frequent accidental introductions, global trade in plants and plant products creates the added problem of providing possible pathways for intentional introductions. There are many access points in global plant distribution networks into which plant pathogens could be easily introduced. Because many of these pathogens are of regulatory concern with quarantine implications, the presence alone of the pathogen could have significant economic impact without actually causing disease in a plant system.

Assigning attribution in the case of an act of terrorism in a plant system may be further complicated by climate change. Among the many impacts predicted by climate change models are climate-induced changes in plant physiology, the geographic redistribution of plant populations, the emergence of new pathogens or new pathogen–vector associations, and the geographic redistribution of existing pathogens (Price-Smith 2002). These issues will make it difficult to determine if an outbreak was the result of an intentional introduction; is a new outbreak the result of bioterrorism or a change in local environmental conditions that allowed the establishment of a pathogen and the development of disease in a previously non-receptive environment?

10.2.2 Specific Threats to Plant Biosecurity

There are several lists of specific pathogens that are potential threats to plant biosecurity (Table 10.1). The different approaches taken to identify threats can explain, in part, the discrepancies among the lists. Most of the organisms identified in these lists are specific with respect to the plant species at risk; for example, pathogen threats to soybean production systems in the United States, pathogen threats to forest ecosystems in Europe. One limitation of these lists of specific threats is our inability to predict invasiveness with any degree of certainty; that is, which species will get introduced into a specific geographic area, and more importantly, which species will get established after an introduction and then, once established, spread beyond the outbreak area. Such lists focus too much attention on the prevention and response to a few pathogens when the systems they are designed to protect are at risk to many pathogens that have a high probability of being introduced accidentally. Equal effort should be placed on developing comprehensive biosecurity strategies for plant systems in addition to specific plans for specific pathogens.

10.3 Bioterrorism as a Threat to Plant Biosecurity

The concept of bioterrorism against a plant system or agricultural production system is difficult for some to accept. After all, inherent in the name and the concept is terror. It is difficult to imagine anyone being terrorized by diseased plants. Leaves with spots, rotting tubers, or even corn plants falling over from stalk rot are not likely to send people running. When diseased plants make the news, it is in reference to the economic or ecological damage incurred; disappointment yes, terror no. The term bioterrorism though is as much about motive as it is about affect. Agroterrorism (or bioterrorism) against plants is conceptually more about why the act might be committed rather than the emotional response of those affected. The most important consideration is the impact from an introduction whether deliberate, accidental, or natural. Bioterrorism is one more threat to consider when developing a strategy for plant biosecurity.

Why would anyone target a plant system? This question goes to motive, which is a function of human thought and behavior. There is no exact answer. Why would anyone write a computer program, attach it to an email, and send that email around the world so that when it is opened a virus infects the hard drive and destroys the computer of someone they never met? This happens every day and has caused immeasurable impact. The only apparent motive is to disrupt. Is bioterrorism against plant systems as significant a risk as global trade in plants? No, it is not. But to not consider it a possible threat is an unnecessary risk.

Table 10.1 Lists of plant pathogens that could potentially be used in acts of agroterrorism around the world (referenced on the Internet in September 2008, see footnotes) (this table is after Table 10.1 in Latxague et al. 2007; with the publisher's permission)

Code	Origin	Fungi	Bacteria	Viruses
BTWC-SA	Ad Hoc Group of the Biological and Toxin Weapons Convention (WP124 by South Africa)[a]	13	6	1
BTWC-AHG	Ad Hoc Group of the Biological and Toxin Weapons Convention (Procedural Report 56/1)[b]	4	3	1
USDA-APS	Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA), in accordance with the American Phytopathological Society (APS)[c]	4	5	1
USDA-APHIS	Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA), in accordance with the Agricultural Bioterrorism Protection Act[d]	3	5	0
European Union	EU Plant Health Directive 2000/29/CE[e]	19	3	34
EPPO	Lists of pests recommended for regulation in the European and Mediterranean Plant Protection Organization (EPPO) region[f]			
	A1 List	38	11	23
	A2 List	20	22	19
CNS	Center for Non-proliferation Studies (CNS) at the Monterey Institute of International Studies[g]	18	11	3
AG	Australia Group[h]	8	6	3
ISSG-IUCN	Invasive Species Specialist Group (ISSG), a part of the Species Survival Commission of the World Conservation Union (IUCN)[i]	3	1	0
CBWinfo	Chemical and Biological Weapons Info (CBWinfo) website[j]	27	17	1

[a] http://www.bradford.ac.uk/acad/sbtwc/ahg34wp/wp124.pdf

[b] http://www.bradford.ac.uk/acad/sbtwc/ahg56/doc56-1.pdf

[c] http://www.apsnet.org/members/ppb/RegulatoryAlerts/FEDREG8-12-02.pdf

[d] http://www.biosafety.msu.edu/selectagents/Select_Agent_List.pdf

[e] http://www.boku.ac.at/IAM/pbiotech/eppl.pdf

[f] http://archives.eppo.org/EPPOStandards/PM1_GENERAL/pm1-02(16)_A1A2_2007.pdf

[g] http://cns.miis.edu/research/cbw/biosec/pdfs/agents.pdf

[h] http://www.australiagroup.net/en/plants.html

[i] http://www.issg.org/booklet.pdf

[j] vhttp://www.cbwinfo.com/Biological/PlantPath.html

10.3.1 Is Bioterrorism a Real Threat to Plant Biosecurity?

Bioterrorism targeting agricultural systems has been identified as a significant concern by many and of questionable significance by some (Wheelis et al. 2002; Cupp et al. 2004; Nutter and Madden 2005; Young et al. 2008; Wheelis et al. 2008). In light of the potential to influence international travel and trade policies, the funding of research and education programs, and the development of national preparedness plans, it is appropriate to question whether bioterrorism is a real threat to plant biosecurity. Often, the discussion of plant biosecurity and agro-terrorism is evaluated from the perspective human systems. However, the nature and the magnitude of value in plant systems are inherently different requiring a different approach to risk assessment. For plant systems, the intent may be to reduce food production capacity, to render food unpalatable/harmful, to undermine public confidence in food production and food safety systems, and to cause large-scale and sustained economic damage that ultimately lowers a nation's standard of living. To lower a developed nation's food production capacity and/or standard of living would likely take a long period of time and be very difficult to accomplish. Most developed nations have adequate to excess capacity to produce food and/or multiple trade agreements to compensate for deficiencies. To lower a developing nation's food production capacity and/or standard of living could be accomplished in a very short period of time and with relative ease. Many developing nations lack the capacity to produce adequate food and are resource-poor precluding trade to compensate for deficiencies. These nations are very vulnerable to agro-terrorism.

To render food unpalatable/harmful or to inflict significant economic damage to food production systems could be accomplished in a very short period of time in any nation. Many agricultural production and distribution systems are open systems with many possible pathways for the intentional introduction of pathogens. Depending upon the pathogen and the plant system targeted, it would be possible to inflict significant economic damage without causing an epidemic. A quarantine pest or pathogen need only be detected to stop shipment of plants or plant products; it does not actually have to cause disease. Another possible objective might be to destabilize international relations by causing sustained disruption of trade among signatories to bilateral and multilateral trade agreements. Recent shortages in rice and wheat supplies resulted in bans of exports by several nations (IFPRI 2005; Shelburne 2008). Disagreements over trade can create tension between nations. The intentional introduction of a pathogen to reduce the production capacity upon which a trade agreement is based, or a quarantine pathogen to disrupt a trade agreement, could strain international relations and strategic alliances.

Over the last 50 years, most acts of terrorism have targeted humans and/or infrastructure with explosives and incendiary devices. Bombs have immediate and dramatic impacts that provide gripping visual images that extend the impact beyond the targeted area. Two of the most commonly cited objectives of terrorists are to instil fear and to disrupt socio-political systems. Clearly, bombs have those effects. During the previous 30 years, there were several acts of bioterrorism against humans, including, the unsuccessful anthrax attack in Japan and the successful anthrax and

Salmonella attacks in the United States (Ostfield 2007). The anthrax events in the U.S. caused fear in the general population and disruption of socio-political systems as evidenced by the interruption of sessions of the U.S. Congress and the local suspension of normal operations of the U.S. postal system. Would the introduction of a plant pathogen or an insect pest with the ability to cause disease or damage to a natural or agricultural plant system have immediate and dramatic effects? Probably not, but one must consider the spatial and temporal scales of impacts. For human and infrastructure targets, the scale can be quite small yet result in very large impacts. One to several human deaths or one large building damaged can cause fear and disruption in both local and regional populations; the threat is overt and the impact direct. The number of humans directly affected by the U.S. anthrax letter attacks was 27, including five deaths. However, 300 million people were indirectly impacted to varying degrees. The destruction of two buildings (i.e., the World Trade Center Towers) in New York in 2001 had enormous direct local impacts and long lasting global impacts. Fear, disruption, and immeasurable economic impacts resulted from those two terrorist actions. The long-term effects included costly and cumbersome security measures in the form of building infrastructure enhancements, stringent policies regarding human behavior, and the implementation of a legal system that governs the possession, use and transportation of certain microorganisms. Equally costly and cumbersome security measures impacted the transportation sector as well (e.g., infrastructure enhancements, stringent human behavior policies, international travel agreements, strict passport policies). It has been several years since those bioterrorism events occurred, yet the impacts are still evident.

One to several plant deaths, if even noticed, will have little socio-political effect unless those plants are of cultural importance (e.g., the Treaty Oak in Texas that has deep historical and cultural significance, Maraniss 1989), or of deep personal importance (e.g., citrus trees on individual homeowners property, Gottwald et al. 2002). The value in plants and plant systems is usually found in populations of plants or the commodities derived from those plants, not in the individual plants. Consequently, the appropriate concern with plant systems should be measured over time and over large spatial scales. It is possible that acts of bioterrorism targeting plant systems could elicit large-scale effects over time with limited prospects for complete recovery.

10.3.2 Evidence for Bioterrorism in Plant Systems

Historical Perspective Several nations developed the technologies necessary for the large-scale production and deployment of plant pathogens (Rogers et al. 1999; Suffert 2003; Madden and Wheelis 2003). Whether these bioweapons were ever used overtly or clandestinely to target plant systems is not known. Small-scale field tests were successful in demonstrating their effectiveness. Proof of concept has been established.

The Brazilian Cocoa Case Approximately 20 years ago, the intentional introduction of the witches broom pathogen (*Crinipellis perniciosa* (Stahel) Singer) into cocoa plantations in the Bahia region of Brazil was alleged by cocoa producers in the affected area

(Homewood 1991, Junior 2006). Cocoa branches with disease symptoms were reported to have been found wired to trees at the outbreak site. Epidemiologists concluded that the natural dispersal of *C. perniciosa* spores from the Amazon cocoa production area to the Bahia production area was unlikely. Land reform activists were blamed for the act in an attempt to destabilize the local government. Thousands of trees were ultimately affected reducing cocoa yields by 75% and causing serious economic losses (Bowers et al. 2001). Years later, a man confessed to the act of deliberately introducing the pathogen in order to undermine the local government (Junior 2006).

Unsubstantiated Cases There have been many cases of one nation accusing another of using biological weapons against agricultural plant systems (Junior 2006; Suffert et al. 2008; Zilinskas 1999). There is little, if any, compelling evidence to support these claims. The general lack of forensic technologies and protocols specific to plant pathosystems coupled with the existence of natural pathways for the introduction of the plant pathogens associated with these cases make difficult establishing that an introduction was deliberate. Assigning attribution would be extremely difficult unless those responsible claimed responsibility. However, the inability to prove culpability does not equate to proof of innocence.

10.3.3 Plant Systems as Soft Targets

Agricultural systems are vulnerable because of their economic and sociologic importance. Crop and forest systems are vulnerable because they are grown on large, unsecured, poorly monitored areas. Historical evidence indicates that agroterrorism (i.e., anticrop bioterrorism, biowarfare, and biocrime) is not just an academic issue. Throughout history, agricultural systems have been targets in war; crops and forests were trashed or burned to deprive the enemy of food thereby repelling colonists or subjugating rebel populations. During and after the Second World War, several countries developed research programs for biological anti-crop agents targeting the worlds staple crops (*Phytophthora infestans*, agent of potato late blight, *Cochliobolus miyabeanus*, agent of rice brown spot, and *Magnaporthe grisea* agent of rice blast) (Foxwell 2001; Suffert 2002, 2003; Madden and Wheelis 2003). After the Cold War, several countries continued to conduct research on plant pathogens as anti-crop weapons, including *Puccinia graminis* f. sp. *tritici* the causal agent of wheat stem rust (Line and Griffith 2001; Whitby 2002). While countries that signed the Biological and Toxin Weapons Convention (BTWC) in 1972 officially stopped their biological warfare programs, a new cycle of concern over the possible use of biological anti-crop weapons began in the late 1980s, based on the knowledge that several "rogue" countries were developing such weapons (e.g. the wheat smut fungi *Tilletia caries* and *T. tritici* in Iraq). Additionally, there have been sporadic allegations that states have either used plant pathogens against crops or threatened to use them for political purposes. Cuban authorities alleged without significant evidence, that the introduction in the 1970s of *Personospora hyoscyami* f. sp. *tabacina*, the causal agent of tobacco blue mold, and *Puccinia melanocephala*, the causal agent of sugarcane rust, were the results of anti-crop attacks by the US

(Zilinskas 1999). Recent evidence found in caves in Afghanistan suggested interest by Islamic militants in the weaponization of wheat rust (Fletcher et al. 2006). In the 1990s, the United Nations Drug Control Program sponsored anti-coca (using *Fusarium oxysporum* strains) and anti-poppy (using *Pleospora papaveracea* strains) research programs in Andean and Central Asian countries, respectively (Connick et al. 1998; O'Neill et al. 2000); these were officially never used. The use of biocontrol agents as biowarfare agents is controversial (Suffert et al. 2008). From a scientific point of view, the relevance of these drug-control programs to agroterrorism is that the methods used are the same as those used in state-sponsored programs, including the preparation and storage of large amounts of inoculum and the delivery of inoculum clandestinely for the purpose of destroying a cultivated crop.

10.3.4 The Technology Factor

The state-sponsored bioweapons programs of the past were not limited by lack of infrastructure and funding; long-term research programs and large-scale production systems were possible. However, advances in the technologies that underpin modern biological sciences, communication systems and transportation systems overcome the need for large scale infrastructure and funding. The biotechnology industry has made amazing advances in microbe and cell technologies; for example, genetic manipulation, fermentation, and stabilization. Communications technologies and systems (e.g., Internet) make research results and protocols available to everyone worldwide in near real time. Transportation systems move materials around the world in very short periods of time. It is conceivable that someone could set up a laboratory in a concealed location, engineer a plant pathogen with novel virulence traits, produce a significant quantity of the novel pathogen in a stable formulation, and ship that pathogen around the world without being discovered. The technologies that improve our lives also increase our vulnerabilities. Scientific advancements that can be misused have been termed dual use technology. Dual use technology has been the subject of much discussion over the need for regulation of such technology. The dual use dilemma is defining the characteristics that make research dual use and developing an appropriate system of regulations that enhance safety without compromising scientific progress (IOM/NRC 2006). The risk of not doing this type of research may be much greater than the risk posed by the potential for misuse.

10.4 Threat and Vulnerability Assessments

10.4.1 Strategy

There have been very few attempts to propose a methodology specific to the assessment of agroterrorism, which has often been described as "low-tech, high impact" requiring "relatively little specialized expertise and technology" (Rogers et al., 1999;

Wheelis et al. 2002). Most of these discussions are not based on a quantitative analysis of the threat. The success of a malevolent act might be much more uncertain than believed.

Madden and van den Bosch (2002) designed a probabilistic method to compute a global risk index for a plant pathogen, based on the product of the probabilities of single events required for a successful agroterrorist attack (i.e., pathogen introduction, disease establishment, spread, damage and lack of control measures). Extremely low values for some intermediate probabilities and the lack of validation of the assessment method limit the utility of the method for real cases. Schaad et al. (2006) applied an analytic hierarchy process, based on a set of prioritized and qualitatively assessed (high, mean, low) criteria, to eight potato pathogens. Both approaches synthesized the information obtained from a panel of experts in a single risk value rather than in a risk profile. Despite the involvement of pathogen experts, these probabilistic methods appear more useful as theoretical exercises than as tools for stakeholders. In such approaches, the risk may be overestimated for a plant pathogen well-known to many experts in the assessment group.

A third approach, based on the perpetrators' presumed objectives and the expected consequences, emphasized the direct economic consequences of the act; for example, crop loss (Latxague et al. 2007; Suffert et al. 2008). It included psychological and indirect economical (e.g., trade disruption, penury) consequences, which are presumed objectives of an agroterrorist attack (Huff et al. 2004; Waage and Mumford 2007).

In the absence of an unambiguous definition of agroterrorism, a subject of debate among plant pathologists, Suffert et al. (2008) proposed that the risk should be characterized by a foresight approach, which took into account the hybrid nature of the threat, the multiplicity of the perpetrator's objectives and expected consequences and the diversity of *modus operandi*. The methodology includes three successive steps (Fig. 10.1):

1. Build a list of 50 candidate plant pathogens representing potential threats to European agriculture and forest systems (Latxague et al. 2007).
2. Develop a scenario-based, foresight investigation of potential agroterrorist acts in Europe and assign a key pathogen from the candidate list to each of the nine proposed scenarios. Three types of acts were considered (international, state-sponsored biowarfare; non-governmental bioterrorism; and individual or corporate biocrime). Combining the nature of the acts and their potential consequences, nine scenarios of agroterrorist attacks, divided into three sections (synopsis, justification, feasibility), were developed and their socio-economical consequences investigated (Latxague et al. 2007).
3. Design a risk assessment scheme (RES), derived from a standard Pest Risk Analysis (PRA) (IPPC 2004; EPPO 2007) and apply it to key pathogens. The RES included five sections (importance of the target crop; ease of use of the pathogen; epidemic potential of the pathogen; obstacles to swift and effective response to an attack; and potential global or regional consequences of an attack) scored using criteria documented with scientific literature (Latxague et al. 2007).

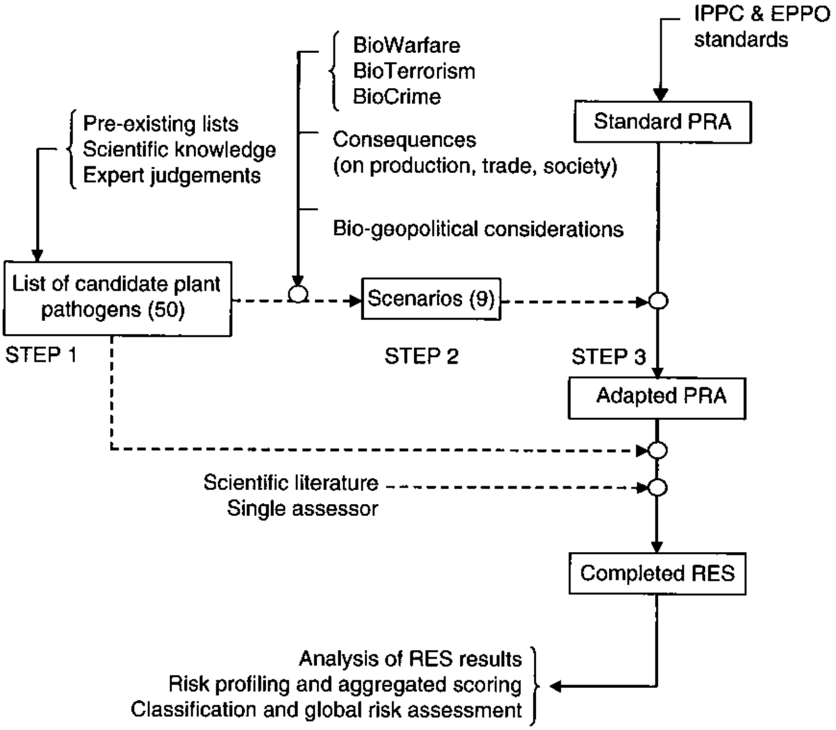

Fig. 10.1 Methodology used by Latxague et al. (2007) for assessing the risk posed by agroterrorism in Europe (after Figure 10.1 in Latxague et al. 2007; with the publisher's permission)

A resulting pentagonal star plot represented the risk profile of each pathogen and an aggregated risk was calculated. This step can be applied by non-experts on particular diseases and thus permits a comparison between crops or pathogens on the basis of the characterization of the threat, and the expected effects of the attack.

10.4.2 Threat Identification and Assessment

Various international working groups and organizations (e.g., the Biological and Toxin Weapons Convention, the Animal and Plant Health Inspection Service of the United States Department of Agriculture, the American Phytopathological Society, the European Union, the European and Mediterranean Plant Protection Organization and the Centre for Nonproliferation Studies) have compiled lists of pathogens of quarantine or agroterrorism concern. Derived list of pathogens were compiled or assessed regarding a specific crop (e.g., potato, Schaad et al., 2006), a pathogen group (e.g., bacteriology; Young et al. 2008), or a target country (e.g., United States; Madden and Wheelis 2003; Slovenia, Boben et al. 2008). Available lists were also critically screened by the partners and experts of the EU CROPBIOTERROR project and updated with relevant scientific information (Gullino et al. 2007). The list of 50 pathogens (35 fungi and oomycetes, nine bacteria and phytoplasmas, and six viruses) included exotic and quarantine pathogens that may induce epidemics causing damage in Europe (e.g., *Ceratocystis fagacearum, Erwinia amylovora, Mycosphaerella populorum, Pepino mosaic potexvirus, Pleospora papaveracea, Plum pox potyvirus, Phakopsora pachyrhizi, Ralstonia solanacearum, Synchytrium endobioticum, Tilletia indica, Xylella fastidiosa*), as well as more common indigenous pathogens causing recurrent epidemics. The indigenous pathogens were selected because they represented particular risk profiles; for example, the production of mycotoxins (e.g., *Claviceps purpurea, Fusarium graminearum, Gibberella zeae, Penicillium expansum*) or the existence of exotic strains that could replace or hybridize with local strains (e.g., *Leptosphaeria maculans, Phytophthora infestans, Puccinia triticina*) (Latxague et al. 2007). Staple food crops represented the majority of targets (24), followed by forest trees (11), industrial and market crops (10), and orchard trees (5). In 32 out of the 50 cases, direct crop loss was predicted following an attack, while trade would be disrupted in 38 out of the 50 cases. Wider, indirect socio-economical consequences, such as poisoning of animals and humans, patrimonial and environmental loss or psychological negative effect on populations, were predicted in 28 cases.

The desired effect of the attack will largely determine the perpetrator's strategy, the target crop, and the pathogen weapon. For example, pathogens with low effect on crop yield could be used for agroterrorism, provided that they disrupt trade via quarantine establishment or produce toxins threatening to human and animal health. A significant practical problem for the perpetrator is to gather the scientific and technical information required for a successful act. The necessary steps in the acquisition of knowledge can make improbable a bioterrorist attack (Suffert et al. 2008). State-sponsored biowarfare scenarios and corporate biocrime scenarios are not resource-limited. Individuals or terrorist groups may require the cooperation of disaffected scientists (a certain scenario has a depraved scientist as the perpetrator), the "phishing" of information in an indirect way and access to laboratory and field facilities. The effective response and management of an agroterrorist attack will depend on the early detection of the pathogen and the rapid implementation of countermeasures; this is similar to the case for the eradication of quarantine pathogens. A state-sponsored biowarfare attack may operate on a large scale with several inoculation sites or utilize an innundative approach in order to overwhelm the countermeasure system set up by the target country. Biocrime operating on a smaller scale may elude early detection thus jeopardizing immediate eradication of the pathogen. In contrast, bioterrorist attacks may be "advertised" by the perpetrators in order to increase psychological confusion and disorganise the countermeasure system; such acts may target crops for which protection measures are difficult to implement or are inefficient.

The aggregated risk score, based upon the sum of risk components, predicted that the importance of the target crop was maximal for wheat and maize and minimal for soybean and poppy; the ease of pathogen use was higher for the saprotrophic pathogens (based on growth on artificial medium) than for the biotrophic pathogens (in most cases not cultivable on artificial medium); the epidemiological potential was maximal for airborne pathogens already established in Europe and adapted to the local environment; the obstacles to swift and effective response to an attack were greatest for pathogens not present in Europe yet and for which quick detection methods are unavailable; and the potential global or regional consequences of an attack was maximal for regulated pathogens (Suffert et al. 2008).

10.4.3 Vulnerability Identification and Assessment

There is broad consensus that the threats to plant biosecurity are increasing due to growing trade, travel, transportation and tourism, the 'four T's' of globalization (Waage and Mumford 2007). A recent scientometric analysis confirmed that the concept of agroterrorism emerged in the scientific literature after 1997 (Suffert et al. 2008); its importance increased after the 11 September 2001 terrorist attacks in the U.S.

Mass destruction of food crops by the introduction of an exotic plant pathogen seems highly improbable in most advanced industrialised countries. However, the malevolent use of plant pathogens could have high social and economic impacts. Moreover, the biosecurity of forest and natural ecosystems should be considered as a serious issue (Cochrane and Haslett 2002). Plant pathogenic fungi that produce mycotoxins, with the potential to affect human and animal health should be considered legitimate threats even though most of them are already a recurrent cause of disease. The low production of mycotoxins and the availability of adequate detection methods lead some to question mycotoxin-producing fungi as serious anti-crop agents (Paterson 2006). However, a deliberate introduction of a toxin-producing plant pathogen could cause significant disruption and a loss of confidence in the food chain. Additionally, a perpetrator with limited technical and scientific skills, using simple intimidation or blackmail could circumvent the unpredictable success of a deliberate contamination by issuing false claims (Huff et al. 2004; Waage and Mumford 2007). These types of events could strain international relations with global consequences (Castonguay 2005; Hennessy 2008).

In two third of the scenarios proposed by Suffert et al. (2008), the perpetrators would conceal their action, while in one third of the scenarios they would claim responsibility. To determine the source of the pathogen, the methods employed, the time of the introduction, and the identity of the perpetrators would require a forensic investigation (i.e., the application of scientific methods in the investigation of possible violations of the law, where scientific knowledge and technology provide evidence in both criminal and civil matters) (Fletcher et al. 2006). Early detection and identification of plant pathogens would be critical to a forensic investigation and the determination that an epidemic was of "suspicious" origin (Stack et al. 2006; Waage and Mumford 2007; Suffert et al. 2008). The longer an outbreak was developing and progressing into an epidemic, the more difficult it would be to detect signal in the background of noise. Those attempting to gather evidence that might aid in determining cause, whether intentional or accidental, will be challenged as the size of the impacted area and the severity of disease increases. This will be true whether the perpetrator claims responsibility or not.

In the context of the World Trade Organisation (WTO) and the Sanitary and Phytosanitary Agreement (SPS), it is possible that a country, in bad faith, could use "agroterrorism" as a justification to impose trade barriers. It is also conceivable that a "rogue" country would clandestinely introduce a regulated pathogen into a shipment imported from another country to justify protecting its traditional markets. The international context makes plausible the bio-geopolitical justification of some biowarfare scenarios (Wheelis et al. 2008; Suffert et al. 2008).

10.5 Security Through International Cooperation

Functionally, the world is a smaller place today. Rapid intercontinental flights speed travelers from hemisphere to hemisphere and high-speed trains from one side of a continent to the other in hours. Demographics are changing as immigrants from politically unstable, war-ravaged or poverty-plagued nations seek better lives in other countries. International commerce is booming; the most-exchanged commodities include thousands of agricultural products. Agriculture and the food chains that support humanity are vulnerable targets; an attack on them could have devastating consequences, not just for health and safety, but also in terms of social and economic impact. It is extremely important to increase international cooperation on biodefense to protect agriculture and food systems worldwide. International cooperation is needed at the scientific, policy, legal, and commercial levels permitting the sharing of views and information. Convergence of ideas and experiences is needed to enhance global preparedness. International cooperation is critical to understanding and addressing the effects of implementing new or enhanced food defense measures on various components of agro-food industries. Agriculture and the food production and distribution systems we depend upon are global in scope requiring an international approach to plant biosecurity (Gullino et al. 2008).

10.5.1 Science

Scientific cooperation often provides a sound basis for cooperation among countries. Scientific communication is different from diplomatic communication; it is based upon the free exchange of ideas and emphasizes commonalities rather than differences. Scientists are outstanding ambassadors for their nations; they interact at a peer level and share mutual respect for their science. The basic needs for knowledge and technology are common to all nations; what varies is the ability of each nation to develop, acquire, and implement new technologies. Duplication of effort in the development, screening, standardization and validation of molecular or serological tests, is inefficient and costly. Networking researchers and plant protection practitioners has many advantages, including enhanced diagnostic, communication and training capabilities. Cooperation will lead to the development and sharing of new standards for diagnostic procedures, for the validation of such procedures and for laboratory certification. International cooperation will accelerate the development of standards and protocols by which to differentiate plant pathogens at the subspecies or isolate level, to identify genetic modifications of known agents, and to permit the determination of events as intentional, accidental or naturally occurring. Collaboration in the development and validation of pathogen modeling and risk analysis tools will enhance security and permit the integration of epidemiology and economic risk assessment into policy formulation. Beyond traditional detection and diagnostics, the new discipline of forensic microbiology (including forensic plant pathology) is another area in which international collaboration will be beneficial. The sharing of sequence data and microbe culture collections will be important to rapid advancement in this emerging discipline. The ability to share information instantly and globally through informational websites, interactive online chat rooms, linked home pages, teaching aids, directories, image libraries and innovative e-publications is limited only by creativity and resourcefulness.

Productive international collaborations can be variable in the number of countries participating as well as in the basis of cooperation: for example, common vulnerabilities and threats, complementation or synergy in technological capabilities and scientist training/experience, etc. It may also be based upon geography (countries of a single region, e.g., European Union) or trade agreements (e.g., the United States and the EU). The goal in any case should be to create mechanisms for exchange of information on diseases of concern. Some European research networks are already addressing issues related to bio-weapons. Among them are Consortia on crop biosecurity (CROP BIOTERROR, TOOLS FOR CROP BIOSECURITY and BIOSEC); WATERSAFE which focuses on drinking water, AEROBACTIS on airborne microorganisms; ASSRBCVUL on radiological, biological and/or chemical agents; BIOSAFENET on genetically modified organisms; and EPIZONE on epizootic diseases in agriculture and aquaculture.

10.5.2 Policy

Officials of governments generally communicate through formal and informal channels. Because they represent sovereign states, they provide official viewpoints and approved positions. The formality of such communication is necessary because of the authority and impact of those interactions. Common policies are important to protect global agriculture and food. In 2004, bioterrorism was included on the G8 Agenda, leading to a statement regarding the issue of "Defending against bioterrorism". In 2005, G8 nations built on this policy foundation and established some of the first-ever international technical and policy initiatives for food defense.

The Asia Pacific Economic Cooperation (APEC) forum also addresses food defense (Ostfield 2007). It is critical that scientists participate in the policy making process by providing the information necessary to ensure that rational plant biodefense policies, based upon sound scientific data, are formulated and adopted.

10.5.3 Law

Preparedness for, prevention of, and response to acts of bioterrorism and biocrime directed against agriculture and food will require international cooperation. Such acts involve breaking one or more national and/or international laws. One specific area for international cooperation is the development and application of microbial forensic technologies and protocols to ensure that attribution is successful and that justice is served following the intentional introduction of a plant pathogen across national borders (Fletcher 2008).

10.5.4 Commerce

Implementing new or enhanced biodefense measures for regulation and oversight might seriously impact public and private components of the agricultural and food industries, particularly small and medium enterprises, ultimately affecting global trade in food and agricultural products. In the event of a terrorist attack, international cooperation will be challenging, with the potential to create short term tension among trade partners, and potential long term and lasting diplomatic tensions (Ostfield 2007).

It is extremely important to increase international cooperation on biodefense to protect agricultural and food systems worldwide. Promoting convergence of ideas and experiences should be a key element of cooperation among all nations, in particular those with trade agreements involving food and other agricultural products. Collaborations will enhance global preparedness while creating mechanisms for understanding the impacts of food defense policies on the agro-food industries within each nation.

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