Food Fraud Vulnerability assessment: reliable data sources and effective assessment approaches

Manning L.[1] and Soon J.M[2]

[1]Royal Agricultural University, Stroud Road, Cirencester, GL7 6LS UK
[2]International Institute of Nutritional Sciences and Applied Food Safety Studies, School of Sport and Wellbeing, University of Central Lancashire, Preston PR1 2HE UK

Corresponding author email: JMSoon@uclan.ac.uk

Accepted by Trends in Food Science and Technology

Abstract

Multiple food fraud vulnerability assessment (FFVA) tools have been developed and refined to capture and quantify food fraud issues in the supply chain. The aim of this research is to review existing FFVA tools and the databases that underpin them and consider the challenges, limitations and opportunities in their use. The databases considered include: the Rapid Alert for Food and Feed Safety (RASFF) database, the Food Fraud Risk Information, Decernis Food Fraud Database, FoodSHIELD, and HorizonScan. Four FFVA tools, Safe Supply of Affordable Food Everywhere (SSAFE), the two Food Fraud Advisor's vulnerability assessment tools and EMAlert, are also critiqued in this paper from the viewpoint of the tools available and their efficacy for food fraud vulnerability assessment.

Keywords: food fraud, vulnerability, intentional, adulteration, database

Highlights

- Vulnerability has multiple attributes that need to be considered in a risk assessment.
- Multiple data source exist their use is limited by subscription only access.
- Behavioural assessment is a key aspect of FFVA tools

1. Introduction

Food fraud involves intentional modification of food products and/or associated documentation for economic gain and may lead to issues of food safety, legality and/or quality depending on the activities undertaken or the agent(s) used. Food manufacturers, as part of the assessment of their vulnerability to food fraud need to identify the individual food materials and products that they procure, supply and/or produce that have a history of illicit activity. Supply chains are complex networks that are shaped by the inter-relationships between actors, the processes undertaken and the inputs and outputs associated with those processes (Wang, van Fleet & Mishral, 2017). Due to the high incidence of reported problems in the past, certain food types, geographic sources and associated supply chains are seen as having historically higher levels of concern with regard to food fraud. For a given supplier organisation, service or ingredient, historic levels of compliance can be used to determine foods or ingredients that are vulnerable to food fraud. These foods include fish, meat, cereals, milk, olive oil, organic product and spices (Xiu & Klein, 2010; Silvis, van Ruth, van der Fels-Klerx & Luning, 2017; van Ruth, Huisman & Luning, 2017). Food fraud is an overarching term and the sub-types of food fraud determined in the literature and emergent standards are outlined in Table 1.

Take in Table 1

For perpetrators, successful modes of food fraud are measured in terms of the degree of financial gain when compared with the risk of detection (Manning & Soon, 2014). As opportunities arise, and the risk of detection decreases, the effort required to commit crime for the benefit derived is reduced. In contrast, the higher the probability of being detected or caught, the lower the returns for the fraudster (Spink & Moyer, 2011a). From an anti-fraud perspective, it is difficult to predict where fraud may occur as fraudsters, if their modus operandi is to remain undiscovered, are constantly required to identify new opportunities and channels for committing fraud (Kingston, 2017). The key to preventing food fraud is the development of measures to assess, detect, mitigate and where possible prevent it from occurring. However, Everstine, Spink & Kennedy (2013) assert that economically motivated adulteration (EMA) differs from other food threats as it is not readily predicted through food safety risk assessments and intervention strategies. Instead food fraud vulnerability assessment (FFVA) systematically considers the factors that create vulnerabilities in a supply chain, *i.e.* where food fraud is more likely to occur (Nestle, n.d.).

The Global Food Safety Initiative (GFSI, 2018) defines a ***food fraud vulnerability*** as "the susceptibility or exposure to a food fraud risk, which is regarded as a gap or deficiency that could place consumer health at risk if not addressed". It is important to differentiate between **intrinsic vulnerabilities** i.e. those vulnerabilities that occur within the business at the micro (individual) and meso (organisational level) and **extrinsic vulnerabilities** that occur at the macro level in the external environment, and as a result are more difficult for the business to control. GFSI (2018) distinguishes between a *hazard*, (something with the a potential to cause harm), and *risk* (the probability of loss or injury from a hazard), stating that susceptibility to a [given] risk is not only linked to the severity of the risk, but also to the company's awareness of their weakness and also how they manage it. This concept provides a distinct approach to considering vulnerability, and underpins the rational for this paper. In this context, the aim of this review is to provide context through comparing and contrasting risk assessment and vulnerability assessment and then analysing existing FFVA tools and the databases that underpin them. This approach allows assessment of the consistency of how food fraud vulnerability is determined by different models.

2. Risk assessment versus vulnerability assessment

2.1 Risk assessment

Risk assessment is the overall process of risk identification, risk analysis and risk evaluation. International Standardisation Organisation (ISO) Guide 73 (2009) states risk assessment (finding, recognising and describing risk) leads into **risk analysis, (**the process to understand the risk and determine its likelihood), and **risk evaluation.** The Guide highlights that risk evaluation is the process of comparing the results of risk analysis with risk criteria to determine firstly the significance of the risk and whether that degree of risk is acceptable i.e. it is a risk identification and quantification process. This approach is thus a separate activity from **risk management**. Risk management is situated to an organisation's activities and drives an approach that leads to continuous improvement in seeking to eliminate or reduce risk. Risk management is integrated into all organisational activities; involves a structured and comprehensive focus that is dynamic and reflects internal and external risk factors; is inclusive and ensures appropriate and timely involvement of necessary stakeholders and considers the degree of uncertainty in the data available; and uses a holistic approach that considers the social (human and cultural) factors that influence risk (ISO 31000, 2018).

Zio (2016, p141) highlights the dangers of reducing risk assessment to a given number or value because "the values of probability in two different situations could be the same, but their assignment may be based on quite different knowledge, data and information, and eventually assumptions [or degrees of uncertainty], which leave quite different room for surprises of unforeseen events and related consequences." These concerns have particular emphasis when considering food fraud risk assessment to then inform risk management systems. Indeed Manning (2019) argues that predictive risk assessment tools such as hazard analysis critical control point (HACCP), threat analysis critical control point (TACCP), and vulnerability analysis critical control point, (VACCP) have limited value in terms of unknown or unquantifiable food crime threats creating the potential for supply chain vulnerabilities to be both unknowable and unrecognised.

The PAS 96 (2017) Guide highlights the process of undertaking risk assessment for food crime including food fraud throughout a food business. The risk assessment process requires the semi-quantitative determination of likelihood and impact, deriving a risk score and then prioritising a risk management process to reduce risk. The process is supported by a risk matrix leading to the development of a threat identification matrix that at each process step identifies threats, vulnerabilities, access, mitigation, and testing programmes. TACCP is thus a risk assessment and a risk management methodology that uses a risk matrix to prioritise internal and external risk associated with fraud in order to prioritise the allocation of resources and the weighting can be arbitary.

2.2 Vulnerability assessment

Vulnerability is a measure of a system's susceptibility, or conversely resilience, to threat scenarios whereas the level of risk focuses on the consequences and their severity should a threat be realised (Ezell, 2007). Zio (2016) suggests there are multiple perceptions of vulnerability and this will ultimately affect how individuals or teams assess vulnerability. Vulnerability can be considered as a product, technical or system attribute namely:

a. The extent to which vulnerability is a *weakness or flaw* i.e. vulnerability as a "gap or an element of the system that is missing". An organisation can apply vulnerability assessment internally or externally to a whole supply chain in order to identify the weak areas or **hotspots** that are vulnerable to food fraud. An internal vulnerability assessment aids understanding of the weaknesses, criticalities and access points within a specific manufacturing environment where there are food fraud vulnerabilities;
b. By seeing vulnerability as a *risk* i.e. the degree of exposure (likelihood x severity) through the use of tools such as HACCP, TACCP or VACCP;
c. Through considering vulnerability in terms of the *consequences* i.e. the degree of loss or damages;

d. By assessing vulnerability in terms of it reducing the *capacity of an organisation or supply chain to return to a steady state* i.e. determining vulnerability in terms of ability to return to the status quo; or

e. As *failure to be resilient* where resilience is seen as continuous improvement into the long term i.e. determining vulnerability as a failure to be sustainable.

As previously explored in this paper, vulnerability can also be assessed at the micro, meso and macro level of a food system with the resultant challenge that vulnerability assessment requires systems rather than linear (cause and effect) thinking. Vulnerability assessment, if undertaken appropriately, can define the actions required to eliminate weak points, or vulnerability points, and reduce the potential for food fraud to a level the organisation deems acceptable. The GFSI Position Statement on Mitigating the Public Health Risk of Food Fraud (GFSI, 2014) defines FFVA as a two-stage approach. Firstly, " information is collected at the appropriate points along the supply chain (including raw materials, ingredients, products, packaging) and evaluated to identify and prioritise significant vulnerabilities for food fraud" and then secondly, appropriate control measures need to be in place to reduce the risk arising from these vulnerabilities. (GFSI, 2014). Thus, a relevant FFVA informs the development of a control plan. Four years later, the GFSI develop this rationale further into two elements a FFVA, and then a food fraud mitigation plan (GFSI, 2018). Therefore, vulnerability assessment considers the strength, or weakness, of an organisation's food fraud mitigation strategy (Cavin, Cottenet, Blancpain, Bessaire, Frank, & Zbinden, 2016).

Marvin et al. (2016) drew together a set of variables that influence an organisation's vulnerability to food fraud. These criteria including **economic factors** (*e.g*. price, supply and demand); **national factors** associated with the country of origin (*e.g*. governance) and **specific incident related factors** such as fraud type, complexity and the potential for fraud detection to then be able to identify headline predictors of food fraud. Price Waterhouse Cooper (PwC,

2016) differentiates between economic and market factors such as economic conditions, value attributes, financial strains, level of competition and associated strategies, and supply/demand and pricing and **cultural and behavioral factors** such as personal gain or desperation, corruption level, blackmail, victimisation and ethical business culture. As well as the determination of what vulnerability is and how vulnerability is articulated within FFVA tools, the other factor that influences the effectiveness of these tools is the source, situational applicability, quality and validity of the data and then the type of methodological assessment approach in which the data is used. A typology of sampling has been synthesized in this research that is utilised within this paper to differentiate between data and information sources used for a given FFVA (Table 2).

Take in Table 2

The type of sampling is important because it has an impact on how the dataset that is derived can be interpreted. The data can be influenced by whether its source is from regulatory sampling that is based on purposive, random, probability or suspect sampling (see Table 2). Further, the sampling method will influence the accuracy of assessment and also the level of confidence that can be attributed to the result. Further, differentiated categorisation of incidents in databases together with differences in the rationale for how the data is collected can reduce the opportunity for comparative analysis and influence the ability to compare or pool data from multiple datasets (Kowalska, Soon & Manning, 2018). This makes the assessment of food fraud vulnerability based on information held in databases an evolving art.

3. Food information databases

This section compares a series of databases that contain information that can be used by an organisation in assessing their internal or external vulnerability to food fraud. Five databases critiqued here are either open access platforms e.g. the European Union (EU) Rapid Alert for Food and Feed Safety Portal (RASFF) and others are commercial databases that require a subscription payment for access or have some free to access components and other pay to download elements.

3.1 Rapid Alert for Food and Feed Safety (RASFF) Portal - Information Exchange Forum

The RASFF provides an information exchange forum for member states and regulatory bodies to provide food and feed control authorities with information about the measures taken to respond to serious problems either detected in relation to food or feed being imported into the EU or being transferred within the EU (RASFF, 2017). These problems include food safety issues and instances of food fraud. The EU RASFF database is a centralised and searchable database where urgent notifications can be sent, received and responded to (RASFF, 2018). Members, including the European Commission, EU members, the European Food Safety Authority (EFSA), the European Free Trade Association (EFTA) Surveillance Authority, (i.e. Iceland, Liechtenstein and Norway) and Switzerland (RASFF, 2018).

The EU Administrative Assistance and Cooperation (AAC) system operates alongside the RASFF system with the aim of effective information sharing to ensure a swift reaction following detection of public health risks in the food chain and the EU Food Fraud Network (FFN) exchanges information within this system (EC, 2019a). However, data is not freely available except in the form of historic reports. The FFN was established to manage requests for cross-border cooperation and to ensure the rapid exchange of information between the Commission and national authorities in the event of suspected fraudulent practices (Bouzembrak et al. 2018). The use of the RASFF database, either solely or in conjunction with data from national databases has informed research into the types of incidents as well as the value of such databases in informing risk or vulnerability assessment (Tähkäpää, Maijala, Korkeala & Nevas, 2015; Bouzembrak & Marvin, 2016; Marvin et al. 2016). However it should be noted that the data comes from a variety of sources and whilst some standardisation of food classifications has taken place these classifications do not replicate those in other databases which limits the drawing of inference from the pooling of information from multiple datasets

The European Food Safety Authority (EFSA, nd) states: "A standardised system for classifying and describing food makes it easier to compare data from different sources and perform more detailed types of data analysis." The system used by the EFSA for classification is FoodEx2. The EFSA uses RASFF data together with other data from competent authorities throughout the EU to inform the risk assessments undertaken. The EFSA also differentiate between databases in terms of the degree of openness of a dataset and define four maturity levels:

- **Beginners**: in the early stages of transition to an open data policy;
- **Followers**: with a basic open data policy and some advanced features on their portal, but there are limitations for the public use/reuse of datasets;
- **Fast trackers**: greater advancement in their open data journey than followers; and
- **Leaders**: who have implemented an advanced open data policy with extensive portal features (Foster et al. 2019).

These criteria will be used to determine the maturity of the databases considered in this paper in the critique in Table 3.

Take in Table 3

3.2 Food Fraud Risk Information Database

Food Fraud Risk Information (https://trello.com/b/aoFO1UEf/food-fraud-risk-information) is a free and accessible database on incidences of food fraud and emerging threats (Food Fraud Advisors, 2017; Food Fraud Risk Information, n.d.). The site is designed in an easy to navigate manner with highlights of the most recent food fraud incidences by month or by product category. The site allows users to view incidences according to food and drink categories including packaging materials and marketing claims. There is an internal risk rating (low through to high), but the criteria for how risk has been determined is not outlined. Individual incidents can be accessed for free but there is no free downloadable reporting function. A static off-line historic database can be downloaded as an Excel spreadsheet for a on-off fee. The source of information is important here especially in terms of its validity and representativeness. Through exposing incidents, the media plays an increasingly important role in providing the evidence that underpins food fraud governance, influencing the behaviour and attitudes of government, food producers and consumers. However, Zhu, Huang and Manning (2019) highlight there is a difference between the number and type of incident being reported by government reports and those by the media as the media tends to report incidents that have a public interest element and outline more of a "story" associated with the problem (see also the work of Bouzembrak et al. 2018). In essence, developing databases through the use of media material as a source of evidence means that such databases are socially rather than an objectively constructed, thus the evidence is not independent of the social norms that frame it.

3.3 Decernis Food Fraud Database

The former US Pharmacopoeia (USP) Food Fraud Mitigation Database has been renamed the Food Fraud Database and is owned by Decernis. The food fraud database contains information about more than 4000 ingredients with 9000 related records that arise from a variety of sampling activities and methods of data collection (Decernis, 2019). The global database is continuously updated with information from scientific articles, media, regulatory and judicial reports and food industry and trade associations. The database is not open access. The database is developed with incident and inference reports, surveillance records, and analytical methods classified by ingredient (Decernis, 2019). The database allows searching and trend identification with weekly EMA incident reports. The incident reports are given a weighting factor based on the quality of source/evidence with high being allocated to scientific or legal sources and media sources being assigned either a medium or low weighting.

This means that the weighting is based on an objective-subjective paradigm i.e. from objective scientific or legal data to subjective, often socially constructed reports.

3.4 Food Adulteration Incidents Registry (FAIR)

The US Food Protection and Defense Institute (FPDI), is located at the University of Minnesota. The FPDI's Food Adulteration Incidents Registry (FAIR) is a database that compiles global data on both EMA and intentional adulteration of foods. It provides limited access to all users to search entries such as food category, date, adulterated food products, adulterants, method of adulteration and originated location (FAIR, 2019). However, access to recent incidents (within the 5 past years) requires the payment of a subscription. The database catalogues a wide range of EMA incidents and is searchable according to incident characteristics such as food adulterant, production location, data, morbidity or mortality data within a wider interaction of databases for food fraud and food defense.

3.5 Food Integrity Network (FIN)

The Food Integrity (FI) Network (FIN, 2019) is a platform for stakeholders and experts to exchange knowledge and expertise in food authenticity, safety and quality; and to rapidly share information and intelligence about suspected and actual incidents to protect consumers and food products from damaging effects of food misdescription (Source: https://secure.fera.defra.gov.uk/foodintegrity/expertdb/index.cfm). HorizonScan is an associated global database that monitors commodity safety (more than 500 commodities), tracks over 22,000 suppliers and scans the official sites of over 180 countries and more than 100 independent sources daily. The database is searchable by commodity. It is a subscriber only service (FERA, 2019). Email alerts can be tailored to the commodities and issues important to the food business.

3.6 European Commission's Joint Research Centre Europe Media Monitor (EMM) System

The EMM allows users to explore current news items reported by the world's online media in 70 languages over 20000 RSS feeds and HTML pages sites from 7000 generic news portals and 20 commercial news wires (EMM, 2019). The Medical Information System or Medisys is a subset of this dataset that seeks to identify potential threats to public health e.g. communicable disease, terrorist attacks or chemical or nuclear accidents (EMM, 2019). Medisys (Source: http://medisys.newsbrief.eu/) continuously monitors about 900 specialist medical sites plus all the generic EMM news on the main site. The open access site but requires specific searching to access information on food fraud issues. The JRC provide a monthly news report which is freely available online about food fraud incidents.

Researchers have used the Medisys database in their research. An Early Warning System (EWS) was developed that can detect potential food fraud (Mojtahed, 2018). EWS harvests data from the EMM that analyses, curates and aggregates information from traditional and social media globally (EU Science Hub, 2017). The EWS has been further refined and developed into a food fraud tool (MedISys-FF) that collects, analyses and presents food fraud reports published in worldwide media (Bouzembrak et al. 2018). The tool was benchmarked against RASFF, EMA (now FAIR) and HorizonScan and the MedISys-FF system collected food fraud information with high relevance (>75%).

3.7 The US Food And Drug Administration (FDA) Recalls, Market Withdrawals and Safety Alerts Database

The US FDA Recalls, Market Withdrawals and Safety Alerts Database is the US regulators database of recalls (older information is archived but available). The database is searchable and the data can be filtered using key words (see https://www.fda.gov/safety/recalls/). This database has a wider scope than food fraud as it includes all incidents that required a regulatory recall.

3.8 UK Food Surveillance System (UKFSS) Database

The UKFSS is a UK regulatory database that records the analytical and examination results for all food and feed samples, submitted for analysis and/or examination by official control laboratories on behalf of UK local authorities and port health authorities (Food Standards Agency (FSA), 2019). In Scotland, the food sampling data is held separately in the Scottish Food Sampling Database. This public analysis data is not available to the public as an open source.

3.9 Private laboratory databases

Major private laboratories that provide analytical testing and services could contribute formally or informally to the creation, validation and sharing of the data. In the UK such organisations including Campden BRI. Campden BRI have also established with their food company members the Food Industry Intelligence Network (FIIN). The objectives of FIIN are:

- To help ensure the integrity of food supply chains and protect the interests of the consumer;
- To address the recommendations from "The Elliott Report" (Elliott, 2014) for industry to establish a 'safe haven' to collect, collate, analyse and disseminate information and intelligence;
- To share intelligence with governmental bodies to better understand where risks may sit in the UK Food Industry from food fraud, and
- To help divert, detect, deter and disrupt those activities and in doing so, further enhance the reputation of the UK Food Industry (CBRI, 2019).

Other private testing laboratories also hold data on food fraud incidents that may, or may not, be openly available.

3.10 Summary

This section has highlighted the range of databases that can be used to identify historic levels of a particular kind of food fraud associated with a particular food, country or company. The databases are mostly subscribe to view which makes it difficult for small and medium sized companies (SMEs) to access this data in order to be better informed when undertaking FFVA. Spink, Moyer and Speier-Pero (2016) differentiate between four sources of data that ultimately inform FFVA for a given organisation: static external databases, dynamic external internet searches and automated keyword alerts (e.g. Google Alerts); internal datasets on known food fraud incidents within the organisation and lastly subject matter expert insight databases e.g. through groups such as FIIN. Spink, Moyer and Speier-Pero (2016) also developed a four stage food fraud risk assessment. The first stage was a Food Fraud Initial Screening (FFIS) step as a precursor to a FFVA leading to a Corporate Risk Map and then a Resource Allocation Decision. The FFIS approach is divided into 4 steps:

(i) define the assessment scope (*e.g.* specify supply chain and region) and qualitative risk ranking terminologies (*e.g.* very high / high / medium / low / very low);

(ii) (ii) review incidents and suspicious activities *(e.g.* derived from internal sources, expert opinion or external databases);

(iii) (iii) screen for health hazards and enterprise risks *(e.g.* risk assess and rank health hazard and enterprise [financial] risks and post the screening phase, and then to

(iv) (iv) plot the food fraud risks on a risk matrix.

Once completed, the business can then prioritise risks and make informed decisions on the application of resources to mitigate the risk. Spink et al. (2016) conclude that the main advantage of FFIS is that the initial screening will allow for product groups with lower risks or with established controls to be removed from a following FFVA thus allowing subsequent vulnerability assessment to focus more specifically on higher risks. In order to undertake FFIS and the FFVA effectively, the assessment team needs to have access to appropriate data that can inform their decision-making. The tools that are available for FFVA are now considered.

4.0 Food fraud vulnerability assessment (FFVA) tools

The development of FFVA tools and the extent of their usage is now critiqued. The Wolfe and Hermanson (2004) seminal "fraud diamond" model proposes that four factors influence the potential for fraud: motivation, pressure, capability, and opportunity. Capability depends on the individual perpetrators and their ability to undertake fraudulent activities and opportunity to commit the activity, and also the degree of deterrence (Kowalska, Soon, & Manning, 2018). Pressure in this context can be considered to be regulatory or political pressure or alternatively supply chain pressure which can be influenced by market dynamics such as supply and demand gaps, cost pressures, and increasing pressure to meet supply chain standards. Motivation to commit fraud can be simply economic gain, other forms of self-interest or a wish to cause disruption or chaos. The FFVA concept by van Ruth, Huisman & Luning (2017) consists of three key elements and six groups of factors: two elements of the fraud diamond: *opportunities* (in time and place), *motivations* (economic drivers, culture and behaviour), and also *vulnerability reduction* in terms of implementing effective control measures (technical and managerial measures). The FFVA tool was developed and made available as a free downloadable app (van Ruth, Luning, Silvis, Yang, & Huisman, 2018).

4.1 Safe Supply of Affordable Food Everywhere (SSAFE)

Safe Supply of Affordable Food Everywhere (SSAFE) is a not for profit organisation supported by a range of multi-national corporations that has developed a free, science-based online FFVA tool (Excel spreadsheet, online or a phone app) that could be used across the food supply chain (http://www.ssafe-food.org/our-projects/?proj=365#) (SSAFE, 2019). SSAFE developed the FFVA tool with Price Waterhouse Cooper (PwC), Wageningen University, VU University Amsterdam and following consultation with global food industry leaders (PwC, 2019). The use of this tool is advocated by the GFSI (2014). The advantage of the tool is its flexibility and applicability to different products, business size and region. Other key strengths associated with this tool is its versatility (available in 11 languages and maximise tool accessibility), and its online and offline usage capability. The tool is built upon the principles of HACCP as the FFVA also requires a team approach (*e.g*. security, finance, quality assurance). Users are guided by an initial decision tree analysis to determine the scope of assessment and then are taken through a series of questions (n=50). Each question contains 3 fixed answers. This tool uses a systematic approach where users are provided with an explanation of why the question is important and each fixed answer contains information to assist users in selecting the most appropriate answer. Once completed, users will be able to assess the level of food fraud vulnerability and the means for its control (SSAFE, 2019). This tool is designed to be a practical vulnerability assessment tool suited to guiding manufacturers who may not have detailed and specific knowledge on food fraud and vulnerability. SSAFE can be used as both an intrinsic and extrinsic vulnerability assessment tool. Examples of intrinsic vulnerability assessed by SSAFE are internal processing activities, ethical business culture and business strategies. Extrinsic vulnerability can include the price of raw materials, corruption level of countries where suppliers are located and the level of competition across a selected food sector. The tool does not provide for developing specific mitigation techniques for a given vulnerability, but instead users can refer to information sources and references provided in the tool for further guidance.

4.2 Food Fraud Advisor's Vulnerability Assessment Tool

Food Fraud Advisors have designed two types of vulnerability assessment tool one being the generic FFVA (now version 3) and the other based on the method recommended by the British Retail Consortium (Food Fraud Advisors, 2018). The tools are based on Excel spreadsheets that develop a vulnerability assessment for each raw material and ultimately a report that can be used for management and third party audits (see Table 4). The tool is not free a fee is payable for its use.

Take in Table 4

The FFVA BRC Method tool allows the user to assess their raw materials and ingredients only for vulnerability to EMA, substitution and dilution. A series of questions are used to assess the likelihood of occurrence (*e.g.* historic incidents, price fluctuations, complexity of supply chain) and likelihood of detection (*e.g.* direct sourcing, supply chain audits, routine testing) by answering simple yes / no questions. Answers and user's comments are generated in the results page providing food businesses with the scope, vulnerability rating and description of the characteristics of the raw materials / ingredients. The extrinsic vulnerability rating is based on a semi-quantitative 5 x 5 matrix of likelihood of occurrence x likelihood of detection which generates three levels of risks (high, medium and low). The questions do address elements of the fraud diamond including pressure, capability and detection.

The other conventional FFVA is designed to meet the requirements of GFSI food safety standards such as FSSC 22000 and has a wider scope in terms of the types of food fraud addressed (see Table 1) and the scope includes processing aids and packaging. There is also the option of the pre-screening method. This approach can then inform the controls required to reduce vulnerability.

4.3 EMAlert – Economically Motivated Adulteration – Vulnerability Assessment Tool

The Grocery Manufacturers Association (GMA) and Battelle have worked in partnership to develop EMAlert, a software tool that enables food manufacturers to analyse and understand EMA vulnerabilities (EMAlert, 2019). This tool is different to the others in that it includes a behavioural model to consider fraudster decision making and how this impacts on food fraud vulnerability. The tool is a pay for use subscription based system. The advantage of this system is that it can assess a greater number of commodities (50) in one analysis compared with SSAFE and EMAlert considers economic (motivation, pressure, opportunity), ease (capability) and historical drivers.

4.4 Challenges with FFVA

The challenge with FFVA is that there is a risk of under or over predicting when using the qualitative criteria developed within the assessment tools. Some tools as outlined use a matrix approach. A risk matrix is a proven mechanism to semi-quantitatively characterise and rank risks but the overall risk score obtained by categorising likelihood and severity can be imprecise and vague (Markowski & Mannan, 2008). This semi-quantitative approach can produce uncertainties in the risk category determined (Manning, 2013). Some tools may use a summative approach to determining risk, others to use multiplier factors when this is combined with overprediction or underprediction of some risk factors *e.g.* likelihood this will lead to a lack of consistency across the tools that can be used. Lack of technical know-how, failing to access appropriate databases, poor datasets or inappropriate use of databases will also limit the efficacy of FFVA tools. The emerging nature of food fraud incidents with there always being the potential for new actors, new agents being used means that the use of FFVA should not be an annual activity that is static and historic, but needs to be real-time and reactive if the process is going to provide a meaningful and relevant risk score.

As outlined in this paper there is multiple terminology being used to determine vulnerability and risk which is a challenge in itself. This emerging terminology from evolving definitions of authenticity (Sumar & Ismail, 1995) to consideration of types of fraud and the lack of a harmonized definition of food fraud (Bouzembrak et al. 2018), human behavioral science, motivation, methods, ethical problems and social and criminal implications (Spink and Moyer, 2011; Manning & Soon, 2016; Lord, Elizondo, & Spencer, 2017). Specialists from social science and criminology backgrounds tend to give more emphasis to the social, economic and legal aspects of food fraud, while food scientists tend to focus on chemical characteristics of food, economic gain and the impact in terms of public health concerns. More collaborative work should be done, particularly with social science specialists, to achieve a universal definition of food fraud. CODEX proposed an Electronic Working Group (EWG) to review CODEX gaps and to create a definition and scope for food fraud, food integrity, food authenticity and other food fraud related terms. This is a major step forward to potentially incorporate food fraud into the formal Codex Alimentarius which can revamp the food supply chain as food fraud countermeasures will become a requirement when conducting business (Spink, 2017).

Undertaking a supply chain FFVA requires the collection of information at the appropriate steps (points) along the supply chain including raw materials, ingredients, products, packaging, dispatch; evaluating each step to identify and prioritizing significant vulnerabilities for food fraud, and then developing appropriate countermeasures such as monitoring and testing strategies, supplier audits and anti-counterfeit technologies (GFSI, 2014). Within a manufacturing business, effective FFVA requires the collection and evaluation of information on potential food fraud vulnerability associated with the products, processes and people employed (SSAFE, 2019a). Spink and Moyer (2011a) argue that FFVA tools are not holistically applicable to quantify or predict food fraud incidents because an understanding of criminology and behavioural science is also required. However, FFVA will allow food businesses to map possible fraud scenarios associated with the materials and products that the organisation procures, produces and sells, in order to accurately identify the potential threat, the controls required and the mechanisms for updating such assessments if the evidence changes in the future. Therefore, vulnerability is specific to the supply base, ingredients, product, processes and activities undertaken by a given food manufacturer, processor or retailer. The vulnerability assessment process is dynamic and needs to be revisited both routinely in line with formal procedures and also reactively in the event that FFVA outputs are out of date, for example a vulnerability changes or appears because of a new supplier, harvest failure associated with one particular material or an increase in demand for a particular material when supply remains constant. Therefore, FFVA tools identify the degree of food fraud vulnerability at a given time and in a given set of circumstances.

5.0 Discussion

Collaborative efforts between private and non-profit sector and governmental bodies will help to grow food fraud networks to address and tackle food fraud at a landscape level are hampered by the "pay to use" requirements of many incident databases and FFVA tools. A lack of consistency in coding within databases and the lack of a universal definition of food fraud needs to be addressed so it is possible to link, harmonise and connect multiple databases to share information and intelligence within and between networks. Food fraud assessment networks are developing. In the EU the FIN network is developing these collaborative knowledge building as is the work of the JRC (EU Science Hub, 2016). To date four EU wide coordinated control plans (horsemeat, fish, honey and online food supplements and novel foods) had been developed to determine the extent of fraudulent practices in the food sector (EC, 2018). These approaches are considering food fraud together with food and feed safety in a concerted approach but there is no global, universal, central intelligence database that is available to the food industry, regulators and investigators that brings together all the intelligence and information that is currently available. This creases an inequity in the food sector in that many SMEs cannot access such information. However some databases and tools are free to download and if they have sufficient knowledge and understanding SMEs can use this tools to start undertaking FFVA. Whilst some FFVA tools aid organisations to develop a vulnerability profile or vulnerability register for the business, not all go to the next step of developing a control plan. As social network analysis research develops with regard to food fraud especially when combined with crime data mining and criminal network analysis this will assist further in the development of FFVA tools. Emerging tools that use data mining will take existing FFVA and detection approaches forward towards more predictive food fraud modelling.

Manning and Soon (2014) sought to draw together the elements of both a predictive and a reactive model for determining food fraud. This model included: determining the situational and contributing factors for food fraud, identifying the databases that provided information of interest in order to use FFVA tools and then to identify the factors that influence the resultant risk ranking. This approach is underpinned by the use of intelligence from industry, enforcement bodies, media and social network surveillance, economic trends, unusual factors that could affect supply and demand dynamics and consider their effect. The detect and react phase of the Manning and Soon (2014) model differentiates between passive laboratory surveillance as part of routine testing programmes and active laboratory surveillance which is targeted on known adulterants that is utilised when the risk ranking status changes. This brings forward an important element of vulnerability assessment that is the use of passive (static) systems and models or the use of reactive and smart systems that are constantly evolving as new intelligence comes in. In these tools it can be shown that vulnerability can be considered as a product, technical or system attribute: in terms of a weakness or flaw. An internal vulnerability assessment can build understanding of the weaknesses, criticalities and access points within a specific manufacturing environment where there are food fraud vulnerabilities. Other tools, or stages within tool application see vulnerability as a *risk* i.e. the degree of exposure (likelihood x severity) reflect on vulnerability in terms of the *consequences* i.e. the degree of loss or damages should the incident occur. The other two elements of vulnerability described in this paper are: the ability or capacity of an organisation or supply chain to return to a steady state i.e. determining vulnerability in terms of ability to return to the status quo; and the need for resilience and for the organisation or supply chain to drive continuous improvement in the medium to long term. This needs to be addressed in further iterations of models that drive effective vulnerability reduction action plans.

6. Conclusion

The databases considered here both complement and underpin the various FFVA tools described, but due to multiple types of food fraud issue, a lack of skills and understanding by people of how to use FFVA and variable scopes of assessments means that inconsistency in vulnerability scoring can occur. There is a clear requirement for more industry level cohesiveness and consistency in how FFVA is undertaken to address both intrinsic and extrinsic food fraud vulnerability.

FFVA tools differ from conventional purely food safety hazard analysis or risk assessment tools as FFVA also requires consideration of a number of socio-economic factors. These include: economic conditions, social and opportunistic issues, knowledge levels of organization that might make them more vulnerable to fraud, as well as an understanding of criminal behavior. The impact of fluctuations in market conditions that influence both perpetrator opportunity, level of economic gain derived and thus the rationalization of whether to commit fraud, or not are also of importance in assessing vulnerability. The challenge for policy makers and the industry is therefore to develop FFVA tools so that they can support assessment of existing vulnerabilities and also overcome knowledge gaps in where and how fraud might occur. Further, the situational vulnerabilities for a given organization or food supply chain is of importance to effectively inform the appropriate options for food fraud control and mitigation at the organization and supply chain level.

References

Ali, M. H., Tan, K. H., & Ismail, M. D. (2017). A supply chain integrity framework for halal food. *British Food Journal, 119*(1), 20-38.

BRC Global Standards (2018). Food safety. Available at: https://www.brcglobalstandards.com/brc-global-standards/food-safety/ [Accessed 19 August 2018]

Bouzembrak, Y., Steen, B., Neslo, R., Linge, J., Mojtahed, V. & Marvin, H. J. P. (2018). Development of food fraud media monitoring system based on text mining. *Food Control, 93*, 283-296.

Bouzembrak, Y., & Marvin, H. J. (2016). Prediction of food fraud type using data from Rapid Alert System for Food and Feed (RASFF) and Bayesian network modelling. *Food Control, 61*, 180-187.

Brucker (2018). FT-NIR for targeted and non-targeted adulterant screening. Available at: https://www.bruker.com/applications/food-agriculture/food-safety/food-fraud.html [Accessed 3 June 2018]

Campden BRI (2019). Food Industry Intelligence Network (FIIN). Available at: https://www.campdenbri.co.uk/news/fiin.php [Accessed 20 April 2019]

Cavin, C., Cottenet, G., Blancpain, C., Bessaire, T., Frank, N., & Zbinden, P. (2016). Food adulteration: from vulnerability assessment to new analytical solutions. *CHIMIA International Journal for Chemistry, 70*(5), 329-333.

CWA 17369:2019 – "Authenticity and fraud in the feed and food chain – Concepts, terms, and definitions" Available at: https://shop.bsigroup.com/ProductDetail?pid=000000000030390716 [Accessed 3 June 2019]

Davidson, R. K., Antunes, W., Madslien, E. H., Belenguer, J., Gerevini, M., Torroba Perez, T., & Prugger, R. 2017. From food defence to food supply chain integrity. *British Food Journal, 119*(1), 52-66

Decernis (2019). Food Fraud Database. Available at: https://decernis.com/solutions/food-fraud-database/ [Accessed 14 April 2019]

de Kieffer, D. E. (2010). Chapter 10: Where is the gray market? Underground economies and illegal imports. Legal and business strategies to address illegitimate commerce. Oxford University Press, Oxford.

Dennis, M.J (1998). Recent developments in food authentication. *Analyst, 123*(9), R151-R156.

EMAlert (2019). EMAlert Vulnerability Assessment Tool. Available at: https://www.emalert.org/ [Accessed 19 April 2019]

European Commission (EC) (2014). Horsemeat: one year after – Actions announced and delivered! Available at: http://europa.eu/rapid/press-release_MEMO-14-113_en.htm [Accessed August 2018].

European Commission (EC) (2018). EU coordinated control programmes. Available at: https://ec.europa.eu/food/safety/official_controls/eu-co-ordinated-control-plans_en [Accessed 3 June 2018]

European Commission (EC) (2019a). Administrative Assistance and Cooperation System Available at: https://ec.europa.eu/food/safety/food-fraud/aas_en [Accessed 20 April 2019]

EC Regulation 882/2004. Regulation (EC) No 882/2004 of the European Parliament and of the Council. Official Journal of the European Communities L165/1. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004R0882 [Accessed 3 June 2018]

ECHA (European Chemicals Agency) (2016), Forum methodology for recommending analytical methods to check compliance with REACH Annex XVII restrictions. European Chemicals Agency, 2016 Helsinki, Finland. doi: 10.2823/904598

EFSA (European Food Safety Authority) (nd) Data standardization. Available at: https://www.efsa.europa.eu/en/data/data-standardisation {Accessed 16 March 2019]

Elliott, C. (2014). Elliot review into the integrity and assurance of food supply chain networks – final report, a national food crime prevention framework report. HM Government, London.

Europe Media Monitor (EMM) (2019). European Commission's Joint Research Centre. Competence Centre on Text Mining and Analysis. Europe Media Monitor Available at: http://emm.newsbrief.eu/overview.html [Accessed 19 April 2019]

EU Food Fraud Network (2018). EU Food fraud network. Available at: https://ec.europa.eu/food/safety/food-fraud/ffn_en [Accessed 3 June 2018]

Eurofins (2018). Food authenticity. Available at: https://www.eurofinsus.com/food-testing/testing-services/authenticity/ [Accessed 3 June 2018]

Eurostat (2010). Typology of sampling strategies. Eurostat European Commission. Working group “Food Safety Statistics". May 2010. Available at: https://circabc.europa.eu/sd/d/2fc47bd9-237a-4c79-93e0-6a4665cf3591/201_Typology_sampling_strategies.pdf. [Accessed 16 March 2019]

EU Science Hub (2016). The JRC in Geel (Belgium). Available at: https://ec.europa.eu/jrc/en/about/jrc-site/geel [Accessed 3 June 2018].

EU Science Hub (2017). Europe media monitor – Newsbrief. Available at: https://ec.europa.eu/jrc/en/scientific-tool/europe-media-monitor-newsbrief [Accessed 3 June 2018]

Everstine, K. Spink, J., & Kennedy, S. (2013). Economically motivated adulteration (EMA) of food: common characteristics of EMA incidents. *Journal of Food Protection*, *4*, 560-735.

Ezell, B. C. (2007). Infrastructure vulnerability assessment model (I-VAM). *Risk Analysis: An International Journal*, *27*(3), 571-583.

FAIR (2019). Food Adulteration Incidents Registry. Available at: https://foodprotection.umn.edu/tools-services/food-adulteration-incidents-registry-fair [Accessed 18 April 2019]

FERA (2019). HorizonScan. Available at: https://www.fera.co.uk/food-safety/support-tools/horizon-scan [Accessed 20 June 2019]

FIN (Food Integrity Network) (2019). Food Integrity Network. Available at: https://secure.fera.defra.gov.uk/foodintegrity/expertdb/index.cfm [Accessed 19 April 2019

Fiorino, G. M., Garino, C., Arlorio, M., Logrieco, A. F., Losito, I., & Monaci, L. (2018). Overview on untargeted methods to combat food frauds: A focus on fishery products. *Journal of Food Quality*, doi.org/10.1155/2018/1581746

Food Fraud Advisors (2017). Food fraud risk database. Available at: https://www.foodfraudadvisors.com/food-fraud-risk-information/ [Accessed 3 June 2017]

Food Fraud Advisors (2018). Vulnerability assessment tools. Available at: https://www.foodfraudadvisors.com/vulnerability-assessment-tools/ [Accessed 19 August 2018]

Food Fraud Risk Information (n.d.). Recent food fraud incidents. Available at: https://trello.com/b/aoFO1UEf/food-fraud-risk-information [Accessed 3 June 2018]

Food Standards Agency (2019a) Privacy Notice. UK Food Surveillance System. Available at: https://www.food.gov.uk/about-us/privacy-notice-uk-food-surveillance-system [Accessed 19 April 2019]

Foster, D., Locker, A., Maldonado, A., O'Dea, E., Llorente, J.S., Sõgel, J. Tapanainen, H Thomas, S., Tirian, A. Richardson, J., Marsic, I., Pintado, C. Czomba, B., Ringwald, F., & Gabbi, S. (2019). Publication of scientific data from EU-coordinated monitoring programmes and surveys. European Food Safety Authority (EFSA). EN-1544 Available at: http://www.efsa.europa.eu/sites/default/files/scientific_output/EN-1544.pdf [Accessed 16 March 2019]

GFSI. (Global Food Safety Initiative). (2014). GFSI Position on mitigating the public health risk of food fraud July 2014. Available from: http://www.mygfsi.com/news-resources/news/295-gfsi-position-paper-on- mitigating-the-public-health-risk-of-food-fraud.html. [Accessed 4 April 2019].

GFSI (Global Food Safety Initiative). (2018). Tackling food fraud through food safety management systems. Available at:

https://www.mygfsi.com/files/Technical_Documents/201805-food-fraud-technical-document-final.pdf [Accessed 4 April 2019].

Huddersfield University (nd) Glossary of terms, Available at: http://onlineqda.hud.ac.uk/glossary.php [Accessed 16 March 2019]

ISO 31000: 2018 Risk management. Guidelines ISO. Paris

ISO Guide 73:2009 Risk management vocabulary ISO. Paris

Kendall H, Naughton P, Kuznesof S, Raley M, Dean M, Clark B, et al. (2018) Food fraud and the perceived integrity of European food imports into China. *PLoS ONE* 13(5): e0195817.

Kingston, J. K. C. (2017). Representing, reasoning and predicting fraud using fraud plans. *11th International Conference on Research Challenges in Information Science* (RCIS), doi: 10.1109/RCIS.2017.7956528

Kowalska, A., Soon, J. M., & Manning, L. (2018). A study on adulteration in cereals and bakery products from Poland including a review of definitions *Food Control*, *92*, 348-356

Lord, N., Elizondo, C. J. F., Spencer, J. (2017). The dynamics of food fraud: The interactions between criminal opportunity and market (dys)functionality in legitimate business. *Criminology & Criminal Justice, 17*(5), 605-623.

Lotta, F., & Bogue, J. (2015). Defining food fraud in the modern supply chain. *European Food and Feed Law Review*, 114-122.

López, M. I., Trullols, E., Callao, M. P., & Ruisánchez, I. (2014). Multivariate screening in food adulteration: Untargeted versus targeted modelling. *Food chemistry*, *147*, 177-181.

Manning L. (2019), Food defence: refining the taxonomy of food defence threats, *Trends in Food Science and Technology,* 85, 107-115,

Manning, L., & Soon, J.M., (2016). Food safety, food fraud and food defense: a fast evolving literature, *Journal of Food Science*, 81(4) R823–R834

Manning, L., & Soon, J. M. (2014). Developing systems to control food adulteration. *Food Policy*, *49*, 23-32.

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

Manning, L. (2016). Food fraud: policy and food chain. *Current Opinion in Food Science, 10*, 16-21.

Markowski, A. S. & Mannan, M. S. (2008). Fuzzy risk matrix. *Journal of Hazardous Materials*, *159*(2008), 152-7.

Marvin, H. J., Bouzembrak, Y., Janssen, E. M., van der Fels-Klerx, H. J., van Asselt, E. D., & Kleter, G.A. (2016). A holistic approach to food safety risks: Food fraud as an example. *Food Research International*, *89*, 463-470.

Mojtahed, V. (2018). Early warning system for food fraud detection: Machine learning applied to food big data. Food Integrity. Available at: https://www.fera.co.uk/media/wysiwyg/events/Food_Integrity_WP8-Fera.pdf [Accessed 3 June 2018]

Nestle (n.d.). Food Fraud Prevention, Economically Motivated Adulteration, Available at: http://www.nestle.com/asset-library/documents/library/documents/suppliers/food-fraud-prevention.pdf [Accessed on 28 August 2018].

PAS 96 (2017). Guide to protecting and defending food and drink from deliberate attack. Available at: https://www.food.gov.uk/sites/default/files/pas962017.pdf [Accessed on 28 August 2018].

PwC (Price Waterhouse Cooper) (2019) Food fraud vulnerability assessment. Available at: https://www.pwc.com/foodfraud [Accessed 20 April 2019]

PwC (Price Waterhouse Cooper) (2016). Food Fraud Vulnerability Assessment and Mitigation: Are you doing enough to prevent food fraud? Available at: https://www.pwc.com/gx/en/services/food-supply-integrity-services/assets/pwc-food-fraud-vulnerability-assessment-and-mitigation-november.pdf [Accessed 25 August 2018]

RASFF (2018). The Rapid Alert System for Food and Feed. Available at https://ec.europa.eu/food/safety/rasff_en [Accessed 28 August 2018]

RASFF (2017) The Rapid Alert System for Food and Feed: 2017 Annual Report. Available at: https://ec.europa.eu/food/sites/food/files/safety/docs/rasff_annual_report_2017.pdf [Accessed 16 March 2019]

Silvis, I. C. J., van Ruth, S. M., van der Fels-Klerx, H. J. & Luning, P. A. (2017). Assessment of food fraud vulnerability in the spices chain: An explorative study. *Food Control, 81*, 80-87.

Slovic, P. (1999). Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. *Risk analysis*, *19*(4), 689-701.

Soon, J. M., & Manning, L. (2017). Whistleblowing as a countermeasure strategy against food crime. *British Food Journal*, *119*(12), 2630-2652.

Spink, J. (2017). Review – CODEX CCFICS23 Meeting summary – Action to define food fraud and related terms. Available at: http://foodfraud.msu.edu/2017/05/05/review-codex-ccfics23-meeting-summary-action-to-define-food-fraud-and-related-terms/ [Accessed 23 June 2018]

Spink, J., & Moyer, D. C. (2011a). Defining the public health threat of food fraud. Journal of Food Science, 76(9), R157–R162.

Spink, J., & Moyer, D. C. (2011b). Backgrounder: Defining the public health threat of food fraud, in research grants. Minneapolis, MN: National Center for Food Protection and Defense (NCFPD) (pp. 7). Minneapolis, MN: National Center for Food Protection and Defense (NCFPD). http://www.ncfpd.umn.edu

Spink, J., Moyer, D. C., & Speier-Pero, C. (2016). Introducing the Food Fraud Initial Screening model (FFIS). *Food Control*, *69*, 306-314.

SSAFE (2019). Introduction to SSAFE Food Fraud Vulnerability Assessment tool. Available at: http://www.ssafe-food.org/our-projects/?proj=365# [Accessed 20 April 2019].

Sumar, S., & Ismail, H. (1995). Adulteration of foods – past and present. *Nutrition & Food Science*, *95*(4), 11-15.

Tähkäpää, S., Maijala, R., Korkeala, H., & Nevas, M. (2015). Patterns of food frauds and adulterations reported in the EU rapid alert system for food and feed and in Finland. *Food Control*, *47*, 175–184.

U.S. Food and Drug Administration, U.S. FDA (n.d.). Vulnerability assessment resources. Available at: https://www.accessdata.fda.gov/scripts/FDTraining/course_01/module_03/lesson_04/FD01_03_04_030.cfm [Accessed 17 August 18]

U.S. Food and Drug Administration, U.S. FDA (2017). Food defense plan builder download. Available at: www.accessdata.fda.gov/scripts/fdplanbuilder/download.cfm [Accessed 17 August 18]

Van Ruth, S. M., Luning, P. A., Silvis, I. C. J., Yang, Y., & Huisman, W. (2018). Differences in fraud vulnerability in various food supply chains and their tiers. *Food control*, *84*, 375-381.

Van Ruth, S. M., Huisman, W. & Luning, P. A. (2017). Food fraud vulnerability and its key factors. *Trends in Food Science & Technology*, *67*, 70-75.

Wang, C.-S., Van Fleet, D. D. & Mishra, A. K. (2017). Food integrity: a market-based Solution. *British Food Journal*, *119*(1), pp.7-19,

Wolfe, D. T., and Hermanson. D.R. 2004. The Fraud Diamond: Considering the Four Elements of Fraud. *CPA Journal*, 74(12), 38-42.

Wright, M., Ibrahim, F., Manning, L. & McKellar, D. (2014). Research to explore the current and historic trends in food sampling with particular reference to sampling and surveillance undertaken by Local Authorities and Port Health Authorities. Report for the Food Standards Agency. Available at: [Accessed 16 March 2019]

WHO (World Health Organization) (2008), *Terrorist threats to food. Guidance for establishing and strengthening prevention and response systems*. World Health Organization. Food Safety Issues Series. WHO, Geneva.

Xiu, C., & Klein, K. K. (2010). Melamine in milk products in China: Examining the factors that led to deliberate use of the contaminant. *Food Policy*, *35*, 463-470.

Zhu, X., Huang, I.Y & Manning, L. (2019). The role of media reporting in food safety governance in China: a dairy case study, *Food Control* 96, 165-179

Zio, E. (2016). Challenges in the vulnerability and risk analysis of critical infrastructures. *Reliability Engineering & System Safety*, *152*, 137-150.

Table 1. Types of food fraud. (Adapted from Spink & Moyer, 2011a; 2011b; Lotta & Bogue, 2015; Spink et al., 2016: CWA,17369:2019).

Types of food fraud
Deception during manufacture Overrun (intentional overproduction, sometimes called the "third shift" Overtreating (including adding more water than allowed by regulation),
Diversion into illicit supply chains Diversion, Smuggling Theft
Duplication Simulation, Counterfeiting
Interventions with the food product Adulteration Addition Substitution, Product tampering Removal Unapproved processes
Misrepresentation Misdescription Record tampering Misrepresentation of food characteristics, country of origin, food ingredients or food packaging, Claim violation False or misleading statements made about a product for economic gain Underweight product

Table 2. Types of sampling

Term	Description
Sampling	The process of selecting a subgroup of a population to represent the entire population.
Sampling strategy	A sampling strategy is the approach used to select the units of the target population subject to official controls e.g. businesses, foodstuffs, etc
Routine surveillance	Sampling strategy where samples are taken to check compliance levels and detect previously unidentified issues. Routine surveillance may be risk-based, with samples selected to match some form of risk rating. Surveillance may be planned and funded at a national level, such as through EU competent authorities through national sampling programmes, or locally determined. Local sampling plans may be informed by national priorities as well as local assessment of risks.
Types of sampling	
Availability sampling	See convenience sampling
Census sampling	Sampling strategy that samples the totality of the population on which the data is reported.
Convenience or convenient sampling	A non-probability sampling strategy that uses the most easily accessible people (or cases) to participate in a study. Also know as opportunity sampling and availability sampling or strategy based on the selection of a sample for which units are selected only on the basis of feasibility or ease of data collection. It's a not random sampling. The data reported refer themselves to units selected according to this strategy.
Judgmental sampling	See suspect sampling
Objective sampling	Selection of a *random sample* from a population on which the data are reported.
Opportunity sampling	See convenience sampling
Probability sampling	The probability sampling method gives each eligible element/unit a known (and commonly equal) chance of being selected in the sample; random procedures are employed to select a sample using a sampling frame. Also known as random sampling
Purposive sampling	A non-probability sampling strategy in which the researcher selects participants who are considered to be typical of the wider population (sometimes referred to as judgmental sampling)
Quota sampling	A non-probability sampling strategy where the researcher identifies the various strata of a population and ensures that all these strata are proportionately represented within the sample to increase its representativeness
Random sampling	See probability sampling
Selective sampling	Sampling strategy is based on the selection of a random sample from a subpopulation (or more frequently from subpopulations) of a population on which the data are reported. The subpopulations are can but are not always determined on a risk basis. The sampling from each subpopulation is not proportional: the sample size is proportionally bigger for instance in subpopulations considered at high risk. This sampling includes also the case when the data reported refer to censuses on subpopulations
Snowball sampling	A non-probability sampling strategy whereby referrals from earlier participants are used to gather the required number of participants
Statutory sampling	Official sampling undertaken where the products to be tested as well as frequency of the said testing is set out in law to control specific health risks.
Stratified sampling	Probability based sampling where the population is divided into specific groups (strata) and a sample is drawn from each group.
Suspect sampling	Suspect sampling or enforcement related sampling is a form of judgmental sampling where the selection of an individual product or establishment is done in order to confirm or reject a suspicion of non-conformity. Sampling strategy where samples are taken as part of enforcement investigations.

Sources: (Huddersfield University, nd; Eurostat, 2010; Wright, Ibrahim, Manning & McKellar, 2014)

Table 3. Comparison of databases that provide information that can be used in a food fraud vulnerability assessment.

Name	Accessibility	Openness Maturity Level	Purpose	Functionality	Source of data	Downloading of data	FFVA Capacity
RASFF System	Free to access	Leaders	Competent authority information exchange forum	Searchable with classifications	Purposive, random or reactive, sampling from regulatory sampling	Free to download	Database only no additional vulnerability assessment tool.
Food Fraud Risk Information Database	Free to access top level data – pay to view database	Followers	Information exchange forum	Categorised into lists by product type or time period. Ability to subscribe to a list or an individual card	On-line news items and alerts	Data lists are accessible but pay to download a historic database on a spreadsheet	Database with a risk rating (high, medium, low) risk assessment criteria not shown. No additional vulnerability assessment tool.
Decernis Food Fraud Database	Pay to access Annual subscription or 30 day subscription	Beginners	Database to enable FFVA	Categorised by ingredients with search capabilities and analytics	Scientific articles, media, regulatory and judicial reports and food industry and trade associations	No free data	Database and associated FFVA capability within the tool.
Food Adulteration Incident Registry (FAIR).	Pay to access annual subscription Information over five years old is free	Followers	Incident database	Categorised by incident	Publically available data	Data over five years old is freely accessible	Database and associated with FOODSHIELD a collaborative platform and the Intentional Adulteration Assessment Tool (IAAT) for food defence
Food Integrity Network (FIN)	Subscription based on personal credentials – Stakeholder or expert Horizonscan is a subscription only service	Beginners	Incident database	Categorised by incident	Suspected and actual incidents of adulteration	No free data	Database and knowledge network – linked to Horizon Scan. No FFVA capability.
MedISys-FF	Open access	Leaders	European Commission database	Categorised by type of disease, food safety hazard or threat	Publically available media information	Freely available	Database. No FFVA capability.
The US FDA Recalls, Market Withdrawals and Safety Alerts Database	Open access	Leaders	Regulators database of issued alerts	Categorised by recall type by commodity e.g. food, cosmetics etc.	Regulatory data. Publically available database	Freely available	Database of alerts that is searchable. Older data is archived but available. No FFVA capability.

UKFSS Database	Private database	None	Incident and sampling database	Private system	Regulatory sampling	No freely available data	Database. No FFVA capability.
Private laboratory databases	Private databases	None	Sampling databases	Private system	Market sampling systems	No freely available data	Database. No FFVA capability.

Table 4. Comparison of the two FFVA tools provided by Food Fraud Advisors (2018)

<table>
<tr><th>Vulnerability Assessment Tool v3.0s</th><th>Vulnerability Assessment Tool (BRC method)</th></tr>
<tr><td>Suitable for ingredients, raw materials such as processing aids, additives, packaging materials, finished products, dietary supplements, herbal remedies (oral), functional food additives and ‘boosters’</td><td>Suitable for food ingredients</td></tr>
<tr><td>Addresses all aspects of food fraud</td><td>Addresses economically motivated adulteration, substitution and dilution</td></tr>
<tr><td>Based on the methodology recommended by Michigan State University Food Fraud Initiative</td><td>Based on the method recommended by the British Retail Consortium (BRC)</td></tr>
<tr><td>Generates a report containing:
Purpose and scope
Likelihood of food fraud and impact (severity) of food fraud
The results of the vulnerability assessment in a risk matrix format
Optional initial screening (pre-filter) step
Optional controls report</td><td>Generates a report containing:
Purpose and scope
Likelihood of occurrence of food fraud for the material
Likelihood of detection of food fraud
The results of the vulnerability assessment in a risk matrix format</td></tr>
<tr><td>Suitable to meet the requirements of all major food safety standards and can be used by food businesses that do not operate a formal food safety management system</td><td>Designed to meet the requirements of BRC Food Safety Issue 8.</td></tr>
<tr><td colspan="2">Easy to review and update</td></tr>
<tr><td colspan="2">Results and data can easily be copied and pasted into other documents</td></tr>
<tr><td colspan="2">Save, file and print the results for your next audit</td></tr>
</table>