

## **From food defence to food supply chain integrity**

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# 1 From food defence to food supply chain integrity

## 2 Abstract

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

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

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

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

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

25

## 26 Introduction

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

32 Natural, accidental and deliberate contamination of the food supply chain does happen and our food  
33 and water supplies are considered critical societal infrastructure which requires protection (EU,  
34 2007). Intentional food contamination by terrorist organizations, by criminals, or by people  
35 maximising profit by lowering production expenses, is an unfortunate reality (Table 1) and can have a  
36 considerable impact on the food industry. The resulting foodborne disease outbreak can mimic  
37 natural foodborne outbreaks making identification of intentional attacks challenging. The deliberate  
38 contamination of salad bars with *Salmonella typhimurium* by Rajneeshee sect members caused the

39 food poisoning of 751 people in Oregon, USA (1984). The purpose of the attack was to influence the  
40 political outcome of local elections. However it was initially identified as a food poisoning outbreak  
41 which resulted in the closure of nine of the ten restaurants affected (Manning *et al.*, 2005). Only 12  
42 months later was it recognised as food terrorism. This is a typical example of how a simple and  
43 deliberate contamination event in the food supply chain initially passed unnoticed by public health  
44 authorities and without the information from a former sect member would not have been linked  
45 with terrorism.

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

62

### 63 **Food supply chain integrity**

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

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

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

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

#### 98 **Development of food defence guidelines**

99 In the European Union, the food industry (producers, processors, distributors, wholesalers and  
100 retailers) has the prime responsibility for ensuring that retail foodstuffs are safe for human and  
101 animal consumption. Historically, food operators have used HACCP to identify potential hazards and  
102 have designed their control measures accordingly (EU, 2002; 2004; 2005; 2006; Codex, 2003). The  
103 HACCP methodology is based on scientific data derived from human health risk assessments (Figure  
104 1). However, the HACCP system does not address deliberate acts against the food industry and food  
105 supply chain. The laboratory analyses, aimed at detecting biological, chemical and physical hazards  
106 that might naturally or accidentally occur in that food product, are, on the whole highly specific. The  
107 tests identify harmful pathogens, toxins and certain chemical contaminants but are not suited for the  
108 detection of novel contaminants that are not normally found in that food supply chain (Everstine *et al.*,  
109 2013; Pedersen *et al.*, 2016). It can take considerable time between sampling, analysis and official  
110 notification of product recall. The food and feed may have already been distributed and consumed  
111 prior to issuing an obligatory product recall notification through the Rapid Alert System for Food and  
112 Feed - RASFF (Potter *et al.*, 2012; RASFF, 2015; Stöcker *et al.*, 2011).

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

122 approaches and procedures needed to improve the resilience of their food production process and  
123 improve food supply chain integrity by minimising the risk and consequences of an attack.

124 Two food standards, IFS Food Standard for auditing quality and food safety of food products (IFS  
125 2014) and Global Standard Food Safety (BRC, 2015), are also available for adoption by the food  
126 industry which complement and expand upon EU food safety legislation. These standards include  
127 requirements for internal and independent auditing to ensure that the quality levels are met  
128 throughout the production facility and include site safety and access control as well as the need for a  
129 food defence plan.

130 Food defence methods like Vulnerability Analysis and Critical Control Points (VACCP), Threat  
131 Assessment Critical Control Points (TACCP) and CARVER+Shock (Criticality, Accessibility,  
132 Recuperability, Vulnerability, Effect, Recognizability+ the psychological impact or shock of an attack)  
133 expand upon the original scope of HACCP (BSI, 2014; USDA, 2007). They look for gaps or deficiencies  
134 that could become targets for malicious attacks and identify critical control points for targeted  
135 monitoring in addition to assessing potential threats (Figure 1). These methods give particular weight  
136 to economically motivated contamination, malicious contamination, extortion, espionage,  
137 counterfeiting and cybercrime (Wiśniewska, 2015). The aim is to reduce the likelihood and impact of  
138 deliberate attacks. Vulnerability assessment of the production infrastructure and production  
139 processes allows the industry to identify where an attack is most likely to occur (FDA, 2011; USDA,  
140 2007; Yoe and Schwarz, 2010). These methods require input not only from food safety specialists but  
141 also from food industry employees across a wide range of specialities including HR, procurement,  
142 security and distribution to identify potential threats both from within and outside the food  
143 company. Once these vulnerability and threat assessments have been carried out a food defence  
144 plan can be developed, which records the procedures implemented for minimising intentional  
145 contamination events thereby reducing operational vulnerability, including looking at supply chain  
146 integrity. At the same time these methods can help protect organisational reputation and trading  
147 partners, the media and the general public can see that reasonable precautions are being taken (BSI,  
148 2014). The next step is testing the plan, with a range of scenarios using table top evaluations and  
149 stress tests, to ensure relevance and further refinement of the plan for each site as well as ensuring  
150 that staff are familiar with the procedures.

151

## 152 **Challenges to the adoption of food defence practices by the food industry**

153 The current approach to food defence in the EU was assessed during the EDEN project (End-User  
154 Driven demo for CBRNe, [www.eden-security-fp7.eu](http://www.eden-security-fp7.eu)) by asking food industry (food safety authorities,  
155 testing laboratories, public health authorities) and CBRN (Chemical, Biological, Radiological, Nuclear)  
156 end-users (first-responders, civil defence and policy makers) as well as EDEN partners what the  
157 current gaps and needs were in responding to CBRN incidents in their field. There were 169  
158 participants divided between four workshops, 17 attended two of the workshops, nine attended  
159 three whilst the remaining 108 only attended one of the workshops. Thirty percent of the  
160 participants had experience of direct relevance to the EDEN food scenarios. End-users, during this  
161 series of workshops, highlighted a need for further guidelines and training on risk assessment  
162 methods that have been adapted to food defence (Gerevini *et al.*, 2014; Mo Bjergø *et al.*, 2014). They  
163 also reported a general lack of industry, public health and consumer awareness with regard to food

164 defence practices. The possibility for sharing best practice guidelines and adaptation of crisis  
165 management methodology from other fields such as CBRN was suggested. Crisis management  
166 techniques build upon the security cycle matrix which stepwise address what is needed to prevent  
167 (prevention), be prepared for (preparedness), respond to (response) and recover from (recovery) a  
168 crisis (Boin and McConnell 2007). This way of thinking, combining pro-active measures with reactive  
169 measures, is not only relevant for large scale catastrophes affecting critical national infrastructure  
170 but also can be relevant for smaller scale incidents in critical infrastructure like the food industry  
171 (Figure 2). Figure 2 shows how the security cycle could be applied to the food supply chain given that  
172 official food safety testing methods, based upon HACCP, were not enough to detect intentional  
173 chemical contamination under the conditions tested during the EDEN project (Pedersen *et al.*, 2016).

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

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

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

201 The SNIFFER project (Sensory devices network for food supply chain security), another FP7-Security  
202 European project (<http://www.fp7-sniffer.eu/>), addressed problems related to the detection of  
203 biological and chemical agents in the food supply chain. This project explored the possibility of  
204 marrying commercially available sensors from the food industry and from the CBRN defence industry

205 with novel fluorogenic probes in a sensor network that could be deployed at vulnerable points in the  
206 food supply chain.

## 207 **Results from EDEN and SNIFFER detection tools**

208 A range of detection tools, for targeted and untargeted detection, tamper-evident solutions,  
209 command and control integration systems as well as traceability systems were tested during the  
210 EDEN project food demonstrations. Baseline detection capabilities were assessed by testing  
211 contaminated food matrices (cooked ham, baloney, sugar, salt, water) using standard food safety  
212 methods (Pedersen *et al.*, 2016; Sittaramane *et al.* 2016). The official food safety methods were not  
213 able to detect to high levels of rat poison, norovirus, *Bacillus* spores or mercury chloride in food  
214 matrices (baloney, cooked ham, salt, sugar and water) that would not normally contain these agents.  
215 A number of non-targeted detection tools were tested on their ability to detect the same  
216 contaminants in the same matrices (food and water samples). The technologies employed varied  
217 from spectral analysis and fluorescence to near infra-red technology for the non-targeted detection  
218 of chemical and biological contaminants. Targeted detection tools focused on identifying the  
219 biological and chemical agents using molecular and mass spectrometry methods respectively. Tool  
220 providers were sent a set of 11 reference samples in each matrix containing known levels of  
221 contamination from no contamination to very high levels of contamination (biological  $\times 10^{10}$  and  
222 chemical 40 000 parts per million (ppm)). The food contamination scenarios developed in EDEN were  
223 based upon the final product containing  $10^9$ /g or 400ppm of contaminant which was arbitrarily called  
224 high levels of contamination. A ten-fold increase or decrease represented the next level of  
225 contamination. Each tool provider was asked to analyse these reference samples in triplicate and  
226 report which were contaminated (reference panels described in further detail in Pedersen *et al.*  
227 2016). The tool providers then participated in one or more proficiency tests with each test containing  
228 four samples of unknown contamination status. They had to report which samples were  
229 contaminated and if possible identify and quantify the contaminant. A number of the tools tested  
230 showed promise (Sittaramane *et al.*, 2016) with some providing an alert when different brands of  
231 sugar and salt were used in the reference samples and proficiency test samples, once the system had  
232 been trained to identify the one brand. Some of the tools were also able to identify levels of  
233 biological and chemical contamination at levels well below that described in the scenarios (EDEN  
234 working papers).

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

## 247 **Challenges in combining food defence with food chain integrity**

248 Detecting contaminants in food is not straightforward be it food safety or food defence. It is  
249 understandable the food industry focuses on food safety agents rather than food defence agents  
250 given the need to optimise costs and that food defence is not a legal requirement. Therefore it is  
251 important that food defence practices complement food safety practices. Detection tools need to be  
252 able to discriminate between safe and dangerous levels of naturally occurring and deliberate  
253 contaminants to ensure that legal limits are not exceeded (Nature Editorial, 2015). There is a lack of  
254 standardised testing material and methods for many of the potential contaminants (Alexander *et al.*,  
255 2012). The occurrence of naturally occurring toxins in foods as well as heavy metals requires  
256 particular attention (Choi *et al.*, 2014; Dolan *et al.*, 2010). Testing methods need to be able to  
257 differentiate between hazardous and non-hazardous analogues of a compound, like inorganic  
258 arsenic, linked to cancer, and organic arsenic which naturally occurs in seafood (Hojsak *et al.*, 2015;  
259 Borak *et al.*, 2007). The situation is similar with mercury in fish where the common mercury cation  
260 has to be differentiated from hazardous methyl-mercury levels, which can cause neurological and  
261 developmental deficits (Newland *et al.*, 2006). Many of the detection methods are only suited for  
262 laboratory testing and portable, fast and reliable new methods are required to allow chemical and  
263 microbiological controls on the production line.

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

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

## 283 **Implications for the future**

284 Critical societal infrastructure includes our food supply chain. Food defence practices can help ensure  
285 food supply chain integrity especially with regard to intentional and unintentional contamination of  
286 food products. Policy makers and operational managers in the food industry need to continue to  
287 include food defence as part of an integrated approach to food supply chain integrity both at a local,  
288 national and EU level given the global origin of the foods available to European consumers. Food



289 defence methods and guidelines, such as TACCP, VACCP, or Carver+Shock, are already available and  
290 should be adopted and implemented across the entire food supply chain. This needs to be done in  
291 such a way as to have greatest effect, yet simultaneously, minimise the food producers' economic  
292 burden. New technology requires extensive testing, within each production system, prior to  
293 integration in commercial production lines. EDEN and SNIFFER have provided evidence of the  
294 benefits of non-targeted and targeted detection tools but these have only been tested in a limited  
295 number of food production systems and with a limited range of pathogens and chemical agents.  
296 Researchers should continue to test non-targeted detection systems, as well as targeted detection  
297 tools, in a wide range of food matrices and with a wide range of potential biological and chemical  
298 contaminants, not just those relevant for food safety incidents or product authentication.

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

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

## 318 **Conclusion**

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

## 327 **Legend to Figures**

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

330 Analysis and Critical Control Points) and food defence methodology (TACCP: Threat Assessment and  
331 Critical Control Points; VACCP: Vulnerability Analysis and Critical Control Points; CARVER+Shock:  
332 Criticality, Accessibility, Recuperability, Vulnerability, Effect, Recognizability+ the psychological  
333 impact or shock of an attack) in practice (BSI, 2014; Codex, 2003; USDA, 2007; Yoe and Schwarz,  
334 2010).

335  
336 **Figure 2** shows the security cycle for managing an attack on the food supply chain and includes some  
337 of the measures that can be carried out at each point in the security cycle (BRC, 2015; BSI, 2014; FDA,  
338 2007).  
339

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348

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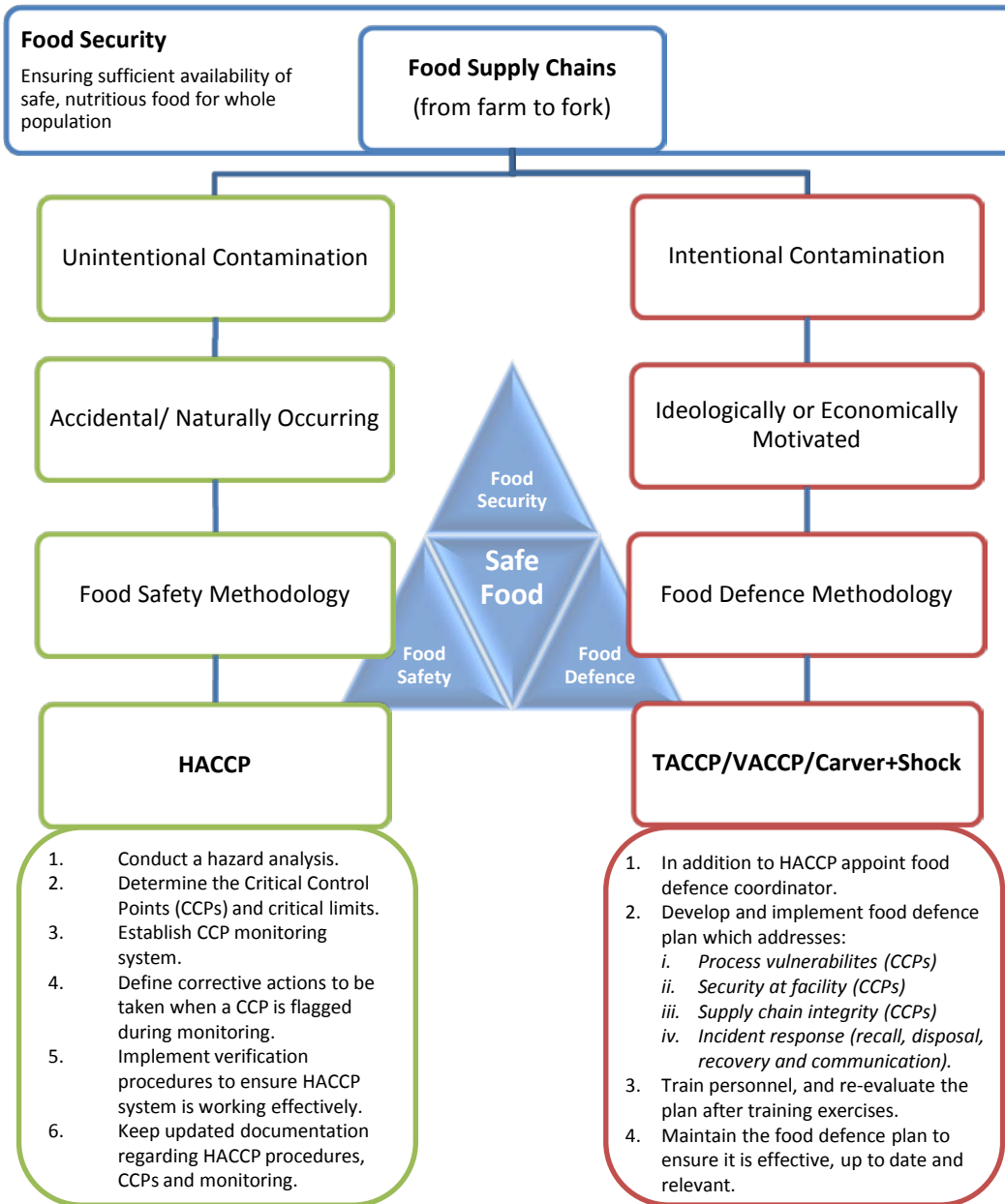
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Stopping an attack before it happens:

- Access control critical areas
- Site security
- Employee practices (recruitment and management policy, staff discussion forum)

Food Defence plan:

- HACCP/TACCP/VACCP/ CARVER+Shock
- Staff training/courses
- Drills/exercises to test critical points
- Controls on raw ingredients



**Business as usual**

Returning to business as normal:

- Clean/decontamination production line
- Communication
- Restoring consumer confidence
- Review of incident management
- Implementing any lessons learnt

**Food contamination incident**

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	<i>Copper chlorophyllin</i> , <i>Copper sulphate</i>	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 <i>B.anthraxis</i> , due to illegal animal slaughtering. Five people hospitalised with suspected symptoms of the disease.	2014	<i>Bacillus anthracis</i>	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 <i>et al.</i> , 2006
Michael Just attempted to extort £250,000 from five British dairies by threatening to contaminate their milk.	1996	<i>Yersinia enterocolitica</i>	Crime	Anderson <i>et al.</i> , 2006
Diane Thompson used <i>Shigella</i> , taken from a hospital laboratory, to infect co-workers' food.	1996	<i>Salmonella dysenteria</i> 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	<i>Salmonella typhimurium</i>	Terrorism	Carus, 2001; Manning <i>et al.</i> , 2005

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

<b>Central tenants to ensuring safe food for consumers</b>	
Term	Definition
<b>Food security</b>	Ensuring the availability and accessibility of nutritious food, for all people at all times to live a healthy life (Gross <i>et al.</i> , 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).
<b>Food safety</b>	Ensuring food: safe to eat and free from dangerous levels of harmful infectious and toxic agents (natural and accidental contamination) (EU 2002)
<b>Food defence</b>	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.
<b>Food Supply chain Integrity</b>	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).
<b>Threats to Food Supply Chain</b>	
Term	Definition
<b>Food adulteration</b>	Natural, accidental or intentional process whereby any foreign substance, with potential human health implications, originates or is introduced into the food (Saxowsky, 2015).
<b>Food contamination</b>	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.
<b>Food crime</b>	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.
<b>Food fraud</b>	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 <i>et al.</i> , 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).
<b>Food terrorism</b>	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).
<b>Agroterrorism</b>	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).
<b>Product tampering</b>	This is defined as intentional alteration of a product, or the labelling or container with an intent to cause harm (CFIA 2014)