Plant Pathology in the 21st Century

Maria Lodovica Gullino
James P. Stack
Jacqueline Fletcher
John D. Mumford *Editors*

Practical Tools for Plant and Food Biosecurity

Results from a European Network of Excellence

Springer

Plant Pathology in the 21st Century

More information about this series at http://www.springer.com/series/8169

Maria Lodovica Gullino • James P. Stack
Jacqueline Fletcher • John D. Mumford
Editors

Practical Tools for Plant and Food Biosecurity

Results from a European Network of Excellence

Volume 8

Springer

Editors
Maria Lodovica Gullino
Università degli Studi di Torino
AGROINNOVA
Grugliasco (TO), Italy

James P. Stack
Department of Plant Pathology
Kansas State University
Manhattan, KS, USA

Jacqueline Fletcher
Department of Entomology
and Plant Pathology
Oklahoma State University
Stillwater, OK, USA

John D. Mumford
Centre for Environmental Policy
Imperial College London
Ascot, Berks, UK

Plant Pathology in the 21st Century
ISBN 978-3-319-46896-9 ISBN 978-3-319-46897-6 (eBook)
DOI 10.1007/978-3-319-46897-6

Library of Congress Control Number: 2016963796

© Springer International Publishing AG 2017
Chapter 12 was created within the capacity of an US government employment. US copyright protection does not apply.
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

In a world facing a growing risk of man-made and natural crises and disasters, the security of citizens and critical infrastructures and the environment protection have become a high priority in the European Union.

Strengthening capacities in crisis management and improving resilience represent key policy and research challenges. To better protect citizens and national infrastructures, the race is now on improving Europe's preparedness and prevention to man-made and natural threats, as well as reinforcing operational response capacities in case of emergency situations.

This book is the outcome of the "Plant and Food Biosecurity" project, a Network of Excellence funded within the security thematic area of the European Seventh Framework Programme for Research and Technological Development (FP7), aiming to invest in knowledge and develop further technologies in order to protect citizens from man-made (accidental or intentional) and natural threats.

Within this framework, the project tackled the threat of and damage from biological incidents of accidental, natural or intentional origin, including acts of bioterrorism, defined as the intentional release of harmful biological agents such as bacteria, viruses or toxins to cause fear, illness or death of people, animals or plants and/or disrupt social, economic or political stability.

The project scope embedded the overall risk management cycle, from preparedness, prevention, detection and surveillance to response and recovery in the topic areas of plant biosecurity and food safety, taking also into account the need to ensure a proper transfer (and implementation) of research outputs – including "practical tools" – to users, namely, producers, policy-makers, scientists, agri-food industry and field practitioners.

A proper and tailor-made exchange of information about research project results is essential to enhance the transfer of research solutions to users in a timely and relevant fashion in order to enable a response to potential agroterrorism threats. Such exchanges are also needed to identify and address users' needs regarding research, technologies and policies, especially in a field where EU capabilities to detect and respond to agroterrorism, or biocriminal acts, are ruled by a number of international, EU and national policies divided among many different organisations.

The book addresses the result of tasks accomplished by 13 partners located in eight different countries, in Europe and beyond: it outlines and characterises threats and gaps in plant biosecurity and food safety areas, analyses the relevant policy framework and the lessons learned from the practice and identifies the most promising tools and methods for risk assessment, detection, diagnostic and containment.

In addition, the authors are also making reference to capacity building, research networking and knowledge transfer, as well as to opportunities for further collaboration in addressing the full spectrum of global biosecurity concerns. As a consequence, this book will be a helpful tool both in becoming more acquainted with the issue of plant and food biosecurity and also in being aware of the possible ways to implement further research and analysis on these subjects.

European Commission
Directorate-General Migration and Home Affair
Rue de la Loi 200, B-1049 Brussels

Philippe Quevauviller

Preface

Biosecurity is a strategic and integrated approach for analysing and managing relevant risks to human, animal and plant life and health and associated risks to the environment. Plant biosecurity aims at protecting all plant resources and the food supply from the natural or intentional introduction, establishment and spread of plant pests, pathogens and noxious weeds. Although most plant disease outbreaks have natural causes or are the result of inadvertent introductions of pathogens through human activities, the risk of a deliberate introduction of a high consequence plant pathogen cannot be excluded.

This book is part of a series of volumes on plant pathology in the twenty-first century, and it stems from Plant and Food Biosecurity (PLANTFOODSEC), a Network of Excellence running from 2011 to 2016 and funded under the European Seventh Framework Programme for Research and Technological Development (FP7). PLANTFOODSEC focused on biological threats having the capacity to affect and damage agriculture, infect plants and ultimately affect food and feed at any stage in the supply chain. The project aimed to develop and implement a virtual centre of competence to prevent, respond to and recover from both intentional (agroterrorism) and unintentional biosecurity threats to EU agriculture, farming and the agri-food industry.

PLANTFOODSEC encompassed plant biosecurity and food safety areas, focusing not only on enhancing capabilities for prevention, detection, response and recovery from threatening plant pathogens but also on mycotoxins and on the contamination of fresh produce and other plant-derived foods by human pathogens on plants (HPOPs) – primarily enteropathogenic strains of *Escherichia coli* and *Salmonella* spp. – that can colonise and contaminate plants at any point along the food production and distribution chains, creating possibilities of outbreaks of food-borne illness.

The considerable amount of research promoted by the European Union – which has also involved non-EU countries such as the United States, Israel and Turkey – has made possible the development of a comprehensive set of tools covering the entire risk management cycle, from prevention to preparedness, detection, response and recovery, which are presented in this book.

In particular, the different chapters cover the identification and regulatory analysis of biosecurity challenges, pest risk assessment, experimental and modelling approaches applied in plant disease epidemiology, decision tools and microbial forensics, diagnostics and detection tools. Moreover, training, dissemination and networking subjects are also covered.

We believe that, besides representing a written testimony of PLANTFOODSEC project, this book will be useful for all the stakeholders in the agri-food chain, including producers, researchers and authorities responsible for plant health and food security interested to go in depth into the world of intentional and unintentional threats to plant biosecurity and to food safety.

We would like to convey our appreciation to all the colleagues who accepted to be part of this book, Zuzana Bernhart and her group at Springer for their kind support and Laura Castellani for her skilful technical assistance.

Grugliasco, Italy	Maria Lodovica Gullino
Manhattan, KS, USA	James P. Stack
Stillwater, OK, USA	Jacqueline Fletcher
London, UK	John D. Mumford

Contents

1 Considering Vulnerabilities, Threats and Gaps in Plant and Food Biosecurity 1
Paul Robb

2 Characterization of the Threat Resulting from Plant Pathogen Use as Anti-crop Bioweapons: An EU Perspective on Agroterrorism 31
Frédéric Suffert

3 Vulnerabilities, Threats and Gaps in Food Biosecurity 61
Jacqueline Fletcher, Hami Alpas, Christine M. Henry, Edward Haynes, Heinz W. Dehne, Li Maria Ma, Yeşim Soyer, Filiz Yeni, Paola Colla, and Paul Robb

4 Recent Outbreaks of Human Pathogens on Plants (HPOPs) on Fresh Produce – Lessons Learned from the Practice 77
Hami Alpas, Filiz Yeni, Yeşim Soyer, and Jacqueline Fletcher

5 A Risk Management Framework for Plant Biosecurity 97
Abraham Gamliel, James P. Stack, and John D. Mumford

6 Integrating Crop Bioterrorism Hazards into Pest Risk Assessment Tools 121
John D. Mumford, Adrian W. Leach, Johnson Holt, Frédéric Suffert, Ivan Sache, Benedicte Moignot, and R. Alexander Hamilton

7 Detection of Mycotoxins in Food: Applications of Rapid and Reliable Tools in a Biosecurity Context 143
Abraham Gamliel, Heinz W. Dehne, Petr Karlovsky, and Jacqueline Fletcher

8 Containment of Mycotoxins in the Food Chain by Using Decontamination and Detoxification Techniques 163
Davide Spadaro and Angelo Garibaldi

9 Decision Tool for Assessing the Likelihood of an Intentional Foodborne Illness Outbreak 179
Li Maria Ma, Jacqueline Fletcher, John D. Mumford, Johnson Holt and Adrian W. Leach

10 Diagnostic Tools for Plant Biosecurity 209
Jane E. Thomas, Thomas A. Wood, Maria Lodovica Gullino, and Giuseppe Ortu

11 The European Union Plant Diagnostic Information System (EUPDIS): A Platform for Collaborative Diagnostics and a Tool for Early Detection of Plant Pathogens 227
Paul J. Verrier, Jane E. Thomas, and James P. Stack

12 Containment and Eradication of Invasive Pathogens 243
Abraham Gamliel and Jacqueline Fletcher

13 Applications and Assessment of Microbial Forensics in a Field Outbreak of Salmon Blotch of Onion in Israel 257
Jacqueline Fletcher, Abraham Gamliel, James P. Stack, Heinz W. Dehne, Yochai Isack, and Ian Moncrief

14 The Fragmentation of Plant and Food Biosecurity Research Networks: A Scientometric Analysis 289
Vincent Cardon and Marc Barbier

15 Developing an International Communications Network: The PlantFoodSec Model 309
Anita Kocic, Marta Bonifert, Alessandro Bertin, Paola Colla, and Maria Lodovica Gullino

16 Training and Knowledge Transfer to Support Strong, Comprehensive National and International Plant Biosecurity Preparedness 327
Christine M. Henry, Charles R. Lane, Paola Colla, and Maria Lodovica Gullino

17 Making the Most of International Opportunities and Experiences for Researchers' Training Within a Large, Multinational EU Project: The Students' Perspective 349
Tania Llera, Ian Moncrief, Yochai Isack, Filiz Yeni, Vincent Cardon, Giovanna Gilardi, James Woodhall, Giuseppe Ortu, and Maria Lodovica Gullino

18 The Need for International Perspectives to Solve Global Biosecurity Challenges 363
John D. Mumford, Maria Lodovica Gullino, James P. Stack, Jacqueline Fletcher, and M. Megan Quinlan

Chapter 1
Considering Vulnerabilities, Threats and Gaps in Plant and Food Biosecurity

Paul Robb

Abstract Whilst the majority of plant derived foods produced for human or animal consumption are safe and wholesome, sometimes complex production and distribution systems are not immune to vulnerabilities, threats and gaps in biosecurity as a number of examples will show. We live in an ever changing world so vigilance is required to identify and prevent new and emerging issues that could impact on production capacity, plant biosecurity or food safety and food chain resilience. Rather than list already well known issues, a number of generic approaches to considering vulnerabilities will be described encompassing natural, accidental and malicious events. Tools such as HACCP, TACCP, PESTLE and plant risk assessments help managers suggest how vulnerabilities and threats in food and plant biosecurity can be managed to tolerable levels. Tools and datasets developed within PlantFoodSec that support a proportionate response are included in discussions to identify predictable issues by stakeholders at all levels.

Keywords Plant food chain • Vulnerability • Risk • Threat assessment • TACCP • PESTLE • Lessons natural and malicious

1.1 Introduction

The vast majority of plant derived foods which are produced for human or animal consumption are safe and wholesome. However, often complex production and distribution systems are not immune to a range of potential threats and imperfections in the "seed to salad on the plate" food chain. There are a wide range of protective systems in place to prevent the adverse consequences of natural, accidental or malicious contamination including disease outbreaks affecting both food plants and consumers. Many of these protective measures have been established following significant outbreaks either in the plants themselves or because of an adverse effect on consumers. The strong science base that exists in this field has built upon the

---

P. Robb (✉)
Fera Science Ltd, York, UK
e-mail: paul.robb@fera.co.uk

M.L. Gullino et al. (eds.), *Practical Tools for Plant and Food Biosecurity*, Plant Pathology in the 21st Century 8, DOI 10.1007/978-3-319-46897-6_1

need to prevent and respond to such events and has made major contributions in particular to the prevention and control of disease and contamination at all stages of this arm of the food chain.

The PlantFoodSec project (https://www.plantfoodsec.eu/) has brought together key members of the international scientific community who understand plant production methods and have experience of developing, establishing and using tools to enhance biosecurity and safeguard the plant food chain. As part of this project team, a small group of specialists (the security panel) provided internal review and guidance to the project teams on matters which may have potential to be misused for malicious purposes. In reality this function provided reassurance to the teams that their work should be published and disseminated as their outputs reinforced protective measures rather than highlight major gaps in knowledge and vulnerabilities in the food chain. The panel also encouraged collaboration with other agencies and promoted project outputs to those engaged in emergency response and in particular with protection of agricultural food production systems. Although the project had a plant focus, the vulnerabilities considered and gaps filled by the project have wider applicability which this chapter aims to demonstrate.

As we live in an ever changing world, vigilance is required to identify new and emerging issues that could impact on production capacity, plant biosecurity or food safety and food chain resilience. In this chapter we will explore a number of ways in which vulnerabilities can be identified, threats evaluated and suggest how gaps in food and plant biosecurity can be managed to acceptable levels. Many of these approaches refer to tools and datasets that have been developed within PlantFoodSec to support a proportionate response to any predictable issues. Rather than highlight particular weaknesses, this chapter seeks to explain some of the many approaches available to stakeholders at different levels to identify gaps in food chain biosecurity.

In this chapter the term "food security" is used in the context of guarantee of supply and "food defence" in the context of safeguarding the food chain from malicious intervention with "food safety" being used in the context of ensuring food is wholesome and can be consumed safely.

1.2 Vulnerabilities

One definition of the term vulnerability is:

"Exposed to the **possibility** of being attacked or harmed, either physically or emotionally" (http://www.oxforddictionaries.com/definition/english/vulnerable). In this context, emotional impacts will include public perception encompassinging, at times, the adverse consequences of intervention. Perception of food safety risks is a topic outside the scope of this work but there is a large literature describing the importance of the topic (e.g. Lobb et al. 2007; Redmond and Griffith 2007; Verbeke et al. 2007).

There is little doubt that closer links between the natural and social sciences are developing with mutual benefits but there are still challenges in developing a common lexicon and shared understanding in this area. Managing stakeholder expectation will continue to be a key aspect of consequence management of unexpected events.

It would be naïve to suggest that the food chain or plant production systems are not open to the possibility of damage or could suffer harmful impacts from natural, accidental or malicious actions but the detailed examination of vulnerabilities (and mitigation measures) is conducted at many levels. For example,

- at the operational level producers or food processors may consider production of single products or crops,
- at the tactical level, larger businesses might consider production and storage options to maximise retailer choice and shelf-life,
- strategically, international businesses or Governments may consider a wider international food chain, cross border issues and multiple supply chains to guarantee supply.

These are not rigid examples but hopefully demonstrate the complexity of assessing vulnerabilities in the food chain and the need to consider a very wide range of stakeholder requirements. Vulnerabilities can arise for a number of reasons and it is convenient to consider these as natural, accidental or malicious.

1.3 Natural Vulnerabilities

Plants for food or feed are rarely grown aseptically outside of specialised research institutes (some hydroponic systems may be near to this) and the growing environment is itself vulnerable to a range of naturally occurring events that impact upon food/feed plants.

Perhaps the most obvious natural vulnerability is susceptibility to disease outbreaks (e.g. Johnson and Cummings 2015) or pest infestation (e.g. http://www.fao.org/emergencies/emergency-types/plant-pests-and-diseases/en/) which can affect yields, impact upon availability or affect nutritional value with an impact on food security (guarantee of supply), especially in those countries where alternatives are scarce or uneconomically viable to access.

Water security is increasingly becoming recognised as being a key vulnerability in some countries with impacts on irrigation as well as biosecurity, e.g. where disinfection or processing of water is needed before use. Control of water will become more important if recent changes in weather patterns continue to develop with a shift in deposition causing a change in drought and flooding patterns across the globe.

Other natural vulnerabilities include events such as the eruption of the Eyjafjallajökull volcano in Iceland in April 2010 which received widespread press coverage (http://news.bbc.co.uk/1/hi/world/europe/8634944.stm). Significant impacts of this event included restrictions on air travel from the resulting ash cloud which impacted across many parts of Europe. Whilst direct impacts on food were limited to potential increased fluoride levels in deposited ash affecting nearby pasture and grazing, indirect impacts were felt on transportation of short shelf-life produce which is mainly conducted by air. Not only does a freeze on air travel result in financial losses as perishable goods deteriorate but also a potential biosecurity challenge and waste disposal issues.

Without needing to engage in the climate change debate (http://www3.epa.gov/climatechange/science/overview.html, http://www.worldbank.org/en/topic/climatechange/overview), the world is clearly undergoing a series of weather variances that are impacting on plant production with increased vulnerability to weather extremes, changes in growing seasons and increased prevalence of diseases that previously would have been classified as being exotic being observed.

In addition, natural evolutionary change in organisms has caused problems that have impacted across Europe. For example an outbreak of Shiga-toxin producing *Escherichia coli* (STEC), serotype O104:H4 (Karch et al. 2012) originally reported in Germany (European Food Safety Authority 2011) in May 2011, proved to be a significant event. This was initially associated with consumption of fresh vegetables although later, this was linked to consumption of seed sprouts. Assignment of the source of infection in consumers was initially flawed and attributed in error to cucumbers grown in Spain where German laboratories detected *E. coli* in imported cucumbers. Application of the precautionary principle (http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri = URISERV:l32042&from = EN) meant that, in the absence of data to the contrary at the time, large volumes of cucumbers in Spain were consigned to landfill (as well as other salad vegetables which consumers felt were at risk). Compensation payments from the EU to the affected producers of €210 million did not meet all losses with substantial reputational loss by a major industry. Further examination of the organisms detected in the cucumbers identified a different strain of E Coli to that causing serious health issues.

Consumption of sprouted seeds was subsequently associated with occurrence of an identical outbreak in France in June of 2011 with evidence suggesting a common source. Eventually, tracing suggested that the contaminated material most likely arose from a specific consignment of fenugreek seeds imported from Egypt.

The situation was complicated by the fact that STEC O104:H4 was a very rare serogroup in humans in the EU and indeed worldwide with only low single figure cases being reported before the outbreak. At the end of the outbreak, a total of 3911 cases had been reported to the ECDC and WHO.

This is a good example of how vulnerable the plant food supply chain can be from naturally evolving organisms. It is not uncommon for assignment of the causative agent for food poisoning to be made from clinical isolates rather than from examination of the foods consumed. It is of course a key protective measure that the food industry tests routinely for microbial contamination in produce. Nevertheless genetic mutation of *E. coli* O104 impacted on the assays used by National and EU Community Reference Laboratories (NRL and CRL) but rapid diagnostic method development by the CRL allowed NRL to begin testing with minimal method development which aided public reassurance and eventual control of a complex situation. This infrastructure was a significant resource used to manage the outbreak.

It may be worthwhile describing the precautionary principle used by regulatory authorities across Europe to safeguard consumers. This is invoked "when a phenomenon, product or process may have a dangerous effect, identified by a scientific and objective evaluation, if this evaluation does not allow the risk to be determined with sufficient certainty" (http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri = URISERV:l32042&from = EN).

This principle may only be invoked when the following three conditions are met after a suitable risk assessment where:

- Adverse effects or potentially adverse effects have been identified;
- Scientific data available has been evaluated and
- Scientific uncertainty has been taken into account.

In addition, any response should,

- Ensure proportionality between the measures taken and the chosen level of protection;
- Maintain non-discrimination in application of the measures;
- Require consistency of the measures to be taken with similar measures already used in similar situations or using similar approaches;
- Include an examination of the benefits and costs of action or lack of action;
- Review the measures in the light of scientific developments.

The legislation notes that "in the case of an action being taken under the precautionary principle, the producer, manufacturer or importer may be required to prove the absence of danger."

Producers/suppliers requiring additional testing to demonstrate lack of hazard will add to pressures on finite laboratory resources and in practice collaboration between authorities and producers can be mutually beneficial.

In general, food production chains are protected by well-established mechanisms operating at local, national and international levels so as to safeguard products from a range of challenges throughout their life cycle.

The majority of plant based foods are grown in environments which are controlled to a greater or lesser extent by human activity. Growers will tend crops with the aim of maximising yields which can be a driver towards increased biosecurity (prevention of infection/infestation) and biosafety (prevention of harm arising from a biological infection).

1.4 Accidents

Accidental contamination of food plants occurs from time to time from man-made or natural events but in general, accidental chemical contamination occurs much more frequently than biological. However, one of the more common sources of accidental biological contamination arises from non-ideal storage of harvested crops. There are many examples of this resulting in fungal growth with generation of toxin.

One example of popular interest concerns recent theories regarding the Salem Village (USA) Witch Trials in the late 1690s. Environmental conditions in the village of Salem Massachusetts in 1691–3 were possibly favourable for growth of the fungal contaminant, ergot, producing LSD like compounds which could induce hallucinations and symptoms thought at the time to be associated with demonic possession (Caporael 1976). Whether this was the case or not, it remains a credible example of possible accidental food poisoning with disastrous consequences for those affected.

Food poisoning from preparation of regional delicacies can be due to carelessness, poor hygiene or in some cases an unfortunate combination of events. For example, the Indonesian delicacy Tempeh Bongkrek is made by fermenting coconut presscake or coconut milk with the fungus *Rhizopus oligosporus*. When the mould grows, the mycelia physically bind the coconut together to form a cake. However, if the product is contaminated with *Burkholderia cocovenenans*, an aerobic gram-negative bacteria, then serious poisoning can occur with 34 deaths per year being reported in the ostensibly plant based product between 1951 and 1975, at which time it was banned (although illicit kitchens were suspected as still producing the delicacy). *Burkholderia cocovenenans* has some interesting biology and when particular nutrient combinations are available, the organism will produce toxins with bongkrekic acid being the main toxin produced (Garcia et al. 1999; Scotter et al. 2015).

Accidental release from experimental facilities remains another vulnerability, albeit such facilities operate under tight controls. Research into highly infectious diseases is normally conducted in specialised high containment laboratories or assessing invasive species in tightly controlled environments. Such facilities are tightly managed and will include measures to prevent accidental release, safe disposal of wastes and fumigation routines to mitigate the risk from spills or other adverse events. Some plant pathogens do not require such high containment (biosafety level 3 or 4) but if they are exotic (not endemic in the area where research is being conducted) then additional precautions offered by such containment facilities (biosafety level 3 for example) may be useful in risk mitigation.

Many generic biosecurity measures are aimed at limiting the impact of accidental importation or releases of plant disease or pests. For example, the UK plant biosecurity strategy published in 2014 (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307355/pb14168-plant-health-strategy.pdf) describes a number of the key considerations that need to be taken:

- activity should be directed at priority pests and pathways and be informed by comprehensive risk assessment
- includes plant pathology, population dynamics, and
- epidemiology, as well as the social sciences to understand the values at stake
- meets EU and international obligations, to enable businesses to trade in clean material and grow

- ensures everyone (government and its agencies, industry, NGOs, landowners and the public) shares a common understanding of biosecurity and their role and responsibilities
- ensures that those who benefit from plant biosecurity activity should, where appropriate, be responsible for that activity and bear the cost of it
- ensures the Plant Health Services are able to respond effectively to new and emerging threats
- ensures GB as a whole is resilient, capable and prepared to respond flexibly to new and emerging threats
- ensures GB production has a good reputation to allow exports of plants and plant products to develop, with consequent economic and social benefits

As part of this strategy, work is taken:

- pre-border through collaboration with international authorities to share understanding of disease movement through Europe and understanding of novel threats,
- at the borders to assess incoming plant material (and some soils) to mitigate the risk of accidental importation of invasive species,
- inland to detect any new infections quickly and develop/exercise eradication contingency plans.

Similar approaches are taken across Europe although managing plant material movements across land borders has additional challenges.

Good biosecurity is key to management of accidental outbreaks. Biosecurity is very much scenario dependant but hinges on good hygiene, high levels of diligence in plant product inspection, effective record keeping to aid tracing and importantly shared risk assessments on specific hazards. As an example the UK plant pest risk register (https://secure.fera.defra.gov.uk/phiw/riskRegister/downloadEntireRiskRegister.cfm) contains over 800 pests affecting food and decorative plants.

Vulnerabilities are not limited to agricultural crops or imported material and even the so called "free foods" (wild fungi, fruits, berries, etc.) are not immune to natural disease outbreaks and disease reservoirs in companion plants (e.g. in hedgerows) can be an important factor in risk evaluation, mitigation and outbreak recovery.

There may be overlap between natural and accidental vulnerabilities and it may not always be easy to identify malicious events if they are covert in nature.

1.5 Malicious Actions

Fortunately, malicious attacks against plant production are relatively rare. Nevertheless they do occur. Gardening competitions such as "Britain in Bloom" can attract unwanted addition of pesticides by rivals to flower baskets/beds with disastrous consequences for competitors. However, although such events and domestic dispute equivalents are reported from time to time, there are few malicious attacks either against food plant production capacity using biological agents or using food plants as a delivery mechanism. However, there has been a widely publicised attack using salad vegetables as a delivery vector in an attempt to affect human health on a local population.

In 1981, the Rajneeshee cult bought a 64,000 acre farm in Oregon USA as part of a plan by their leader, an Indian philosopher Bhagwan Shree Rajneesh, to build a Utopian city on their new land. Having taken over control of the local town council through elections, the cult was able to gain permissions to undertake limited development but was still unable to obtain the regional planning consents they required to expand their development into a new city.

In the middle of September 1984, several locals became ill from salmonella food poisoning with all having eaten at a local restaurant. *Salmonella typhimurium* was quickly recognised as the causative agent and those affected recovered after treatment with normal therapies (Torok et al. 1997). Initial views of investigating authorities were that this was a natural event with poor food handling being suspected as the root cause.

However, a week or so later, the total number of affected persons in the outbreak reached over 750 in a biphasic epidemic. A major response was initiated with local hospitals dealing successfully with 45 hospitalised casualties but fortunately again there were no fatalities. At that time, there was no evidence of deliberate contamination. Once again poor food handling practices were considered as being the cause although the relatively high number of restaurants involved was unusual. The incident would have remained a natural/accidental contamination event but a year later, a disaffected member of the cult alerted the authorities to the possibility that the food poisoning was deliberate.

On further investigation, US authorities found covert laboratories within the cult premises with identical *Salmonella typhimurium* to the outbreak strain being found. Prosecutions resulted and it later became clear that cult members had been encouraged to avoid restaurants during the period in which salad bar items were contaminated. This was to reduce the number of non-cult voters who would attend the polls at a local election thus influencing the election results in favour of cult members. This example highlights that detection of covert biological attacks is challenging although response (health management) processes are virtually identical for covert and overt releases.

1.6 Assessing Vulnerabilities and Gaps

There are well documented approaches to assessing food chain vulnerabilities (e.g. http://www.sigmachain.eu/uploads/dateien/fp6-518451_stakeholders_guide_on_vulnerabilities_web.pdf; http://www.springer.com/978-90-481-9557-2) which may also apply in general to plant production systems. Plant and wider food production systems encompass a “farm to fork” process which can be extremely variable in scale and complexity.

At the simplest end of this spectrum, production can be at a local level with the aim of growing food for personal consumption. At the other end of the spectrum, large industrial scale facilities may be producing millions of units daily (e.g. billions of loaves of bread annually from the 731.6 million metric tons of wheat produced each year) which often feed into broad distribution and retail networks from which consumers make an informed choice. In the latter instance the food chain is not widely vulnerable to a short term disturbance of a few days in one particular location (e.g. a spoilage problem caused by transport disruption in one country). Whilst this could impact locally, an international supply chain would support larger scale users who could switch suppliers to overcome limited timespan shortages. However, should a plant disease outbreak occur in the major wheat producing countries affecting yields, then this could have a much wider impact, especially if the genetic pool of plants used is common amongst producers and is susceptible to the same diseases.

Products themselves can be complex involving large numbers of ingredients and the growing demand in industrialised nations for “ready to cook” products means that a single unexpected contaminant in a common ingredient can have major consequences. In the UK, a major product recall in the period 2003–2005 (http://tna.europarchive.org/20111030113958/http://www.food.gov.uk/safereating/chemsafe/sudani/) was initiated because widely used ingredients (chilli powder) had been coloured with non-permitted Sudan Dyes to make them more visually attractive to users (perhaps based on adding a red coloured chemical to make the chilli seem hotter.).

The recall included contaminated spices themselves, sauces made from them in products destined for retail consumption and for use in commercial production facilities or in pre-prepared foods. With around 600 retail and wholesale product types being recalled by UK and EU authorities because of a potential health impact from the genotoxic and carcinogenic contaminant, there was a significant impact on regulators, producers and significant concern for consumers.

Mislabelled foods and fraudulent descriptions are all known vulnerabilities but much work has been conducted to improve traceability of foods and in effective labelling to ensure authenticity of products (Kelly et al. 2011; Vemireddy et al. 2015; Phelan and Jonker 2015).

Whether a production system is simple or complicated, it is important to consider and document considerations of vulnerabilities and the different compartments in the food chain often include quite specific production and distribution networks. It is common practice for each link in the chain to consider relevant microbiological, chemical and physical hazards and to establish and document effective interventions using the Hazard Analysis and Critical Control Point (HACCP) approach. More recently, Threat Analysis Critical Control Point (TACCP) and Vulnerability Analysis Critical Control Point (VACCP) approaches have become parts of the method by which the food chain can be reviewed, allowing high risk activities to be mitigated and safeguards introduced to prevent rather than manage the risks.

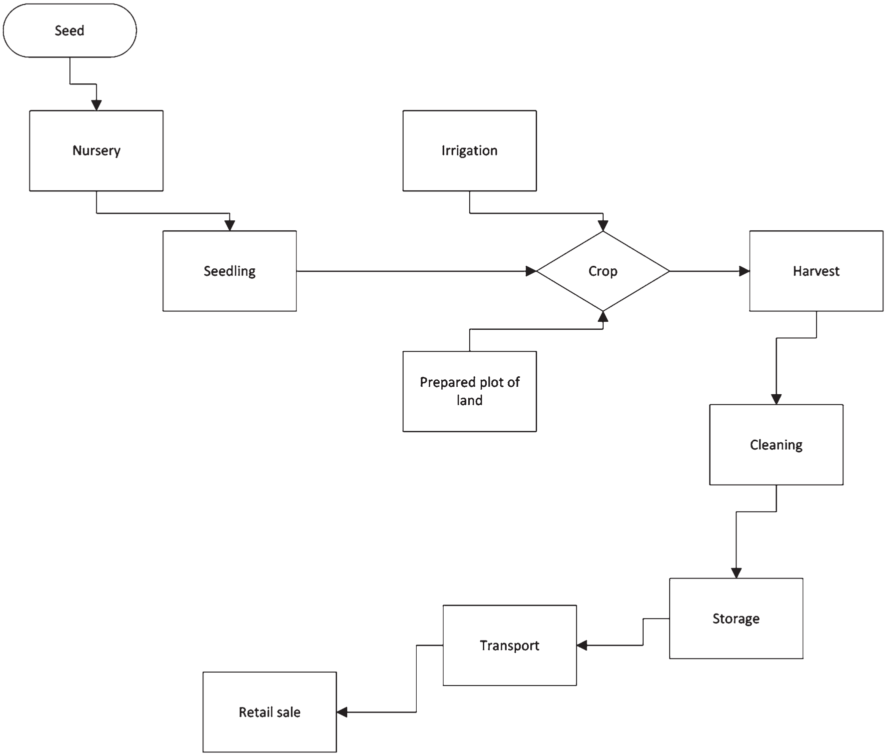


Fig. 1.1 Process map for a generic plant based food production system

A variant, Risk Analysis Critical Control Point analysis (Serra et al. 1999), has also been reported in which the consequences of product or process variation on the consumer/end user are assessed but this is not, as yet, in common use.

These approaches are not developed specifically for any one part of the food chain but can be applied generically both vertically (up and down a food chain) and horizontally (encompassing the detail of a particular element of the chain). Whilst the level of detail will vary from a farmer producing a single crop to a retailer ensuring that multiple short shelf-life product lines remain available for consumers, similar approaches are possible.

There is no intention to describe HACCP in detail in this chapter as the wide literature on the subject is easy to obtain with formal training courses being readily available from a range of providers. Suffice to say that in common with other critical control point assessments, the first stage is to map the process under consideration. A simple process map or process flow is shown in Fig. 1.1 as an example. Process maps will vary in detail but it is important to prioritise efforts in complex systems, for example, work undertaken which identified agents of concern has been extended to include naturally occurring diseases and food crops (Suffert et al. 2009).

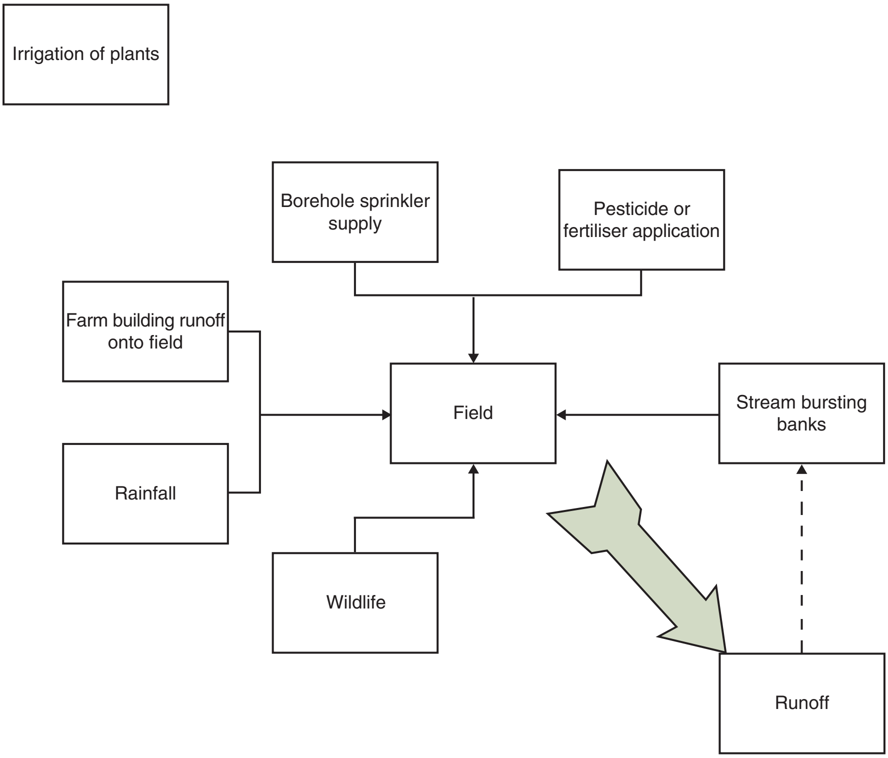


Fig. 1.2 Process map for one element of a plant based food production system

From a HACCP perspective, this may be too high a level of detail with each box in Fig. 1.1 having to be broken down into more detail to identify intervention points that would reduce the possibility of a biosecurity breach. Figure 1.2 shows a more detailed breakdown of the irrigation element of the system outlined in Fig. 1.1.

Clearly each of the boxes shown in Fig. 1.2 can be broken down further, for example, the borehole sprinkler system box may need to include microbiological loading of the water, whether there is an intermediate storage tank for the irrigation system, dead legs in the system, etc.

In the system described in Fig. 1.1, ensuring that certified disease free seed is used may be a critical control point, or perhaps ensuring that the post-harvest cleaning process does not produce a reservoir of disease in a dip tank may be another. Ensuring the soil used for planting is clean of disease and the field margins are free of other plants that can harbour crop disease could be other key steps. For each critical node in the process, a monitoring and control plan should be developed with associated record keeping and management infrastructure to develop and inform contingency plans for dealing with anomalous occurrences. Importantly this can be used to reassure customers (wholesalers, retailers and consumers) that production is under control.

1.7 Learning Lessons

Despite best endeavours, food poisoning and plant disease outbreaks will occur from time to time but understanding the reasons for outbreaks is vital in identifying vulnerabilities in the food chain and informing risk assessments.

For example, in 2006, an *E. coli* outbreak in the USA (Grant et al. 2008) was found to have been caused by contamination of spinach leaves in retail "ready to eat" salad leaf packets. In that outbreak nearly 200 persons were affected with 3 fatalities and haemolytic-uremic syndrome was observed in a number of infections.

The disease was identified in 13 samples of product from a single production run (as shown by a common batch code which highlights the importance of product traceability) but the impact was felt across the USA (http://www.cdc.gov/ecoli/2006/spinach-10-2006.html). Sourcing staple foods from a wide geographical area is not uncommon and a faulty product could be quickly spread over a wide geographical area (perhaps controlled by different regulatory authorities) which could make epidemiology based tracing based on clinical cases challenging.

However, in this instance, tracing of infected material using production batch codes suggested contaminated packages had used plant material sourced from potentially 4 ranches. Investigation teams visited these premises and relatively large numbers of feral swine were observed on at least one of them (Jay et al. 2007). The teams took swab samples from captured feral animals and on one ranch in particular, the strain of disease found was very similar to the outbreak strain. With 149 animals (estimated) on these premises, this was considered to be a likely cause of the outbreak. Major incidents are quite often the result of multiple factors and although *E. coli* was not observed in local waterways (a common vector in the environment to plant transfer chain), faecal contamination by feral animals direct onto the plants or adjacent soil was also considered possible.

The fencing used around production fields was not sufficient to prevent ingress of animals onto the fields (swine can dig under fences) and signs of rooting were observed in the soil where plants were grown. In addition, the machine used to harvest baby spinach could also pick up faecal material on soil along with the plants harvested and thus could have contributed to contamination of the produce.

Lessons from this outbreak would suggest that enhanced monitoring of water sources, improved physical separation of large wildlife from spinach fields, a different harvesting approach and improved washing/process water testing with an increased sampling rate for final product testing may be worth considering. Such lessons are invaluable in highlighting issues that might have wider applicability and are a major resource for those wishing to improve food chain resilience.

Additional monitoring of the finished product gives extra reassurance for consumers and may increase the probability of finding contamination "hot spots". However in large scale production systems finding spot contamination in time to be of use is a significant challenge given finite analytical resources, some relatively lengthy analytical turnaround times and a short shelf-life product.

Focussing the use of finite resources to key control points is a significant benefit of a HACCP approach both in terms of cost effectiveness and consumer protection. In the above example, it may well be that monitoring the wash water used to clean multiple plants could show the system was under control compared to the benefits of extending finished product examination. Each compartment in the process flow is potentially specific to that scenario and assessments need to be undertaken by staff trained in risk assessment who fully understand the processes under consideration and the limitations of microbiological examination methods.

Irrigation water is a significant potential source of contamination; particularly for those crops which undergo limited processing (crops undergoing heat treatment may be less vulnerable). Other control points worth considering in HACCP assessments would include operator hygiene, machine cleaning regimes, process/cleaning water condition and storage conditions.

Protecting plants growing in the fields from infection by plant pathogens is also critical to ensure a satisfactory yield and quality of product. This will require consideration of seed quality – is the seed stock from disease free sources?, is there a need to use coated seed and are there associated risks, if the farmer chooses to use young plants from a nursery?, what checks are required to ensure the seedlings are disease free?, is there a history of plant disease in the fields to be used?, can the plants in the margins of the field act as reservoirs of disease?. A HACCP approach needs to consider a very wide range of issues and expert advice may need to be developed and maintained by a multi-disciplinary team.

1.8 Microbiological Examination

One of the major technical challenges facing microbiologists is rapid detection of food poisoning organisms or plant pathogens at infectious dose levels in produce. Whilst modern molecular methods such as RT-PCR (e.g. Szabo et al. 2015; Zhang et al. 2011), or LAMP (e.g. D'Agostino et al. 2015; Wu et al. 2015) are sensitive and can detect for example *salmonella, listeria* and some *yersinia* spp. at levels likely to cause infection, this is not the case for all human pathogens. Some *E. coli* (Lynch et al. 2009; Friesema et al. 2008), norovirus (Cook et al. 2014), *Shigella* spp (Lewis et al. 2009) for example can have infective doses in food of the order of 10–100 colony forming units (cfu) which would be challenging to detect rapidly unless large sample volumes were taken for testing or if culturing was performed to grow microbes up to detectable levels. Inevitably culturing of bacteria takes time (e.g. 8–36 h) and with short shelf-life foods, this approach may only give a result after the product has been purchased and possibly consumed. Nevertheless it is clear that technologies are getting closer to being suitable for routine use in real time production system monitoring with increasing research consideration being given to development of field side testing capability, especially for plant pathogens. (Tomlinson et al. 2005).

An alternative approach to looking for target organisms that originate from faecal contamination is to look for other indicators of contamination (e.g. coliform markers rather than specific bio-threats) as these may be easier to find at higher concentrations that the biothreat agent (e.g. Harwood et al. 2014; Amoah et al. 2006). Optical detection of such contamination or disease on plants, e.g. using hyperspectral imaging (Bock et al. 2010) has been developed to the point where commercial food scanners are now becoming available. Test samples are irradiated with specific wavelengths of light and reflectance or fluorescence is used to detect surface anomalies where disease or faecal contamination may be present. Faecal material residues can be seen on plants using scanners at levels below that possible using the naked eye and are being evaluated for screening salad leaf crops and apples and isolate cultures. This is a rapidly evolving application (Pu et al. 2015) of established technology and scanners can range well beyond the visible spectrum on a production line.

Classical microbiological approaches to identifying plant disease or contamination are not discussed here but many of the "gold standard" methods available to laboratories require intensive and time consuming effort to develop, validate and obtain agreement that they are fit for purpose, examples being the many methods established as ISO standards (http://www.iso.org/iso/home.html). Even so, escalation of capacity to deal with an unexpected outbreak can be challenging if laboratories need to expand their scope or scale of operations, e.g. to develop high throughput methods (Adams et al. 2013) or consider unusual organisms. Many relevant laboratories have a portfolio of accredited methods or management systems (e.g. to ISO 17025:2005 (http://www.iso.org/iso/catalogue_detail.htm?csnumber = 39883) or ISO 9001:2015 (http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=62085)) and thus can demonstrate a quality infrastructure around which extensions to scope or quality control of examinations can be based.

Networks of plant protection laboratories are key to safeguarding the plant food chain. Organisations such as the EPPO (http://www.eppo.int/), an intergovernmental organization which facilitates for European cooperation in plant health, develops international strategies to prevent the introduction and spread of dangerous pests and promote safe and effective control methods. The World Trade Organisation and the International Plant Protection Convention are also key drivers in this area (https://www.wto.org/english/thewto_e/coher_e/wto_ippc_e.htm). Human pathogens on plant issues are managed through a mixture of plant examination specialists and human health expertise, e.g. the European Centre for Disease Prevention and Control (http://ecdc.europa.eu/en/Pages/home.aspx) and their regional/national counterparts. The links between such control laboratories are vital in advising of outbreaks, novel developments (either in disease evolution or novel testing methods) and in managing cross-border issues.

Increasing surge capacity can be problematic in the midst of an outbreak where rapid screening is required and alternative examination methods may need to be considered, even if there are relatively large uncertainties associated with testing outcomes. As long as there is a low false negative testing rate and confirmatory methods are used to evaluate presumptive positive findings from screening, then less well defined methods may have utility if large numbers of samples are to be examined.

1.9 Other Critical Control Points

HACCP tends to be used close to production but more strategic considerations are also valuable, looking at where a wider food chain may be vulnerable or where a processing facility could be open to malicious abuse. Considering the latter point, threat assessment critical control point (TACCP) evaluations are a relatively new approach but work by the UK Food Standards Agency (https://www.food.gov.uk/) and Centre for Protection of the National Infrastructure (CPNI) (http://www.cpni.gov.uk/) has resulted in a helpful description of TACCP being published by the British Standards Institute under the reference PAS-96 (http://www.food.gov.uk/sites/default/files/pas96-2014-food-drink-protection-guide.pdf). In this type of control point assessment, a multi-disciplinary approach to protective security is applied to food production.

Once again a process flow is developed but in this case from the perspective of more than accidental or natural contamination. Experts from a number of disciplines (ingredient supply, security, personnel, engineering, marketing, distribution, production, packaging, etc.) consider the processes that go into getting a product to market and identify where there are weaknesses which could be exploited for financial or political gain. Many large scale suppliers, transportation companies and wholesale/retail outlets will routinely take steps to prevent such risks to their businesses in any event although there is a tendency to focus on fraud and similar criminal activity.

Having identified vulnerabilities in the process flow, a mitigation plan needs to be developed and decision makers have the options of:

- Treating the risk – taking action to remove the cause or take steps to prevent the risk from maturing. This could be as simple as locking up key ingredients when not in use to prevent loss or deliberate contamination or a more complex activity involving supplier audits and background checks on staff to increase trust in service provision.
- Tolerate the risk – the risk is accepted even though mitigating activities are not likely to be effective. In general, this categorisation would be for low probability events which cannot be managed. One example may be the risk of hurricane damage to a farm during the growing season where these were 1 in 1000 year events. Understanding the risk appetite of the stakeholders is critical in this option.
- Transfer the risk – this is where the risk is changed by moving it to another organisation. An example of this may be to move to planting seedlings rather than seed to reduce the risk of germination failure.
- Terminate the risk – use another process. The risk of deterioration of soil quality affecting production efficiency could be mitigated by switching to hydroponic methods or planting an alternative crop not susceptible to an endemic disease.

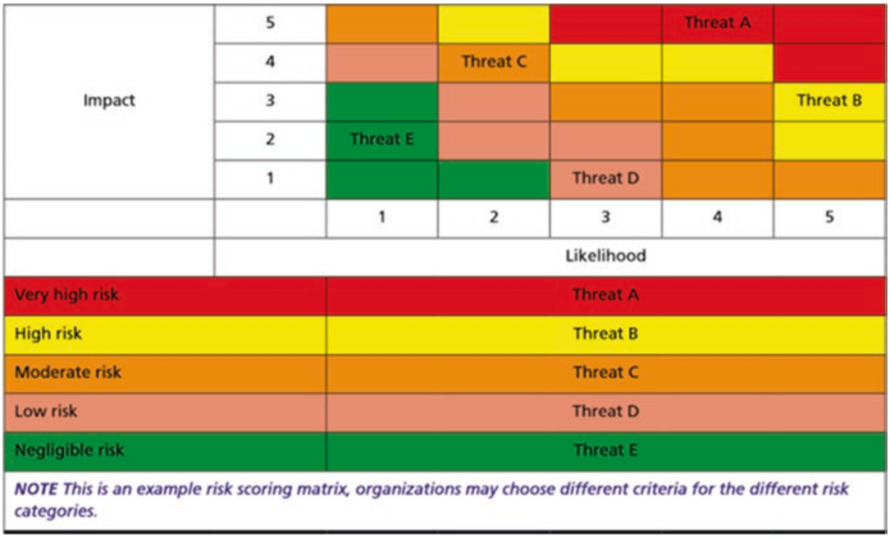
Simple TACCP mitigation actions may be as simple as knowing the staff on the farm, making sure they are appropriately supervised by trusted managers, opportunities for mischief are minimised (e.g. lock up cleaning materials and essential equipment when not in use by designated staff). However, with all of these assessments and recommended actions it is important to ensure that a proportionate response is maintained and that actions are prioritised appropriately.

Prioritisation of risk is essential. For example, although there are contingency plans within UK Government Departments to deal with risks ranging from extreme weather to a satellite falling to Earth and hitting the UK (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61354/lead-government-department-march-2010.pdf), a structured approach to considering likelihood and impact is sometimes helpful in deciding how to best use limited resources.

1.10 Risk Prioritisation

There are a number of methods of risk ranking (e.g. as discussed by the European Food Safety Agency (EFSA) (van der Fels-Klerx et al. 2015)) ranging from a simple grid approach to quantitative assessments considering data uncertainty and detailed plant risk assessments for new species of plant/organism. A widespread, but simple, approach to prioritisation is to give the probability of a risk maturing a value from 1 (unlikely) to 5 (very probable) and an impact score from 1 (nothing appreciable) to 5 (major impact). Multiplying likelihood and impact gives a score which can be used to prioritise risks (Fig. 1.3)

This approach has the advantage of identifying those risks which can be tolerated (green scale), those that should be treated if cost effective (pink/amber) and those that must be treated or transferred (yellow/red).



Impact	5				Threat A	
	4		Threat C			
	3					Threat B
	2	Threat E				
	1			Threat D		
		1	2	3	4	5
	Likelihood					
Very high risk	Threat A					
High risk	Threat B					
Moderate risk	Threat C					
Low risk	Threat D					
Negligible risk	Threat E					

NOTE This is an example risk scoring matrix, organizations may choose different criteria for the different risk categories.

Fig. 1.3 Risk scoring matrix (PAS96:2014)

More complex quantitative processes and expert elicitation methods can be used to consider individual risks in significantly more detail which has benefits for policy makers to reduce risk profiles at national or international level.

One of the tools considered in PlantFoodSec was the so called PESTLE approach.

1.11 PESTLE

The so called PESTLE methodology was initially developed as a marketing tool but more recently has been expanded to assess impacts (with implicit risks) and to identify response triggers to complex scenario risks. The approach (or precursors) have been used since the late 1960s and provide a framework in which Political, Economic, Sociological, Technological, Legal and Environmental factors can be reviewed in a structured manner to produce a comparative framework that can be used to assess the relative management or impact priorities different scenarios. There are some differences to the simple 1–5 risk/impact method described above but once again a numerical score can be assigned for each PESTLE factor. The benefit of the approach is that it is flexible but because it is subjective a sense check should be included in the process to ensure it is not biased.

Experience has shown that one of the more effective approaches to scoring is to use:

- negligible outcomes score zero,
- low/very low outcomes score 1,
- a medium one gives a 3 and
- a significant/major outcome has a score of 9.

A non-linear approach encourages the assessor to differentiate which can be helpful in complex scenarios where key outcomes need to be identified.

The following describes a potential implementation of the approach. Examples are given for information only and do no describe a particular threat or vulnerability.

1.12 Political

There are several aspects to political risks and impacts ranging from whether national policies exist to support management of a given type of incident to considering the national and international impacts that might arise.

As an example, a malicious attack conducted using human pathogens on plants would require a multi-agency response with several agencies working in parallel. A clearly criminal act would require forensic investigation, affected persons would require treatment, guidance would need to be issued to consumers, epidemiology conducted to trace affected produce and steps taken to protect consumers and

Table 1.1 Political criteria and scores – an example

Criteria	Score
A minor incident dealt with by prompt action from local responders/officials/ landowner.	0
A minor event requiring formal action but with limited impact outside of emergency response community and key stakeholders/affected premises, easily managed.	1
Public is aware of the issue with Government(s) issuing targeted guidance to public and stakeholders. Appreciable public and media interest with local responders being at full stretch but coping.	3
National/international disquiet with significant public and media interest. Special control measures are required with use of emergency legislation or other special measures. A significant response to the situation is required (major resource utilisation) as local/regional response mechanisms are overwhelmed.	9

growers from further exposure. Coordinating activities would be necessary at local, regional, national and potentially international levels (Table 1.1). Understanding and managing these interfaces requires careful planning and very importantly exercising.

In general, existing food safety legislation, phytosanitary and health protection measures at local, national and international levels could work closely with counter-terrorism and criminal investigation authorities although detailed briefing may be needed to give context to any incident. Whilst there may be some debate as to which agencies would take the lead (unless agreed in advance), existing coordination mechanisms should enable decisions to be made promptly. The lead department may also change as the scenario develops from crisis to recovery to restoration, with the latter perhaps being a lengthy process of return to normality. Rating political factors could therefore focus on mitigation and consequences.

Where the incident is self-limiting and no special powers need to be enacted, the scores will be relatively low. However, as the *E.coli* 0104 outbreak in Germany demonstrated (Caprioli et al. 2012; Appel et al. 2012) a significant but local challenge can quickly build up into an outbreak with serious international consequences. One feature of the PESTLE approach is that regular reviews are required as incidents progress. This can provide evidence of when the different phases of incident can be considered as being over.

1.13 Economic

Economic impacts of an incident affecting food plants can result from direct consequences or appear in the form of collateral damage. Direct impacts could include losses due to seizure and destruction of infected crops or withdrawal of foods from sale and remedial action costs (land remediation, enhanced biosecurity, treatment costs, etc.). Collateral damage could include loss of reputation and therefore loss of

Table 1.2 Economic criteria and scores

Criteria	Score
No significant impact for a local incident beyond individual producers or small groups of enterprises. Financial losses < €10,000	0
Limited impact (albeit painful for those impacted upon) with losses of < €1 m expected	1
A major response is required with intervention affecting multiple stakeholders. Losses of < €10 m expected.	3
Major impact affecting the viability of the sector or sub-sector of the market. Losses in excess of €10 m likely with impacts beyond the food or agricultural sectors.	9

market share for affected foods or countries of origin or additional surveillance costs to allow positive release of fresh material. In positive release scenarios, the produce must be tested and shown to be contaminant free before release to wholesalers or retailers.

Fresh plant foods tend to have short shelf-lives with production chains being designed to allow a high turnaround of produce. Where the source of infection is unknown then collateral damage can be high because application of the precautionary principle will require intervention for more than the minimum number of products.

The numerical values in Table 1.2 are arbitrary and are for demonstration purposes only.

1.14 Sociological

The impact of a disease outbreak on society depends upon the societal groups involved or targeted, lifestyle choice adjustments either chosen or enforced because of the outbreak, and the impact of control measures at a cultural level.

Using the Rajneeshee cult attack on salad bars example described earlier, targeting salad items would have a disproportionate effect on those who choose not to eat meat if such items were removed from restaurants or the wider marketplace. It is likely that societal pressures would only ease with proactive measures, e.g. positive release of foods as being contamination free or re-certification of plant seedstock, etc to build stakeholder confidence.

Where food supplies are scarce, migration may be induced by poor crop yields with substantial social impacts, including potential unrest and cross-border issues (Table 1.3).

Perception of risk or hazard is an important aspect of managing vulnerabilities in the food chain and the social and natural sciences must work closer together to better manage incidents in future.