Chapter 2
Characterization of the Threat Resulting from Plant Pathogen Use as Anti-crop Bioweapons: An EU Perspective on Agroterrorism

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Abstract This chapter provides an analysis specific for Europe of the risk of plant pathogens being used as anti-crop bioweapons, taking into account both the biological and human dimensions of the threat. An historical review of anti-crop bioweapons lays down the starting point of the characterization and contextualizes the threat in Europe. Four types of threat are developed and provide a structure for the analysis: (1) from military state programs to allegations of attacks; (2) from 'rogue state' hidden programs to claimed terror attacks; (3) biocrime, sabotage, private allegations and conspiracy theories on social media; (4) from the overzealous application of phytosanitary measures to the deliberate introduction of a regulated pest to justify trade protectionism. A database consisting of 21 important target crops and of 63 potentially dangerous pests (selected from a list of 570 pests) are combined with the development and categorization of 'scenarios'. This is proposed as a starting point of a prospective approach to quantify the risk of agroterrorism in Europe. Four challenges ('Convergence Tactics', 'Constraints', 'Climate', and 'Conspiracy') are suggested to be the most important determinants of the forthcoming evolution of the threat. The prospect for Europe to successfully confront the increasing risk and challenges for the next decade is discussed.

Keywords Agroterrorism • Anti-crop bioweapon • Biocrime • Biosecurity • Bioterrorism • Biowarfare • Epidemiology • Plant pathogen • Prospective scenario • Risk analysis • Target crops

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2.1 Introduction and General Concerns

The globalization of markets and social links poses new challenges for plant health, food safety and security. 'Crop biosecurity', defined by Brasier (2008) as "protecting a state from invasive plant pathogens", is usually ensured by plant health policies and regulatory measures imposed by the state, often by the national government. Maintaining biosecurity has become a subject of widespread concern, heightened by the recent focus on failures in biosecurity, such as disease emergence and pest introductions (Anderson et al. 2004) and by the world-wide increasing scrutiny of pest risk analysis (PRA) as the basis for commodity trade regulation (Schrader and Unger 2003). Europe has been concerned about biosecurity for some time, due to the specificities of its agriculture and its dominant commercial position in the international markets.

Several plant pests are perceived as serious threats to agricultural biosecurity and to agricultural industries and forestry in both developing and industrialized countries. The recent decades of booming trade in commodities and horticultural plants led to many new pest introductions (Waage and Mumford 2008; Sache et al. 2011). Some plant pests threaten natural ecosystems as well as managed ones. One of these introductions was, for example, the fungus *Phytophthora ramorum*, which threatens indigenous forest trees in the United Kingdom (Brasier et al. 2004). Another was the pine wood nematode *Bursaphelenchus xylophilus*, which currently is regarded as a major threat to French forests following its establishment in Portugal in 1999 (Mota et al. 1999). Another recent example of disease emergence is the bacteria *Xylella fastidiosa*, which was first recorded in Puglia (Italy) in 2013, where it causes serious damage to olive trees, and in Corsica (France) in 2015, where it affects the ornamental hosts *Polygala myrtifolia*.

The International Plant Protection Convention (IPPC) promotes global harmonization of phytosanitary measures that are imposed by the different national plant protection organizations to prevent accidental introductions of exotic pests through trade imports. Regional plant protection organizations, such as the European and Mediterranean Plant Protection Organisation (EPPO), improve the harmonization of plant health protocols on a regional level. Today in the European Union (EU) approximately 300 pests have been identified as quarantine pests, largely on the basis of EPPO's recommendations. In order to comply with the requirements of the new EU plant health regime (regulation EU 2016/2031 of the European Parliament of the Council of 26 October 2016 on protective measures against pests of plants), some European countries, such as the United Kingdom and France, have developed methodologies for prioritizing plant health risks from pests at the national level (Moignot and Reynaud 2013; Baker et al. 2014). These efforts have focused on conventional threats of exotic, invasive plant pests that historically have been either accidentally introduced through trade or passively spread, for example by wind currents. Until recently, little attention has been paid to the possible, deliberate misuse of plant pathogens as 'weapons' against agroecosystems.

As Josling et al. (2003) observe "since the terrorist attacks (…) on September 11th 2001 (…), biosecurity has taken on new dimensions and products that move across borders are treated more suspiciously, [creating] uncertainty and transaction costs that impinge particularly on trade that could put domestic animal, plant or human populations at risk". The term 'agroterrorism' corresponds to the deliberate misuse of biological agents against agriculture, including crops and cattle, by non-state actors, that is, a subset of 'bioterrorism'. 'Biocrime' and 'biowarfare', however, can be included in a general definition referring to the "intentional use, as well as the threat or simulation of use of plant pathogens by any individual or group in order to cause direct damage to crops or forests, or to indirectly affect the agricultural sector" (Latxague et al. 2007). The distinction between bioterrorism, biocrime and biowarfare was made for several transdisciplinary components, especially concerning the legal framework and risk assessment (Chap. 6). This distinction also acknowledges that each of these 'agro-risks' possesses a number of distinct characteristics, across a wide range of prospective scenarios. The economy of Europe is heavily dependent on its agricultural resources. Crops and forests cannot be entirely monitored and protected because they are grown on large and often patchy areas. Scientists and government stakeholders in several countries are reconsidering the vulnerability of agroecosystems to plant pests potentially used as bioweapons because of the socio-economical significance of crops and forests (Rogers et al. 1999; Foxwell 2001; Cochrane and Haslett 2002; Suffert 2003; Madden and Wheelis 2003; Khetarpal and Gupta 2007; Caldas and Perz 2013; Khalil and Shinwari 2014). The vulnerability of Europe is extremely difficult to assess, probably because the definition of the concept of the 'agroterrorist threat' is weak due to its dual nature: it has both a biological and a human dimension (Barbier 2008). This creates a paradoxical combination of science-based discourse about 'plant pathogens' or 'pests' (the weapons) and subjective views about 'perpetrators' (the human entity): Who are they, why are they acting, what are their capacities and knowledge? Understanding the ideologies and motivations that would direct a person, an organization or a state to attack the agricultural sector through biological means is important for understanding how better to assess the risk for Europe (Chap. 6). There are many ideological, economical and geopolitical interests that could lead to agroterrorism. Perpetrators can be motivated by a variety of objectives, including some specific to Europe. The tactics used to accomplish these objectives may be as varied as the motivations. The choice of attacking crops as a target could be aimed at a number of outcomes: inducing yield losses, undermining confidence in the agricultural sector, creating a profit-making opportunity, extorting money by threatening to introduce a pest, coertion or intimidation of a government, provocation of a response to support insurgent forces, etc. The risk assessment of such a scenario would be erroneous if it focuses only on a single type of act or perpetrator. This could result from the attention arising from the events or the topics reported by news media. On the other hand, the risk assessment also would fall short if it does not take into account the current context related to the human dimension.

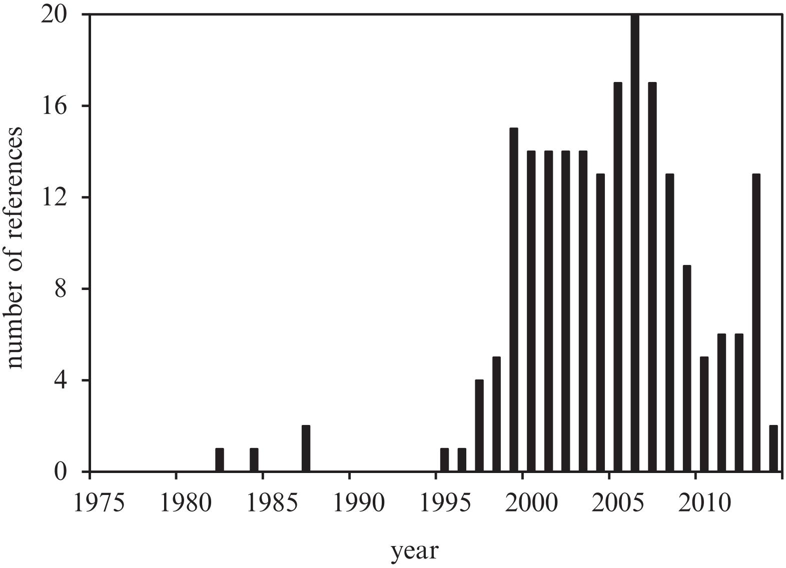

Fig. 2.1 Evolution of the number of books, scientific articles and public reports in English or French related specifically to anti-crop bioweapons and misuse of pest against plants, crops or agro-ecosystems, and the occurrence at least of one of the following keywords: agricultural biosecurity, crop biosecurity, agricultural terrorism, agroterrorism, anti-crop bioterrorism, environmental terrorism, ecoterrorism, rural crime, biowarfare, agro-warfare, anti-crop bioweapons (from Suffert et al. 2008, updated)

For the past two decades, agroterrorism has received increased attention (Fig. 2.1) and it has been subject to greater discussion within academic, media, and government circles, especially in the United States after the September 11, 2001 terrorist attacks and the subsequent anthrax infections. Studies around that period began arguing that agroterrorism represents a new and dire threat to national security (Casagrande 2000; Madden and Wheelis 2003; Cupp et al. 2004; Polyak 2004). Agroterrorism was framed as a specific issue of security research for crop protection, which contributed to the emergence of agricultural bioforensics (application of scientific methods to the investigation of possible violations of the law, where scientific knowledge and technology provide evidence in both criminal and civil matters) in the US during the 2000s (Budowle 2003; Murch 2003; Fletcher et al. 2006; Kamenidou et al. 2013). The vulnerability of the US agro-industrial sector was considered – rightly or wrongly – as high (Wheelis et al. 2002). Such a perception seems to be mainly based on the assessment of the human dimension of the threat, considering that the 'intentionality' correlated to the traumatic impact of terrorist attacks in the US. In reality, this intentionality is still very difficult to assess (Rohn and Erez 2013). The perception could be summarized by the motto "Because it's not a question of IF, but a question of WHEN" (Suffert et al. 2008), warning that agroterrorism is an imminent threat that should be taken seriously. In retrospect, the alarmist conclusions of some US reports were conjecture, based on worst case scenarios. This can be viewed by the other countries as too simplistic and, therefore, erroneous.

The asymmetry of knowledge between the biological and the human dimensions of the threat remains a key component of this issue. The lack of a common definition of agroterrorism, probably due to the recent more widespread interest in this topic, explains in part why the agroterrorist threat for European crops and forests had not yet been exhaustively assessed by appropriate methods. Unverified allegations (Table 2.1), alarmist reports (Rogers et al. 1999; Wheelis et al. 2002) and programs disclaimed for their cost (Schwägerl 2005) did not favor the recognition of agroterrorism in Europe as the real threat that the author believes it is. In this context the EU launched two successive research projects named CropBioterror (Gullino et al. 2006) and PlantFoodSec (Gullino et al. 2011). The goal was to build up expertise and develop awareness and preparedness concerning the risk of intentional threats against crops or the food chain, and to assess possible economic outcomes of such an attack in Europe. Those projects were complemented by a third, AniBioThreat, concerning the threat of agroterrorism against animals (Knutsson et al. 2013). The projects resulted in a scientifically-based framework, scientific knowledge and tools that can be used to delimit the scope of the issue and its associated narratives.

The goal of this chapter is to draw up an inventory and a specific analysis of agroterrorism risks for Europe based on both historical approaches and contextualization of the 'dual threat' (biological and human dimension). The chapter also attempts to describe and qualify the potential threat, before considering assessment of the overall risk (Chap. 6). The first problem with the term 'agroterrorism', as defined for example by Latxague et al. (2007), is that it refers to different types of acts related to the multiplicity of potential perpetrators, motivations, targets (crops) and agents (pests). In addition to the three main categories characterized by distinct objectives (biological warfare, bioterrorism, and biocrime; Latxague et al. 2007), a typology of consequences was proposed: impact on production (destruction of crops or reduced yields), impact on trade in agricultural products (due to prohibition or additional measures linked to the conditions caused by agroterrorism), impact on human or animal health, impact of an environmental and heritage nature, psychological impact on consumers, and social destabilization. This classification based on motivations and potential consequences was used to draw up and then analyze several prospective scenarios (Chap. 6).

2.2 Historical Review of Agroterrorism and Anti-crop Bioweapons: Starting Point of the Characterization and Contextualized of the Threat in Europe

The starting point of agroterrorism risk qualification is a global review of historical programs, allegations and acts. Analysis of such data is necessary to contextualize the assessment and to adapt it to the present and future European situation.

Table 2.1 Reports of 'agroterrorism' threats *sensu lato* against plant in different agro-ecosystems, from verified state programs to alleged accusations (after Suffert et al. 2009); human pathogens on plants (Fletcher et al. 2013) and case of malicious biocontamination of food (Elad 2005) not listed here (Chap. 5)

Pest	Target crop	Year	Target area	Origin[a]	Type of acts[b]	Threat veracity[c]	References[d]	
Puccinia triticina	Wheat	1950, 1970	USA	Soviet Union	BW2	++	A	Whitby (2002); Rimmington (2000)
		1950	Soviet Union	USA	BW2	++	A	Madden and Wheelis (2003)
		1990	India	Pakistan	BW2	+	A	Shoham (2014)
Puccinia graminis f. sp. *tritici*	Wheat	1950, 1970	USA	Soviet Union	BW2	++	A	Line and Griffith (2001); Rimmington (2000)
		1950	Korea	USA	BW2	++	A	Whitby (2002)
Puccinia striiformis	Wheat	1990	India	Pakistan	BW2	+	A	(Shoham 2014)
Tilletia tritici	Wheat	1980	Iran	Iraq	BW2	++	A	(Whitby 2002)
Tilletia laevis	Wheat	1980	Iran	Iraq	BW2	++	A	(Whitby 2002)
Tilletia indica	Wheat	2002	Afghanistan	India	BW2	–	A	Shoham (2014)
Aspergillus sp.(aflatoxin)	Wheat	1980	Iran	Iraq	BW2, BT1	+	A	Whitby (2002)
Cochliobolus miyabeanus	Rice	1940	Japan	USA	BW2	++	A	Madden and Wheelis (2003)
Magnaporthe grisea	Rice	1940	Japan	USA	BW2	++	A	Madden and Wheelis (2003)
		1940	China	Japan	BW2	++	A	Madden and Wheelis (2003)
		1950	USA	Soviet Union	BW2	+	A	Madden and Wheelis (2003); Rimmington (2000)

		1960	China, Korea	USA	BW2	++	A	Madden and Wheelis (2003)
Phytophthora infestans	Potato	1940	China, Southeast Asia	France	BW2	++	A	Madden and Wheelis (2003)
		1950		USA, Canada	BW2	++	A	Madden and Wheelis (2003)
		1950	USA	Soviet Union	BW2	++	A	Madden and Wheelis (2003)
Leptinotarsa decemlineata	Potato	1940	France	Germany	BW2	+	A	Madden and Wheelis (2003)
		1940	Germany	UK	BW2	+	A	Garrett (1996)
		1950	East Germany (GDR)	USA	BW2	–	G	Burns (2013)
Puccinia melanocephala	Sugarcane	1960	Cuba	USA	BW2	–	A	Zilinskas (1999)
Peronospora hyosciami f. sp. *tabacina*	Tobacco	1960	Cuba	USA	BW2	–	A	Zilinskas (1999)
Thrips plami	Several vegetables and ornamental plants	1960	Cuba	USA	BW2	–	A	Zilinskas (1999)
Hemileia vastatrix	Coffee	1950	Guatemala	USA	BW2	–	A	Suffert et al. (2008)
Crinipellis perniciosa	Cacao	1980	Brazil		BW2	–	A	Junior (2006); Caldas and Perz (2013)
Diabrotica virgifera	Maize	2000	Europe	Agrobiotech compagny	BC3	–	A	Suffert et al. (2008)
Pleospora papaveracea	Opium poppy	1990	Central Asia (Afghanistan)	UNDCP[e], USA, UK, Uzbekistan	BW3	++	A	O'Neill et al. (2000) and Jelsma (2001)

(continued)

Table 2.1 (continued)

Pest	Target crop	Year	Target area	Origin[a]	Type of acts[b]	Threat veracity[c]	References[d]	
Fusarium oxysporum f. sp. *erythroxyli*	Coca	2000	Andean Countries (Columbia)	US, Columbia	BW3	++	A	Connick et al. (1998); Jelsma (2001)
Fusarium oxysporum f. sp. *cannabis*	Cannabis	1980	USA, Europe		BW3	++	A	McCain and Noviello (1985)
Melampsora larici-populina	Larch	1990	France	France (eco-warriors)	BT2	–	A	Suffert et al. (2008)
Xylella fastidiosa	Olive tree	2013	Italy	Italy (property developers)	BC3	–	G	Simpson (2015)
Helicoverpa Armigera	Cotton, soybean	2013	Brazil			–	G	Anonymous (2013)
Pomacea canaliculata (snail)	Rice	2010	Spain			–	G	Pérez Pons (2012)
Glycaspis brimblecombei	Eucalyptus		USA			–	G	Corbyn (2012)
Gonipterus scutellatus	Eucalyptus		USA			–	G	Corbyn (2012)
Microcylus ulei	Rubber tree	1980	Sri Lanka	Sri Lanka (Tamil guerrillas)	BT1	–	G	Gurr and Cole (2000)

[a]Countries accused, suspected or known to have been involved as potential state-sponsors (or harboring perpetrators) in anti-crop programs or in agroterrorist acts planning
[b]*BW* biowarfare, *BT* bioterrorism, *BC* biocrime
[c]++ verified threat or program (considered as proved), + probable threat or program (with limited evidence), – unverified, alleged accusation (without significant evidence, very probably wrong)
[d]*A* for academic literature (scientific article, published report, book, etc.), *G* for grey literature (internet website, press article)
[e]United Nations International Drug Control Program

Indeed, the socio-economic and geopolitical situation in Europe is changing and is not always similar to other areas in the world.

2.2.1 First Type of Threat: From Military State Programs to Allegations of Attacks

The qualification of risk of agroterrorism was, and still is, strongly affected by the military dimension of the threat, particularly in reference to state biowarfare programs or 'state allegations'. The experience of the Second World War and the geographical and geopolitical nexus of the tensions between the US and the Union of Soviet Socialist Republics (USSR) during the Cold War has made Europe particularly concerned about this aspect. Biowarfare aimed at crops was state-sponsored in some European countries between 1920 and 1940. Around the Second World War, some countries developed research programs on anti-crop agents targeting staple crops, for instance potatoes (with late blight caused by the oomycete *Phytophthora infestans* and the Colorado potato beetle *Leptinotarsa decemlineata*; Table 2.1; Madden and Wheelis 2003; Suffert 2003). During the Cold War, the USSR Ministry of Agriculture was tasked with conducting a program codenamed 'Ekology' that aimed to develop biological weapons against animals and plants (Rimmington 2000; Alibek 1999); this anti-crop program was discontinued in the late 1980s. The US program of such research was the largest, until President Richard Nixon dismantled it in 1969 (Whitby 2002). In both the US and USSR, the most emblematic researched agents were probably *Puccinia graminis* f. sp. *tritici*, the cause of wheat stem rust (Table 2.1; Line and Griffith 2001) and *P. infestans* (Table 2.1; Madden and Wheelis 2003). In the German Democratic Republic (GDR), almost half of all potato fields were infested in the 1950s by the Colorado potato beetle, *Leptinotarsa decemlineata*, known as 'Amikäfer' (Yankee beetles; Table 2.1, Fig. 2.2) and the GDR government made the claim that the beetles were dropped by American planes. Similar allegations were made by Cuba, which accused the US of a biological attack with *Puccinia melanocephala* (sugarcane rust) and *Peronospora hyosciami* f. sp. *tabacina* (tobacco blue mold) in the 1960s (Table 2.1; Zilinskas 1999). During the same period, a wide range of plant pathogens, including *Magnaporthe grisea*, were the subject of research by Japan; the potential impact of these programs on Europe was low as they mainly concerned the rice crop.

2.2.2 Second Type of Threat: From 'Rogue State' Secret Programs to Emerging Terrorist Groups

While the states that signed the Biological and Toxin Weapons Convention (BTWC) in 1972 have officially renounced the development of biological warfare programs, a new cycle of concern over the possible use of anti-crop bioweapons began in the

Fig. 2.2 Leaflet taken from a GDR propaganda press campaign during the Cold War (1950) depicting the potato beetles (*Leptinotarsa decemlineata*) as tiny US soldiers (http://www.bbc.com/news/magazine-23929124)

late 1980s. This was based on the knowledge that several 'rogue states' (conducting their policy in a dangerously unpredictable way, disregarding international law or diplomacy) were trying to acquire this type of weapon. The 1980–2000 period, viewed as the transition from the Cold War to the globalization era, also raised concerns among several EU member states that some countries suspected of harboring potential anti-crop agents may be involved in developing them as weapons. More recently, evidence was purportedly found in caves in Afghanistan that suggested interest by Islamic militants in the weaponization of wheat rust (Fletcher et al. 2006). Following the First Gulf War, the United Nations Special Commission's inspections revealed that Iraq had expressed an interest in acquiring the military capacity to destroy Iranian crops and that progress had been made in research and development for the weaponization of wheat smut fungi (*Tilletia caries* and *T. tritici*) and aflatoxin-producing strains of the fungus *Aspergillus* (Table 2.1; Whitby 2002). The existence of an anti-crop state program was firmly established, while the supposed Iraqi stock of bioweapons subsequently used as pretext to start the Second Gulf War did not actually exist. The fact that some scientists involved in such research had studied in European universities raised the question of the tracking of students (both foreign and domestic) likely to be selected subsequently by malicious regimes for an anti-crop program. The emergence of the so-called Islamic State (ISIS), while not a state *sensu stricto*, has increased global concerns about terrorism and impacted a large part of the civilian population in Syria and northern Iraq. The terrorist attacks in Paris in 2015 and in Brussels in 2016 had a large impact on the European pschye and proved the motivation and the deployment capability of the organization.

Three elements should now suggest that the threat of agroterrorism for Europe coming from rogue states or terrorist organizations is not negligible. Firstly, the agriculture sector is strategic for Europe and also for isolated states or any organization attempting to hold large teritory (e.g. for ISIS, see Hansen-Lewis and Shapiro 2015). Secondly, anti-crop bioweapons programs have been developed in the past by states anticipating conflict. Thirdly, there is evidence of intentionality and the technical ingenuity – not yet related to agroterrorism capacity – among terrorist groups. Media reports (McElroy 2014) tell of a computer seized in 2014 from a Syrian rebel group contained a manual on how to turn bubonic plague into a bioweapon. These elements indicate that Europe has probably entered a new risk cycle in which the agroterrorism threat, possibly originating even from neighboring regions, has never been so high. Nevertheless, it is difficult to know if the risk level is unchangeable or how to reduce it.

2.2.3 Third Type of Threat: Biocrime, Sabotage, Private Allegations and Conspiracy Theories on Social Media

In the past there have been either false or unverified allegations that states or militant organizations have either used plant pathogens against crops or threatened to use them (Table 2.1; Junior 2006; Zilinskas 1999; Caldas and Perz 2013). An allegation of the deliberate introduction of the Western corn rootworm (*Diabrotica virgifera*) into European maize fields in the 1990s appeared on social media by internet; the fact that a population genetics study demonstrated the occurrence of multiple transatlantic introductions of the pest made it harder for the general public to reject the claims (Table 2.1). Scholarly publications are often ignored in this setting (Miller et al. 2005; Ciosi et al. 2008). One conspiracy scenario involved the deliberate release of the Western corn rootworm by a private company in order to sell biotech solutions in Europe, where the introduction of genetically modified organisms has been intensively debated. Now, after each new accidental introduction of a pest, allegations of deliberate introduction can be found on internet.

This was the case after the detection of *Xylella fastidiosa* in Italy in 2013. Accusations have ranged from a deliberate plot by a private company to introduce strains of olive trees that resist the bacteria to a mafia plot to force farmers to sell their land to land developers at low prices after the eradication olive trees. Much more seriously, in December 2015 nine scientists were investigated for a possible role in negligently enabling the disease outbreak by Italian prosecutors. They worried that *Xylella* strains may have been imported from California for a scientific training workshop in 2010, and may then have been released into the environment. Plant pathologists were officially suspected of "negligent spreading of the plant disease, presenting false information and materials to officials, environmental pollution and disfiguring natural beauty". Currently the truth of the matter is not established but this case illustrate that the consequences of allegations of deliberate introduction on the agricultural sector, from growers to scientists, are almost as high as from the introduction itself. Furthermore, the potential of intensified judicial involvement in a phytosanitary crisis will modify the posture of scientists and experts working in the field of plant protection.

Some plant pathogenic fungi that produce mycotoxins are already a recurrent cause of plant disease, such as *Fusarium graminearum* and *F. culmorum* on wheat or *Penicilium expansum* on apples (Russell and Paterson 2006). European assessments did not consider mycotoxin-producing fungi as serious anti-crop agents because of the low levels of mycotoxins and the availability of detection methods. However, based on biotechnical considerations and the fact that these may potentially affect human or cattle health, these pathogens might be reassessed. For example, the previous assessment disregarded the potential psychological effects of a malevolent contamination of food on the population. A deliberate introduction of a plant pathogen may cause significant public panic and a loss of confidence in a segment or the whole of the food chain, seriously affecting niche sectors of European agriculture (such as organic farming). Additionally, a perpetrator with limited technical and scientific skills would increase the potential impact by using simple intimidation or blackmail rather than actually attempting to contaminate the target: fear would have sufficient repercussions on trade and economy (Turvey et al. 2003, 2010; Waage and Mumford 2008).

2.2.4 Fourth Type of Threat: From the Application of Phytosanitary or Sanitary Measures in Response to Deliberate Introduction of a Regulated Pest to Justify Trade Protectionism

According to the Agreement on the Application of Sanitary and Phytosanitary Measures of the World Trade Organization (WTO 1995), every member country has the right to impose import restrictions to protect the health of crops and forests, or consumers in regard to food safety, as long as no unfair discrimination or hidden trade barriers are created. Import restrictions should be technically justified (so, for plant pests "justified on the basis of conclusions reached by using an appropriate pest risk analysis or, where applicable, another comparable examination and evaluation of available scientific information"; IPPC 2004; Heather and Hallman 2008). It is conceivable that a state or other actor could intentionally introduce a plant pest into an import consignment as a pretext to justify trade protectionism. The intention could be to preserve a domestic market, or disparage a competing supplying country. The objective of this kind of operation would not be to provoke direct damage to a crop, but to induce a false detection of a regulated pest or of a food hazard to cause the imposition of protectionist measures. However, trade disruption may not automatically follow a detection of a quarantine organism, unless there is an indication to the authorities of an ongoing unacceptable risk.

2.3 List of Targets Crops and Pests as Biological Data Base: Starting Point of a Prospective Approach to Quantify the Risk in Europe

Officially no act of agroterrorism has occurred in Europe in the past, excluding some criminal cases of human food poisoning. Programs existed, but none was applied. Yet the threat exists and European agriculture is a critical part of the regional economy. The combined agricultural and food sector forms an important part of the EU economy, accounting for 15 million jobs (8.3 % of total employment) and 4.4 % of the gross domestic product (GDP). The EU is the world's largest producer of food and beverages, with combined production estimated at 675 billion Euros (European Commission, Eurostat, November 2014). The self-sufficiency of the EU in basic agricultural products is vital, not only for the wellbeing of its citizens, but also for the geopolitical independence of its member states. The economic, social and political importance of agriculture is therefore much greater than its share in the GDP of the EU.

Crops and forests are vulnerable because they are grown over large ares, often with low levels of management. Although the opportunity for monitoring production areas in Europe is greater than in the rest of the world, these areas cannot be 'protected' from attack. A perpetrator may consider there is a low chance of being observed releasing plant pathogens in a field and there is little that can done initially to limit disease or pest spread (Madden and Wheelis 2003; Madden and van den Bosch 2002). In reality, results of risk assessments showed that, contrary to the assertion that agroterrorism is 'low tech, high impact' (Wheelis et al. 2002), deliberate contamination of plants in large forest areas, for example, are not technically easy to achieve (Suffert et al. 2009) and success of such an attack is not guaranteed. The misperception may result from an erroneous militarization of the threat. Lastly, while the probability that a given crop in a given European country will be a target for a given motivation by a given perpetrator is low, the overall probability that Europe will be concerned someday by an act of agroterrorism *sensu lato* is relatively high.

2.3.1 Types of Scenarios, Human Dimension of the Threat

The foresight approach developed in Chap. 6 is aimed at exploring the diversity of the potential scenarios (Table 2.2). They consist of a list of conditions and assumptions, pertaining to potential attacks, and a list of rules.

Table 2.2 Description of the nine types of agroterrorism scenarios

	Biowarfare
BW1	Attack by a country on the agricultural sector of another country. The aim of the attacker is to block commercial imports of the targeted products and prevent their entry into its national market or to enhance its own exports.
BW2	Attack by a country on the agricultural production of another country, in order to weaken the targeted country by reducing its domestic food supplies. This action could be undertaken before a military intervention or replace it.
BW3	Use of biological agents by a country to eradicate illicit crops in another country, such as drug cultivation.
	Bioterrorism
BT1	Terrorist attack targeting food crops. The use of the agent may have negative impacts on human or animal health.
BT2	Attack against planted trees or crops by ecowarriors who want to carry out a radical ecological action.
BT3	Terrorist attack aimed to damage a crop or a tree species that belongs to the patrimony of a country or a group of countries.
	Biocrime
BC1	Attack by activists or farmers groups against the production of a concurrent country.
BC2	Isolated attack by an individual working in the crop protection field, looking for revenge upon a colleague or an institution.
BC3	Deliberate use of a plant pathogen by a private company. The aim would be to render farmers dependant on specific cultivars or plant protection products.

From Latxague et al. (2007)

2.3.2 Target Crops, First Component of the Biological Dimension of the Threat

A comprehensive list of crops (cultivated plants or tree species) of economic or patrimonial interest was used as starting point. The listed species were cultivated or naturally present in Europe (27 EU member states, Switzerland, Norway, Iceland, Croatia, the Former Yugoslav Republic of Macedonia [FYROM], Montenegro, Bosnia-Herzegovina, Serbia, Albania, and Moldova, excluding outermost regions [OMR]). Species present in OMR[1] were excluded, while some crops that are not present in Europe but have a strategic importance for the European industry were taken into account (e.g. rubber plantations). The crops were organized in 11 groups: field crops, vineyards, orchards, vegetable crops, nursery and ornamental horticulture, medicinal and aromatic plants, forest production, beverage crops, straw, tree

[1] The most remote regions of the EU, known as the outermost regions are: Guadeloupe, French Guiana, Réunion, Martinique, Mayotte and Saint-Martin (France), the Azores and Madeira (Portugal), and the Canary Islands (Spain).

sap, seeds. In total 451 crops were inventoried and considered in the subsequent risk analysis. A first classification of the most important crops was established on the basis of the economic value of production (cultivated area × mean yield × mean price; data Eurostat). Crops were preliminarily selected when value of production exceeded 200 million Euros; 79 cultivated plants or tree species were concerned. For these 79 crops and tree, 17 criteria were filled. They were organized in 4 meta-criterias (MT1, 'economical importance'; MT2 'sociological importance'; MT3 'consumption importance'; MT4 'environmental importance') which were completed and assessed by as describe in Table 2.3.

Finally, a short prioritized list of 21 target crops strategic for Europe, chosen as important for socio-economic reasons, was established (Table 2.4).

Figure 2.3 illustrates that the use of a correction index modified the rank of only three crops (oilseed rape, oil olive and dessert apple) that did not appeared to be more important than others (e.g. sugar beet) if the "value of production" only was used for the ranking. The importance of tree species, such as scots pine, Norway spruce and oak, is probably underestimated because this considered only the annual wood production (in average, approximated by the annual increase in wood biomass). In this context, the importance of perennial crops (wine grape, oil olive, dessert apple, orange, peach) is probably also underestimated considering their replacement cost values (the actual cost to replace the crop to its pre-loss condition). This issue can be illustrated by the real socio-economical impact of extreme climatic events or epidemics that have destroyed plantations in the past, for example the *Phylloxera* which destroyed most of the European vineyards in the late nineteenth century, the consequence of the 1999 storm for forests along the Atlantic coasts, or more recently the French outbreak of *Ceratocystis platani* which led to the decision to cut down some plane trees along the Canal du Midi.

2.3.3 Pests Used as Bioweapons, Second Component of the Biological Dimension of the Threat

A non-prioritized comprehensive list of pests comprised of 570 pests of plant hosts cultivated or naturally present in Europe or having an high economic importance for some European countries was established based on historical lists of a similar nature (Table 2.5), and was completed by several experts.

Each pest that could have an impact on at least one of the 21 crops listed in Fig. 2.3 and which was listed in at least four historical reviews (Table 2.5) was added in the non-prioritized short list of pests (Table 2.6), then taken into account to assess the risk of agroterrorism for Europe. This short list was completed by adding a pest which was specifically used to elaborate the WP3 agroterrorist scenario (Table 2.3; Chap. 7).

Table 2.3 Criteria and metacriteria used to assess the importance of crops and forest trees for Europe

Criteria	Code	Unit	Data source	Definition	Coverage
Cultivated area	C1	ha	Crops: Eurostat (crops products; annual data; apro_cpp_crop)	Mean surface by country from 2005 to 2010 (sum EU27)	224 crops
			Forests: Köble and Seufert 2001		36 forest tree species
Mean yield	C2	t/ha/year	Crops: Eurostat (crops products; annual data; apro_cpp_crop)	Mean yield = production/surface (sum for EU27, from 2005 to 2010)	224 crop groups
		m3/ha/year	Forests: Köble and Seufert 2001		11 forest tree species groups
Mean price	C3	euro/t	Crops: EuroStat (selling prices of crop products; absolute annual prices 2000; apri_ap_crpouta)	Mean price (mean for EU27, from 2005 to 2010)	98 crop groups
Value of production	C4	euros	Calculated	Cultivated area × mean yield × mean price (C1 × C2 × C3)	98 crop groups
Volume of trade export	C5	t	Eurostat (international trade detailed data; EU27 trade since 1988 by CN8; DS_016890)	Mean export quantities from 2005 to 2010 (reporter EU27; partner extraEU27)	Over 10,000 products including agricultural and forestry products
Volume of trade import	C6	t	Eurostat (international trade detailed data; EU27 trade since 1988 by CN8; DS_016890)	Mean import quantities from 2005 to 2010 (reporter EU27; partner extraEU27)	Over 10,000 products including agricultural and forestry products
Agro-industrial integration	C7		Expert says	1 = null or low;	
				2 = moderate;	
				3 = high	
MT1, Economical importance					
Correction coefficient = mean(ln[(C1 × C2 + C5 + C6)/(C5 + C6) + exp(1)−1]; C7)					
States concerned by the crop	C8	number	Crops: Eurostat (crops products; annual data; apro_cpp_crop)	From 0 to 27 (number of states not concerned: with null mean surfaces or no data from 2005 to 2010)	224 crop groups

Farms concerned by the crop	C11	number	Number of farms and crop areas according to the farm size (SAU; area NUTS 2; ef_oluaareg)	Number of farms per country in 2007 (sum for EU27; max = 12000000)	76 crop groups
Territorial density	C12		Expert says	1 = diffuse production;	
				2 = large areas moderately specialized;	
				3 = highly specialized basins	
Patrimonial importance	C13		Expert says	1 = low;	
				2 = high	
MT2, Sociological importance					
Correction coefficient = mean(1 + C8/27;1 + 4 × C9/12000000; C10/2; C11)					
Importance in cooking traditions	C14		Expert says	1 = low or irrelevant;	
				2 = moderate;	
				3 = high	
Importance for feeding	C15		Expert says	1 = low or irrelevant;	
				2 = moderate;	
				3 = high	
MT3, Consumption importance					
Correction coefficient = mean(C12; C13)					
Significant presence in recreative areas	C16		Expert says	1 = yes;	
				2 = no	
Significant presence in protected areas	C17		Expert says	1 = yes;	
				2 = no	
MT4, Environmental importance					
Correction coefficient = mean(C14; C15)					

Table 2.4 Short prioritized list of 21 target crops strategic for Europe

Rank	Common name	Latin name
1	bread wheat	*Triticum aestivum*
2	potato	*Solanum tuberosum*
3	wine grape	*Vitis* spp.
4	maize	*Zea mays*
5	tomatoes	*Solanum lycopersicum*
6	barley	*Hordeum vulgare* subsp. *vulgare*
7	rape	*Brassica napus*
8	scots pine	*Pinus sylvestris*
9	sugar beet	*Beta vulgaris* subsp. *vulgaris*
10	oil olive	*Olea europaea*
11	dessert apple	*Malus domestica*
12	norway spruce	*Picea abies*
13	lettuce	*Lactuca sativa*
14	orange	*Citrus* spp.
15	bell pepper	*Capsicum annum*
16	peach	*Prunus persica*
17	alfalfa	*Medicago sativa*
18	strawberry	*Fragaria* spp.
19	carrot	*Daucus carotta*
20	sunflower	*Helianthus annuus*
21	oak	*Quercus* spp.

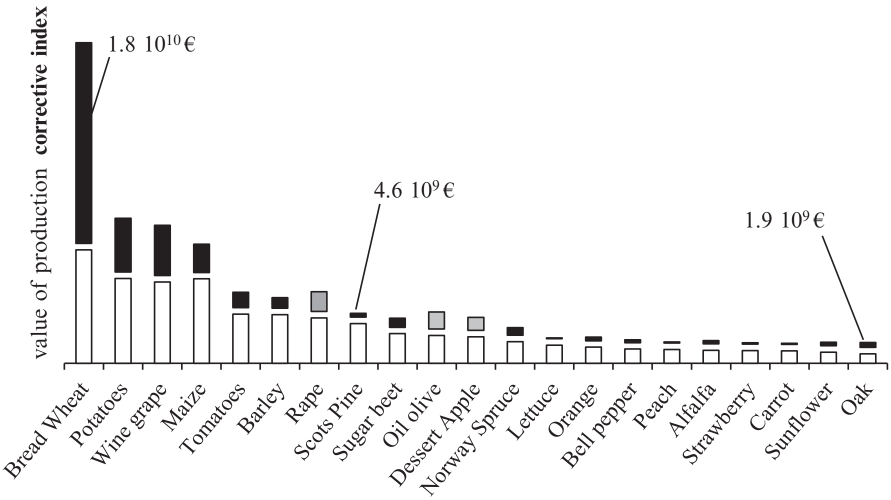

Fig. 2.3 Short list of the most important crops and forest tree species for Europe for socio-economical reasons. The classification was based on the value production, completed by a supplementary value obtained using a correction coefficient to take into account non-economic criteria (Table 2.3). Species whose rank was slightly modified after the use of this correction coefficient are indicated with *grey bars*

Table 2.5 Referenced lists of plant pathogens harmful to plants and plant products which could potentially be used in acts of agroterrorism in Europe (updated in September 2015)

Organization	List	Fungi[a]	Bacteria[b]	Viruses	Nematode
BTWC-SA	Plant pathogens important for the BTWC of the WP124 by South Africa[c]	13	6	1	0
BTWC-AHG	Ad Hoc Group 56/1 Procedural Report[d]	4	3	1	0
USDA-APS	List of biological agents and procedures for notification[e]	4	5	1	0
USDA-APHIS	Agricultural select agents and toxin list[f]	5	2	0	0
MRS	Microbial Rosetta Stone Central Agricultural Database[g]	65	16	12	5
UE-2000/29/CE	EU Plant Health Directive 2000/29/CE, Annex I[h]	18	3	34	5
UE-CBRN	EU list of high risk biological agents[i]	7	7	0	1
EPPO-A1	A1 list of pests recommended for regulation in Europe[j]	36	15	24	5
EPPO-A2	A2 list of pests recommended for regulation in Europe[k]	28	27	22	11
EPPO-Alert	Alert list of pests presenting a risk for Europe[l]	5	1	6	3
CNS	Select agent list of pathogens and toxins[m]	18	11	3	0
Australia Group	List of plant pathogens for export control by the countries member of the Australia Group[n]	11	5	2	0
ISSG-IUCN	100 of the World's worst invasive alien species[o]	3	0	1	0
ANSES	Prioritized list of pests by ANSES for the French Agricultural Ministry[p]	57	38	51	17
FR-31/07/2000	Additionnal list of pests regulated in metropolitan France[q]	3	7	4	3
INRA-CropBioterror	Candidate pathogens list of the UE CropBioterror project[r]	36	9	5	0
FERA-PlantFoodSec	FERA list of top pests of 21 major crops for the EU PlantFoodSec project[s]	38	13	5	10
Suffert	List compiled by Suffert et al. (2009)[t]	18	1	0	0

(continued)

Table 2.5 (continued)

[a]and oomycetes

[b]and phytoplasmas

[c]Established by the **Ad Hoc Group of the Biological and Toxin Weapons Convention (BTWC)** signed on April 10, 1972. T, (BWC/AD HOC GROUP/WP.124). The list, entitled "Plant pathogens important for the BWC", was drawn up at the 4th session of the Ad Hoc Group. It was re-evaluated and presented at the 6th session, held in Geneva **on 3–21 March 1997, in the Working Paper by South Africa**. The following criteria were used to develop the list

– agents known to have been developed, produced or used as weapons

– agents which have severe socio-economic and/or significant adverse human health impacts, due to their effect on staple crops

List: http://www.bradford.ac.uk/acad/sbtwc/ahg34wp/wp124.pdf

[d]Established by the **Ad Hoc Group of the Biological and Toxin Weapons Convention (BTWC)** signed on April 10, 1972. The list belongs to the **Procedural Report of the 23rd session**, held in Geneva, **23 April –11 May 2001** (BWC/AD HOC GROUP 56/1). "Each state party shall declare agents and toxins from the lists set out in Annex A, section I, in accordance with the format for declarations of facilities, activities and transfers referred to in Annex A, section IV". The following criteria were used to develop the list

– potential of individual agents and toxins to be used as weapons

– scientific and technological developments that may affect the potential of individual agents or toxins to be used as weapons

– effects of potential inclusion or exclusion of an agent or toxin in the list on scientific and technical research and development

List: http://www.bradford.ac.uk/acad/sbtwc/ahg56/doc56-1.pdf

[e]Established by the **American Phytopathological Society (APS)** and the **Animal and Plant Health Inspection Service (APHIS)** of the **United States Department of Agriculture (USDA)**. The list, published in the Federal Register of **August 12, 2002**,is displayed on the APS website, together with a paper that presents APS recommendations on countering agricultural bioterrorism with crop biosecurity practices. This list was prepared as part of the **Agricultural Bioterrorism Protection Act**, which was designed to "improve the ability of the United States to prevent, prepare for, and respond to bioterrorism and other public health emergencies that could threaten public health and safety or American agriculture". The following criteria were used to develop the list

– effect of an agent or toxin on animal or plant health or on products

– virulence of an agent or degree of toxicity of the toxin and the methods by which the agents or toxins are transferred to animals or plants

– availability and effectiveness of medicines and vaccines to treat and prevent any illness caused by an agent or toxin

– other criteria that the Secretary considers appropriate to protect animal or plant health, or animal or plant products

List: http://www.apsnet.org/publications/apsnetfeatures/Documents/2002/FEDREG8-12-02.pdf

[f]Established by the **Animal and Plant Health Inspection Service** of the **USDA**. In accordance with the **Agricultural Bioterrorism Protection Act**, implementing regulations detailing the requirements for possession, use, and transfer for select agents and toxins, this list was published by Heath and Human Services (HHS) and APHIS on **March 18, 2005**. The list was updated on **November 17, 2008**. It specifies select agents and toxins

List: http://www.selectagents.gov/SelectAgentsandToxinsList.html

[g]Established by Kamenidou et al. (2013) and published as special report in the APS Journal "Plant Disease". The list includes plant pathogens having significant potential for damage to US agricultural and natural ecosystems. Easily accessible informational resource tool was also developed to assist law enforcement personnel in the event of a disease investigation by providing key information on pathogens of concern

(continued)

Table 2.5 (continued)

List: http://apsjournals.apsnet.org/doi/pdf/10.1094/PDIS-03-12-0263-RE

[h]Established by the **European Union (EU)**. The Annex I of **Plant Health Directive 2000/29/EC** of **8 May 2000** on protective measures against the introduction into the EU of organisms harmful to plants or plant products and against their spread within the Community contain a list of quarantine pests. Published in the Official Journal L169, July 10, 2000

List: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:169:0001:0112:EN:PDF

[i]Established by the **European Union (EU) CBRN Action Plan**, adopted in **2009**. This plan aimed at strengthening CBRN security in the EU and reducing the threat and damage from CBRN incidents of accidental, natural and intentional origin. It is broadly based on an all-hazard approach, including terrorist threats, and contributes to the implementation of the EU Counter Terrorism Strategy. A EU list of high risk biological agents is under discussion since 2013

List: not public

[j]Established by the **European and Mediterranean Plant Protection Organization (EPPO)**, which is the regional plant protection organization for Europe, under the International Plant Protection Convention (IPPC). One of EPPO's aims is to inform its member countries about dangerous pests, thus helping them to prevent their entry or spread. The organization has therefore been given the task of identifying pests that may present a risk, and of making proposals on the phytosanitary measures that can be taken

The **EPPO A1 list** contains pests which have been evaluated as presenting a risk for Europe, which are absent from the EPPO region and which it recommends regulating as quarantine pests. The last version of this list, updated each year, was approved by EPPO Council in **September 2016**

List: http://www.eppo.int/QUARANTINE/listA1.htm

[k]Established by the **EPPO**, the **A2 list** contains pests which have been evaluated as presenting a risk for Europe and which are locally present in the EPPO region. The last version of this list, updated each year, was approved by EPPO Council in **September 2016**

List: http://www.eppo.int/QUARANTINE/listA2.htm

[l]Established by the **EPPO**, the main purpose of the **Alert List** is to draw the attention of EPPO member countries to certain pests possibly presenting a risk to them and achieve early warning. This list is updated each year

List: http://www.eppo.int/QUARANTINE/Alert_List/alert_list.htm

[m]Established by the **Center for Non-proliferation Studies (CNS)**, at the Monterey Institute of International Studies. It is the largest non-governmental organisation in the United States devoted exclusively to research and training on non-proliferation issues. It strives to combat the spread of weapons of mass destruction by training the next generation of non-proliferation specialists and disseminating timely information and analysis. The "select agent" list of pathogens and toxins was published in **November 2002** and compiles the data given by eight other biological agent lists. Authors: Croddy E. and Newhouse L

List: not public

[n]Established by the **Australia Group**, updated in **June 2012**. The Australia Group is an informal group with the aim of allowing exporting or transhipping countries to minimize the risk of assisting chemical and biological weapon proliferation. Participants in the Australia Group do not undertake any legally binding obligations: the effectiveness of their cooperation depends solely on a shared commitment to CBW non-proliferation goals and the strength of their respective national measures. All states participating in the Australia Group are parties to the Chemical Weapons Convention (CWC) and the Biological and Toxins Weapons Convention (BTWC). This group has established a list of plant pathogens for export control

List: http://www.australiagroup.net/en/plants.html

[o]Established by the **Invasive Species Specialist Group (ISSG)**, which is part of the **Species Survival Commission of the World Conservation Union (IUCN)**. The ISSG is an international group of scientific and policy experts on invasive species. It aims to reduce threats to natural ecosystems and the native species they contain by increasing awareness about invasive alien species, and defining ways to prevent, control or eradicate them. Species included in the list of "100 of the

(continued)

Table 2.5 (continued)

World's worst invasive alien species" were selected according to two criteria: their serious impact on biological diversity and/or human activities, and their illustration of important issues related to biological invasions. This list was updated in **2013**
List: http://www.issg.org/database/species/search.asp?st=100ss
[p]Established in **2013** by the **French Agency for Food, Environmental and Occupational Health & Safety** (ANSES) for the French Agricultural Ministry
List: not public
[q]Established by the **French Agricultural Ministry** in **Annex A of the 31 July 2000 decree**. This additionnal list of pests contain organisms harmful to plants and plant products subject to mandatory measures, which are not listed in the Annex I of EU Plant Health Directive 2000/29/CE
List: http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000584174
[r]Established by **INRA** in the **Workpackage 1 of the EU FP6 CropBioterror Project 2004–2007**. The list, delivered to the European Commission in 2005 consists of 50 candidate pathogens representing potential agroterrorist threats to the European agriculture and forests. It includes not only exotic and regulated pathogens, but also endemic pathogens with specific characteristics such as mycotoxinogenic ability, high potential of mutation and hybridization and records of highly pathogenic exotic strains
List: not public
[s]Established in **2012** by a group of experts of the **UKFood and Environment Research Agency** (FERA) coordinated by Dr. Christine Henry as part of the **EU FP7 PlantFoodSec Project 2011–2016**
List: not public
[t]Established by Suffert et al. (2009) and updated in **2016** (Table 2.1)

Table 2.6 Non-prioritized short list of pests considered a potential threat for Europe

Code	Name of the pest
1	Andean potato latent virus
2	*Anoplophora glabripennis*
3	*Aphelenchoides besseyi*
4	Beet leaf curl virus
5	*Bemisia tabaci*
6	*Bursaphelenchus xylophilus*
7	*Candidatus Liberibacter africanus*
8	*Candidatus Liberibacter americanus*
9	*Candidatus Liberibacter asiaticus*
10	*Candidatus Phytoplasma vitis (Grapevine flavescence dorée)*
11	*Ceratitis capitata*
12	*Ceratocystis fagacearum*
13	*Ceratocystis platani*
14	*Citrus tristeza virus*
15	*Clavibacter michiganensis subsp. sepedonicus*
16	*Diabrotica virgifera virgifera*
17	*Diaphorina citri*
18	*Ditylenchus dipsaci*
19	*Didymella exitialis*
20	*Endocronartium harknessii*

(continued)

Table 2.6 (continued)

Code	Name of the pest
21	*Erwinia amylovora*
22	*Fusarium graminearum (Gibberella zeae)*
23	*Globodera pallida*
24	*Globodera rostochiensis*
25	*Gymnosporangium yamadae*
26	*Leptinotarsa decemlineata*
27	*Leptosphaeria maculans*
28	*Meloidogyne chitwoodi*
29	*Meloidogyne fallax*
30	*Microcyclus ulei*
31	*Monilinia fructicola*
32	*Mycosphaerella pini*
33	*Mycosphaerella populorum*
34	*Paysandisia archon*
35	*Penicillium expansum*
36	*Pepino mosaic virus*
37	*Peronosclerospora philippinensis*
38	*Peronospora hyoscyami f.sp. tabacina*
39	*Phakopsora pachyrhizi*
40	*Phellinus weirii*
41	*Phoma tracheiphila (Deuterophoma tracheiphila)*
42	*Phytophthora infestans*
43	*Phytophthora ramorum*
44	*Pleospora papaveracea*
45	Plum pox potyvirus
46	Potato spindle tuber viroid
47	*Pseudomonas syringae pv. actinidiae*
48	*Pseudoperonospora cannabina*
49	*Puccinia graminis f. sp. graminis*
50	*Puccinia striiformis*
51	*Puccinia triticina*
52	*Ralstonia solanacearum race 3 biovar 2 (Pseudomonas solanacearum)*
53	*Sclerophthora rayssiae var. zeae*
54	*Synchytrium endobioticum*
55	*Tilletia indica*
56	*Tilletia laevis*
57	*Tomato spotted wilt virus*
58	*Tomato yellow leaf curl virus*
59	*Ustilago maydis*
60	*Xanthomonas axonopodis pv. citri*
61	*Xanthomonas campestris pv. campestris*
62	*Xylella fastidiosa (Pierce disease)*
63	*Xylophilus ampelinus*

2.4 Prospect for Risk Assessment and Management in the Next Decade

2.4.1 Evolution and Contextualization of the Threat in Europe

Anti-crop biowarfare was a relevant geopolitical and military issue until the 1980s. Awareness for biosecurity has increased from 1990 to 2000 owing to growing 'Trade', 'Travel', 'Transportation', and 'Tourism', summarized pertinently as the "four T's" components of globalization by Waage and Mumford (2008). While agroterrorism was a minor issue until the past two decades, it strongly emerged after 1997 (Suffert et al. 2008; Fig. 2.1). Subsequent general issues of agricultural biosecurity would be influenced during the next decade by a large set of different components. The nature of the changes was complex and it is necessary to identify in light of the current situation which modifications in the geopolitical and socio-economical context could transform the perception of the agroterrorist threat in Europe. After several years of in depth and, to the degree possible, neutral analysis, the threat of agroterrorism seems to fall into four categories by important determinants of the change. These can be identified presently as the "four C's" components 'Convergence Tactics', 'Constraints', 'Climate', 'Conspiracy'.

Convergence Tactics The different international terrorism activities, which have permanently altered the pschye of nations, from September 11th 2001 in New York to December 19th 2016 in Berlin, give evidence of intentionality, innovative strategies and motivation to look for novel technical means. Because of such undeniable motivation for novel action, the risk of bioterrorism in general, including agroterrorism, has significantly increased. The 'Convergence Tactics' of individual or small group actors who carry out guerilla style attacks may result from ideological or political motivations that differ greatly but all aim at vengeance or destruction of existing structures, systems, and states. The style of tactical convergence across borders initiated by ideologically motivated terrorism groups represents probably the most serious threat for the next decade.

Constraints The rise in research on potentially dangerous plant pests reflects the need to find solutions to new problems, but can also lead to problems if there are not adequate constraints on private commerce in such substances or illicit access by countries considered by Europe as 'rogue states' potentially involved in the development of bioweapons. Emerging capacity in biotechnology may allow intentional or unintentional proliferation of a wide range of dual-use technologies. The potential of future anti-crop biowarfare programs could rely on the effectiveness of constraints on both private and public research, in terms of preventing distribution of dangerous stock but also in terms of limiting access by students and researchers who are not in agreement with the principles of the BTWC and civil society. In this uncertain forthcoming context, international initiatives such as the 'Australia Group' could have a strategic importance for agricultural biosecurity in Europe and its actual exposure to agroterrorism. It is an informal forum of countries, including 30

European states, which use licensing measures to ensure that exports of certain chemicals, biological agents, and dual-use manufacturing facilities and equipment, do not contribute to the spread of chemical and biological weapons, including potential anti-crop agents (Table 2.4).

Climate When US Senator Bernie Sanders stated that “climate change is directly related to the growth of terrorism”, he probably was thinking of the increase in drought and flooding and extreme weather disturbances as a result of climate change, and the added pressure and frustration that means to vulnerable people all over the world. While his statement was not substantiated, it raises the question of the relation between climate change, agricultural biosecurity and agroterrorism. This relationship must not be neglected under the pretext that it is complex, or not yet clearly established. During the next decade, climate change and a wide range of global and regional policies applied to minimize its adverse impacts will certainly modify the perception of the risk of agroterrorism in Europe. Furthermore, new forms of threat such as ‘ecoterrorism’ (Liddick 2006; Lodadenthal 2013) should be taken into consideration.

Conspiracy Several allegations about deliberate introduction of plant pests, viewed as the expression of a conspiracy theory, developed on the internet and social networks since the 2000s. In the past, allegations usually were state propaganda. Most of allegations are now ‘civilian’, in the sense that they are raised by private citizens or pressure groups, sometimes organized at an international level. Perpetrators or malicious whistleblowers can use social media as their modus operandi, while defenders, including organizations in charge of crop protection, can use it for peaceful purposes (i.e. for collecting valuable information and monitor social media before, during, and after an act of agroterrorism). The impact of this dual-use dilemma of social media in biopreparedness was analyzed by Sjöberg et al. (2013) in the case of an animal bioterrorism incident. Furthermore, Rohn and Erez (2013) asserted that early detection of ‘data’ enables preventive measures using overt data sources on internet is the best risk-management approach; however, to be efficient, this approach must allow to distinguish between between plausible and implausible allegation. In this context, the risk of ‘false positive’, such as the risk of considering that a pest introduction was deliberate while a natural or accidental cause was established, is as high as the risk of ‘false negative’, such as the risk of not being able to establish the deliberate nature of the pest introduction.

2.4.2 Current and Future Answers to Agroterrorism: Real or False Solutions?

The dual use potential of biotechnology research should be considered to pose a risk to crop biosecurity. For example, the United Nations Bioweapons Office has stated concern over the possibilities for weaponization of the ‘gene drive’ technology

(Begley 2015). There are some methods (e.g., CRISPR-Cas9 genome editing) that consists of designing a gene delivery system that will cause it to be inherited at greater than the usual inheritance rate, thereby possibly spreading into an entire insect or pathogen population in a relatively short time period. Although beneficial uses, such as control of disease vector, are under study, the possibilities for weaponizing gene drives range from suppressing populations of pollinators to giving innocuous insects the ability to carry plant diseases. This example raises the question of the need for surveillance of possible dual-use research, for example by the 'Australia Group'.

As Suffert et al. (2009) stated, the capacity of European countries to prevent an act of agroterrorism requires the involvement of all parties interested in crop biosecurity. They are expected to consider the multiplicity of threats and to collaborate to implement specific countermeasures. Regulation in terms of national biosecurity may not be a sufficient preventive approach to control intentional use of plant pathogens that have been found to fulfil the proposed criteria for a biological weapon. Furthermore, Pasquali (2006), Young et al. (2008) and Suffert et al. (2009) hold a view that European academic and scientific activities should not be inhibited by specific regulations (censure of scientific knowledge, restriction of exchanges of scientific material and movement of scientists, etc.). After the detection of a suspicious disease outbreak, in which a plant pathogen may have been used as an anti-crop weapon, an efficient response would require a collection of evidence that allows identification of the source as early as possible, as well as the method and timing of introduction, and of course the perpetrators (Schaad et al. 2003). In other words, such a situation would have a similar approach to a criminal investigation. To this end, the use of legal molecular-based detection technologies, summarized in the term 'bioforensic' (Fletcher et al. 2006), would be necessary to flag the occurrence of suspicious epidemics.

Biotechnology is only a tool, however, not the finality. The purpose of any investigation performed in a putative 'scene of agroterrorism' is to acquire epidemiological evidences, by both deductive and inductive reasoning and to gain knowledge of the events surrounding the alleged criminal act (Chap. 9). The main difference with a classical scene of crime is that the demonstration of the criminal nature of the contamination event (contrary to natural or accidental event) should be the first objective (Elbers and Knutsson 2013). It is also a real challenge. Bioforensic tools (Fletcher et al. 2006) and databases (Kamenidou et al. 2013) need to be coupled with classical epidemiological approach for assessing the likelihood that a plant disease outbreak may have been intentionally incited. One of the goals of the PlantFoodSec project was to produce scientific knowledge on the build-up, persistence and release of primary inoculum and the early stages of epidemics of selected plant pathogens to differentiate between the consequences of natural and deliberate field contamination. Would investigators be able to differentiate the deliberate introduction of a plant pathogen from an 'accidental' or 'natural' outbreak? In several cases the answer is probably no, because the main issue, "How does a natural epidemic start", is still a poorly resolved question in plant disease epidemiology. The concept of 'initial inoculum' persists as a black box. Two cases study of important pathogens of wheat, *Puccinia triticina* (the cause of leaf rust) and *Zymoseptoria tritici* (the cause of septoria leaf blotch) were developed by combining experimental and modeling approaches (Morais et al. 2015, 2016a, b; Soubeyrand et al., 2017) in order to track the early onset of epidemics. Despite the approach suggested above, countermeasures based exclusively on early detection would be ineffective in regard to the specific features of some prospective scenarios (Latxague et al. 2007; Suffert et al. 2009).

Despite the aforementioned challenges, the need for greater preparedness in Europe remains. The contributions of the PlantFoodSec project should improve the chances of 'getting it right' under the pressure of encountering possible agroterrorism in an increasingly uncertain world.

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