



Short Communication

Role of analytical testing for food fraud risk mitigation – A commentary on implementation of analytical fraud testing

Role of analytical testing for food fraud mitigation



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ABSTRACT

Food fraud is of high concern to the food industry. A multitude of analytical technologies exist to detect fraud. However, this testing is often expensive. Available databases detailing fraud occurrences were systematically examined to determine how frequently analytical testing triggered fraud detection. A conceptual framework was developed for deciding when to implement analytical testing programmes for fraud and a framework to consider the economic costs of fraud and the benefits of its early detection. Factors associated with statistical sampling for fraud detection were considered. Choice of sampling location on the overall food-chain may influence the likelihood of fraud detection.

1. Introduction

Food fraud and economically motivated adulteration is a serious issue for the food industry. As food chains become more complex and global in their range, the opportunities for food fraud has multiplied and become more diverse in their nature. Food fraud can arise as a result of misrepresentation associated with: product integrity (e.g. counterfeit product, expiration date); process integrity (e.g. diversion of products outside of intended markets); people integrity (e.g. characterizations such as the cyber criminals and hacktivist) and data integrity (e.g. improper, expired, fraudulent or missing common entry documents or health certificates) of information accompanying the food item throughout the supply chain (Manning, 2016; Manning and Soon, 2018; Bouzembrak et al., 2018). Food fraud can occur at all stages in the food and feed chain. A number of high profile food fraud events in recent years, melamine in infant formula (FAO, 2008), the horse meat incident in Europe (Elliott, 2014; O'Mahony, 2013), have contributed to an increased focus by manufacturers and regulatory authorities on fraud prevention. A large amount of analytical approaches and tools have been developed for the detection of fraud or

adulterated food products and ingredients in the food supply chain (Downey, 2016). An analytical tool is any instrumental based test for an attribute (or multiple attributes) in a food. The challenge for food businesses is to identify potential fraudulent activity that could affect their operation which may require the implementation of a monitoring programme to detect the fraud. This monitoring programme could in part be paper based and augmented by analytical testing. However, many of the developed analytical tests are expensive. The challenge is to decide when to use any or improved analytical testing and the nature and frequency of testing in a cost effective fashion.

The objective of this work is to explore several aspects relating to the role of analytical testing for food fraud risk mitigation. In the first instance, available databases detailing fraud occurrences were systematically examined to determine how frequently analytical testing triggered fraud detection. This work was complemented by a structured survey of industry stakeholders to determine their experience of using analytical detection to detect fraud. This paper then develops a framework for deciding when to implement analytical testing programmes for fraud and a framework to consider the economic considerations in fraud

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detection. The economic risks of food fraud provide the input for a cost-benefit analysis of more rigorous testing programmes to detect fraud. Finally, some of the main factors associated with statistical sampling for fraud detection are outlined.

2.1. Food fraud occurrence

As a starting point, a number of publicly available databases were examined to assess the use of analytical testing in detecting fraudulent behaviour. The European Union Rapid Alert System for Food and Feed (RASFF) is a food safety management and reporting system that also records food fraud incidents but only in cases where there is a non-compliance or potential threat to public health. Previous studies have used the RASFF database to predict food fraud type using a Bayesian network modelling approach (Bouzembrak and Marvin, 2016; Marvin et al., 2016). Analysis of food fraud alerts reported in RASFF and reports collected from the media by the food fraud filter in the MediSys (<http://medisys.newsbrief.eu>) database for the period 2014–2015 suggested that only a small portion of the food frauds reported (<8%) were detected due to analytical control (Bouzembrak et al., 2018). The majority of the food fraud reports in RASFF were related to missing or improper documentation. This can be understood as passive fraud, but it does not include deceptive practices to consumers. To obtain further information on the use of analytical measurements by industry in food fraud protection, a web based survey among industry stakeholders (approximately 60 potential respondents) of the EU FP7 funded FoodIntegrity project (www.foodintegrity.eu) was carried out in the period April 2017 to June 2017. These companies were approached because of their previously shown interest in food fraud and knowledge on this topic obtained via the FoodIntegrity project dissemination activities. Because of the limited sample size and the bias regarding the companies involved, this survey should be considered as exploratory. In this survey all types of food fraud were considered and a definition including examples were provided at the beginning of the questionnaire. In total, there were 29 respondents, representing a large variety of food sectors (fruit (n = 7), vegetables (5), dairy (11), feed (3), alcohol (5), meat (6), fish (1), pasta (1), eggs (1)). Note that in the survey, several large food companies were included that operate in different food sectors and that therefore several sectors will be selected by respondents representing these companies. For 86% of the respondents, fraud monitoring was reported to be part of their quality assurance programme. For those undertaking fraud monitoring, 67% used both documentation control and analytical measurements; 26% used documentation only control; whereas 7% reported using only

analytical measurements. Interestingly, 38% of the respondents undertaking fraud monitoring reported that fraudulent activity had been detected in the previous 24 months and this was mostly due to analytical measurements (77%). Frequently, targeted methods (81.5%) were used (Fig. 1A) and involved testing for authenticity, intentional contaminations and mixing (Fig. 1B). The majority of the respondents (63%) indicated that analytical methods should be improved and both non-targeted and rapid (hand held) methods were mentioned in their written submissions. In summary, this survey indicated that food fraud monitoring is important for the industry sector and is often embedded within the Quality Assurance function.

2.2. Food fraud impact and risk analysis

The impact of food fraud incidences depend on the magnitude of the fraud, the vulnerability of the food industry to the harmful consequences of the fraud and the frequency of the fraud occurring. The reported frequency of fraud incidences is on the rise (Fig. 2). In the period from 2010 to 2016, 2847 food fraud incidences were recorded in the HorizonScan database (<https://horizon-scan.fera.co.uk>). Almost half of the incidents were reported by RASFF and the other half were gathered from other sources such as national websites of regulatory authorities. The peak in Fig. 2 in 2013 is clearly the response to the well-publicised horsemeat fraud event as public awareness and regulatory activities were high. As a response to this increasingly reported threat, the industry needs to revise their food fraud management schemes to be able to effectively mitigate

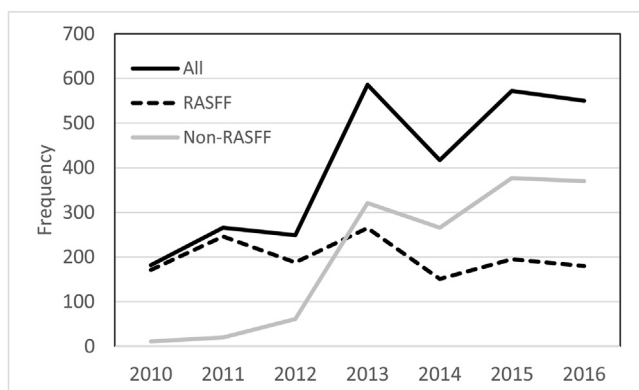


Fig. 2. Reported international food fraud trends (Source HorizonScan, 2017).

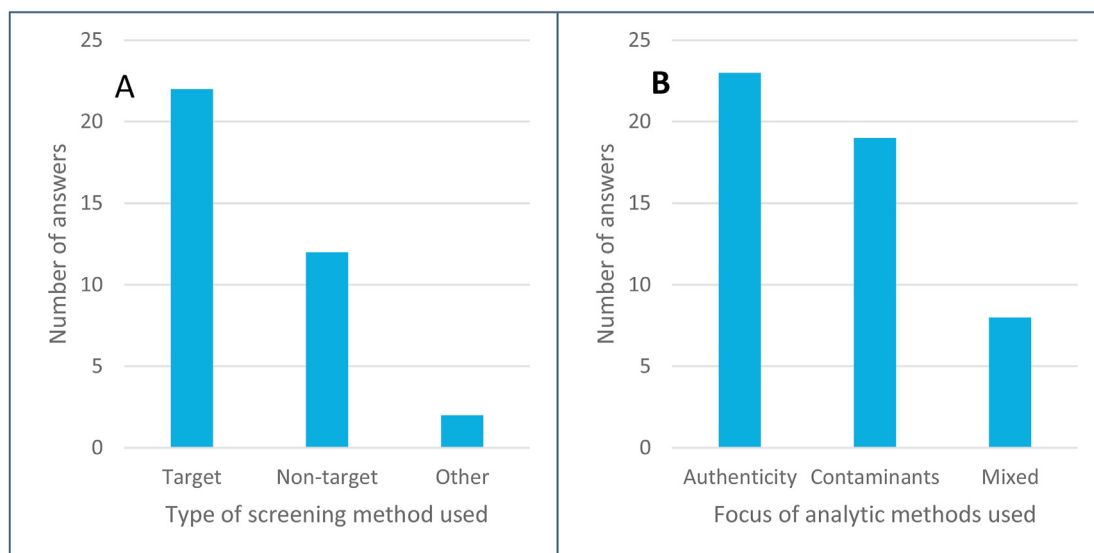


Fig. 1. Types of screening methods used (A) and focus of analytical methods (B) used by respondents to detect fraud.

such risks in the future. Assessing and monetizing fraud risk is a critical component of any broader risk management strategy undertaken by a food business. An effective strategy requires decision makers to allocate their (limited) resources across all risks including fraud risk as well as the more traditional hazards associated with chemical and microbial contaminants.

The total economic cost of food fraud comprises of a combination of direct or indirect and tangible or intangible damages that needs to be avoided. The below table outlines a conceptual framework for the economic impact damage of food fraud risks developed within the FOODINTEGRITY project. Tangible damages are costs that there are markets for valuing them, e.g. brand damage. Intangible damages are costs that there is no market for them to be estimated, such as environmental costs. Direct damages are those that are directly related to producer/distributor of fraudulent commodity during the time (usually immediately after) or geographical boundary of the event/incident. Indirect damages follow and last for a longer time after the occurrence of the incident and affect other entities beyond the producer/distributor e.g. loss of tax income. The economic risks of food fraud can be categorized into 4 quadrants based on whether the damages are tangible/intangible or direct/indirect (Fig. 3).

Traditionally, risk analysts only focused on the first quadrant (i.e. direct tangible) as data are readily available for its assessment and the end users such as food industry is more interested in this category. However, policy makers including national food safety authorities should also be aware of other three quadrants as they have an impact on the broader welfare of the society. In summary, the total damages associated to a food fraud incidence can go beyond the traditional measurement of financial risks because it must include the overall burden of it on the society, environment and industry beyond a given food business operator or industry. The true damages of food fraud incidences can so include damages (i.e. benefit losses) which are in general difficult to identify or quantify since other factors may need to be considered. The total damages of fraud comprise of combination of direct or indirect and tangible

or intangible costs that are ultimately carried by both the company involved and society itself.

In setting up a framework to assess the vulnerability to fraud, two important questions are i) what to look for and ii) how to prioritise potential fraudulent activities (Van Ruth et al., 2017). The starting point to set up a screening or monitoring system for food fraud issues is the development of a simple decision tree or checklist that risk managers can follow. It starts with the requirement for a good and thorough knowledge of the product portfolio and the supply chain with a keen appreciation for potential food fraud issues and vulnerabilities, preferably informed using available databases documenting previous fraud incidences relating to the products in question (Cnossen et al., 2009). The use of a simple two dimensional matrix approach adapted for food fraud issues is suggested, further adapted from an approach detailed by Spink et al. (2017). Based on production volume against value (Fig. 4), a priority estimate can be made for ingredients, raw materials or products present in the company. A more detailed approach could take into account other issues such as the expected level of safety risk and the case that a low volume/low value combination could lead to a high impact if the adulterated product is used as a minor ingredient and mixed with expensive products. At the same time, fraud risks can also be prioritised based on a probability assessment, which uses several factors that need to be assessed or addressed by the company (Fig. 4). This can be compared to a failure mode effects analysis (FMEA) approach where a two dimensional risk matrix is extended with an additional dimension representing detection (Scipioni et al., 2002; Cnossen et al., 2009). Firstly, price volatility research is needed to show whether the price is relatively constant or very volatile and how the commodity or product is traded. From this a judgement can be made as to the potential economic gain that could be made through fraudulent activity under the prevailing conditions. This assessment is dynamic and may change with time, requiring regular revisits and/or continuous reassessment. Secondly, supply chain information is required: how is the supply chain organized and certified

	Tangible	Intangible
Direct	Logistic and shipping costs Warehousing Replacement costs Production shutdown Brand damage Destruction cost Crisis management costs Value of the contaminated products Loss of share value Legal fees Penalties and fines	Loss of trust in businesses Health costs Loss of lives Environmental damage
Indirect	Loss of gross profit (loss of future contracts, ...) Rehabilitation costs (advertising, brand restoration, etc.) Loss of tax revenue for government/authorities Loss of jobs Increase costs of insurance premium Increase costs of testing and quality assurance New regulation costs	Loss of trust in authorities Social welfare costs due to loss of jobs Bereavement Long terms health impacts

Fig. 3. Conceptual framework for the economic impact of food fraud risks.

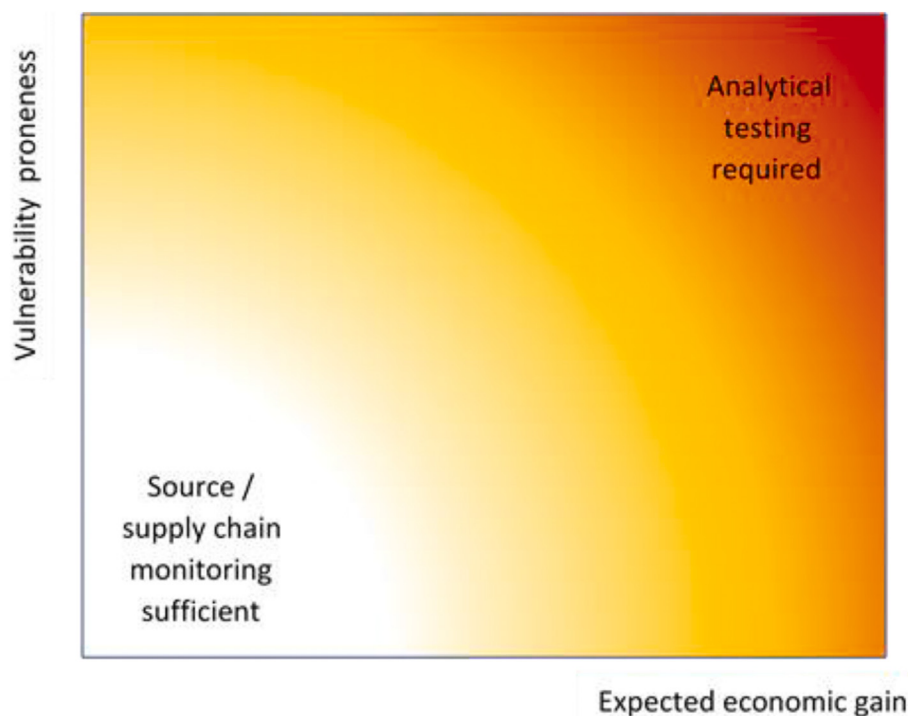


Fig. 4. Food fraud risk probability analysis.

(audited); are there supply chain vulnerabilities? Vulnerability could be possibly called a passive characteristic of product in the chain. A more active characteristic would be what we call 'Fraud Prone Factor' - does the product or chain have specific attributes that attract opportunities and attention from fraudsters. As can be seen in Figs. 3 and 4, both matrices allow a relative quantification to set priorities. Although this is based on common sense and expert intervention, these simple tools can guide companies to set the right priorities and allocate budget and resources appropriately.

For priority fraud risks, a management matrix can then be used to help identify mitigation measures and actions (Fig. 5). We distinguish three categories of mitigation measures and actions: i. information and data management; ii. sampling and analysis; and iii. risk management measures. Information and data management is primarily a desk top action where data integration and interpretation needs to take place. Incoming (external) information can be gathered with commercial tools and services (including expert consultation) but more general information from within the company, from customers and suppliers, as well as media sources locally and internationally. One of the major goals here is to "see the opportunity - think like a criminal" (Van Ruth et al., 2017). Sampling and analysis decisions are clear when within the food business own responsibility, but this also covers certified analysis results from suppliers and authorities. Risk management measures are the actual implementation of systems, procedures, processes, and desk top analyses. The final question remains - what to look for? Again, we distinguish three categories of fraud to cover (Fig. 5), a known fraud, a situation where a fraud vulnerability has been identified and an unknown/unexpected fraud. These three potential fraud categories have different fraud mitigation strategies as outlined in Fig. 5. Obviously, with hindsight experience for some products or ingredients, it is known what sort of potential frauds can be expected. Here the most concrete measures and actions are described: regular targeted analysis, supply chain auditing and analysis, and source directed measures.

Once a proper vulnerability analysis has been performed (internally and externally), a screening of these vulnerabilities is opportune, both with good information management and more or less random analytical control, both targeted at typical changes and deviations (but not

necessarily anomalies). Consistent and up to date quality systems and procedures help to eliminate and detect vulnerabilities (Van Ruth et al., 2017). Of course, the unknown and unexpected will always appear, but for certain with the above mentioned measures and actions some will surely be detected, although most probably not as an early warning. To complement these measures and actions, additional approaches are the use of advanced and innovative tools for horizon scanning and emerging risk identification (Van de Brug et al., 2014). One can use this type of information, combined with practical and historical knowledge to perform a scenario analysis and preparation for what might arise as realistic scenarios. In doing so, by merely being aware of early signals and developments, a company raises its fraud preparedness as some frauds will not be completely new or unexpected. Instrumental analytics here are not targeted but multi screening with the use of advanced statistics to find the anomalies in the "forest of peaks". Anomaly searching and finding is the key start in this area of the unknown and unexpected. There is an urgent need for better analytical screening methods that could potentially screen for multiple adulterants. More often than not analytical methods are targeted and based on intelligence, suspicion or random scanning. However, the availability of appropriate screening techniques would enable food businesses and regulators to routinely scan foods at various levels in the production/processing chain. To this end, food profiles should be enabled so that any change in a profile can easily be detected and examined. This should be relatively easy for simple foods like oils, sugars and single ingredient foods, though more challenging but not impossible for multi-ingredient foods.

2.3. Sampling issues

Sampling for fraudulent activity poses several unique challenges compared to other sampling activities regularly undertaken in the food industry such as for chemical or microbiological hazards. Unique challenges include:

- The nature of the fraud and its occurrence in the food chain may not be known.
- The occurrence of the fraud may well be transitory.

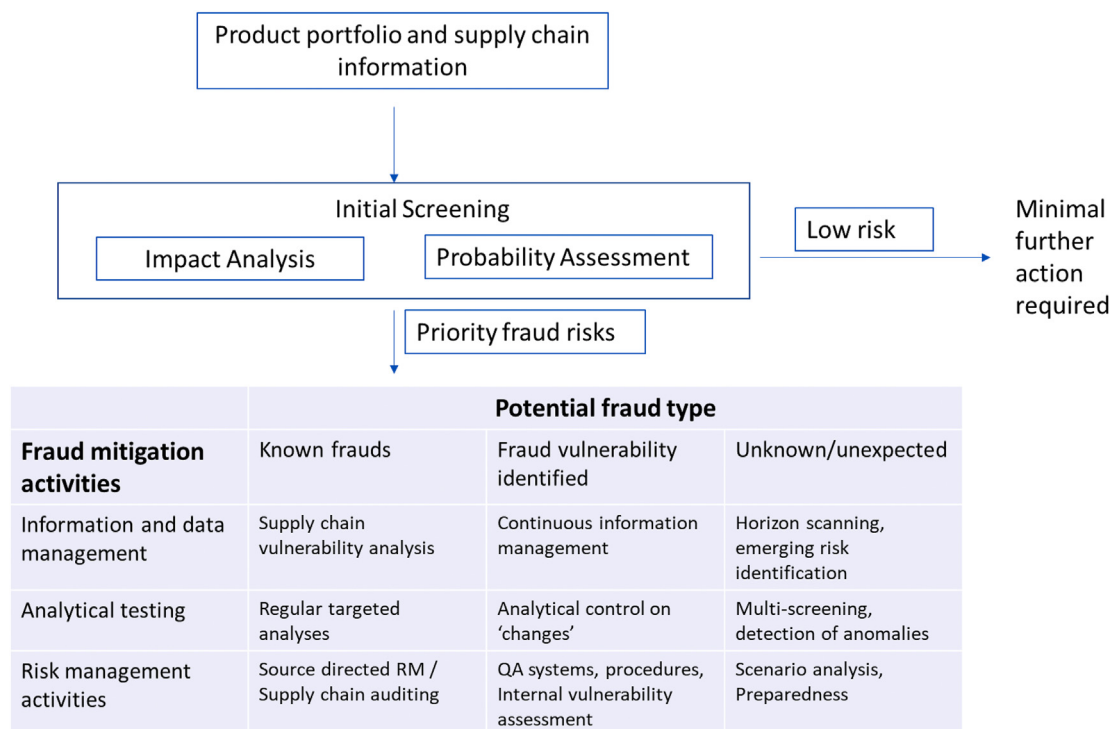


Fig. 5. Priority food fraud management framework.

- The occurrence of the fraud may be targeted at a particularly weak point in the chain to avoid detection.
- Fraudulent activity could well be occurring in the chain outside a food business direct area of control.
- The perpetrators of the fraud will most likely take active steps to hide the fraudulent activity.

If after applying the food fraud analysis decision tree approach outlined in Section 2.2, it is decided to use analytical techniques to monitor for food fraud, an appropriate sampling plan needs to be developed. In general, the effectiveness of a sampling plan is dependent on the analytical technique, the number of sample units taken and the size of the sample unit taken (FAO/WHO, 2016). When fraudulent activity is suspected, additional information, perhaps arising from audit activity, documentary evidence or previous experience may influence the sampling plan and the extent and focus of sampling carried out. The actual amount of testing may be limited or focused in its nature. The analytical techniques may well be used simply to confirm that suspect product is indeed fraudulent.

In the absence of such additional information, the choice of a statistically robust sampling plan is essential if analytical technologies are being considered to monitor for food fraud. Testing for fraudulent material is generally a form of acceptance sampling whereby the decision to accept or reject is based on the number of non-conforming sample units detected. Acceptance sampling can be done by either variables sampling plans or attribute sampling plans (Montgomery, 2005). With variable sampling, the analytical test returns a numerical measurement; an example would be using freezing point depression as the basis of detecting added water in milk. In attribute sampling, the test result is either 'conforming' or 'nonconforming' – genuine or fraudulent. Generally the effectiveness of a sampling plan can be assessed using an operating characteristic curve which indicates the probability of acceptance depending on the percentage of non-conforming items. The principle of operating characteristic curves is well described in a FAO/WHO publication (FAO/WHO 2016). The shape of an operating characteristic curve depends on the parameters of the sampling plan adopted. The limitation of all acceptance sampling plans is that for modest sample numbers, the

probability of detecting non-conforming material becomes very low once the percentage of non-conforming material drops below about 1%. As an example, with attribute sampling, if the sample number is five units and the acceptance number is zero, then that sampling plan will accept 95.1% of batches when the level of non-conforming material is 1%. This has significant implications for the detection of fraudulent product if the level of fraudulent product is only a small fraction of the total market. The often substantial cost of testing for fraudulent product has to be set against the likelihood of detecting the fraud using analytical approaches.

Simple acceptance sampling plans assume that the non-conforming material is homogeneously distributed in the food stuff. However, fraudulent or adulterated product will often be heterogeneously distributed in the supply chain. The fraudulent material will typically enter the food chain at a distinct point and will be subsequently propagated through the food chain, often getting more and more dispersed as it moves. This could be further complicated if the food fraud attribute that is being tested is not directly related to the actual fraud event perpetrated. As a theoretical example, a fraudulent operator may introduce a consignment of genetically modified soya bean into a food chain specifying non-genetically modified (GM) product only. To start with, this consignment will represent a 'point source' contamination of the supply chain. However, as this consignment of GM soya bean is mixed with other consignments of non-GM soya bean and gets transported along a distribution chain, the GM material will become more and more mixed and dispersed through non-GM material, potentially making detection of the GM material more and more difficult. The fact that fraudulent material is often unevenly distributed (heterogeneously distributed) has implications for the likelihood of detection. The heterogeneous distribution of microbial contamination in foods has been actively investigated in recent years (Jongenburger et al., 2012; Gonzales-Barron and Butler, 2011; Mussida et al., 2013). Heterogeneity often makes it more difficult to detect the non-conforming material and may require additional sampling. Simulation work has indicated that in certain fraud situations, systematic sampling can increase the probability of detection compared to random sampling when there is localised or heterogeneous distribution of defective product (Butler, 2017). Bouzembrak and Van der Fels-Klerk (2018) investigated sampling strategies to detect a

heterogeneously distributed contamination in a batch of herbs and concluded that the effectiveness of the sampling plan was influenced by the sampling strategy.

Location of the sampling point in the food chain is a consideration. If sampling is undertaken at a point in the food chain upstream of where the fraudulent material is being introduced, then clearly no fraudulent material will be detected. If sampling is undertaken at or shortly after the point of insertion of the fraudulent product, the fraudulent product will be comparatively concentrated (heterogeneously distributed) with implications for the likelihood of detection. However, if fraudulent material is successfully detected at this point, the source of the fraud may well be identified and a significant amount of the fraudulent material may be recovered or prevented from entering the market place. If testing is carried out later in the food chain, the fraudulent material will most likely have become more dispersed and in the event of a positive detection, a more limited amount of fraudulent product may be recovered and the original source of the fraud may not be identified.

Test sensitivity (the ability of the test to correctly identify fraudulent material) and specificity (the ability to correctly identify genuine material) is an important consideration in designing a sampling plan. Ideally any analytical technique being considered for detecting fraud should have a high sensitivity and specificity. [Cajka et al. \(2016\)](#) discussed the validation process (including the determination of test sensitivity and specificity) required for mass spectrometry-based approaches for food fraud detection. With some analytical techniques, a high sensitivity can be achieved. [Von Bargaen et al. \(2014\)](#) reported a high sensitivity for a HPLC–MS/MS based method for the detection of horse or pork in a beef meat matrix using specific marker peptides down to a concentration of 0.24% horse or pork in beef. Tandem mass spectrometry was also used successfully to quantify beef and pork meat concentration in a Bolognese sauce, a highly processed food ([Prandi et al., 2017](#)). However, authenticity of products such as olive oil in terms of geographical origin or adulteration with cheaper oils can be more problematic. [Vaclavik et al. \(2009\)](#) reported a limit of detection of 6% addition of hazelnut oil in extra virgin olive oil using advanced mass spectrometry techniques. The ability of many analytical techniques will be problematic when the level of addition of fraudulent material is low or has been diluted by subsequent mixing operations later in the food chain.

In summary, the sampling issues associated with potential fraud detection pose several distinctive challenges as the occurrence of the fraud may well be transitory, happening at any stage in the production/distribution chain and actively hidden by the perpetrators. The choice of location within the chain to conduct sampling is critical. Too early, and the fraudulent activity may be missed entirely. Monitoring late in the chain, close to retail, runs the risk that the fraudulent product has been mixed or dispersed and potentially more difficult to detect. The final choice of location will generally be specific to individual products, however, issues relating to the best point in the chain to sample should always be included when developing a sampling plan to detect fraud.

3. Conclusion

The decision to use analytical testing for food fraud risk mitigation is not straightforward. The decision is influenced by many factors including the nature of the fraud, the likelihood of it occurring, the cost to the company arising from the fraud, the economic cost of testing, the probability of detection and availability of appropriate test techniques. In many cases, the decision to use analytical testing for fraud detection may be triggered by documentary or other irregularities that have aroused suspicion of fraud. In these situations, the decision to use analytical techniques and the scope of testing required may be relatively well defined. However, food safety management systems encourage preventative management of hazards. The preventative management of food fraud presents unique challenges to the food industry as the nature of the fraud and its occurrence in the food chain most likely will not be known

in advance and the occurrence of the fraud may well be transitory. It is therefore recommended to maintain an ongoing baseline level of intelligence gathering activities that may detect potential irregularities within the food supply chain. This may then trigger a decision to perform more specific or extensive analytical testing of material likely to be fraudulent. The nature and potential for fraud is very dependent on the food product, its complexity and number of ingredients, the scale of operation, the location of manufacturing facilities and its supply/distribution chains and many other relevant factors. For these reasons, every food business operator must make a structured assessment of the risk of fraudulent activity to their business and the implementation of proportional risk management measures. This commentary provides a structured guidance to the food industry and regulatory authorities as to when it is appropriate to use analytical testing to mitigate food fraud risk, the economic considerations in making that decision as well as some of the statistical sampling issues that will arise to counteract fraudulent activity.

CRedit authorship contribution statement

Francis Butler: Conceptualization, Project administration, Funding acquisition, Writing – original draft. **Niels Lucas Luijckx:** Investigation, Funding acquisition, Writing – original draft. **Hans J.P. Marvin:** Investigation, Funding acquisition, Writing – original draft. **Yamine Bouzembrak:** Investigation, Writing – original draft. **Vahid Mojtahed:** Investigation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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