From food defence to food supply chain integrity

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Abstract

Purpose: Consumer confidence in the European food industry has been shaken by a number of recent scandals due to food fraud and accidental contamination, reminding us that deliberate incidents can occur. Food defence methods aim to prevent or mitigate deliberate attacks on the food supply chain but are not a legal requirement. This paper discusses how proactive and reactive food defence practices can help prevent or mitigate malicious attacks on the food chain and also food fraud, food crime, and food safety. We look at how food defence differs from food safety and how it contributes to food supply chain integrity.

Design/methodology/approach: Food defence has been the focus of two different EU FP7 Security projects, EDEN and SNIFFER. Food industry stakeholders participated in workshops and demonstrations on food defence and relevant technology was tested in different food production scenarios.

Findings: Food industry end-users reported a lack of knowledge regarding food defence practices. They wished for further guidelines and training on risk assessment as well as access to validated test methods. Novel detection tools and methods showed promise with authentication, identification, measurement, assessment and control at multiple levels of the food supply chain prior to distribution and retail.

Practical implications: The prevention of a contamination incident, prior to retail, costs less than dealing with a large foodborne disease outbreak. Food defence should therefore be integral to food supply chain integrity and not just an afterthought in the wake of an incident.

Originality/value: It is argued that food defence practices have a vital role to play across the board in unintentional and intentional food contamination incidents. The application of these methods can help ensure food supply chain integrity.

Introduction

Public perception of the European Union (EU) food industry was severely shaken by the 2013 horsemeat (Avery, 2014) and milk alflatoxin (Le Blond, 2013; Dutch News.nL, 2013) scandals, as well as foodborne disease outbreaks and scares (Bernard *et al*., 2002; Covaci *et al.*, 2008; EFSA 2008; Buchholz *et al.*, 2011). The cumulative effect has led many consumers to question how safe our food really is. These scandals have had significant economic impact on the food industries involved.

Natural, accidental and deliberate contamination of the food supply chain does happen and our food and water supplies are considered critical societal infrastructure which requires protection (EU, 2007). Intentional food contamination by terrorist organizations, by criminals, or by people maximising profit by lowering production expenses, is an unfortunate reality (Table 1) and can have a considerable impact on the food industry. The resulting foodborne disease outbreak can mimic natural foodborne outbreaks making identification of intentional attacks challenging. The deliberate contamination of salad bars with *Salmonella typhimurium* by Rajneeshee sect members caused the food poisoning of 751 people in Oregon, USA (1984). The purpose of the attack was to influence the political outcome of local elections. However it was initially identified as a food poisoning outbreak which resulted in the closure of nine of the ten restaurants affected (Manning *et al.*, 2005). Only 12 months later was it recognised as food terrorism. This is a typical example of how a simple and deliberate contamination event in the food supply chain initially passed unnoticed by public health authorities and without the information from a former sect member would not have been linked with terrorism.

The terminology used to describe different incidents in food can be confusing: food safety, food security, food defence, food supply chain integrity, product integrity, food fraud, food adulteration, food contamination, food tampering, food crime and food terrorism (Table 2). For example, food terrorism and food crime can be perceived by most consumers as similar, but they differ at the level of motivation and objectives. Criminals may be motivated by personal revenge, financial gain (like extortion) or psychological pathologies, but they are not driven by ideological or political objectives like terrorists (Carus, 2001). Likewise food fraud is a type of food crime, but one which goes beyond economically motivated contamination since it also includes misbranding, tampering, counterfeiting and smuggling (Charlebois *et al.,* 2016; Spink *et al.,* 2016). In this paper we wish to address how food defence practices can be applied by the food industry to ensure safe food beyond the concepts of traditional food safety by encompassing intentional threats to the food supply chain (Table 2). This holistic approach, combines food safety, food defence and food security considerations in a triad with the ultimate aim of providing safe food for the consumer, that is food that is free from accidental, natural and deliberate contamination (Figure 1). We show how detection tools, tested in two EU projects (EDEN and SNIFFER), have the potential to improve overall food supply chain integrity.

Food supply chain integrity

In Europe we are privileged in having both food security, with a wide choice, and strict food safety requirements. But as the scandals show, the system is not perfect. Food supply chain integrity is a complex and multifaceted concept (Elliot, 2014; Lipp, 2014). It encompasses food safety, security, traceability, origin authenticity, quality attributes and product information resulting in a final food product with integrity. The consumer automatically assumes that food available for purchase is safe to eat unless quality cues, like changes in consistency and sensory perception, prompt them to think otherwise (Grunert, 2002; Verbeke *et al.,* 2007). Consumers purchase food based on their personal basic and credence integrity requirements, such as safe food which is inherently assumed by the consumer (basic requirement) and quality features (credence requirements, like protected origin products) that the consumer obtains from product labelling and prior experience (Green *et al.* 2003; Grunert, 2002). Product integrity is therefore a combination of basic and credence requirements and food scandals, like the horsemeat scandal, challenge consumer confidence (Barnet *et al.* 2016).

Ensuring product integrity throughout the food supply chain, from farm to fork, is crucial for consumer brand confidence (Barnet *et al.* 2016). Integrity throughout the food supply chain requires food safety methods (HACCP) to prevent or mitigate unintentional hazards; food defence methods to prevent or mitigate intentional hazards (including countermeasures for food fraud); as well as ensuring product credence requirements are met, like provenance and labelling (Spink *et al.* 2016).

Spink *et al.* (2016) have proposed an additional separate risk assessment method for evaluating food fraud and GFSI is currently developing food fraud vulnerability assessment and prevention plan guidance documents (GFSI, 2014). However food fraud with substitution, addition or artificial enhancement could also be detected using food defence technology such as non-specific detectors (Sittaramane *et al.,* 2016).

The food industry may argue that given the very low probability of a deliberate food contamination event, the costs of implementing food defence in addition to food safety are disproportionate. Calculating risk levels, defining the probability of an event combined with the consequences should such an event occur, and threat levels, defining the likelihood that someone has the intention and capability to carry out the threat, can be challenging given the large number of unknown factors (Holton, 2004; WHO, 2002). Given the costs related to responding to and recovering from previous food scares, food fraud and foodborne illness events, regardless of the hazard, the consequences can be considerable (Johnson 2014; Fickling, 2013). Therefore even with a very low probability, the risk of such an event is sufficient to warrant addressing food defence issues. We argue that food defence therefore should become a basic requirement of food supply chain integrity and provide some preliminary findings from two EU projects which investigated new food defence technologies: EDEN and SNIFFER.

Development of food defence guidelines

In the European Union, the food industry (producers, processors, distributors, wholesalers and retailers) has the prime responsibility for ensuring that retail foodstuffs are safe for human and animal consumption. Historically, food operators have used HACCP to identify potential hazards and have designed their control measures accordingly (EU, 2002; 2004; 2005; 2006; Codex, 2003). The HACCP methodology is based on scientific data derived from human health risk assessments (Figure 1). However, the HACCP system does not address deliberate acts against the food industry and food supply chain. The laboratory analyses, aimed at detecting biological, chemical and physical hazards that might naturally or accidentally occur in that food product, are, on the whole highly specific. The tests identify harmful pathogens, toxins and certain chemical contaminants but are not suited for the detection of novel contaminants that are not normally found in that food supply chain (Everstine *et al.*, 2013; Pedersen *et al.*, 2016). It can take considerable time between sampling, analysis and official notification of product recall. The food and feed may have already been distributed and consumed prior to issuing an obligatory product recall notification through the Rapid Alert System for Food and Feed - RASFF (Potter *et al.,* 2012; RASFF, 2015; Stöcker *et al.*, 2011).

Recently the food industry, regulatory authorities and consumers have started to focus on the need for effective food defence systems (EU, 2007; BRC, 2015). Food Defence was coined and developed in the US with the aim of protecting critical points in the food supply chain against malicious events (Knechtges, 2012; FDA, 2011; USDA, 2005; FDA, 2009, FDA *et al.,* 2007; AIB, 2013). The 2007 European Union's Green Paper on bio-preparedness (EU, 2007) stimulated a debate at European level on how to reduce biological risks and how to improve EU food defence capacity. Individual member states have started to address some of these issues. In 2008, the British Food Standards agency published their guidelines for food defence: PAS 96. These guidelines, which have recently been updated (BSI, 2014), provide food business managers with a detailed description of the approaches and procedures needed to improve the resilience of their food production process and improve food supply chain integrity by minimising the risk and consequences of an attack.

Two food standards, IFS Food Standard for auditing quality and food safety of food products (IFS 2014) and Global Standard Food Safety (BRC, 2015), are also available for adoption by the food industry which complement and expand upon EU food safety legislation. These standards include requirements for internal and independent auditing to ensure that the quality levels are met throughout the production facility and include site safety and access control as well as the need for a food defence plan.

Food defence methods like Vulnerability Analysis and Critical Control Points (VACCP), Threat Assessment Critical Control Points (TACCP) and CARVER+Shock (Criticality, Accessibility, Recuperability, Vulnerability, Effect, Recognizability+ the psychological impact or shock of an attack) expand upon the original scope of HACCP (BSI, 2014; USDA, 2007). They look for gaps or deficiencies that could become targets for malicious attacks and identify critical control points for targeted monitoring in addition to assessing potential threats (Figure 1). These methods give particular weight to economically motivated contamination, malicious contamination, extortion, espionage, counterfeiting and cybercrime (Wiśniewska, 2015). The aim is to reduce the likelihood and impact of deliberate attacks. Vulnerability assessment of the production infrastructure and production processes allows the industry to identify where an attack is most likely to occur (FDA, 2011; USDA, 2007; Yoe and Schwarz, 2010). These methods require input not only from food safety specialists but also from food industry employees across a wide range of specialities including HR, procurement, security and distribution to identify potential threats both from within and outside the food company. Once these vulnerability and threat assessments have been carried out a food defence plan can be developed, which records the procedures implemented for minimising intentional contamination events thereby reducing operational vulnerability, including looking at supply chain integrity. At the same time these methods can help protect organisational reputation and trading partners, the media and the general public can see that reasonable precautions are being taken (BSI, 2014). The next step is testing the plan, with a range of scenarios using table top evaluations and stress tests, to ensure relevance and further refinement of the plan for each site as well as ensuring that staff are familiar with the procedures.

Challenges to the adoption of food defence practices by the food industry

The current approach to food defence in the EU was assessed during the EDEN project (End-User Driven demo for CBRNe, www.eden-security-fp7.eu) by asking food industry (food safety authorities, testing laboratories, public health authorities) and CBRN (Chemical, Biological, Radiological, Nuclear) end-users (first-responders, civil defence and policy makers) as well as EDEN partners what the current gaps and needs were in responding to CBRN incidents in their field. There were 169 participants divided between four workshops, 17 attended two of the workshops, nine attended three whilst the remaining 108 only attended one of the workshops. Thirty percent of the participants had experience of direct relevance to the EDEN food scenarios. End-users, during this series of workshops, highlighted a need for further guidelines and training on risk assessment methods that have been adapted to food defence (Gerevini *et al.,* 2014; Mo Bjergø *et al.,* 2014). They also reported a general lack of industry, public health and consumer awareness with regard to food defence practices. The possibility for sharing best practice guidelines and adaptation of crisis management methodology from other fields such as CBRN was suggested. Crisis management techniques build upon the security cycle matrix which stepwise address what is needed to prevent (prevention), be prepared for (preparedness), respond to (response) and recover from (recovery) a crisis (Boin and McConnell 2007). This way of thinking, combining pro-active measures with reactive measures, is not only relevant for large scale catastrophes affecting critical national infrastructure but also can be relevant for smaller scale incidents in critical infrastructure like the food industry (Figure 2). Figure 2 shows how the security cycle could be applied to the food supply chain given that official food safety testing methods, based upon HACCP, were not enough to detect intentional chemical contamination under the conditions tested during the EDEN project (Pedersen *et al*., 2016).

Food-industry end-users identified a further five main areas needing further prioritisation (Gerevini *et al.*, 2014; Mo Bjørgo *et al.,* 2014). During the series of workshops the paucity of detection equipment capable of providing sensitive results with a low false alarm rate was discussed. Participants also mentioned that most of the detectors currently available have not been tested in a sufficiently wide range of food matrices and contaminating agents. Such testing was deemed beyond the scope of industry. The next issue raised concentrated on access control to food production premises and laboratories, not only the use of physical barriers but also the vetting of employees with access to particular sensitive areas. The temporal lag between food production (and the contamination event) and the identification of foodborne illness in consumers requires closer collaboration between the food industry and public health authorities. But no suggestions were forthcoming as to how this could be best achieved.

Lastly, participants indicated the need for EU harmonised traceability solutions with authentication, item-level identification, aggregation/disaggregation and tamper-evident capabilities. One up-one down traceability is required by EU law (EU, 2002; CODEX, 2006) from "farm to fork". Multiple suppliers may have different tracing and registration protocols, data formats and coding structures in addition to the different regulatory requirements between countries (Bhatt *et al.,* 2013). Mapping the full food supply chain takes time and adds to delays in product withdrawal/recall. The increased transparency in the food supply chain, as a result of improved traceability systems could reduce the risk for food fraud and intentional contamination plus boost consumer confidence (van Rijswijk and Frewer, 2012). However this increased transparency could also potentially reveal vulnerabilities that could be exploited.

Once mapping of the gaps and needs had been carried out a secondary aim of the food defence work in the EDEN project was to test new technologies that could be used for food defence purposes. It was hoped that these technologies could help reduce the time taken to identify contaminated products and increase product recall speed and some of the tools were tested in three food defence demonstrations. The EDEN store (https://eden.astrium-eu-projects.eu) includes a technological catalogue with integrated solutions for food industry, food safety and public health end-users.

The SNIFFER project (Sensory devices network for food supply chain security), another FP7-Security European project (http://www.fp7-sniffer.eu/), addressed problems related to the detection of biological and chemical agents in the food supply chain. This project explored the possibility of marrying commercially available sensors from the food industry and from the CBRN defence industry with novel fluorogenic probes in a sensor network that could be deployed at vulnerable points in the food supply chain.

Results from EDEN and SNIFFER detection tools

A range of detection tools, for targeted and untargeted detection, tamper-evident solutions, command and control integration systems as well as traceability systems were tested during the EDEN project food demonstrations. Baseline detection capabilities were assessed by testing contaminated food matrices (cooked ham, baloney, sugar, salt, water) using standard food safety methods (Pedersen *et al.*, 2016; Sittaramane *et al.* 2016). The official food safety methods were not able to detect to high levels of rat poison, norovirus, *Bacillus* spores or mercury chloride in food matrices (baloney, cooked ham, salt, sugar and water) that would not normally contain these agents. A number of non-targeted detection tools were tested on their ability to detect the same contaminants in the same matrices (food and water samples). The technologies employed varied from spectral analysis and fluorescence to near infra-red technology for the non-targeted detection of chemical and biological contaminants. Targeted detection tools focused on identifying the biological and chemical agents using molecular and mass spectrometry methods respectively. Tool providers were sent a set of 11 reference samples in each matrix containing known levels of contamination from no contamination to very high levels of contamination (biological $x10^{10}$ and chemical 40 000 parts per million (ppm)). The food contamination scenarios developed in EDEN were based upon the final product containing 10^{9}/g or 400ppm of contaminant which was arbitrarily called high levels of contamination. A ten-fold increase or decrease represented the next level of contamination. Each tool provider was asked to analyse these reference samples in triplicate and report which were contaminated (reference panels described in further detail in Pedersen *et al.* 2016). The tool providers then participated in one or more proficiency tests with each test containing four samples of unknown contamination status. They had to report which samples were contaminated and if possible identify and quantify the contaminant. A number of the tools tested showed promise (Sittaramane *et al.,* 2016) with some providing an alert when different brands of sugar and salt were used in the reference samples and proficiency test samples, once the system had been trained to identify the one brand. Some of the tools were also able to identify levels of biological and chemical contamination at levels well below that described in the scenarios (EDEN working papers).

It was concluded that combining non-specific at-line sensor technology, providing an alert if the food product did not meet predetermined specifications, with identification tools in the food testing laboratory, gave rapid detection of contaminated batches and the subsequent identification helped to minimise false alarm rates in the processed meat and sugar food supply chains. The SNIFFER project investigated the use of fluorogenic probes for the detection of cereulide, the emetic toxin from *Bacillus cereus*, in food matrices, which has of course considerable food safety relevance. Previous studies have shown how these probes can differentiate between different heavy metal contaminants (Díaz de Greñu *et al*., 2015), chemical warfare agents (Díaz de Greñu *et al*., 2014) and pyrrolizidine alkaloids (García-Calvo *et al*., 2015). The probes were successfully combined with commercially available technologies to form a sensor network capable of rapidly detecting and identifying chemical and biological contaminants in the milk production food chain (SNIFFER working paper).

Challenges in combining food defence with food chain integrity

Detecting contaminants in food is not straightforward be it food safety or food defence. It is understandable the food industry focuses on food safety agents rather than food defence agents given the need to optimise costs and that food defence is not a legal requirement. Therefore it is important that food defence practices complement food safety practices. Detection tools need to be able to discriminate between safe and dangerous levels of naturally occurring and deliberate contaminants to ensure that legal limits are not exceeded (Nature Editorial, 2015). There is a lack of standardised testing material and methods for many of the potential contaminants (Alexander *et al.,* 2012). The occurrence of naturally occurring toxins in foods as well as heavy metals requires particular attention (Choi *et al.,* 2014; Dolan *et al.,* 2010). Testing methods need to be able to differentiate between hazardous and non-hazardous analogues of a compound, like inorganic arsenic, linked to cancer, and organic arsenic which naturally occurs in seafood (Hojsak *et al.,* 2015; Borak *et al.,* 2007). The situation is similar with mercury in fish where the common mercury cation has to be differentiated from hazardous methyl-mercury levels, which can cause neurological and developmental deficits (Newland *et al.,* 2006). Many of the detection methods are only suited for laboratory testing and portable, fast and reliable new methods are required to allow chemical and microbiological controls on the production line.

The non-targeted detection tools could be used to screen ingredients as well as the final product. The non-targeted detection tools that are currently being developed and tested in recent EU FP7 Security programs like EDEN and SNIFFER can have a multi-use function helping alert food producers to many different kinds of product adulteration. But these tools require further testing prior to implementation in each food supply chain. Ideally detection tools should be able to detect both food safety and food defence contaminating agents (Crean, 2015). The screening of ingredients with non-targeted detection tools, prior to production, can ensure that food integrity is maintained as well as preventing contaminated ingredients entering the production line. This was highlighted by the tools capable of distinguishing between an authorised brand of salt and a replacement using a non-authorised brand during proficiency tests carried out in the EDEN project (Sittaramane *et al.* 2016) as well as in other similar studies using spectral analysis to determine authenticity (Caligiani *et al.* 2016; Wilkes *et al.* 2016)

The incorporation of food defence practices with food safety practices address the issue of intentional (food crime such as food fraud and food terrorism) and unintentional contamination (accidental and naturally occurring) in the food supply chain thus ensuring product integrity during the production phase. The food industry can approach food supply chain integrity using the same approach as the food defence security cycle. They can consider aspects that can be done to prevent, and to be prepared for, respond to and recover from a food supply chain integrity breach such as intentional or unintentional contamination events.

Implications for the future

Critical societal infrastructure includes our food supply chain. Food defence practices can help ensure food supply chain integrity especially with regard to intentional and unintentional contamination of food products. Policy makers and operational managers in the food industry need to continue to include food defence as part of an integrated approach to food supply chain integrity both at a local, national and EU level given the global origin of the foods available to European consumers. Food defence methods and guidelines, such as TACCP, VACCP, or Carver+Shock, are already available and should be adopted and implemented across the entire food supply chain. This needs to be done in such a way as to have greatest effect, yet simultaneously, minimise the food producers' economic burden. New technology requires extensive testing, within each production system, prior to integration in commercial production lines. EDEN and SNIFFER have provided evidence of the benefits of non-targeted and targeted detection tools but these have only been tested in a limited number of food production systems and with a limited range of pathogens and chemical agents. Researchers should continue to test non-targeted detection systems, as well as targeted detection tools, in a wide range of food matrices and with a wide range of potential biological and chemical contaminants, not just those relevant for food safety incidents or product authentication.

Another stumbling block is that currently food contamination incidents are often only detected once clinical cases are diagnosed in the health system. Unless the perpetrator provides a statement or threat the authorities may not realise that the contamination was carried intentionally. Public health and food testing laboratories may need to provide even higher resolution regarding the genotypes, serovars or chemical composition of the contaminating agents which could be used to not only link outbreaks epidemiologically but also to criminal incidents, like the theft of chemicals and pathogens from laboratories, research and medical centres. It is imperative that health authorities work closely with food safety authorities in suspected outbreaks and that law enforcement agencies are involved as soon as intentional contamination is suspected.

Rapid product recall is another important way in which to prevent distribution of contaminated lots. This can be challenging given that today's legal framework does not require pedigree traceability, there are different national standards and the various tracking systems are not cross-compatible. Policy makers should work together with the food industry to provide a harmonised European standard to ensure cross-compatibility thus helping speed up product recall. Notification and alerting systems for product recall (RASFF, 2015) exist but ensuring sufficient coverage can be difficult. Therefore the industry needs to consider combining current methods of customer communication (loyalty schemes, apps, discount offers, newsletters, and social media accounts) with product safety information, such as product recall (Swinkels *et al.,* 2014) to target only those that have purchased a product in a given timeframe.

Conclusion

Our food supply chain is complex and maintaining food supply chain integrity is especially challenging. However food defence practices can help prevent deliberate contamination, be it motivated by economic, revenge or ideological reasons, and thus build consumer confidence. It is far cheaper to prevent an incident from occurring than dealing with the aftermath of a large foodborne disease outbreak. Food defence should therefore be an integral part of food supply chain integrity and not just an afterthought in the wake of an incident. The detection tools investigated by EDEN and SNIFFER have potential but a wider range of contaminants and food matrices needs to be investigated before these tools could be broadly adopted.

Legend to Figures

Figure 1 showing the triad that contributes to safer food (food security, food safety and food defence) and a comparison of the key differences in principles between food safety (HACCP: Hazard

Analysis and Critical Control Points) and food defence methodology (TACCP: Threat Assessment and Critical Control Points; VACCP: Vulnerability Analysis and Critical Control Points; CARVER+Shock: Criticality, Accessibility, Recuperability, Vulnerability, Effect, Recognizability+ the psychological impact or shock of an attack) in practice (BSI, 2014; Codex, 2003; USDA, 2007; Yoe and Schwarz, 2010).

Figure 2 shows the security cycle for managing an attack on the food supply chain and includes some of the measures that can be carried out at each point in the security cycle (BRC, 2015; BSI, 2014; FDA, 2007).

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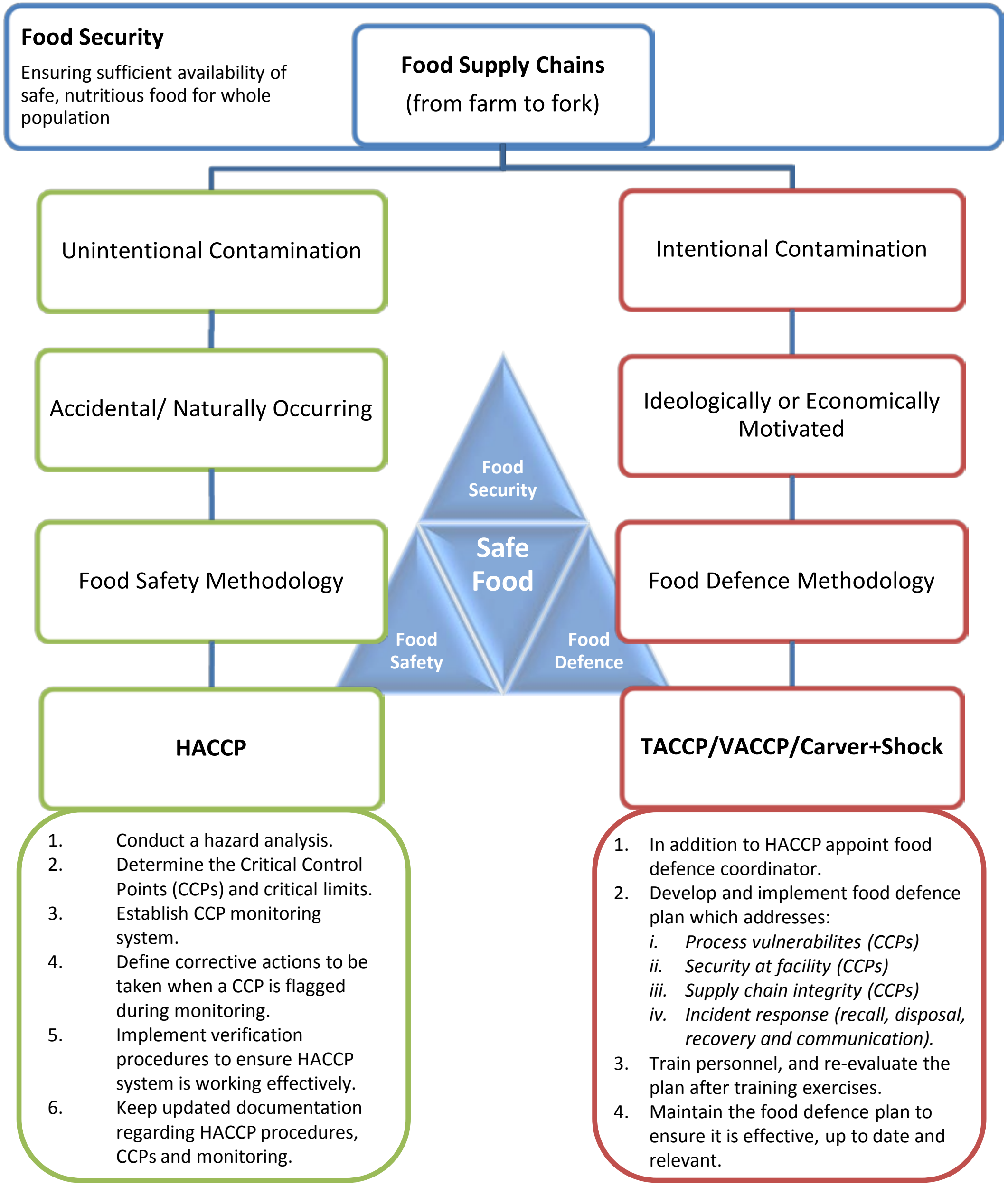
Food Security
Ensuring sufficient availability of safe, nutritious food for whole population
Food Supply Chains
(from farm to fork)
Unintentional Contamination
Intentional Contamination
Accidental/ Naturally Occurring
Ideologically or Economically Motivated
Food Security
Safe Food
Food Safety
Food Defence
Food Safety Methodology
Food Defence Methodology
HACCP
TACCP/VACCP/Carver+Shock
1. Conduct a hazard analysis.
2. Determine the Critical Control Points (CCPs) and critical limits.
3. Establish CCP monitoring system.
4. Define corrective actions to be taken when a CCP is flagged during monitoring.
5. Implement verification procedures to ensure HACCP system is working effectively.
6. Keep updated documentation regarding HACCP procedures, CCPs and monitoring.
1. In addition to HACCP appoint food defence coordinator.
2. Develop and implement food defence plan which addresses:
i. Process vulnerabilites (CCPs)
ii. Security at facility (CCPs)
iii. Supply chain integrity (CCPs)
iv. Incident response (recall, disposal, recovery and communication).
3. Train personnel, and re-evaluate the plan after training exercises.
4. Maintain the food defence plan to ensure it is effective, up to date and relevant.

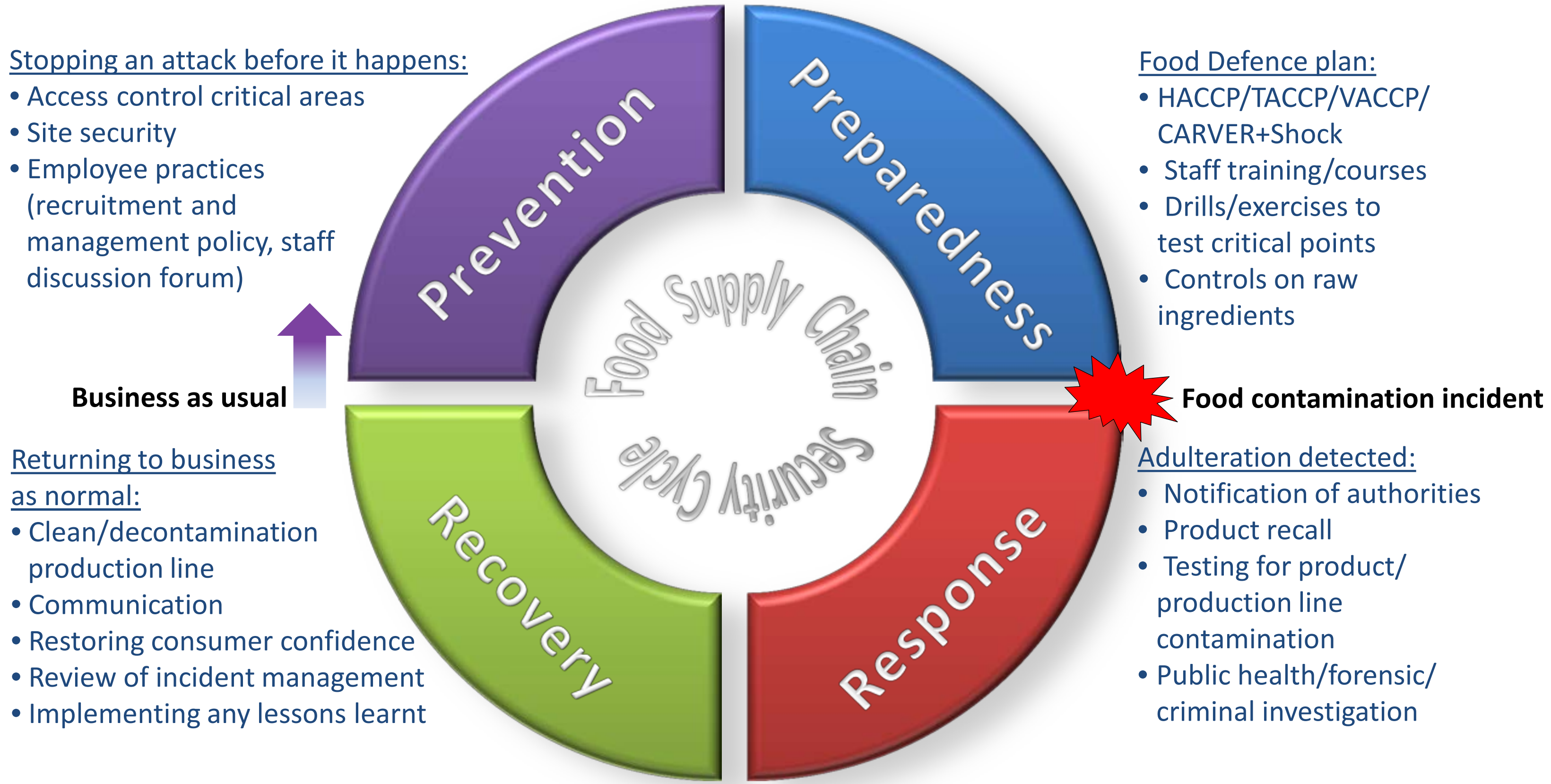
Stopping an attack before it happens:
• Access control critical areas
• Site security
• Employee practices (recruitment and management policy, staff discussion forum)
Prevention
Preparedness
Food Defence plan:
• HACCP/TACCP/VACCP/ CARVER+Shock
• Staff training/courses
• Drills/exercises to test critical points
• Controls on raw ingredients
Food Supply Chain Security Cycle
Business as usual
Food contamination incident
Returning to business as normal:
• Clean/decontamination production line
• Communication
• Restoring consumer confidence
• Review of incident management
• Implementing any lessons learnt
Recovery
Response
Adulteration detected:
• Notification of authorities
• Product recall
• Testing for product/ production line contamination
• Public health/forensic/ criminal investigation

Table 1: a selection of different deliberate contamination events in the food supply chain, with the agents involved and classification as Food crime: either economically motivated (fraud); or personal motivation (crime); or Food terrorism (ideological motivation).

Action	Year	Agent	Event	Reference
Olives chemically treated to appear greener, olive oil and olives labelled incorrectly as being of 100% Italian provenance.	2015/ 2016	*Copper chlorophyllin, Copper sulphate*	Crime: Fraud	Granitto, 2016
The toy in a Kinder Surprise egg replaced by a Zofenopril tablet. Police concluded that the act was deliberate, but not sure who did it or why it was done.	2015	Zofenopril	Crime	The Local, 2016
Hungarian case of beef meat contaminated with *B.anthracis*, due to illegal animal slaughtering. Five people hospitalised with suspected symptoms of the disease.	2014	*Bacillus anthracis*	Crime: Fraud	Lee, 2014
Horsemeat detected by Irish food-safety inspectors, in frozen beef-burgers and subsequently found in beef-labelled ready meals in the UK.	2013	Horse meat	Crime: Fraud	Avery, 2014
Sanlu Group was responsible for the contamination of milk infant formula with melamin in China. Chinese authorities estimate 300.000 people affected and 54.000 babies were hospitalized.	2008	Melamin	Crime: Fraud	Avery, 2014
Chen Zhengping contaminated food at a rival's pastry shop in Tangshan, near Nanjing, with a toxin from red whelk. Up to 300 people fell sick and 38 died.	2002	Tetramine	Crime	Anderson *et al.,* 2006
Michael Just attempted to extort £250,000 from five British dairies by threatening to contaminate their milk.	1996	*Yersinia enterocolitica*	Crime	Anderson *et al.,* 2006
Diane Thompson used *Shigella,* taken from a hospital laboratory, to infect co-workers'food.	1996	*Salmonella dysenteria* type 2	Crime	Carus, 2001
Debora Green poisoned husband's food with ricin.	1995	Ricin	Crime	Carus, 2001
Rajneeshees contaminated salad bars, in a number of restaurants, with pathogenic bacteria. The motivation was to influence the outcome of local elections.	1984	*Salmonella typhimurium*	Terrorism	Carus, 2001; Manning *et al.*, 2005

Table 2: Definitions of the different terms and how they have been applied in this paper.

Central tenants to ensuring safe food for consumers	
Term	Definition
Food security	Ensuring the availability and accessibility of nutritious food, for all people at all times to live a healthy life (Gross *et al.,* 2000). This means that there is sufficient food at regional and national levels, households have access to this food (i.e. it is affordable) and at an individual level there is nutritional adequacy (EU 2008).
Food safety	Ensuring food: safe to eat and free from dangerous levels of harmful infectious and toxic agents (natural and accidental contamination) (EU 2002)
Food defence	Some authors use this to indicate ideologically motivated incidents of malicious food adulteration (Manning and Soon 2015; GFSI 2014) whereas other use a broader definition to include other protection activities (BRC 2015). In this paper food defence is defined as the methodology and countermeasures taken to prevent and mitigate the effects of intentional incidents and threats to the food chain. The type of threat that can be addressed by food defence practices can range from food crime, food fraud, tampering, and food terrorism.
Food Supply chain Integrity	Multifaceted framework includes food safety, security, defence, traceability, authenticity, ethics and product information, including labelling, throughout the food supply chain (from farm to fork) (Elliot 2014).
Threats to Food Supply Chain	
Term	Definition
Food adulteration	Natural, accidental or intentional process whereby any foreign substance, with potential human health implications, originates or is introduced into the food (Saxowsky, 2015).
Food contamination	Some authors differentiate between contamination (unintentional) and adulteration (intentional) (Lipp 2014; Manning and Soon 2016). In this paper we use the terms deliberate or malicious to indicate intentional contamination and natural or accidental to indicate unintentional contamination and have chosen not to use adulteration to avoid confusion.
Food crime	Elliot (2014) defined food crime as being an organised activity by larger groups aimed at deceiving or injuring consumer via food products. In this paper we use a broader definition to include any nefarious activity, within the food supply chain, perpetrated by groups or single individuals, whose motivations can vary from personal revenge to financial gain, by indirectly inflicting losses to a food company or product, through deceiving, and or injuring those purchasing a food product or by extortion, such as hoax threats (Knechtges, 2012). Economically motivated contamination would fall in this category for example. Food terrorism is a type of food crime however the motivation is ideological rather the financial or personal.
Food fraud	EU legislation does not define food fraud but fraudulent practices have an "intent to deceive" as well as resulting in financial benefits (EU 2013; 2016). Food fraud can be further divided by the different types of fraudulent acts aimed at deceiving consumers (Avery, 2014; Elliot, 2014; GFSI 2014; Zhang and Xue 2016): substitution; artificial enhancement; addition; tampering; and dilution; which together are often grouped under economically motivated deliberate contamination (Everstine *et al.,* 2013); as well as product overrun; misrepresentation which can range from incorrect labelling of ingredients to product simulation and counterfeiting; as well as diversion and theft (Spink and Moyer, 2011).
Food terrorism	An act or threat of deliberate contamination of food for human consumption with chemical, biological or radiological or nuclear agents for the purpose of causing injury or death to civilian populations and/or disruption of social, economic or political stability (Karaca, 2012; WHO, 2002). The perpetrator has ideological or political motivations behind the attack/threat of attack rather than personal or financial motivations (Carus 2001).
Agroterrorism	Deliberate act which intends to introduce an animal or plant disease, with the purpose to cause fear, economic losses or social disturbance like the infection of animals/plant crops with pathogenic microorganisms or contamination of animal feed/ plant fertilisers with chemical, biological or radiological hazards (Gyles, 2010, Monke, 2004).
Product tampering	This is defined as intentional alteration of a product, or the labelling or container with an intent to cause harm (CFIA 2014)