



Article

Developing systems to control food adulteration

Manning, Louise and Soon, Jan Mei

Available at <http://clock.uclan.ac.uk/14025/>

Manning, Louise and Soon, Jan Mei ORCID: 0000-0003-0488-1434 (2014) Developing systems to control food adulteration. Food Policy, 49 (1). pp. 23-32. ISSN 0306-9192

It is advisable to refer to the publisher's version if you intend to cite from the work.
<http://dx.doi.org/10.1016/j.foodpol.2014.06.005>

For more information about UCLan's research in this area go to <http://www.uclan.ac.uk/researchgroups/> and search for <name of research Group>.

For information about Research generally at UCLan please go to <http://www.uclan.ac.uk/research/>

All outputs in CLoK are protected by Intellectual Property Rights law, including Copyright law. Copyright, IPR and Moral Rights for the works on this site are retained by the individual authors and/or other copyright owners. Terms and conditions for use of this material are defined in the [policies](#) page.

Elsevier Editorial System(tm) for Food Policy
Manuscript Draft

Manuscript Number: FOODPOLICY-D-13-00249R2

Title: Developing systems to control food adulteration

Article Type: Full Length Article

Keywords: food fraud; adulteration; economically motivated adulteration; crime; criminally; standards

Corresponding Author: Dr. Louise Manning, PhD

Corresponding Author's Institution:

First Author: Louise Manning, Ph.D

Order of Authors: Louise Manning, Ph.D

Abstract: The objective of this study is to explore the current strategies available to monitor and detect the economically and criminally motivated adulteration of food, identifying their strengths and weaknesses and recommend new approaches and policies to strengthen future capabilities to counter adulteration in a globalized food environment. Many techniques are used to detect the presence of adulterants. However, this approach relies on the adulterant, or means of substitution, being "known" and an analytical method being available. Further techniques verify provenance claims made about a food product e.g. breed, variety etc. as well as the original geographic location of food production. These consider wholeness, or not, of a food item and so do not need to necessarily identify the actual adulterant just whether the food is complete. The conceptual framework developed in this research focuses on the process of predicting, reacting and detecting economically and criminally motivated food adulteration

Highlights

Discussion of economic and criminally motivated food adulteration

Reviews challenges that exist in the supply chain using food supply examples

Reviews techniques for determining food adulteration product wholeness

Conceptual framework developed focuses on the process of predicting, reacting and detecting economically and criminally food adulteration

Developing systems to control food adulteration

Louise Manning¹ and Jan Mei Soon²

¹Royal Agricultural University, Stroud Road, Cirencester, Gloucestershire UK

²Faculty of Agro Based Industry,

Universiti Malaysia Kelantan, Kelantan, Malaysia

Corresponding author¹

Keywords: economically, criminally, motivated, adulteration, substitution

*Response to Reviewers

Ms. Ref. No.: FOODPOLICY-D-13-00249R1
Title: Developing systems to control food adulteration
Food Policy

Reviewers' comments:

Reviewer #1: The paper has been greatly improved with this revision and I do recommend publication after some minor revisions suggested below.

Response: Thank you

General comments:

Abstract & highlights: change "economically and criminally food adulteration" to "economically and criminally motivated food adulteration"

Response: Thank you for the suggestion. We have added „motivated“ into the text (Line 19, pg. 1).

Whole paper: Suggest replacing the term "wholeness" with integrity throughout the entire paper. The concept of food integrity is in principal the same as wholeness, but the former is a more established term in food policy.

Response: Thank you for the comment this has been changed Line 31, pg.2; and as required later in the paper

Page 3: I suggest toning down "It was determined that global anti-counterfeiting activities for the food and drug sector are projected to be worth \$79.3 billion by 2014 (Li 2013)." to "It has been suggested that..." All numbers in literature on the economic cost of EMA (although I haven't reviewed this particular reference) are based on anecdotal evidence and not science, so this should be toned down.

Response: The word determined has been toned down to suggested (line 58, pg. 3).

Page 3: A better definition for the specific type of adulteration (EMA) discussed in this paper should be used and referenced (see below refs). It is helpful to use the term "Economically Motivated Adulteration" instead of just "adulteration" since the later in some countries like the USA has a different meaning in regulations.

Moore, Jeffrey C., John Spink, and Markus Lipp. "Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010." *Journal of food science* 77, no. 4 (2012): R118-R126.

Everstine, Karen, John Spink, and Shaun Kennedy. "Economically motivated adulteration (EMA) of food: common characteristics of EMA incidents." *Journal of Food Protection*® 76, no. 4 (2013): 723-735.

Spink, John, and Douglas C. Moyer. "Defining the public health threat of food fraud." *Journal of food science* 76.9 (2011): R157-R163.

Response: Term adulteration has been amended to food adulteration and specific focus on economically and criminally motivated adulteration. This has been refocused throughout the paper. A definition of ENA has been inserted. (Spink and Moyer, 2011:32). Line 75; pg 3

Page 12: The following phrase is no longer accurate: "a comprehensive database about known problematic ingredients and detection methods does not currently exist" and should be replaced by "a comprehensive database about known problematic ingredients and detection methods did not exist until 2012 when the USP Food Fraud Database was established"

Response: The word determined has been toned down to suggested (line 238, pg. 10).

Page 14: Replace "Moore et al. (2012) reviewed and collected over 1000 records of food frauds and analytical methods in the US Pharmacopeia Food Chemicals Codex" with "Moore et al. (2012) reviewed and collected over 1000 records of food frauds and analytical methods published in the USP

Food Fraud Database"

Response: Changed to USP Food Fraud Database (line 296, pg. 12).

Page 20: References and discussion on FDA's Vulnerability Assessment Software and Carver + Shock tool is not accurate. These tools are not designed to assess vulnerabilities in a food supply for EMA issues, but rather, intentional food defense issues. Would suggest re-framing this point to an argument that tools are needed to assess the likelihood or probability of food fraud/adulteration occurring and that current tools like FDA's Vulnerability Assessment Software and Carver + Shock are not suitable for this purpose. You can reference US FDA's recent proposed rule on Intentional Adulteration part IV-F on EMA.

Response: The authors have re-framed the CARVER + Shock and VAS Tools as focused on predicting attacks (from a food defense point of view) (lines 462-471, pg. 18-19).

Figure 1 is very difficult to understand. I suggest revising this figure or explaining more clearly in the text. For example the box "earliest time before food and feed is adulterated..." does not make sense to me as it appears to fall before the beginning of the food chain.

Response: The authors have placed the text box "earliest time before food and feed is adulterated..." to the start of the food chain (on the right) and explained in detail the reactive and predictive systems from lines 541-564 (pg. 21-22).

Reviewer #2: I would recommend that this paper undergo another revision to reduce the history and provide more support for the theories that make up the framework. The figure demonstrating the framework was the strength of this paper and should become a greater focus. As it currently read, the history and legislation regarding food adulteration is the focus. The author's point can be made that there is a long history and much current activity in this field, and there is movement toward enhanced legislation, but there are many issues that cannot be solved with this approach. A framework to enhance investigation is required.

Response: History element has been reduced – Line 72 onwards – pg. 3
Wording changed to reflect comments on framework

For further assistance, please visit our customer support site at <http://help.elsevier.com/app/answers/list/p/7923> Here you can search for solutions on a range of topics, find answers to frequently asked questions and learn more about EES via interactive tutorials. You will also find our 24/7 support contact details should you need any further assistance from one of our customer support representatives.

1

2

3

4

5

6

7

8

Abstract

9 The objective of this study is to explore the current strategies available to monitor and detect the
10 economically and criminally motivated adulteration of food, identifying their strengths and
11 weaknesses and recommend new approaches and policies to strengthen future capabilities to
12 counter adulteration in a globalized food environment. There are many techniques used to detect
13 the presence of adulterants, however this approach relies on the adulterant or means of substitution
14 being “known” and no food item can ever be declared truly free of adulteration on that basis.
15 Further techniques will verify the provenance claims made about a food product e.g. breed, variety
16 etc.as well as techniques to identify original geographic location of food production. These consider
17 wholeness, or not, of a food item and do not need to necessarily identify the actual adulterant. The
18 conceptual framework developed in this research focuses on the process of predicting, detecting and
19 reacting to economically and criminally motivated food adulteration.

20

21

Introduction

22 Food adulteration is an age-old problem especially where there is a challenge between the physical
23 availability of, and the market demand for, a food item. This is further impacted if there is
24 juxtaposition between the cost of production, say of meat or meat-based products, and the price the
25 supply chain customer (at a supplier/customer interface) or the end user is prepared to pay for the
26 product. The objective of this study is to explore the current strategies available to monitor and

27 detect the economically and criminally motivated adulteration of food, identifying their strengths
28 and weaknesses and recommend new approaches and policies to strengthen future capabilities to
29 counter adulteration in a globalized food environment. This paper begins by discussing the context
30 of economically and criminally motivated food adulteration and then reviews the evolving
31 techniques used to detect the presence of known adulterants, to identify product integrity, or
32 otherwise, of foodstuffs as well as techniques to identify original geographic location of food
33 production. A conceptual framework is developed and then its application discussed.

34 Whilst there is much focus in the literature, quite rightly, on the definitions of food safety and the
35 agents that render food unsafe there is less emphasis on the nature of product integrity or
36 wholeness. Adapting the term for “wholeness” in the Collins Dictionary (2013), the term product
37 integrity can be described as the inherent quality of containing all the component parts necessary to
38 form a total; i.e. completeness. Product integrity in this context could be further described as
39 meeting the agreed specification that has been laid down in terms of expressing the total
40 completeness of the item that is “undiminished, without removal of part” (Adapted from Sykes
41 1976). By inference, failure to meet this specification indicates, to the limits of the testing methods,
42 that a food may have been contaminated, have undergone substitution or has been adulterated. This
43 approach does not require the party undertaking the testing to identify the specific contaminant
44 rather just to identify that the specification of integrity for that commodity has not been met. As
45 analytical techniques become more accurate the depth of the specification of “what described
46 integrity” for a given food item will change and develop as discussed later in this paper. Defra
47 (2013) states that food standards legislation sets out specific requirements for the labelling,
48 composition and, in some cases, safety parameters for specific high value foodstuffs that are
49 potentially at risk of being misleadingly substituted with lower quality alternatives. This is as
50 opposed to food safety that addresses food that is injurious to health (Food Safety Act, 1990). In
51 their *Food Law Enforcement Plan 2010/2011*, the London Borough of Tower Hamlets (2010: 3)
52 states that “*standards inspections are seen as a second priority*” to that of food hygiene and as a

53 result, far less sampling for composition, labelling, claims, allergens, etc. is done. It is food
54 standards that this research particularly focuses on and dependent on the adulterant or substitution
55 concerned this may, or may not, also be a food safety problem.

56

57 **Adulteration in a globalized food environment**

58 It has been suggested that global anti-counterfeiting activities for the food and drug sector are
59 projected to be worth \$79.3 billion by 2014 (Li, 2013). In order to outline the context of this
60 statistic this section compares and contrasts a number of food adulteration and fraud cases in both
61 developed and developing countries.

62 **United Kingdom / European Union**

63 Scally (2013) argues that the lengthening of food supply chains, accompanied by the increased
64 industrialization of the food business, has had a profound effect on the food culture of developed
65 countries. Indeed he proposes that modern food processing has created the opportunity to practice
66 consumer fraud on a truly massive and international scale. The fraud can be undertaken in one
67 country and then the actual impact can be in countries far removed from the perpetrators especially
68 so as the globalization and consolidation of food procurement increases further (Manning *et al.*
69 2005). Therefore, it is possible to contaminate food in a country where regulatory and market
70 controls are limited and cause major human health consequences and economic disruption in
71 another where on the surface such controls appear stringent.

72 Food adulteration can be described as the actions that are taken to add or adjust a food item or
73 composite food product by the use of extraneous, substandard, or inferior ingredients. Food fraud
74 may be carried out intentionally for economic gain, with the associated actions undertaken to avoid
75 detection by regulatory bodies or consumers (Grundy *et al.* 2012). Economically motivated
76 adulteration (EMA) has been described as “*The fraudulent, intentional substitution or addition of a*
77 *substance in a product for the purpose of increasing the apparent value of the product or reducing*
78 *the cost of its production, i.e. for economic gain.*” (Spink and Moyer, 2011:32). Economically and

79 criminally motivated food adulteration is nothing new. Accum (1820) identified that at that time
80 that there had been a range of successful prosecutions in the United Kingdom (UK) for
81 counterfeiting and adulteration of tea, coffee, bread, beer, and pepper. These were both a concern
82 with regard to food safety as well as being of a food standards issue. Accum determined that
83 adulteration was a widespread practice involving a number of food items and also exposed the
84 culinary fraud practices in London and detailed how bakers cut their flour with alum, chalk, plaster
85 and sawdust to make them heavier. Other fraud cases at the time involved brewers adding bitter
86 substances such as strychnine to beer and the use of lead, copper or mercury salts to make bright
87 coloured sweets and jellies.

88 In April 2013, the European Commission reported on testing that had been carried out in the wake
89 of concern over meat product adulteration (EC, 2013). The results indicated that, for the products
90 tested for the presence of horse DNA (n=4144), 4.7% revealed positive traces of horse DNA. For
91 the products tested for the presence of phenylbutazone (n=3115) 0.51% showed positive traces of
92 the drug. In addition, Member States (MS) reported tests performed by food business operators
93 (producers, processors and distributors; n=7951) for the presence of horse DNA; 1.38% had horse
94 DNA present. The UK Food Standards Agency (FSA) also identified products labelled as “Halal”
95 that contained pork (FSA, 2013). Beef adulteration in Europe highlights not only the continued
96 problem with food fraud, but also the potential for unwitting cross-contamination at “micro levels”
97 during standard meat processing activities where multi species meats are processed/prepared in the
98 same vicinity and using the same equipment. This means that products (that would have previously
99 been declared as “free from” or “whole” in terms of being suitable for a certain cultural or religious
100 group) as analytical methods develop, and as limits of detection reduce, may not indeed be found to
101 meet that specification. The discrepancy may be at the level of parts per million (ppm) or parts per
102 billion (ppb) but this may not be acceptable to consumers e.g. in terms of pesticide residues or the
103 presence of DNA from other animal species. This creates a current and future challenge that the

104 industry will need to address both in practical terms in trying to reduce these minimal levels further
105 and also with meeting cultural expectations.

106

107 **United States**

108 There is much work from the United States (US) that focuses on food fraud and food adulteration
109 (Everstine *et al.*, 2013; Spink and Moyer 2013; Moore *et al.*, 2012; Spink and Moyer 2011) As an
110 example of the types of incidents identified, a 2012 report on food fraud in US restaurants and retail
111 outlets (Warner *et al.* 2012) concluded that 58% of the eighty-one retail outlets sampled, sold
112 mislabeled fish with small markets having a higher incidence of fraud (40%) than national chain
113 grocery stores (12%). Furthermore, all of the sushi bars (n=16) tested sold mislabeled fish and 94%
114 of the “white tuna” tested was not tuna at all. As previously discussed this type of adulteration
115 could be caused for a variety of reasons e.g. by accidental means due to a failure in either process or
116 supply chain controls or as a result of premeditated criminal activity.

117

118 **India**

119 One of the key problems in India is the intentional contamination of food with look-alike
120 substances. The look-alike substances were substituted in items like incidents of brick powder in
121 red chillies, lead chromate in turmeric and vegetable oil contamination with milk fat (Shukla *et al.*,
122 2014). A 2011 survey in India of adulteration in liquid milk found that 68% of the randomly
123 collected samples tested (n=1791) were non-conforming (FSSAI, 2011). In some states the level of
124 non-compliance was 100%. The non-conformity of samples in rural areas was found to be 31% of
125 which 81% were loose (unpacked) samples. In urban areas 69% of samples were non-conforming
126 (67% loose samples). Detergent was found (8%); skimmed milk powder (45%) and glucose (27%)
127 of the samples. In seven Indian states all samples taken were found to be impure. This demonstrates
128 the level of milk adulteration being practiced in India. The biggest dairy food fraud incident to date
129 using melamine, that also had serious implications for public health, was in China.

130

131 **China**

132 Melamine is rich in nitrogen and contains 67% nitrogen per mass unit (Merck Research
133 Laboratories, 2001). Due to the high nitrogen content, melamine was added, as an adulterant, to
134 food commodities such as milk and wheat gluten to “increase” the perceived protein content and
135 avoided detection as milk was tested for protein using a method based on total nitrogen content
136 (Schoder, 2010). In 2006 dairy production in China faced rising feed prices so 40% of dairy farmers
137 were losing money and a further 30% were just breaking (Jia *et al.* 2012). Whilst dairy processing
138 firms were demanding increased milk supply as a result of consumer demand some farmers were
139 culling their herds due to the lack of profitability. This aggravated the already tight milk supply in
140 China. In early 2007 the new shortage of milk supplies threatened to push up the price of milk
141 products (Jia *et al.* 2012). The use of protein powders in milk was prohibited; such powders could
142 be sourced from ground animals’ parts, soy and other food sources. Later, manufacturers of plastics
143 started seeing a demand for melamine, but there was no connection made between the two
144 supposedly separate incidents.

145 An increased incidence of kidney stones and renal failure among infants was identified in China in
146 December 2007 and Sanlu Customer Service Department received consumer complaints about their
147 products (Xiaojing, 2011). [Concurrently there was a pet food recall for melamine contamination of
148 pet food ingredients in the US due to contamination of wheat gluten.] In June 2008 complaints
149 appeared on the State Council Administration for quality, supervision, inspection and quarantine
150 (AQSIQ) website. Official inspectors then assessed the commodities produced by Sanlu, and once
151 adulteration was identified all batches produced up to December 2007 were recalled. In August
152 2008 melamine was reported as being detected in 15 out of 16 lots tested, but a recall was not
153 instigated until the government ordered Sanlu to stop production and distribution of product in
154 September 2008 (Xiaojing, 2011). In that month it was announced that 59 infants had developed
155 kidney stones and one child had died. In September 2008, the WHO (2008) identified that there had

156 been 6240 cases of kidney stones in China with three deaths. The WHO reported that at least 22
157 dairy manufacturers across China were found to have melamine in some of their products (the
158 levels varied between 0.09mg/kg and 2.560 mg/kg). Gossner *et al.* (2009) determined that kidney
159 and urinary tract effects, including kidney stones, affected about 300,000 Chinese infants and young
160 children, with six reported deaths.

161 Further forty-seven countries received the melamine-contaminated products and sixty-eight
162 countries banned or recalled foods suspected of containing melamine (Gossner *et al.* 2009 citing
163 Bhalla *et al.* 2009). Food fraud, as in this example, can occur in commercial circumstances when
164 there is an issue with the bridging of the supply of and demand for a food commodity. Substitution
165 can arise as a result of an illegal activity to fill the “supply gap” or to meet the cost structure at the
166 stages of the food supply chain where there is a reticence or inability for increasing operational
167 costs to be passed through to the end consumer.

168 As a result of this incident, the Chinese government was forced to react to ensure the safety and
169 quality of Chinese food products through the implementation of food safety laws, increasing
170 penalties for illegal practice and by instituting a system of risk evaluation that included monitoring
171 500,000 companies (Ramzy, 2009). It should be stressed that within the diverse and complex global
172 food supply chains there are constraints to addressing food safety, food standards and corruption at
173 local, national and international levels. Furthermore, maintaining confidence in a food supply chain
174 in order to ensure continued economic growth is not an issue localized only to China. The Chinese
175 case study merely serves as an example of the challenges presented with regard to control of food
176 adulteration. As Accum (1820) identified such activities were evident in a developing UK food
177 culture and the examples given in this paper highlight they continue to be prevalent today.

178 Although the use of melamine in China as a food adulterant gained attention from 2007,
179 adulteration continues to be a problem with further arrests and prosecutions in China in 2011
180 (Coghlan, 2011). Melamine contamination has also been identified in milk purchased in twelve out
181 of fourteen samples from markets in Iran (Hassani *et al.* 2013). These examples highlight the

182 continued use of this adulterant and why routine product testing for melamine is so critical to verify
183 continued product compliance and to seek to prevent contaminated materials from being used in the
184 food supply chain and/or consumed. However, often food fraud is undertaken with the full
185 knowledge and understanding of the systems of surveillance and control and the analytical tests that
186 are currently used at borders and within countries. The constituents used for emerging and re-
187 emerging food fraud are targeted on this basis either for the reason that they are not currently
188 routinely tested for in surveillance and verification testing and food import control protocols or that
189 the adulterant used will pass existing analytical tests without identification.

190

191 **Economically motivated adulteration**

192 Contamination maybe accidental or unintentional particularly when farmers or processors are
193 unaware of that a set of circumstances they put in place could potentially lead to contamination of
194 food. However, when food adulteration becomes intentional, this is when criminal and
195 economically driven factors can come into play. Practices of deliberate contamination of food and
196 drug ingredients may be widespread and also avoid detection in poorly regulated markets where
197 surveillance is minimal. For example, in China there are over 500,000 food processing businesses
198 and slim profit margins drove some owners to cut cost by substituting food with cheaper ingredients
199 (Zach *et al.* 2012). Substitution may include diluting infant formula (Xiu and Klein 2010), using
200 diethylene glycol as a substitute for glycerin (FDA 2008), using illegal red dyes in duck eggs (Du
201 and Sun, 2007) and relabeling of seafood products (D'Amico *et al.* 2014). If deliberate
202 contamination is motivated by financial gain, the practices are likely to be concealed and if
203 undiscovered, to recur (Brown and Brown 2010).

204 Due to their high market value, meat products are often targets for species substitution and
205 adulteration (Cawthorn *et al.* 2013). A study undertaken in South Africa on processed meat
206 products (n=139) identified that 68% of samples contained species that were not declared on the
207 product labelling, with the incidence being highest in sausages, burger patties and deli meats i.e.

208 processed foods rather than carcass meats. Soya and gluten were identified as undeclared plant
209 proteins in a large number of samples (28%), whilst pork (37%) and chicken (23%) were the most
210 commonly detected animal species. Cawthorn *et al.* (2013) also reported that unconventional
211 species such as donkey, goat and water buffalo were discovered as species that had been substituted
212 for another origin. They conclude that mislabeling of processed meats is commonplace in South
213 Africa and this not only violates food labeling regulations, but also poses economic, religious,
214 ethical and health impacts.

215 In the EU, syndicates took advantage of the price-support structure of the European Common
216 Agricultural Policy for financial gain. For example, butter produced within the EU receives a
217 subsidy payment because of lower market prices when exported to a „third“ (non-EU country). Then
218 the same consignment of butter was re-labeled as produce of the third country before being re-
219 imported back into the EU. The re-labeled butter was subjected to income tax at a lower rate than
220 the original subsidy paid on the export. Hence, by re-labeling the origin of the butter, syndicates
221 were able to make illegal profit of up to £30,000 per 25,000 kg consignment of butter (Kelly *et al.*
222 2005). Spink and Moyer (2011) identified seven types of food fraud (Table 1) namely adulteration,
223 counterfeit product, diversion of products outside of intended markets, over-run, simulation,
224 tampering and theft. Each type of food fraud generates different potential levels of monetary gains
225 and the degree of gain is dependent on how well the „fraud“ has been carried out and if detection of
226 the crime occurs. For example, when white sturgeon caviar is substituted with beluga caviar,
227 consumers pay five times more than they should for the product (Cohen 1997).

228

229 **Take in Table1**

230

231 Everstine *et al.* (2013) argue that EMA incidents reveal voids in quality assurance testing
232 methodologies that can be exploited for intentional harm. Indeed gaps in traceability, quality
233 assurance programmes or interfaces between different certification schemes will be exploited where

234 they occur by some individuals for economic benefit. Everstine *et al.* (2013) suggest in their study
235 that 137 documented and distinct EMA incidents had been identified. The food product categories
236 ranged from protein products to spices and sweeteners. Moore *et al.* (2012) determine that whilst
237 food ingredient fraud and EMA are emerging risks, a comprehensive database about known
238 problematic ingredients and detection methods did not exist until 2012 when the USP Food Fraud
239 Database was established. The proliferation of potential adulterants demonstrates that any
240 “screening based” approach needs to be diverse and wide reaching in its scope. Product testing can
241 be costly and introduce time delays, especially at border inspection points, in a food supply chain
242 that is both highly price sensitive and continuously driving towards a just in time approach to
243 minimize the costs of holding/storing stock. Organizations will vary in the extent to which they
244 use/undertake risk-benefit evaluations such as hazard analysis critical control point (HACCP) for
245 food safety and a threat or vulnerability analysis critical control point (TACCP or VACCP)
246 assessment to determine the risk of vulnerability to fraud or bioterrorism incidents. These
247 approaches identify the process controls and product testing that is deemed necessary to minimize
248 risk to the organization, their customers and the final consumer (FDA, 2013a).

249 The WTO/SPS agreement (WHO, 1997) introduced the term "appropriate level of sanitary or
250 phytosanitary protection" (ALOP) i.e. the level of protection deemed appropriate by a Country or
251 Member State establishing a Sanitary and/or Phytosanitary (SPS) measure to protect human, animal
252 or plant life or health within its borders. By setting a food safety objective (FSO), competent
253 authorities can determine a risk-based limit that should be achieved operationally within the food
254 chain, while providing flexibility for different production, manufacturing, distribution, marketing,
255 and preparation approaches (CAC, 2007). Furthermore, a performance objective (PO) can be
256 determined i.e. the maximum frequency and/or concentration of a food safety hazard in a food at a
257 specified step in the food chain before the time of consumption that provides or contributes to an
258 FSO or ALOP (CAC, 2011). However, the FSO and PO can only be determined if the food safety
259 hazard or contaminant is “known” and there has been a scientific risk-based determination of the

260 acceptable level of the hazard within a food. In the case of “unknown unknowns” this risk
261 assessment approach falls down. By its nature EMA is often within this category as the food
262 adulteration or substitution has the potential to cause harm if ingested. In instances of food fraud
263 only the fraudsters know how the food has been manipulated and to what extent the substitution is a
264 labelling or a food safety issue and also how it was introduced into the food supply chain. However,
265 the fraudsters may neither care nor have the knowledge, the expertise, or the resources to determine
266 if the substitution or manipulation undertaken poses any acute or chronic risk to consumers. Hence,
267 the public health risks of adulterated food are often unknown until it is too late (Moore *et al.* 2012).
268 Spink and Moyer (2011) also state that the public health risks from adulterated food are more risky
269 than traditional food safety threats because the contaminants are often unconventional. There are a
270 non-exhaustive number of potential EMA contaminants and a risk-based approach requires a high
271 degree of knowledge or expert opinion in order to appropriately quantify the level of risk. However
272 such expert knowledge will be lacking or non-existent with some EMA, since this is the very reason
273 why they were chosen in the first place. Economic influences will create a situation where
274 alternative ingredients or materials are sought by supply chain partners that are “cheaper” than
275 standard ingredients and can go largely undetected in the current product monitoring and
276 verification regimes. Food analysis is often at the accuracy level of ppm or ppb and this has led to
277 the development of techniques often described as food forensics. This particular field will need to
278 develop strongly in order to meet the global challenges of food fraud.

279

280 **Food forensics**

281 The use of nonspecific analytical tests in routine product testing is one of the risk factor for the
282 incidence of EMA (Everstine *et al.* 2013). The wide range of substances that can be used in food
283 fraud coupled with the impossibility to analyse them all, make conventional testing unsuitable for
284 food adulteration problems. In order to cover the widest range of adulterants usually requires
285 sophisticated analytical equipment such as mass spectrometry (Di Stefano *et al.* 2012). It could be

286 argued that the melamine adulteration incident occurred because the analytical method used to
287 determine protein content was non-specific and thus by adulteration a “false” reading could be
288 obtained. Kjeldahl or combustion (Dumas) method measures the protein content based on total
289 nitrogen content and do not differentiate between protein nitrogen or non-protein nitrogen (Moore
290 *et al.* 2010). As a result of this, individuals took advantage of their „misused“ food chemistry
291 knowledge to enhance the determined level of the protein content of milk, knowing that the tests
292 were of non-specific nitrogen tests.

293 The US Pharmacopeia (2012) advocates a proactive approach i.e. the testing of food ingredients for
294 authenticity rather than testing for the absence of specific adulterants (Moore *et al.* 2012). Moore *et*
295 *al.* (2012) reviewed and collected over 1000 records of food frauds and analytical methods
296 published in the USP Food Fraud Database. The database is useful to identify trends and
297 developments and provide stakeholders with information on methods to detect food frauds.
298 According to Primrose *et al.* (2010), determining the description of food in terms of its total
299 composition, processing or origin is challenging, but there are a number of techniques that have
300 been successful in verifying the authenticity of food. This includes stable isotope analysis,
301 genomics and proteomics.

302 In 2005 a code of practice was developed for the control of basmati rice sold in the UK (BRC,
303 2005). If a product is identified as “basmati rice” then the non-basmati rice element cannot exceed
304 7% of the packed product. It is difficult to differentiate between basmati and non-basmati grains
305 based on visual test or physicochemical tests but research has been undertaken to identify
306 adulteration of basmati rice as low as 1% in a sample through the use of tests that focus on variety-
307 specific allele profiles (Archak *et al.*, 2007). In the Uonuma district of Japan, high quality rice has
308 been bred with a specific genetic marker. The genetically distinctive rice sold under licence to
309 Uonuma farmers will prevent inferior rice from being falsely sold under the district’s name
310 (Ravilious 2006; Kitaoka *et al.* 2010). Kitaoka *et al.* (2010) suggested that the method would be
311 able to identify food from a particular location. This is also of importance when considering

312 provenance i.e. the country of origin or geographic indication claims associated with food products.
313 Grundy *et al.* (2012) citing Kelly (2003) and Kelly and Bateman (2009) argue that analysis of stable
314 isotopes in foods can reveal EMA such as addition of cheap sugar syrups to extend honey and
315 maple syrup; watering down of wine; preparation of fruit juice described as “freshly squeezed”
316 from concentrate; verification that chicken has been “corn-fed”; determination of whether ethanol
317 and vinegar and flavorings are natural or synthetic; and differentiation between organic and
318 conventional farming methods. All food and drink contains hydrogen and oxygen elements that
319 originate from where the animal or plant received water from the local water sources. Both
320 hydrogen and oxygen have heavy and light isotopes and the ratio of light to heavy isotopes is a
321 unique marker for climate and geographical area. Carbon isotopes can be used to differentiate plant
322 groups. Kelly *et al.* (2005) suggested that as a first approximation, natural abundance measurements
323 would provide information on plant „type“ or diet (carbon and nitrogen isotope ratios), and
324 geographical origin (hydrogen, oxygen, sulphur and strontium isotope ratios). Therefore local
325 agricultural practices and animal diet can affect $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$ ratios respectively. Indeed, the
326 geographic origin (rearing location) of animals used in meat production can be determined (Heaton
327 *et al.* 2007). Beef reared in the US (n=23) and Brazil (n=10) was found to be isotopically different
328 from northern European beef (n=35), mainly because of contrasting proportion of plants with C3
329 and C4 photosynthetic pathways in the cattle diets (Schmidt *et al.*, 2004). Isotopic maps of Europe
330 are being developed so that prized, regional products such as Champagne, Gloucestershire cheese
331 and Scottish salmon can be confidently matched with their places of origin (Ravilious 2006). More
332 recent research has utilized stable isotope techniques in reviewing egg authentication schemes
333 (Rock, 2012); geographic origin of beef (Liu *et al.* 2013); and authenticity and quality of food of
334 animal origin (Vinci *et al.* 2012).

335 One of the drawbacks of using purely chemical analytical techniques in seeking to detect food
336 adulteration is that as previously described there is a finite number of analytes that have been
337 determined and thus methods developed to determine their presence/absence at a defined limit of

338 detection. Utilising spectral or chromatographic techniques can identify patterns that can be
339 compared with standards for unadulterated foods and anomalies to be identified even if the exact
340 constituent that is causing the variability is unknown. However in some instances such as the
341 adulteration of foods with Sudan 1 targeted analysis is required. This is true of spectral methods
342 such as near infra-red spectroscopy (IR) and nuclear magnetic resonance (NMR). Fingerprinting
343 refers to the spectrum or the image generated by certain analytical tools and the types of
344 fingerprinting can be classified into three categories (Table 2): spectral fingerprinting and
345 chromatographic fingerprinting and electrophoresis fingerprinting (Zhang *et al.* 2011). The use of
346 such fingerprinting technology has seen the detection of source, materials and components in food
347 such wines (Casale *et al.* 2010), cereals (Valeria *et al.* 2005) and fish protein (Hubert *et al.* 2008;
348 Serge *et al.* 2007). Table 3 shows the application of the different kinds of food fingerprinting in
349 food detection analysis.

350 **Take in Tables 2 and 3**

351

352 Additionally, DNA barcoding is a powerful method in determining morphologically unidentifiable
353 fish or meat product samples as long as the DNA is preserved in the sample (Maralit *et al.* 2013). It
354 is effective in determining the origin of raw materials and the detection of adulteration e.g. by
355 mixing products from different taxonomy such as rice and ginseng (Galimberti *et al.* 2013; Niu *et*
356 *al.* 2011). The primary goal of DNA barcoding is to assembly reference libraries of code sequences
357 for known food species in order to develop reliable, molecular tools for identification (Hubert *et al.*
358 2008). DNA tests, sequencing and databases can be developed for all meat types and will make it
359 possible to trace the meat to the individual animal type, breed and locality of origin along with
360 isotope analysis. In the UK, such tests are not part of routine surveillance and DNA sampling can
361 cost £200 to £500 per food sample (Thomson 2013). This prohibits its use as an on-line quality
362 assurance and process test method. Having outlined the role of both product verification activities
363 what is the value of process verification in addressing EMA?

364

365 **Process vs. Product verification**

366 Food standards assessment activities focus on both product and process verification. Process
367 verification through the assessment of documentation, certification and traceability data is less
368 costly than destructive product inspection and testing, but such verification rests on the ability to
369 assess valid evidence in terms of documentation, records, labelling and evidence of certification.
370 Fraud prevention and anti-counterfeiting tools can be used to track and trace movements of food
371 products through the supply chain. Machine readable devices (barcodes, QR codes, data matrix)
372 allow a number of checks to be enhanced and the electronic data can be shared (Dabbene, Gay and
373 Tortia, 2013). Information shared between the different partners in the supply chain can decrease
374 potential food frauds as the number of traceable units are documented and monitored for suspicious
375 transactions.

376 It is important that the traceable resource unit (TRU) or distinct batch must be uniquely identified
377 (Moe, 1998 citing Kim *et al.*, 1995). Over time, product traceability methods have been developed
378 that are based on the ability to identify products uniquely as a result of physical marking on the
379 product or its package or by the use of associated records (Moe, 1998). Moe argued that a
380 traceability system could be split into two elements firstly the “route” of the product and the
381 sequence of steps that it passes through so it is traceable through manufacturing, distribution and
382 the retail system and the “scope” of the traceability in terms of the inherent nature of the product.
383 This has been built on in more recent years with the introduction of “mass-balance” traceability
384 checks for a TRU. Mass balance traceability is an essential pre-requisite within the food supply
385 chain for assuring extrinsic quality. This process assures that identity preserved products are indeed
386 what they purport to be. Mass balance checks routinely determine an organization’s ability to
387 identify, locate and “contain” a specific TRU of ingredient, part-processed or final product. The
388 capacity to do this is critical in the event of a product withdrawal or a full product recall from the
389 supply chain. It is also important to determine that the volume of product being sold as a specific

390 TRU where provenance, production method (organic, free range or Fairtrade) or cultural claim e.g.
391 slaughter method (halal) and whether this could have indeed been produced in that quantity from
392 the resources that were claimed to have originally been made available. This is largely an
393 electronic record and/or a paper-based exercise especially if the “stock” has left the production
394 premises. This is problematical when the reliability and authenticity of data is subverted in the
395 event of food fraud. Therefore process verification alone is of limited value in determining or
396 identifying EMA.

397 The UK Independent Farming Regulation Task Force in their 2011 report (IFRTF, 2011)
398 recommended that industry engage “fully with Government and third party assurance bodies to
399 develop a workable system of „earned recognition“”. Third party certification schemes cover the
400 certification of the management of the production, storage and handling of the products at a discrete
401 point in the supply chain and are not, in the main, product specific certification schemes, although
402 the generic product types are identified in the scope of certification for each organization. This
403 means that in their current form, third party certification schemes have limited impact on the control
404 of product verification only in as much as there was compliance with supply chain specifications on
405 the day of the audit. This form of verification is more about the process and generic controls.
406 Furthermore, verification of process and product through review and auditing provides the auditor
407 with a range of evidence, or audit observations, which can be both qualitative e.g. interviews,
408 observations and records or quantitative based on measurement and test. However, it is important to
409 consider whether third party certification of organizations against management system standards
410 can either guarantee increased compliance with statutory food standards product requirements or
411 that such certification activities will address covert fraudulent behaviour which by its nature
412 involves the falsification of product, labelling and/or documentation at one point or several points in
413 the supply chain. If the records or labelling verified was:

- 414 • falsified outside of the discrete bounds of the scope of the certification, and/or

- 415 • the processes being undertaken do not include re-confirmation of the validity of such
416 documentation and labelling with the product batch delivered, and
- 417 • there is no analytical or organoleptic evidence available of fraudulent activity when the
418 product is being inspected,

419 then the fraud will not be readily identified or prevented by this type of third party certification.
420 Indeed, fraudulent behaviour, by its criminal nature, is unlikely to occur during a timetabled third
421 party certification audit. The Elliott Review Interim Report (HM Government, 2013) suggests that
422 the food industry moves to reducing the number of announced certification audits undertaken and
423 replacing them with unannounced audits. However unless the certification standards contain
424 specific elements that will be assessed with regard to EMA and food fraud this will have limited
425 benefit. The effectiveness of the certification activity depends upon the cooperation of the
426 organization being audited, which in the event of criminal activity may well mean the auditor will
427 face limited disclosure. It should also be considered that if an auditor discovers criminal activity
428 during a certification audit, by the illegal nature of the issue the auditor's well-being and safety
429 should be assured.

430 The process sampling activities used within such certification audits are constrained by the time
431 available, planned frequency of verification activities, volume of data to be assessed, any planned or
432 unplanned sampling bias, and the potential for deviation from the scope of the audit (Manning,
433 2013). Martz (2010) suggested that "evaluation myopia", the inability of the auditor to identify side
434 effects or side impacts due to the rigid application and non-reflective use of a certification standard
435 or a "checklist" may also occur. This can lead to an auditor only verifying the effectiveness of the
436 control of food safety and food management standards criteria that have been defined in the
437 certification or audit standard or are already "known". As already discussed the checklist does not
438 implicitly address food standards, but instead focuses on food safety and food quality, then the
439 potential for EMA, or its actual practice, might go unverified. The Elliott Report (HM Government,
440 2013) recommends that third party accreditation bodies should collect and analyse food surveillance

441 samples as this would act as an additional deterrent to food businesses knowingly trading in
442 fraudulent food. This has potential to address known types of fraudulent activity; however emerging
443 hazards or “unknown unknowns” are outside the scope of a biannual or triennial updating of a
444 certification scheme and associated product sampling so emerging issues cannot be addressed by
445 this approach and still pose an issue unless regular revision activities take place within the
446 certification body and by the “standard owner” e.g. the British Retail Consortium. Therefore this
447 approach has limitations in addressing EMA and food criminality.

448

449 **Role of food policy in minimising food adulteration**

450 Food fraud that results in public health risk is often unknown until it is too late and the product is
451 already in circulation and has potentially been ingested. Even then the illegal activity may only be
452 identified by chance or as a result of a horizon scanning activity rather than from a formal risk-
453 based approach or an annual third party audit. Predicting types of adulterants and ways of
454 manipulation can be carried out using the Rational Choice Theory (assuming rational choices by the
455 fraudsters which may not be the case) or indeed in terms of food bioterrorism where irrational
456 behaviour may well underpin the behaviours that occur. The CARVER + Shock tool is a food
457 defensive tool to assess how vulnerable a food system or infrastructure is to an attack (Manning and
458 Soon, 2013). It allows food regulators to think like the attackers. This methodology has led to the
459 development of Vulnerability Assessment Software (VAS) tool (FDA, 2013a). This has been
460 designed to be a prioritization tool that can be used to assess the vulnerabilities within a system or
461 infrastructure in the food industry in order to build an effective food defense system. Carver +
462 Shock and VAS tools focused on predicting attacks, but are not designed to assess vulnerabilities in
463 the food supply chain for EMA issues. The attacker(s) of a food system ultimately wants to hurt
464 consumers, cause economic losses and/or reputation and to generate chaos. It is carried out with the
465 goal that the attack will be revealed within a period of time. Since food fraud or EMAs are carried
466 out for economical gains, fraudsters will conceal their act in order to gain as much profit as

467 possible. Similar systems can be developed to assess the likelihood of food fraud or EMA occurring
468 in the food chain. In this case, the critical points for food adulteration are points where fraudsters
469 have the opportunity to use/substitute/addition different ingredients (i.e. agricultural/veterinary
470 inputs / processing stage) and different packaging/labeling (i.e. at packaging or distribution stage)
471 (Figure 1). In future, after incorporating food fraud methodology into certification standards, supply
472 chain assurance and product verification, it may be equally difficult to remember a national or
473 organizational food standards control programme without there being a food fraud preventive
474 system in place as it would be now a food safety system without the use of HACCP plans (Spink
475 and Moyer, 2013). The following section discusses the policy initiatives in the US, and UK/EU that
476 address food adulteration including EMA.

477

478 **United States**

479 The US Federal Food and Drugs Act 1906 was introduced to prevent the manufacture, sale, or
480 transportation of adulterated or misbranded or poisonous or deleterious foods, drugs, medicines, and
481 liquors, and for regulating traffic therein (FDA, 2013b). The Meat Inspection Act (1906) was
482 passed on the same day. This was superseded by the Federal Food, Drug, and Cosmetic (FDC) Act
483 of 1938, and then the Public Health Security and Bioterrorism Preparedness and Response Act of
484 2002 with Section 302 specifically addressing protection against the adulteration of food (FDA,
485 2013c). Section 302 gives high priority to increasing the number of inspections of food offered for
486 import with the greatest priority given to inspections to detect intentional adulteration. The US
487 passed the Food Safety Modernization Act (FSMA) in January 2011. This is considered a landmark
488 law that shifts the food safety focus from reactive to preventive thus more in line with the European
489 approach. The FSMA addresses imported food safety under the Foreign Supplier Verification
490 section where importers have the responsibility to verify inspection, testing and trace back systems
491 (FDA 2013d). In the US, there are three main federal agencies that have primary responsibility for
492 the safety of imported foods (Zach *et al.* 2012):

- 493 • Bureau of Customs and Border Protection (CBP);
- 494 • USDA Food Safety Inspection Service (USDA/FSIS); and
- 495 • US Food and Drug Administration (FDA)

496 Under the FSMA, these three agencies (CBP, FSIS, FDA) enforce, collaborate and communicate
497 between each other to reduce the risk of unsafe food.

498

499 **United Kingdom / European Union**

500 The UK introduced the Preventing the Adulteration of Articles of Food or Drink Act into law in
501 1860 and it was revised by the Adulteration of Food and Drugs Act 1872. This led to the formation
502 of the Society of Public Analysts in 1874. The advent of the “due diligence” defense in the UK
503 Food Safety Act 1990 meant that organizations had to then prove that they were proactive in
504 ensuring the food they had been supplied was not injurious to health and was of the nature,
505 substance and quality demanded by the purchaser. The legislation differentiated between food that
506 was sold at retail stages that was “branded” or “own-label” i.e. sold under the retailers’ brand.
507 Under the Food Safety Act 1990, any supplier of a branded product was responsible for the safety
508 of that product, and enforcement could be taken against a wholesaler or retailer even if the offense
509 was caused by other parties in the food chain (Lee, 2006). Whilst major multiple food retailers in
510 the UK gained commercial advantage from increased sales of own-branded food products, it also
511 exposed them to greater risks in the event of product failure. This encouraged retailers to institute
512 stringent private assurance programmes with their suppliers (Fearne, 1998). This so called “field to
513 fork” or “plough to plate” approach led to systems that were complex and very costly elements of
514 the procurement of own-label products (Henson and Northern, 1998). As a means to mitigate this
515 cost the food retailers initiated the development of third-party inspection and then third-party
516 certification of their suppliers, as previously described in this paper whilst still seeking to maintain
517 an acceptable level of risk with regard to product failure in terms of their own verification activities.

518 European legislation (EC Regulation 178/2002) lays down the general principles and requirements
519 of food law, the establishment of the European Food Safety Authority (EFSA) and it also defined
520 procedures in matters of food safety. Article 8 addresses protection of consumers' interests in the
521 European Union (EU) and states that food law shall aim at the protection of the interests of
522 consumers and “*shall provide a basis for consumers to make informed choices in relation to the*
523 *foods they consume. It shall aim at the prevention of:*

524 *(a) fraudulent or deceptive practices;*

525 *(b) the adulteration of food; and*

526 *(c) any other practices which may mislead the consumer”.*

527 The requirements of Article 8 also differentiate between food safety and food standards criteria.
528 This led onto the development of the Rapid Alert System for Food and Feed (RASFF) in Europe for
529 identifying non-conformance within the MS. The Emerging Risk Exchange Network (EREN) is the
530 principal body for exchanging information on emerging risks between the EFSA, MS, the EC and
531 also international organisations. The network consists of national experts and allows information
532 exchange through the facilitation of access to and exchange through sharing of databases (Randles,
533 2012). In the UK, the intelligence from the EREN network along with data from other sources feeds
534 into the Food Fraud Database. The data from these sources will feed into the predictive element of
535 the systems to address EMA and food crime on a global scale, however localised EMA and food
536 crime also needs to be considered.

537

538 **Developing a conceptual framework**

539 The conceptual framework developed as a result of this research focuses on the process of
540 predicting, reacting and detecting economically and criminally food adulteration and builds on the
541 work of Ribble *et al.* (2013) (Figure 1). At the beginning of the chain, integrity can be assured at a
542 specific point that is before any potential attacks or substitution is possible. As the food and/or feed
543 is utilized, produced or processed within the supply chain, or supply network, opportunities arise for

544 criminals and fraudsters to add/extract/substitute/mix/dilute the material with any substance that
545 diminishes the integrity of such food. If EMAs were to take place at any point in the food chain, the
546 food safety and food standards system relies solely upon the reaction / detection protocols and
547 system that have been developed. These protocols and systems may work through a process of
548 either passive or reactive surveillance activity. The use of supply chain intelligence needs to feed
549 into these protocols to enhance their ability to react to potential attacks or to suspicion of EMA
550 activity. Inspection protocols and product testing programmes are developed through a risk
551 assessment process that might only be undertaken on an annual basis and such attacks may occur
552 much more frequently. Further product testing has been focused historically on looking for specific
553 “known” adulterants rather than determining the degree of product integrity. However as shown in
554 Tables 2 and 3 fingerprinting technologies are developing and their more widespread use will assist
555 to determine product integrity. Furthermore compliance, or not, with an integrity fingerprint does
556 not require the test to determine the actual agent used in an EMA, just that an attack has taken place
557 and that product integrity is now uncertain. If the food adulterant manages to bypass passive
558 mechanisms of control, the adulterated food may ultimately cause acute or chronic illness in the
559 population or the concern over such illness cause substantial economic loss.

560 Concurrent risk assessment studies on economic and social factors (e.g. pressure on food prices,
561 animal disease outbreaks, or weather events causing crop loss) together with associated predictive
562 modeling can be utilized to predict the potential for EMA and wider food crime. Policy measures
563 introduced require the implementation of both predictive measures and also reaction and detection
564 methods.

565 **Take in Figure 1**

566 Prediction of food adulteration rests upon the appropriate analysis of intelligence through the use of
567 predictive tools and expert knowledge. Cassidy and Buede (2009) argued that expert accuracy is, in
568 general, no better than that achieved by chance as increased experience is often accompanied by an
569 unjustified increase in self-confidence. They assert that there is a strong general tendency for

570 overconfidence when making predictions or statements of uncertainty, i.e. the predicted probability
571 of an event is often not calibrated with its actual likelihood of occurring based on the work of
572 Koehler *et al.* (2002), Yates *et al.* (1998) and Lichtenstein *et al.* (1982). Whilst this research was
573 looking at the ability to determine risk associated with issues such as whether it could be suggested
574 that this factor of expert accuracy is the same when qualitatively, or semi-qualitatively determining
575 the risk associated with food adulteration or food crime too. Koehler *et al.*, (2002) identified five
576 areas for calibrating expert judgment:

- 577 • Overprediction: always assigning probabilities that are high;
- 578 • Underprediction: Always assigning probabilities that are low
- 579 • Overextremity: overestimating high probabilities and underestimating low probabilities
- 580 • Underextremity: Underestimating high probabilities and overestimating low probabilities
- 581 and
- 582 • Overconfidence: being either overprediction or overextremity.

583 Angner (2006) in his work on overconfidence with economic experts highlighted that
584 overconfidence increases with difficulty i.e. the more unknown a factor the more likely that
585 overconfidence occurs. Whilst this may in part lie within the requirements of the precautionary
586 principle associated with European food policy there is potential concern when considering EMA
587 and food fraud that the expert assessment will be incorrect and then the resultant decision on the
588 actions to take. Anger (2006) further argues that in their role as “experts”, individuals may not
589 receive adequate outcome feedback i.e. they will never know what would have happened in the
590 absence of the implementation of their recommendations. It is equally important that the actual
591 outcomes of the implementation of their advice is fed back into the expert analysis of the future.
592 However it is important in this case in hindsight not to exaggerate the predictability of past events.
593 Therefore, how can the bias of overconfidence be mitigated in frameworks such as Figure 1?
594 Angner (2006) suggests:

- 595 • Accepting that overconfidence will occur and if possible eliminating it over time by
596 requiring experts to give arguments against their view and the reasons why they may be
597 wrong and providing feedback on decisions that is frequent, prompt, and unambiguous;
- 598 • Require clarity in predictions and decisions so that they are not ambiguous and ensure
599 predictions are on the public record; and
- 600 • Minimise interpersonal differences between experts.

601 In predicting EMA and food crime it is important to consider the contributing factors that influence
602 the incidence of food crime such as the motive, ability to detect the adulterant (known/unknown)
603 the ability of the fraudster/criminal to cheat existing analytical tests, the strength of regulatory and
604 market controls at the point of adulteration/criminal activity and at the point of consumption, the
605 economic or supply chain factors (pressure on food prices, factors impacting on balance between
606 supply and demand) and the complexity of supply chain and the influence of cross-border activity.
607 Databases and risk assessment measures as well as predictive modelling and intelligence gathering
608 will be undertaken in order to identify the potential for EMA and food crime. Reaction and
609 detection measures will depend on the agents of adulteration/substitution and the type of food fraud.
610 Table 1 identified seven different types of food fraud and the reaction/detection measures will vary.

611

612

Conclusion

613 Activities to predict the potential for adulteration or even bioterrorism have an inbuilt weakness
614 because the quantification of risk is usually based on historical data that may, or may not be
615 available or may/may not reflect the actual risk now at any given time in the future. Food fraud that
616 results in public health risk is often unknown until it is too late and may only be identified by
617 chance rather than from a formal risk-based approach; however there is a need to develop such
618 predictive models for the future.

619 Historically, analytical screening techniques were used to identify EMA, and wider food crime, but
620 this is only of value if the nature of the adulterant is known. There are evolving food forensics

621 techniques that will be able to determine food integrity through techniques such as isotope analysis
622 or spectroscopy that do not require the contaminant to be known rather that food integrity or purity,
623 to the level of detection, cannot be shown. This investigative framework is valuable as a means to
624 fight food fraud/EMA. However, these tests are costly and will by and large, in the short term
625 anyway, be used as a tool of verification and not as a form of analysis for routine batch release.
626 Therefore they cannot be used as either a preventative control, or an on-line, real-time monitoring
627 activity within an established quality plan.

628 The objective of this study was to explore the current strategies available to monitor and detect the
629 EMA and their relative strengths and weaknesses and recommend new approaches and policies to
630 strengthen future capabilities to counter adulteration in a globalized food environment. The
631 conceptual framework developed in this research focused on the process of predicting, reacting and
632 detecting economically and criminally food adulteration, with specific emphasis on calibrating the
633 confidence of experts as this underpins the horizon scanning, risk assessment and predictive
634 processes as well as informing the requirements to ensure effective reactions and detections are
635 undertaken.

636

637 **References**

- 638 Accum, F. (1820), *A treatise on adulterations of food and culinary poisons*. London: Longman,
639 1820. Available at:
640 <http://ia600300.us.archive.org/18/items/treatiseonadulter00accurich/treatiseonadulter00accurich.pdf>
641 [Date accessed 17.10.13]
642
- 643 Brown, C. A. and Brown, S. A. (2010). Food and pharmaceuticals: Lessons learned from global
644 contaminations with melamine/cyanuric acid and diethylene glycol. *Veterinary Pathology* 47(1):
645 45-52.
646
- 647 Archak, S., Lakshminarayanareddy, V., and Nagaraju, J. (2007) High-throughput multiplex
648 microsatellite marker assay for detection and quantification of adulteration in Basmati rice
649 (*Oryzasativa*).*Electrophoresis* 28, 2396–2405
650
- 651 Bhalla, V. Grimm, P.C., Chertow, G.M., and Pao AC. (2009), Melamine nephrotoxicity: an
652 emerging epidemic in an era of globalization. *Kidney Int.*75:774–779.
653
- 654 Blyth, A.W. (1896), *Foods: Their Composition and Analysis*, 1896, Edition 4, Charles Griffin and
655 Company Limited, London.
656
- 657 BRC (2005), Code of Practice on Basmati Rice. In Consultation with the Local Authorities Co-
658 ordinators of Regulatory Services (LACORS) and the Association of Public Analysts (APA). July
659 2005. Available at: http://www.brc.org.uk/Downloads/Basmati_Code.pdf[Date accessed
660 10/05/2013]
661
- 662 CAC (Codex Alimentarius Commission) (2011), “The 20th Edition of the Procedural
663 Manual of Codex Alimentarius Commission”, Available at
664 http://www.codexalimentarius.net/web/procedural_manual.jsp[Date accessed 08/04/12]
665
- 666 CAC (Codex Alimentarius Commission) (2007), “Principles and Guidelines for the Conduct of
667 Microbiological Risk Management (MRM)”, (CAC/GL 63-2007)”, Food hygiene basic texts,
668 available at: www.codexalimentarius.net/download/standards/10741/cxg_063e.pdf[Date accessed
669 17.10.13]
670
- 671 Casale, M., Oliveri, P. and Armanino, C. (2010). NIR and UV-vis spectroscopy, artificial nose and
672 tongue: comparison of four fingerprinting techniques for the characterisation of Italian red wines.
673 *AnalyticaChimicaActa*668: 143-148.
674
- 675 Cawthorn, D., Steinman, H.A., and Hoffman, L.C., (2013). A high incidence of species substitution
676 and mislabelling detected in meat products sold in South Africa, *Food Control*, 32 (2): 440-449
677
- 678 Charlton, A. (2010). Addressing Emerging Issues of Food Adulteration and
679 Authenticity.Fera/JIFSAN symposium, 16-18 June 2010.York, UK
680
- 681 Chirnside, R.C, and Hamence, J.H. (1974), *The Practising Chemists, A History of the Society for*
682 *Analytical Chemistry 1874-1974*, 1974, The Society for Analytical Chemistry.
683
- 684 Clare, P and Clare, M. (2012), The Life and Times of Alfred Henry Allen, Sheffield's First Public
685 Analyst, *Journal of the Association of Public Analysts (Online)* 40: 39-59 Available at:
686 http://www.apajournal.org.uk/2012_0039-0059.pdf [Date accessed 17.10.13]
687

688 Coghlan, A (2011) China makes 96 arrests over toxic milk scandal New Scientist 13 January. Available at:
689 <http://www.newscientist.com/blogs/shortsharpscience/2011/01/china-makes-96-arrests-over-to.html>
690 [Accessed 17/04/2013]
691

692 Cohen, A. (1997) Sturgeon poaching and black market caviar: a case study. *Environmental Biology*
693 *of Fishes* 48: 423-426.

694 Collins Dictionary (2013) Available at
695 <http://www.collinsdictionary.com/dictionary/english/wholesome> [Date accessed 17.10.13]

696 Dabbine, F., Gay, P. and Tortia, C. (In Press). Traceability issues in food supply chain management:
697 A review. *Biosystems Engineering*.

698 Defra (2013) The Defra website [https://www.gov.uk/food-standards-labelling-durability-and-](https://www.gov.uk/food-standards-labelling-durability-and-composition)
699 [composition](https://www.gov.uk/food-standards-labelling-durability-and-composition) [Date accessed 17.10.13]

700 D'Amico, P., Armani, A., Castigliero, L., Sheng, G., Gianfaldoni, D. and Guidi, A. (2014). Seafood
701 traceability issues in Chinese food business activities in the light of the European provisions. *Food*
702 *Control* 35(1): 7-13.
703

704 Di Stefano, V., Avellone, G., Bongiorno, D., Cunsolo, V., Muccilli, V., Sforza, S., Dossena, A.,
705 Drahos, L. and Vekey, K. (2012). Applications of liquid chromatography – mass spectrometry for
706 food analysis. *Journal of Chromatography A* 1259: 74-85.
707

708 Du, Z. and Sun, S. (2007). Determination of SUDAN Red I-IV in duck egg yolk using ultra
709 performance liquid chromatography-tandem mass. *Chinese Journal of Chromatography* 25(5): 705-
710 710.
711

712 EC/178/2002 laying down the general principles and requirements of food safety law, establishing
713 the European Food Standards Agency and laying down procedures in matters of food safety OJ
714 L/31 1.2.2002 pp. 001 – 024.
715

716 EC (2013). Commission publishes European test results on horse DNA and Phenylbutazone: no
717 food safety issues but tougher penalties to apply in the future to fraudulent labelling Available at:
718 http://europa.eu/rapid/press-release_IP-13-331_en.htm [Date accessed 18.10.13]
719

720 Everstine, K., Spink, J., and Kennedy, S, (2013). Economically Motivated Adulteration (EMA) of
721 Food: Common Characteristics of EMA Incidents. *Journal of Food Protection*, 4: 560-735
722

723 Fearn, A. (1998). The evolution of partnerships in the meat supply chain: insights from the British
724 beef industry. *Supply Chain Management: An International Journal* 3(4): 214-231.
725

726 FDA (2013a) The Federal Food and Drugs Act (1906) Available at:
727 <http://www.fda.gov/regulatoryinformation/legislation/ucm148690.htm> [Date accessed 17.10.13]

728 FDA (2013b) Public Health Security and Bioterrorism Preparedness and Response Act of 2002
729 (PL107-188) Available at: [http://www.fda.gov/ohrms/dockets/dailys/03/jul03/070303/02n-](http://www.fda.gov/ohrms/dockets/dailys/03/jul03/070303/02n-0277_emc-000029-04.htm)
730 [0277_emc-000029-04.htm](http://www.fda.gov/ohrms/dockets/dailys/03/jul03/070303/02n-0277_emc-000029-04.htm) [Date accessed 17.10.13]

731 FDA (2013c) Vulnerability Assessment Tool Available at:
732 <http://www.fda.gov/Food/FoodDefense/ToolsEducationalMaterials/ucm295900.htm> [Date accessed
733 18.10.13]
734

735 (The) Food Safety Act (1990), c.16, The Stationery Office (TSO) Limited, London.

736 FSA (2013a).FSA issues statement following Ministry of Justice announcement about non Halal
737 meat. Available at: <http://www.food.gov.uk/news-updates/news/2013/feb/m-o-j#UXwOkLWG2So>
738 [Date accessed 20.10.13]

739

740 FSAAI (2011) [National survey in India of adulteration in liquid milk](http://www.fssai.gov.in/Portals/0/Pdf/sample_analysed(02-01-2012).pdf). Available at:
741 [http://www.fssai.gov.in/Portals/0/Pdf/sample_analysed\(02-01-2012\).pdf](http://www.fssai.gov.in/Portals/0/Pdf/sample_analysed(02-01-2012).pdf)[Accessed on 23/04/2013]
742

743 Galimberti, A., De Mattia, F., Losa, A., Bruni, I., Federici, S., Casiraghi, M., Martellos, S. and
744 Labra, M. (2013). DNA barcoding as a new tool for food traceability.*Food Research*
745 *International*50(1): 55-63.

746

747 Gossner, C.M., Schlundt, J., Embarek, P.B., Hird, S., Lo-Do-Wong, D., Beltran J.J.O., Teoh, K.N.,
748 and Tritscher, A., (2009) The Melamine Incident: Implications for International Food and Feed
749 Safety *Environ Health Perspect.* 117(12): 1803–1808.

750

751 Grundy, H.H., Kelly, S.D., Charlton, A.J., Donarski, J.A., Hird, S.J., and Collins, M.J., (2012).
752 Food Authenticity and Food Fraud Research: Achievements and Emerging Issues, *Journal of the*
753 *Association of Public Analysts (Online)*40: 65-68

754

755 Hassall, A.H, (1855).*Food and its adulterations; comprising the reports of the analytical sanitary*
756 *commission of 'The Lancet' for the years 1851 to 1854*. London: Longman, 1855. Available at:
757 <http://archive.org/stream/foodanditsadult01commgoog#page/n8/mode/2up> [Date accessed 18.10.13]
758

759 He Dan (2011) Whistleblower says watchdogs relying on fines. China Daily. Available from:
760 http://europe.chinadaily.com.cn/china/2011-04/20/content_12360918.htm [Accessed 27 November
761 2013]

762

763 Heaton, K., Kelly, S. D.,Hoogewerff, J and Woolfe, M. (2007) “*Verifying the geographical origin*
764 *of beef: The application of Multi-element Isotope and Trace Element Analysis*” *Food Chemistry*,
765 107, 506–515

766

767 Henson, S., and Northen, J., 1998.Economic determinants of food safety controls in supply of
768 retailer own-
769 branded products in United Kingdom *Agribusiness*14(2): 113-126.

770

771 Hubert, N., Hanner, R., Holm, E. Mandrak, N. E. and Taylor, E. (2008).Identifying Canadian
772 freshwater fishes through DNA barcodes.*PLoS ONE* 3(6): e2490.

773

774 HM Government (2013) Elliott Review into the Integrity and Assurance of Food Supply Networks
775 – Interim Report Available at <https://www.gov.uk/government/publications>PB 14089.

776

777 IFRTF (2011) The report of the independent Farming Regulation Task Force. Striking a balance:
778 reducing burdens; increasing responsibility; earning recognition. A report on better regulation in
779 farming and food businesses.Summary of Recommendations. May 2011 PB13528 Available at:
780 [https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69202/pb13528-](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69202/pb13528-farm-reg-task-summary1.pdf)
781 [farm-reg-task-summary1.pdf](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69202/pb13528-farm-reg-task-summary1.pdf) [Accessed on: 09/05/2013]
782

783 Jia, C. and Jukes, D. (2013). The national food safety control system of China – A systematic
784 review. *Food Control* 32(1): 236-245.

785

786 Jia, X., Huang, J., Luan, H., Rozelle, S., and Swinnen J. (2012) China's Milk Scandal, government
787 policy and production decisions of dairy farmers: The case of Greater Beijing. *Food Policy* 37:
788 390–400
789

790 Kelly, S.D., and Bateman A.S. (2009), Comparison of Mineral Concentrations in Commercially
791 Grown Organic and Conventional Crops - Tomatoes (*Lycopersicon esculentum*) and Lettuces
792 (*Lactucasativa*), *Food Chemistry*, 119: 738–745
793

794 Kelly, S., Heaton, K. and Hoogewerff, J. (2005). Tracing the geographical origin of food: The
795 application of multi-element and multi-isotope analysis. *Trends in Food Science & Technology*
796 16(12): 555-567.
797

798 Kelly, S.D. (2003), Using Stable Isotope Ratio Mass Spectrometry in Food Authentication and
799 Traceability, Food Authenticity and Traceability, Michele Lees (Ed), Woodhead Publishing,
800 Cambridge, UK, ISBN 0-8493-1763-0, 156-183
801

802 Kim, H.M., Fox, M.S. and Gruninger, M. (1995) 'Ontology of Quality for Enterprise Modelling' In
803 Proceedings of WET-ICE, Los Alamitos, CA, USA, pp.105±116, IEEE
804

805 Kitaoka, M., Wada, T., Nishio, T. and Goto, M. (2010). Fluorogenic ribonuclease protection (FRIP)
806 analysis of single nucleotide polymorphisms (SNPs) in Japanese rice (*Oryza sativa* L.) DNA for
807 cultivar discrimination. *Bioscience, Biotechnology and Biochemistry* 74(11): 2189-2193.
808

809 Lee, G.C.-H., (2006). Private food standards and their impacts on developing countries. European
810 Commission
811 DG Trade Unit G2. Available at:
812 http://trade.ec.europa.eu/doclib/docs/2006/november/tradoc_127969.pdf [Date accessed
813 13/03/2013].
814

815 Li, L. (2013). Technology designed to combat fakes in the global supply chain. *Business Horizons*
816 56(2): 167-177
817

818 Liu, X., Guo, B., Wei, Y., Shi, J and Sun, S., (2013) Stable isotope analysis of cattle tail hair: A
819 potential tool for verifying the geographical origin of beef. *Food Chemistry*, Issues 1-2, 1-15 Sept
820 2013 135-140
821

822 Liu, S., Xie, Z., Zhang, W., Cao, X. and Pei, X. (2013). Risk assessment in Chinese food safety.
823 *Food Control* 30(1): 162-167
824

825 London Borough of Tower Hamlets (2010) Food Law Enforcement Plan 2010/2011. [online]
826 Available from: <http://www.towerhamlets.gov.uk/pdf/FSA%20Service%20Plan%202010-11.pdf>
827 [Date accessed 18.10.13]
828

829 Manning, L. (2013), Development of a food safety verification risk model, *British Food*
830 *Journal*, 115(4): 575-589
831

832 Manning L., Baines R.N., and Chadd S.A. (2005), "Deliberate contamination of the food supply
833 chain", *British Food Journal*, 107(4): 225-245.
834

835 Manning, L. and Soon, J. M. (2013), "Mechanisms for assessing food safety risk", *British Food*
836 *Journal*, 115(3): 460-484
837

838 Maralit, B. A., Aguila, R. D., Ventolero, M. F. H., Perez, S. K. L., Willette, D. A. and Santos, M. D.
839 (2013).Detection of mislabelled commercial fishery by-products in the Philippines using DNA
840 barcodes and its implications to food traceability and safety.*Food Control* 33(1): 119-125.
841

842 Martz, W. (2010), “Validating an evaluation checklist using a mixed method design”, *Evaluation*
843 *and Program Planning*, 33: 215-222. Available at:
844 <http://dx.doi.org/10.1016/j.evalprogplan.2009.10.005> [Date accessed 18.10.13].
845

846 Merck Research Laboratories (2001).The Merck index. 13th ed. Merck Research Laboratories,
847 Whitehouse station: New Jersey.

848 Moe T. (1998). Perspectives on traceability in food manufacture.*Trends in Food Science and*
849 *Technology*, 9: 2111-214
850

851 Moore, J.C.Spink, J., and Lipp, M. (2012).Development and application of a database of food
852 ingredient fraud and economically motivated adulteration from 1980 to 2010.*Journal of Food*
853 *Science*, 77(4):R118-126
854

855 Moore, J. C., DeVries, J. W., Lipp, M., Griffiths, J. C.And Abernethy, D. R. (2010). Total protein
856 methods and their potential to reduce the risk of food protein adulteration. *Comprehensive Reviews*
857 *in Food Science and Food Safety* 9: 330-357.
858

859 Niu, L., Mantri, N., Li, C.G., Xue, C., Wohlmuth, H and Pang, E.C. (2011).Detection of
860 *Panaxquinquefolius* in *Panax ginseng* using 'subtracted diversity array'. *J. Sci Food Agri.* 91(7):
861 1310-5

862 Primrose, S., Woolfe, M. and Rollinson, S. (2010). Food forensics: methods for determining the
863 authenticity of foodstuffs. *Trends in Food Science and Technology* 21(12): 582-590.
864

865 Randles, P (2012) Emerging Risks. Paper given to the 57th Meeting of the Advisory Committee on
866 Animal Feedstuffs on 7th March 2012
867 <http://www.food.gov.uk/multimedia/pdfs/committee/acaf1201.pdf> [Accessed on 11.12.13]
868

869 Razmy, A. (2009). Will China’s new food-safety laws work? Time March 3 2009. Available at:
870 <http://www.time.com/time/world/article/0,8599,1882711,00.html>[Accessed 26/04/ 2013].
871

872 Ravilious, K. (2006) Buyer beware: the rise of food fraud. *NewScientist* 15 November. Available at:
873 <http://www.newscientist.com/article/> [Accessed 17/04/ 2013]
874

875 Ribble, C.S., Stitt, T., Burns, T., Dawson, J., Iwasawa, S., Buntain, B., Stephen, C., Rajic, A. and
876 Merten, C. (2013). Structured review and expert opinions on early warning and rapid alert systems
877 applicable to food safety. Technical Report, Centre for Coastal Health and FAO.
878

879 Rock, L. (2012) The use of stable isotope techniques in egg authentication schemes: A review
880 *Trends in Food Science & Technology* 28 (2012) 62-68
881

882 Scally, G. (2013).Adulteration of food: what it doesn’t say on the tin *BMJ* 2013; 346:f1463
883

884 Schmidt, O., Quilter, J.M., Bahar, B., Moloney, A.P., Scrimgeour, C.M., Begley, I.S., and
885 Monahan, F.J., (2004) Inferring the origin and dietary history of beef from C, N and S stable
886 isotope ratio analysis. *Food Chemistry* 91 (2005) 545–549
887

888 Schoder, D. (2010). Melamine milk powder and infant formula sold in East Africa. *Journal of Food*
889 *Protection* 73(9): 1709-1714.

890
891 Sefc, K. M., Lopes, M. S., Mendonça, D., Rodrigues Dos Santos, M., Laimer Da Câmara Machado,
892 M. and Da Câmara Machado, A. (2000). Identification of microsatellite loci in olive (*Olea europaea*)
893 and their characterization in Italian and Iberian olive trees. *Molecular Ecology* 9(8): 1171-1173.
894
895 Serge, R., Ivan, G. and Karoly, H. (2007). Classification of gilthead sea bream (*Sparus aurata*) from
896 ¹H NMR lipid profiling combined with principal component and linear discriminant analysis.
897 *Journal of Agricultural and Food Chemistry* 55: 9963-9968.
898
899 Shukla, S., Shankar, R. and Singh, S. P. (2014). Food safety regulatory model in India. *Food Control*
900 37: 401-413.
901
902 Spink, J. and Moyer, D. C. (2013). Understanding and combating food fraud. *Food Technology*
903 67(1): 30-35.
904
905 Spink, J. and Moyer, D. C. (2011). Defining the public health threat of food fraud. *Journal of Food*
906 *Science* 76(9): R157-R163.
907
908 Sykes, J. B. (1976). *The concise Oxford dictionary*. University Press, Oxford.
909
910 Thomson, H. (2013) DNA tests can prevent the next horsemeat scandal. *NewScientist* 13 February.
911 Available at: [http://www.newscientist.com/article/mg21729043.800-dna-tests-can-prevent-the-next-](http://www.newscientist.com/article/mg21729043.800-dna-tests-can-prevent-the-next-horsemeat-scandal.html?full=true)
912 [horsemeat-scandal.html?full=true](http://www.newscientist.com/article/mg21729043.800-dna-tests-can-prevent-the-next-horsemeat-scandal.html?full=true) [Accessed 16/04/ 2013]
913
914 US FDA (2008). FDA advises consumers to avoid toothpaste from China containing harmful
915 chemical. June 2007. Available from:
916 <http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/2007/ucm108927.htm> [Accessed
917 2 December 2013]
918
919 US FDA (2013). Food Safety Modernization Act (FSMA). U.S. Food and Drug Administration.
920 Available at:
921 http://www.fda.gov/food/guidanceregulation/fsma/ucm247548.htm#TITLE_III [Accessed 1
922 December 2013]
923
924 US Pharmacopeia (2012). Food Chemicals Codex . Available at [http://www.usp.org/food-](http://www.usp.org/food-ingredients/food-chemicals-codex)
925 [ingredients/food-chemicals-codex](http://www.usp.org/food-ingredients/food-chemicals-codex). [Accessed 7/05/2013]
926
927 Valeria, T., Caterina, M. and Antonio, G. (2005). DNA-based methods for identification and
928 quantification of small grain cereal mixtures and fingerprinting of varieties. *Journal of Cereal*
929 *Science* 41: 213-220.
930
931 Vinci, G., Preti, R., Tieri, A., and Vieri, S. (2012), Authenticity and quality of animal origin food
932 investigated by stable isotope ratio analysis. *Journal of the Science of Food and Agriculture* 93 (3):
933 439-448
934
935 Warner, K., Timme, W., and Lowell, B. (2012). Widespread Seafood Fraud Found in New York
936 City Oceana. December 2012 Available at:
937 http://209.183.226.238/sites/default/files/reports/Oceana_NYC_Seafood_Fraud_Report_FINAL.pdf
938 [Date accessed 20.10.13]
939
940 WHO (2008) Melamine-contaminated powdered infant formula in China. Available at:
941 http://www.who.int/csr/don/2008_09_19/en/ [Accessed 26/03/ 2013].

942
943 WHO (1997) "Food Safety and Globalization of Trade in Food, a challenge to the public health
944 sector". WHO/FSF/FOS/97.8 Rev. 1, WHO, Geneva
945
946 Woolfe, M. and Primrose, S. (2004). Food forensics: using DNA technology to combat
947 misdescription and fraud. *Trends in Biotechnology* 22(5): 222-226.
948
949 Xiaojing, L (2011) The cause and effect analysis of the melamine incident in China. *Asian Journal*
950 *of Agricultural Research* 5 (3): 176-185
951
952 Xinhua News (2010). A new incident of formula contaminated with melamine found in Qinghai
953 Province. Available from http://news.xinhuanet.com/food/2010-07/09/c_12314950.htm [Accessed
954 27 November 2013]
955
956 Xiu, C. and Klein, K. K. (2010). Melamine in milk products in China: Examining the factors that
957 led to deliberate use of the contaminant. *Food Policy* 35: 463-470.
958
959 Zach, L., Doyle, M. E., Bier, V. and Czuprynski, C. (2012). Systems and governance in food import
960 safety: A U.S. perspective. *Food Control* 27 (1): 153-162.
961
962 Zhang, J., Zhang, X., Dediu, L. and Victor, C. (2011). Review of the current application of
963 fingerprinting allowing detection of food adulteration and fraud in China. *Food Control* 22(8): 1126-
964 1135.
965
966 Angner, E., (2006) Economists as experts: Overconfidence in theory and practice. *Journal of*
967 *Economic Methodology*, 13 (1) 1-24

968 Koehler, D.J., Brenner, L. and Griffin, D. (2002), "The calibration of expert judgment: heuristics
969 and biases beyond the laboratory", in Gilovich, T., Griffin, D.W. and Kahneman, D. (Eds),
970 *Heuristics and Biases: The Psychology of Intuitive Judgment*, Cambridge University Press,
971 Cambridge.

972 Lichtenstein, S., Fischhoff, B. and Phillips, L.D. (1982), "Calibration of probabilities: the state of
973 the art to 1980", in Kahneman, D., Slovic, P. and Tversky, A. (Eds), *Judgment under Uncertainty:*
974 *Heuristics and Biases*, Cambridge University Press, Cambridge.

975 Yates, J.F., Lee, J.W., Shinotsuka, H., Patalano, A.L. and Sieck, W.R. (1998), "Cross-cultural
976 variations in probability judgment accuracy: beyond general knowledge overconfidence",
977 *Organizational Behavior and Human Decision Processes*, 74 (2) 89-117.

978 Cassidy, M.F., and Buede, D. (2009), Does the accuracy of expert judgment comply with common
979 sense: caveat emptor *Management Decision* 47 (3), 454-469
980
981
982

983
984

Table 1: Types of food fraud (Adapted from Spink and Moyer, 2011)

Type	Definition
Adulteration	A component of the finished product is fraudulent
Counterfeit	All aspects of the fraudulent product and packaging are fully replicated
Diversion	The sale or distribution of legitimate products outside of intended markets
Over-run	Legitimate product is made in excess of production agreements
Simulation	Illegitimate product is designed to look like but does not exactly copy the legitimate product
Tampering	Legitimate product and packaging are used in a fraudulent way
Theft	Legitimate product is stolen and passed off as legitimately procured

985
986
987

Table 2: Classification of fingerprinting technologies (Adapted from Zhang *et al.* 2011)

Methods	Electrophoresis fingerprinting		Spectral fingerprinting	Chromatographic fingerprinting
	Biochemical fingerprinting	Protein electrophoresis, isoenzyme electrophoresis		
DNA fingerprinting	Restriction fragment length polymorphism (RFLP)	Random Amplified Polymorphic DNA (RAPD)	Nuclear Magnetic Resonance (NMR), Infrared (IR)	Gas chromatography (GC)
		Amplified Fragment Length Polymorphism (AFLP)	Ultraviolet and visible spectroscopy (UV)	High performance liquid chromatography (HPLC)
		Pulsed-field gel electrophoresis (PFGE)	Mass spectrometry (MS)	

988
989

990
991
992

Table 3: Application fields of fingerprinting in food detection (adapted from Charlton, 2010; Niu et al., 2011; Sefcet al. 2000; Woolfe and Primrose 2004; Zhang et al. 2011)

Application domain	Products	Detection indicators	Detection Technology
Origin	Tea, beer, mutton, olive oil, wine	Microelements, water, lipid, protein, carbohydrate, aromatic compound, isotope indicators	NMR, IR, PCR
Material/species	Bird's nest, aquatic product, poultry, vegetables, Basmati rice, Genseng	Protein, DNA	SDS-PAGE, Isoenzyme electrophoresis, RFLP, RAPD, AFLP, small sequence length polymorphism (SSLPs)
Component	Milk, fruit, edible oil, tea, beef, ham, health products	Protein, lipid, lecithin, vitamins, sugars, organic acid,	SDS-PAGE, NMR, IR, UV, MS
Additive	Meat, milk, juice, processed food, carbonated beverages, ice-cream	Nitrite, sufan, melamine, clebuterol hydrochloride, colorants, antiseptic	UV, GC, LC, MS
Objectionable constituent in processing	Fried starch products, margarine, barbeque	Acrylamide, trans-fatty acids, benzopyrene	UV, GC, LC, MS

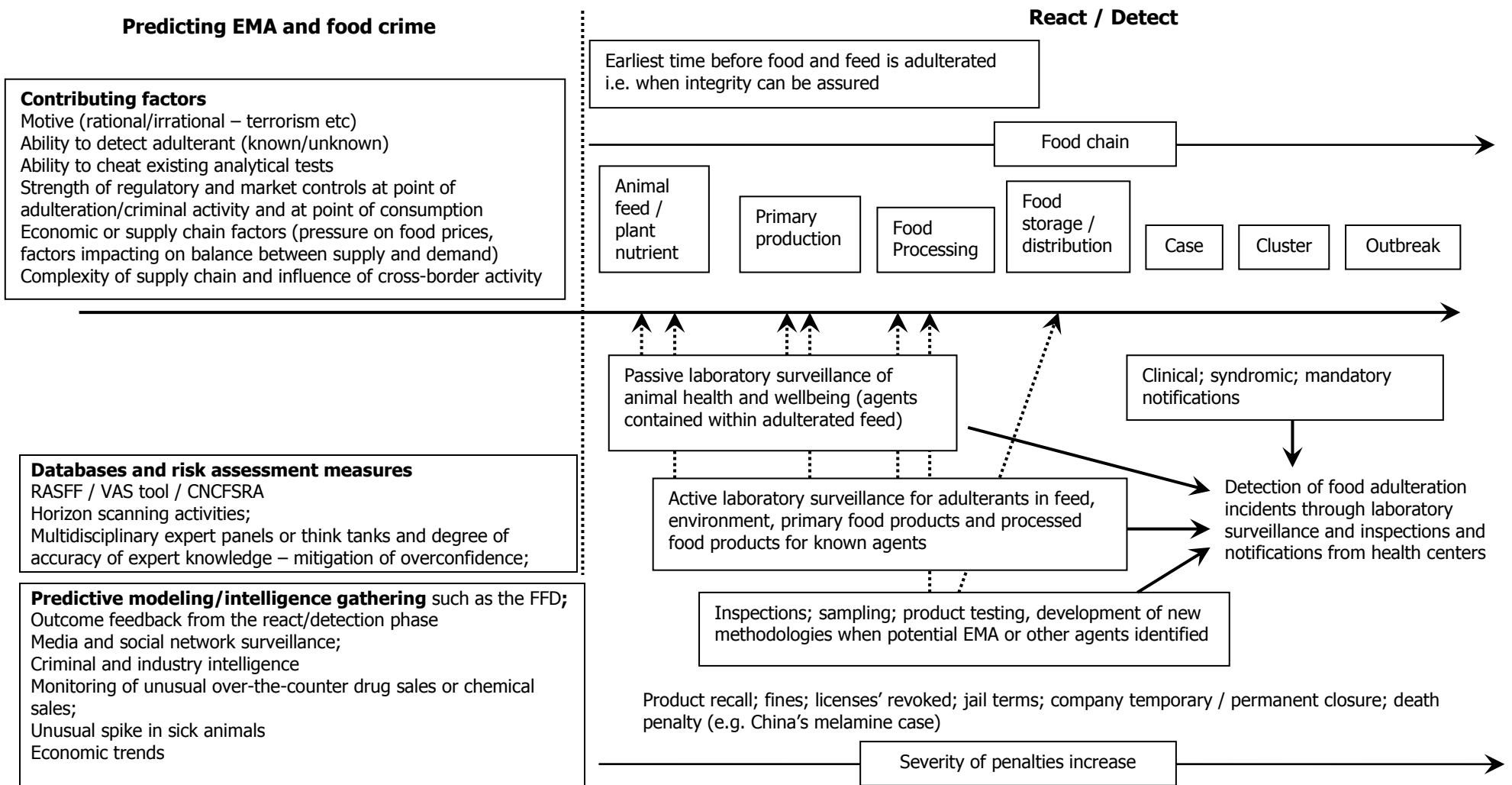


Figure 1. Predictive and reactive systems for food adulteration – role of food policy and risk assessment centres (adapted from Ribble et al. 2013) (Note: RASFF: Rapid Alert System for Food and Feed; VAS – Vulnerability Assessment Software; FFD – Food Fraud Database; CNCFSRA: China National Center for Food Safety)