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A Global Threat With Public Health and Economic Consequences

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1.1 Introduction

Food fraud prevention and risk mitigation has become a fast-evolving area for both regulatory agencies and auditing bodies, as well as the laboratory testing field. Although fraud is economically motivated, it can also have major public health consequences, for example, when unapproved substances or unlabeled food allergens are introduced into the food supply. Three major food fraud incidents that occurred between 2007 and 2013 prompted an increase in regulatory focus on the issue and consumer awareness. The first was the fraudulent introduction of the high-nitrogen chemical melamine (and a secondary contaminant, cyanuric acid) into wheat gluten and other “vegetable protein” products intended for use in animal feed and pet foods (U.S. Food and Drug Administration, 2018). Thousands of animals became sick or died from ingesting the combination of melamine and cyanuric acid, and more than 150 brands of pet food were recalled (Lau, 2011; U.S. Food and Drug Administration, 2018). Unfortunately, this incident portended a similar situation that occurred in the human food supply just a year later. Melamine was found to have been fraudulently added to milk supplies in China, resulting in widespread illness in infants who were particularly at risk due to the consumption of infant formula as their sole source of nutrition (Li et al., 2019). Officially, 300,000 infants were reported as
becoming ill and 6 were reported to have died; however, we will likely never know the true scale of the effects of this incident. Finally, in 2013, authorities reported the detection of horse DNA in food products at retail that were labeled as containing ground beef (Lawrence, 2013). This prompted extensive testing in the marketplace and the discovery of alarming amounts of substitution of horse meat for beef, along with the slow uncovering of a coordinated network of suppliers complicit in the fraud.

Each of these incidents had industry-wide effects and resulted in substantial changes to business and regulatory operations that continue to this day. Because of this, these are the incidents that are most often cited when referring to food fraud. However, there have been numerous other examples of food fraud occurring since 2007. For example, the U.S. Department of Justice (2015) has prosecuted multiple individuals and companies due to the illegal importation of misdeclared honey from China intended to avoid antidumping duties and sometimes known to contain illegal antibiotics. In 2013 turmeric was recalled for containing levels of lead higher than would be expected from environmental causes (Food Safety News, 2013). Lead contamination of spices, which is often determined to be intentionally added, is a pervasive problem that has resulted in lead poisoning cases in children (Hore et al., 2019). In 2019 Europol seized 150,000 L of sunflower oil mixed with coloring agents that was labeled as “extra-virgin olive oil” (Al-Zoubi, 2019). Additional examples are discussed within the other chapters of this book. Food fraud incidents with a direct connection to acute health effects in consumers, or the unwitting consumption of a product that is not typically consumed in some cultures (such as horse meat), tend to be very well reported by media outlets. Those without acute health effects, which is the majority of incidents, result in less media coverage and, by extension, lower consumer awareness. However, all forms of food fraud have damaging effects on brand integrity, consumer confidence, business revenue, and markets.

1.2 Definition and categories of food fraud

Food fraud is generally considered to be the intentional misrepresentation of the identity or contents of a food product or food ingredient for economic gain. Various organizations around the world have adopted definitions for “food fraud.” The Global Food Safety Initiative (GFSI) defines food fraud as “a collective term encompassing the deliberate and intentional substitution, addition, tampering or misrepresentation of food, food ingredients or food packaging, labelling, product information or false or misleading statements made about a product for economic gain that could impact consumer health” (The Consumer Goods Forum and Global Food Safety Initiative, 2018).

The European Commission (2019) has stated that food fraud is “any suspected intentional action by businesses or individuals for the purpose of deceiving purchasers and gaining undue advantage therefrom, in violation of the rules referred to in Article 1(2) of Regulation (EU) 2017/625 (the agri-food chain legislation).” This includes dilution or substitution, concealment (hiding low-quality ingredients), unapproved enhancements (to enhance quality attributes), the production of counterfeit products (intellectual property rights infringement), mislabeling (specifically, false claims on packaging), and gray market/forgery (unofficial production or theft). The Food Standards Agency of the United Kingdom defines food fraud as
“deliberately placing food on the market, for financial gain, with the intention of deceiving the consumer” (Elliott, 2014). In the United Kingdom the term “food crime” has been adopted to refer to the situation where food fraud “no longer involves random acts by ‘rogues’ within the food industry but becomes an organized activity perpetrated by groups who knowingly set out to deceive, and or injure, those purchasing a food product” (Elliott, 2014). Two terms that define the state of food that is free from fraud are “food authenticity” (food that is “not altered or modified with respect to expected characteristics including safety, quality, and nutrition”) and “food integrity” (the state of being “genuine and undisputed in its nature, origin, identity, and claims, and to meet expected properties”) (Morin and Lees, 2018).

The U.S. Food and Drug Administration (FDA) unofficially adopted the term “economically motivated adulteration” (EMA), which is “the fraudulent, intentional substitution or addition of a substance in a product for the purpose of increasing the apparent value of the product or reducing the cost of its production, i.e., for economic gain. EMA includes dilution of products with increased quantities of an already-present substance (e.g., increasing inactive ingredients of a drug with a resulting reduction in strength of the finished product, or watering down of juice) to the extent that such dilution poses a known or possible health risk to consumers, as well as the addition or substitution of substances in order to mask dilution” (Economically Motivated Adulteration; Public Meeting; Request for Comment, 2009). This definition of EMA does not appear to include acts such as counterfeit products, gray market production, and theft. Therefore it is sometimes considered to be a “subset” of food fraud. However, history has shown that, in the case of a prosecuted fraudulent act involving food, US courts will come to their own conclusion about what constitutes adulteration versus mislabeling (or fraud) (Forte, 1966). A recent legal white paper suggested that EMA needed to be defined “more expressly and completely” to allow a “more proactive approach to abating this fraud” (Roberts and Turk, 2017). In addition, a “well-developed definition would help establish a regulatory bar …” and “… facilitate global harmonization.”

For the purposes of this book, we are not aligning to one particular definition of food fraud. We present various definitions in this introductory chapter for context and to demonstrate the similarities among them. This book is intended to broadly cover the concept of intentional food misrepresentation with the goal of economic gain (or reducing loss) in any form. Chapter authors may define their chosen use of terminology for their respective chapters. Certain commodities are more prone to certain types of fraud than others and, therefore, particular chapters may focus on specific types of food fraud. For example, intellectual property infringement (counterfeit) tends to be more of a problem in branded beverages (both alcoholic and nonalcoholic) than in products such as seafood or meat. Finally, the methods for addressing the risk of certain types of fraud—particularly, counterfeit branding, gray market production/sales, and theft—are different from those typically used in a traditional food safety and quality system. Strategies for the prevention of intellectual property infringement, theft of vehicles or warehouse stores, or gray market production will necessarily involve crime prevention efforts such as packaging security. While some of these types of fraud may be addressed in particular chapters, this book is largely focused on those types of fraud that could effectively be addressed in a food safety and quality control system, such as dilution, substitution, and artificial enhancement.
The scope of food fraud globally cannot be known, due in part to the deceptive nature of the act and limitations in surveillance and reporting mechanisms. It is generally acknowledged that some detections of potential fraud within the supply chain, if the fraudulent product has not yet reached the consumer, are handled within business-to-business relationships and not reported publicly. There are various databases and tracking systems for fraud, each of which employs its own methods for data standardization and summarization (discussed in more detail in Chapter 3: Food Fraud Mitigation: Strategic Approaches and Tools). Certain commodities, such as olive oil, honey, seafood, dairy products, meats, and spices, are widely considered to be the most prone to fraud. As shown in Fig. 1.1, the commodity with the highest number of records in the Decernis Food Fraud Database is dairy ingredients, followed by seafood and meat/poultry products. While records for dietary supplements are not currently included in the Food Fraud Database, it should be noted that this commodity is also highly vulnerable to fraud (discussed in Chapter 17: Fraud in Dietary Supplements).

When examining food fraud records separated by category (Fig. 1.2), the most represented type of fraud in the Food Fraud Database is dilution/substitution (the addition of a substance to increase weight or volume or the substitution of one ingredient/food for another), followed by artificial enhancement (the addition of a substance for functional effect), fraudulent labeling (misrepresentation of production practices), and the use of unapproved or undeclared biocides (preservatives, antimicrobials, antifungal agents, etc.). The most common forms of dilution/substitution reported are “nonfood” (the use of a substance that is not

![Graph showing commodities with the highest number of records in the Food Fraud Database, based on a total of 4098 records. Source: https://decernis.com/solutions/food-fraud-database/. Note: This source was used due to familiarity with the database by the book editors; other databases may reflect different results.](image)
approved for use in foods), “animal origin” (the undeclared replacement of a product from one animal species with another), “other” (such as the replacement of a plant-based product with an animal-based product or vice versa), and “botanical origin” (the undeclared replacement of one plant species with another). Records can be associated with multiple types of fraud, and it is notable that almost 20% (768/4098) of fraud records involve dilution/substitution with a substance that is not approved for use in foods.

1.3 Food fraud risk mitigation

In order to address the risks of food fraud, many organizations and government agencies now require companies to develop mitigation plans (discussed in detail in Chapter 2: History of Food Fraud and Development of Mitigation Requirements and Standards). For example, GFSI benchmarking requirements require that companies conduct a food fraud vulnerability assessment and develop a food fraud prevention plan for susceptible food products. The US Pharmacopeia and other organizations have developed a number of resources to assist the food industry in assessing their vulnerability to fraud and developing mitigation plans. These resources will be discussed in Chapter 3, Food Fraud Mitigation: Strategic Approaches and Tools, and additional strategies particular to specific commodities or sectors are presented in later chapters.
Food fraud risk mitigation generally includes a review of various factors that can either contribute to or deter fraud in food supply chains. These factors include a review of what is known about the history of fraud, supply chain structure and supplier relationships, auditing requirements, the geopolitical and economic environment in source countries, and testing methods and frequency. It is generally acknowledged that “you cannot test your way to food safety” and the same is true for food authenticity (or food fraud prevention). Testing plays a vital role in validating procedures and policies, but it cannot be the only solution to the problem of food fraud. Particularly for small- and medium-sized businesses, a heavy reliance on laboratory testing to deter fraud is not always practical or feasible. Therefore this book emphasizes strategies that enable stakeholders to reserve their testing resources for the riskiest ingredients.

1.4 Layout and purpose of this book

This book is meant to serve as a practical resource on the topic of food fraud and compliance with regulatory and industry standards. It is our hope that this book will help the food industry comply with GFSI benchmark and regulatory requirements to address food fraud in a preventative manner. The first part of the book contains chapters that broadly address the history of food fraud, the development of mitigation requirements and standards, strategic approaches and tools for food fraud mitigation, analytical detection methods and strategies, and the criminology of food fraud. Because the nature of the risks and approaches to mitigation can differ by commodity group, the second part of the book presents commodity-specific (or sector-specific) chapters for certain groups of foods and beverages known to be affected by fraud. Each commodity- or sector-specific chapter will cover topics such as specific vulnerabilities to fraud, the main types of fraud committed, a brief discussion of methods for detection, and strategies for mitigation. Our goal is to provide the reader with a greater understanding of the major fraud challenges and vulnerabilities faced by the food and dietary supplement industries; regulatory and industry standards for mitigating vulnerability to food fraud; tools and strategies for conducting a food fraud vulnerability assessment and developing a mitigation plan; and commodity-specific information on food fraud vulnerabilities, detection methods, and strategies for mitigation.

Note to the reader

The chapters in this book were completed prior to or during the early stages of the COVID-19 pandemic. By all accounts, the pandemic has affected the global economy in an unprecedented manner. Some of these chapters cite economic predictions regarding the growth of the food industry that were made before the global economy was impacted by the pandemic. It is also important to note that the pandemic has greatly affected both domestic and global food supply chains. Due to the restricted supply and increased demand for certain foods and food ingredients, there are increased opportunities for fraud to occur. As is the case with any major global event, the effects of the pandemic on food supply

Food Fraud
chains should be considered when conducting a food fraud vulnerability assessment and in the development of food fraud prevention plans. Let us also benefit from the lessons learned during the pandemic and take into account these previously unforeseen events as we plan for the future.

References


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2.1 Introduction

In recent years, food fraud, or economically motivated adulteration, has transitioned from being an occasional under-the-radar business issue that few people talked about to an important concern for consumers, regulators, and industry due, in part, to several high-profile incidents. In most cases, fraud only results in consumers not getting what they paid for and
honest actors in the food system being victimized by criminals. Unfortunately, the experience with melamine as a “protein enhancer” for pet food and dairy products, peanut protein in spices, and other similar events have exponentially raised concerns as they have demonstrated the potential for food fraud to also result in public health harm. The recognition that there are both public health and economic consequences from food fraud is the reason food fraud prevention requirements are included in new regulations in the United States, Europe, and other countries. Food fraud, however, is not new and neither is the potential for public health harm from fraud.

2.2 Early efforts to combat food fraud

Concerns about food fraud go back to antiquity. In the second century BCE in China, there were specific prohibitions about defrauding buyers of food products. These prohibitions were strengthened in subsequent years with severe penalties if the consumption of such products caused illness, including hanging if the illness resulted in death. By 300 BCE, there were laws in parts of today’s India that prohibited fraud in specific types of food such as wine and grains (Hart, 1952). Similar laws were put in place in ancient Egypt. In ancient Rome, Pliny the Elder wrote about fraud associated with wine in CE 77–79, in his Naturalis Historia, a collection of 37 books that set out to capture the extent of knowledge at the time across all domains and became a base for future scholarly work and encyclopedias. He stated the following:

As it is, even the rich never drink it in an unsophisticated state; the morals of the age being such, that it is the name only of a vintage that is sold, the wines being adulterated the very moment they enter the vat (Pliny the Elder, 1469).

The term chosen by Pliny “unsophisticated state” illustrates how food fraud was viewed at that time; it required a degree of skill to accomplish and was of most concern for the foods that were commonly processed, such as ales, honey, wine, and oils. There were of course cases of overweighting goods, particularly meat, flour and bread, and related deceptive practices that continue to this day. A clear reference to this is in Deuteronomy 25:13–15:

Do not have two differing weights in your bag—one heavy, one light. Do not have two differing measures in your house—one large, one small. You must have accurate and honest weights and measures, so that you may live long in the land the Lord your God is giving you (BibleGateway, n.d.).

By the middle ages, food fraud practices proliferated as the complexity of foods and ingredients that were purchased (as opposed to made at home) expanded. With the proliferation of fraudulent practices, there was a drive to more extreme punishments, from bakers selling falsely weighted bread having their ear nailed to their door to the most extreme punishment of a merchant who had adulterated saffron being burned at the stake with a fire of his fraudulent saffron. As nation states began to take more control of the regulation of foods, laws became more consistent and the punishments more commensurate
with the crime (Hart, 1952). In 1202 the Assize of Bread became the first law to impose controls on bread and ale in Europe. The 1516 Bavarian beer purity law Reinheitsgebot codified over 600 years of prior beer purity regulations in the region.

2.3 The industrial age and rapid change in the United Kingdom

Frederick Accum’s seminal 1820 work *A Treatise on Adulteration of Foods and Culinary Poisons: Exhibiting The Fraudulent Sophistications of Bread, Beer, Wine, Spiritous Liquors, Tea, Coffee, Cream, Confectionary, Vinegar, Mustard, Pepper, Cheese, Olive Oil, Pickles and Other Articles Employed in Domestic Economy and Methods of Detecting Them* was the first comprehensive investigation of fraud in foods as the Industrial Revolution was getting underway. It was a breakthrough in that it not only covered the means by which foods were being adulterated, but it also provided methods for detecting the adulteration and documented those who had been found to have adulterated food. The methods for detection were a mixture of early microscopy, measuring basic physical properties (density, color), and wet chemistry. For example, in order to detect the presence of alum in bread, the author recommended the following test: “decompose the vegetable matter of the bread, by the action of chlorate of potash, in a platina crucible, at a red heat, and then to assay the residuary mass—by means of muriate of barytes, for sulphuric acid; by ammonia, for alumine; and by muriate of platina, for potash” (*Treatise on the Falsifications of Food, and the Chemical Means Employed to Detect Them*, 1848).

Due to the combination of a scandal involving library property damage accusations combined with threats from those he exposed, Accum fled England in disgrace. Consequently, his work was not as impactful as it could have been (Shears, 2010). John Mitchell, another chemist, published what he positioned as an update of Accum’s work in 1848, *A Treatise on the Falsifications of Food, and the Chemical Means Employed to Detect Them*. In its preface, he provided an observation that continues to ring ever true as science marches forward:

> From that which has already been stated, it will be seen, that this system of fraud is not of recent origin, and if the subject be examined further, it will be found that England is not the only nation suffering under the curse, for in every nation, and in every time, the same mode of procedure has been adopted and has flourished, the only difference being, that science, and the avaricious disposition and misplaced industry of some parties have raised adulteration to the standing of an art, and so clever have those who deal in its mysteries become, that it requires the greatest tact, labour, and circumspection, to bring their iniquitous proceedings to light (*Treatise on the Falsifications of Food, and the Chemical Means Employed to Detect Them*, 1848).

As an example of the advancement of bench chemistry methods, a notable improvement in the determination of gluten content in flour was a device invented in the 1840s by a French baker M. Boland: the aleurometer. This simple device simulated a baking test and measured the swelling behavior of gluten under heating (4–5 times the original volume); the most common adulterants retarded the swelling and also tended to generate viscous fluids that adhered to the walls of the device and gave off foul odors (*Treatise on the Falsifications of Food, and the Chemical Means Employed to Detect Them*, 1848).

This approach of testing, publishing, and shaming became the primary mode of protecting consumers in the 1800s as there were few regulatory constructs to constrain food
fraud. The editor of the prestigious journal the Lancet persuaded the chemist Arthur Hill Hassall to expand on his initial work on food adulteration to conduct a more thorough investigation. This was published as a series of papers from 1851 to 1854 exposing food fraud in England and then combined into the book *Food and Its Adulterations* in 1855. Table 2.1 shows examples of adulterated foods that were included in the reporting (as summarized by F. Leslie Hart in a later publication).

Another investigator, H. Hodson Rugg, published the pamphlet *Observations on London Milk* that documented the range of adulterants and unsanitary conditions that abounded in the London milk system (Rugg, 1849). These and additional publications forced action in Parliament which led to the Food Adulteration Act in 1860. While this demonstrated a government response, it was mostly symbolic as it only resulted in the appointment of seven “public analysts” who had very little authority to actually take action against those who adulterated food. The follow-on Adulteration of Food and Drugs Act in 1872 made the appointment of sufficient public analysts mandatory and established adulteration as a crime. However, it also required that those charged had to be proven to have had the intent to adulterate the food, which made prosecutions very challenging. Nonetheless, by 1875 there were nearly 1500 convictions under the law.

The Sale of Food and Drugs Act in 1875 strengthened the law and provided for more significant penalties, such as 3 months of hard labor for repeat offenders. The closely related Public Health Act of 1875 built on this by providing the authority to inspect food

**Table 2.1** This table is based on *Food and Its Adulterations* (Hart, 1952) where the second column shows the number of random samples acquired across London, the third column shows the number that tested positive for one or more adulterants, and the fourth column shows the nature of the adulterants found.

<table>
<thead>
<tr>
<th>Food product</th>
<th>Samples tested</th>
<th>Samples adulterated</th>
<th>Adulterant found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coffee</td>
<td>145</td>
<td>127</td>
<td>Chicory, roasted wheat, corn, acorns, burnt beans, iron oxide, roasted wurzelmangel, and coconut shells</td>
</tr>
<tr>
<td>Chicory</td>
<td>75</td>
<td>30</td>
<td>Roasted wheat, acorn, beans, carrots, sawdust, Venetian red, and sand</td>
</tr>
<tr>
<td>Brown sugar</td>
<td>72</td>
<td>40</td>
<td>Grape sugar, potato flour, tapioca, starch, and grit</td>
</tr>
<tr>
<td>Bread</td>
<td>74</td>
<td>74</td>
<td>Alum and mashed potatoes</td>
</tr>
<tr>
<td>Flour</td>
<td>8</td>
<td>4</td>
<td>Alum</td>
</tr>
<tr>
<td>Cocoa</td>
<td>56</td>
<td>48</td>
<td>Coconut shell, colored earth, cocoa shell, and starch</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>30</td>
<td>16</td>
<td>Barley meal and rubble (husk)</td>
</tr>
<tr>
<td>Milk</td>
<td>26</td>
<td>11</td>
<td>Water, fat skimmed off, and formaldehyde</td>
</tr>
<tr>
<td>Mustard</td>
<td>42</td>
<td>42</td>
<td>Flour colored with turmeric and mustard hulls</td>
</tr>
<tr>
<td>Cayenne pepper</td>
<td>28</td>
<td>24</td>
<td>Red lead (12 of the 24), cinnabar, ochre, turmeric, mustard hulls, and rice</td>
</tr>
<tr>
<td>Vinegar</td>
<td>61</td>
<td>32</td>
<td>Sulfuric acid up to 0.6%</td>
</tr>
<tr>
<td>Green tea</td>
<td>50</td>
<td>50</td>
<td>Exhausted tea colored green, mineral pigments, and foreign leaves</td>
</tr>
</tbody>
</table>
and remove from commerce anything found to be unfit for consumption. These served as the foundation for protecting consumers in the United Kingdom from food fraud. Subsequent acts established standards of identity for various products that were used for enforcement. In 1928 all of the various acts were consolidated into a new Food and Drugs Adulteration act, but the framework did not substantially change (Shears, 2010).

2.4 From swill milk to embalmed beef—regulations in the United States

Another form of food fraud was causing deaths in thousands of children in the US in the 1850s. Distillers and brewers in New York City and elsewhere realized that the spent grains from fermentation still had nutritive value. In an attempt to capitalize on this, many of them set up dairies adjacent to their operations. Unlike a farm setting, these cows were housed in urban buildings and confined to their stalls with no exercise, sunlight, and in many cases, no water other than that from the spent grains. The resulting milk was not surprisingly of very poor quality and was distinguished by its blueish tint. To make the milk appear to be of appropriate quality, the unscrupulous merchants would add chalk, eggs, flour, and whatever else they could think of to fraudulently present it as appropriate for sale. The poor nutritive value, at a time when urban consumers were first converting to direct consumption of milk (as opposed to further processed dairy products such as cheese and butter), led to significant numbers of infant and children deaths. The New York Times (1858) estimated that 8000 children died in 1 year alone in New York City.

The practice was unmasked by journalist Frank Leslie in 1858, leading to a public outcry. That this public rancor did not lead immediately to regulatory intervention was an artifact of politics, avarice, and corruption. While many firms stopped the practice, a significant number continued. In New York City, one of the Tammany Hall politicians, Michael Toumey, fought hard to prevent any effective regulation, including getting himself appointed to lead the Board of Health Examination. His motive, as is the case in all food fraud, was his greed and the greed of those he shielded. He was unable to prevent the first milk regulations, but he did work hard to limit their impact (Shears, 2010).

As the industrial revolution moved forward, the population in the most developed countries started to become more urbanized, which increased their distance from primary food production. This inherently provided increased opportunities for food fraud. As consumers increased their purchase and consumption of further processed foods, the opportunity to adulterate for profit grew. Over the next 50 years, 190 bills were introduced in the US Congress related to food quality (primarily purity) and safety (Regier, n.d.). However, most of these bills were limited in scope and only eight became law. This slow slog in the battle among regulators trying to protect the public, food firms who feared regulation, food firms who welcomed regulation, and the public began to gain momentum with the “embalmed beef scandal.” During the 1898 Spanish–American War, the Secretary of War Russel Alger was committed to supporting the Chicago meat packing industry. He went against the normal practice of acquiring local meat from producers located close to US troop operations (“theater” of operations) and instead arranged contracts with the three largest Chicago-based processors (Morris & Company, Swift & Company, and Armour & Company) to provide significant quantities of canned beef for shipment to troops. Both as
a cost saving measure and to conceal the poor quality of the meat being provided, the companies were accused of using significant amounts of preservatives, believed to be boric acid and formaldehyde, although this was not confirmed at the time. Whatever the unscrupulous practice, it was attributed to causing dysentery and death in thousands of soldiers. Commanding General Nelson Miles made exposing this practice a personal mission that was closely covered by the press and led to the President demanding Secretary of War Alger’s resignation.

While the embalmed beef scandal raised awareness of the problems in the meat packing industry, what finally forced meaningful regulatory action was the efforts of ‘muckrakers’ like Upton Sinclair whose book *The Jungle* focused attention on the issue. The publication of this book increased the pressure on Congress to act. James Garfield related his revelations from *The Jungle*, which led President Theodore Roosevelt to read the book and invite Sinclair to the White House for a meeting. While not impressed by Sinclair’s socialist leanings during their meeting, he followed the young author’s advice and sent non-USDA inspectors to supplement the USDA inspectors to validate Sinclair’s assertions. With significant pressure from Roosevelt, the Federal Meat Inspection Act was signed into law in 1906 on the same day as the Pure Food and Drug Act in the United States (*Goodwin, 2013*). These served as the foundation for regulatory controls to prevent food adulteration in the United States.

The Pure Food and Drug Act was superseded in 1938 by the Federal Food, Drug, and Cosmetic Act. While the impetus behind this new act was a contamination of a pharmaceutical substance, the use of diethylene glycol as a solvent for sulfanilamide, it did provide important revisions for preventing food adulteration. It first differentiated between materials intentionally added to the food versus those that were naturally occurring, with there being a higher standard of safety for the former. It formalized the inspection system with the issuance of noncompliance notifications. Perhaps most importantly, subsequent Supreme Court decisions determined that both civil and criminal violations of the Federal Food, Drug, and Cosmetic Act would be handled under the terms of strict liability. This meant that the government did not need to establish intent, only that the adulteration occurred. Following this, there were no significant changes to the regulatory approach to combating food fraud in the United States until 2011.

### 2.5 Commerce as the driver of regulations in France

France and the wine industry provide another example of the slow march forward in combating fraud, and in this case, it was not primarily driven by public health concerns. Until the growth of the export market for French wines of selected regions in the 1800s, watering wine down was an accepted practice so long as the taxes were appropriately paid. In the 1880s, data from the authorities in Paris indicated that one-sixth of the wine consumed in Paris was watered down. The emergence of a working class due to the industrial revolution also led to increasing wine consumption in the mid-1800s that drove an increase in production. However, wine-producing regions were hit by an aphid infestation, phylloxera, that decimated many of the vineyards in France and elsewhere. As growers worked to recover their production, they faced increased production costs...
without a similar flexibility in the revenue they could generate per hectare. As a result, various practices emerged that were designed to meet the demand for wine in the face of a recovering production system (Stanziani, 2009). These included the following:

- importing wines;
- importing strong wines and blending them with lower cost French wines;
- adding sugar to provide an artificially high alcohol content from fermentation so that the resulting wine could be diluted and maintain the alcohol level (a new technique in the 1880s);
- making wine from dried grapes;
- “plastering” wines, which involved adding calcium sulfate (sulfate of lime) after the first fermentation to preserve the wine during variations in temperature or length of transport; and
- adding colors and clarifying agents to watered down wines, including fuchsine (a carcinogen and mild toxin) and arsenic.

As the growing regions began to recover, trade groups sought to better protect their reputation and began pressing for some reforms to the regulations. While public health advocates were also pushing for reform, they were minor players. The need for producers to protect their “brand” led to rules in the 1890s to label wines if they had been plastered (Brousse law of 1891, which also prohibited added alcohol or water), fermented with added sugar (1897), or made from dried grapes (Griffe law of 1889). Of note is that the Brousse law did not prohibit plastering, it only limited it to 2 g/L. These various laws and related regulations were designed to protect various segments of the wine industry, not necessarily the consumer. That this was the focus was driven home by the 1905 French Food Law on “falsification” when, during debate on the law, the leader of the debate said “It is certain that the act of making and selling a liquor which presents a risk to public health constitutes neither fraud nor adulteration. It is simply an act of commerce. However, we are only legislating with reference to fraud and adulteration (Stanziani, 2009).”

In the Parliamentary review of the law, there was an interesting foreshadowing of the challenges to combating food fraud that is just as true today. The law established a framework within which administrative rulings could be constructed to combat food fraud. An advocate of the law was generally opposed to this approach as it felt like transition of authority from the legislative branch to the administrative branch. In this case, however, he stated that this flexibility was necessary because of how nimble the “fraudsters” were and the need to have a body that could react just as nimbly. That question of how to stay ahead of those intent on committing food fraud is still a challenge today.

### 2.6 The emergence of standards of identity

In addition to the French concerns around adulteration of wine, there were also strong stakeholder concerns around the specific origin of the wine. The Appellation d’Origine Contrôlée (AOC) began to form as the industry recovered from phylloxera. Some regions had been hit harder than others, which led to wines being labeled as being from regions with limited production when they were not. The AOC was (and continues to be) contained within the Ministry of Agriculture and regulates that certain wines, cheeses, and
agricultural products that are tied to a geographical region are protected from others using that name and benefiting from their reputation. That means that a wine cannot be labeled as Bordeaux if it was not grown and processed in the Bordeaux region. AOC went through considerable debate for the rest of the 1800s and was not fully finalized until after World War I, but it represents one of the early applications of a standard of identity being applied to control fraud (Stanziani, 2004).

In the United States, butter and oleomargarine were the foods of concern in the first major legislative battle on food product identity. Oleomargarine (margarine, butterine, and other variants) originated through research in France and the technology soon found licensees and advocates in the United States. These products were generally produced with animal fats, vegetable oils, or a combination. Rising in popularity shortly after an agricultural recession in the United States, these products were less expensive and more shelf stable than butter; therefore they were viewed as a threat by the dairy industry. Reports of margarine fraudulently sold as butter, poor-quality products, public health risks, and the negative impacts on the dairy industry set up a significant battle in Congress.

Standards of identify were at the core of the margarine debate (Young, 1979). The end result was a law passed in 1886 that defined milk as being from dairy farming, butter as being a product of milk processing, restricted the use of dyes in margarine to prevent it looking similar to butter, and added a $0.02/pound tax on margarine. The tax was raised to $0.10/pound in 1902. These taxes and regulations disadvantaging margarine producers stayed in place until 1950 when they were repealed under President Truman, and the post-war, technology friendly boom was on (Young, 1979).

In 1903 the International Dairy Federation (IDF) was formed at the first International Dairy Congress by dairy groups from 16 mostly European countries (Argentina, Austria, Belgium, Britain, Denmark, France, Germany, Hungary, Italy, Luxembourg, the Netherlands, Russia, Spain, Sweden, Switzerland, and the United States). Its goal was further the scientific basis for advancing the dairy industry, specifically by advising governments on the “means to combat fraud and to ensure hygienic products.” This work started in earnest with the development of standards of identity for the dairy industry (Smith, 1964). While Codex Alimentarius was not founded until 60 years later, on its website it credits the IDF as “an important catalyst in the conception of the Codex Alimentarius Commission” and lists the development of standards by the IDF as the starting date on its history of Codex timeline (FAO-WHO, n.d.(a)).

Voluntary industry standards spread across food segments as an important way to combat fraud throughout the 1900s, but an important step-change came with the formation of Codex Alimentarius (Codex) in 1963 (FAO-WHO, n.d.(b)). Codex initiated the development of global standards that nation states agreed to be “at least equal to” and without imposing undue regulatory hurdles. The cruxes of Codex are the guidelines, standards, maximum residue limits, and codes of practice for foods (and, in some cases, food production systems) that are agreed to by member countries. Codex standards are intended to first protect public health through science-based risk assessments and then to facilitate international trade by those who adopt the standards. These standards of identity, composition, process, and labeling provide a common framework for regulatory authorities for a wide range of foods. Codex standards establish a common base upon which countries add additional, often more detailed, requirements.
2.7 The early role of technology to prevent fraud

Early mitigation strategies relied on basic organoleptic observations of food articles. By the 1800s, microscopy, wet chemistry, and physical property measurements had significantly advanced detection strategies. Through the later 1800s and early 1900s, there continued to be a series of advancements in these methods. These advancements were unfortunately necessary due to the increasing sophistication of those committing fraud. Harvey Wiley, nicknamed the “father” of the US Pure Food and Drug Act, was pivotal to detection methods. One example of this was his “Poison Squad,” which involved volunteers ingesting preservatives and food chemicals to determine if they were safe. Dr. Wiley drove the Association of Official Agricultural Chemists to publish the *Official and Provisional Methods of Analysis* (Wiley, 1908). The methods were based predominantly on wet chemistry, which continued to be the case through 1950. One of the challenges then as now was that many of the wet chemistry methods were either analyst dependent due to the complexity of the reactions or they were indirect indicator methods that could be subverted. Many of the methods were, and are, dependent on conversion factors that were imprecise and did not fully ensure authenticity of the material. One example is the Kjeldahl method for protein determination that measures elemental nitrogen as a proxy for protein content. This nonspecific test allowed the recent adulteration of milk and vegetable proteins with melamine, which is high in nitrogen.

The advancement of instrumental analytical chemistry apparatus increased sensitivity and specificity while reducing variability related to analyst expertise, but only to a point. Arnold Beckman was one of the early innovators, contributing the pH meter and the ultraviolet spectrophotometer, which were immediately useful in food processing quality assurance and food fraud mitigation. Liquid phase chromatography and infrared (IR) spectroscopy soon entered into general use in the 1940s and 1950s, including the PerkinElmer 21 in 1951 as an instrument marketed specifically to the food industry. IR provided a significant advancement in fraud prevention as it allowed analysts to look for specific peaks that were associated with core actives. Unfortunately, it soon became clear that those peaks could also be masked by other materials for all but the most sensitive instruments.

The next major step forward in instrumental analysis for both food quality and food fraud was gas chromatography (GC). GC was invented in 1952 but did not really become a standard tool in the food industry until the 1970s when fused silica capillary columns transitioned the technique from an art form to a standard analysis. The more powerful high-pressure liquid chromatography increased the sensitivity and specificity even more, but like IR, they shared two points of weakness for fraud mitigation. Peaks could overlap, resulting in a situation where a visible peak was not necessarily due to the component of interest. The larger challenge, however, was that the adulterant must be known, or the analyst must have access to a detailed enough library of results for authentic materials for comparison. Further advancements such as Fourier transform IR, mass spectrometry, GC mass spectrometry, and nuclear magnetic resonance pushed the ability to “fingerprint” a material further (McGorrin, 2009).

Taken together, the rapid advancement and adoption of instrumental analytical chemistry as a bulwark against food fraud has helped one to prevent, or at least catch, fraud. As an example, there was a fraud case from the early 2000s where FDA identified orange
juice being sold as fresh when it was actually reconstituted frozen concentrated orange juice. The detection was accomplished by comparing the isotopic oxygen ratios (O\(^{16}/O\(^{18}\)) of the suspect juice, a validated sample of fresh orange juice, the municipal water in Florida, and the municipal water in the region where the product was sold. The water used to reconstitute the juice did not match the ratio present in the fresh juice, confirming the fraud (G. Hughes, FDA, Office of Criminal Investigations, Personal Communication, 2009). Without such techniques, this and many other cases of food fraud would have gone undetected. Unfortunately, however, powerful instrumental analytical tools have not eliminated fraud, they have just forced those intent on committing fraud to be smarter.

### 2.8 The role of the courts and law enforcement

While criminal penalties are not a new strategy for mitigating the risk of food fraud, the nature of their use has changed. From the draconian burning at the stake for saffron fraud, the passage of food safety and authenticity laws from the 1800s to today have provided various means to impose penalties on those who commit fraud as deterrence to others. The use of criminal penalties was a strategy deployed by FDA in the late 1980s and 1990s as the agency tried to address the rampant problem of fruit juice fraud. Simple dilution of fruit juices with water became more sophisticated as firms began adding sugar to the diluted juice to avoid detection via the common quality assurance test, the BRIX test. FDA pursued action against Beechnut for a multiyear apple juice fraud that included adulteration and mislabeling. The FDA was able to demonstrate that senior leadership knew of the fraud (govinfo, n.d.), and in 1989 the agency secured a $2.4 million dollar fine and jail terms of up to 12 months, but that was not enough of a warning to prevent additional cases of juice fraud in later years (Welles, 1988). Four other companies (Peninsular Products, Flavor Fresh Foods, Paramount Citrus Association, and Everfresh Juice Company) were subsequently taken to court for orange juice fraud resulting in $9,622,000 in fines and up to 5 years in jail. In a case involving Sun Up Foods, Inc., the two principals involved were found guilty of 12 counts of mail fraud, 8 counts of interstate shipment of adulterated food, 8 counts of interstate shipment of misbranded food, 2 counts of adulteration of a food, and 2 counts of misbranding. In addition to $200,000 in fines, these carried 104 months of prison time, the most by far of any of the juice fraud cases (U.S. Government Accountability Office). High civil and criminal penalties have not ended fruit juice fraud, however, as later incidents involving fraudulent high-value juices (such as pomegranate) illustrate. This is not surprising, as noted in 1993 by a chemist at the Analytical Chemical Services company that FDA frequently contracted for analytical support:

> The money to be made is just stupendous. Sugar costs 30 cents a pound, and real juice solids costs between $1 and $2.50 a pound. That’s the temptation right there (Diana, 1993).

There have also been examples where fraud was identified through unconventional means such as law enforcement agencies. In 1985 the Bureau of Alcohol, Tobacco and Firearms identified 12 wines imported into the United States from Austria that were contaminated with diethylene glycol, following identification of the problem by Austrian authorities. The adulteration was first identified not by the primary regulatory authority for
wines but by the tax authorities. The practice of adding diethylene glycol emerged as a way to compensate for poor-quality wines as the chemical, even at a low level, improved the sweetness and the mouth feel of the wine. One chemist came up with the idea and shared it with several producers. The mistake that reportedly exposed the fraud was that one of the producers claimed a refund for diethylene glycol on their tax return (Molotsky, 1985).

In the United States an advance in deterrence may have been made with the use of criminal penalties in a case involving the Peanut Corporation of America (PCA). PCA, under the direction of Stewart Parnell, knowingly shipped *Salmonella*-contaminated peanut products into commerce in 2008 and 2009. The company was aware of the contamination and falsified laboratory testing reports to enable the products to enter into commerce as safe and wholesome products that were clearly adulterated and in violation of regulations. Federal prison sentences for Stewart and his brother Michael were 28 and 20 years, respectively; given their ages, these were effectively life sentences. As the most significant criminal penalties handed out in any food fraud or food safety–related case, these sentences may provide more deterrence but will likely be insufficient to deter all actors.

2.9 High-profile cases, new regulations, and resources

While efforts to modernize the food regulatory system began in the Clinton administration with the National Food Safety Initiative in 1997, there were only incremental changes over the next 14 years. From 2006 to 2010 a series of high-profile food safety and fraud events generated a heightened awareness of the need for an overhaul of the regulations. The *Escherichia coli* O157:H7 outbreak associated with bagged spinach in 2006 was a contributing factor to the need for updated produce regulations. Melamine adulteration of wheat gluten and dairy products in China (in 2007 and 2008) demonstrated the need to better ensure the safety and authenticity of imported foods. The PCA incident described earlier was the largest recall in history, impacting about 360 companies and at least 3900 individual products; in some cases, trace-forward investigations to determine the ultimate destination of contaminated raw materials took up to a year. This highlighted how opaque supply chains could be and the challenges of traceability in food supply chains; it also supported the need for a significant change in the regulatory approach to traceability. With these problems facing all stakeholders in the US food system, a coalition of two groups often at odds when it comes to regulations, consumer advocacy groups and food industry leaders, worked with FDA to implement a new approach to food safety regulations. This culminated in the passage of the Food Safety Modernization Act, which President Obama signed into law in 2011. The core rule, Current Good Manufacturing Practice, Hazard Analysis, and Risk-Based Preventive Controls for Human Food (U.S. Food and Drug Administration, 2015), included specific requirements for economically motivated adulteration or food fraud.

New food safety legislation has also been passed in many other countries over the last 10 years, including the Safe Food for Canadians Act and elements of food safety law in Europe, China, Japan, New Zealand, and Australia, among others. The successful implementation of new laws and regulations has benefited not only from advocacy groups but also industry leaders. Those firms that have high standards for their own practices are...
frustrated when their good reputations are tarnished when others are not held to the same high standards, as consumers see each event as a problem in the industry in general.

Along with new laws and regulations, there are more sources of information now available to assist in mitigating food fraud. The European Union (EU) Rapid Alert System for Food and Feed receives submissions from the food safety authorities of EU member countries and Norway, Liechtenstein, Iceland, and Switzerland on recalls, import rejections, seizures, and other issues associated with food products under their purview (European Commission, 2016). This provides a significant resource for identifying food safety and fraud alerts and thus anticipating future fraud events. The Food Fraud Database, developed by US Pharmacopeia (USP) and now run by Decernis, captures records of fraud events, suspect events, authentication test methods, and other information that can be useful in anticipating fraud (Decernis, n.d.). Several organizations provide “horizon scanning” services that collect information related to issues in the food system and render them useful for subscribers. These include Fera (formerly the Food and Environment Research Agency in the United Kingdom) Horizon Scan (Fera, n.d.). There are many other services and resources available or under development [such as Food Fraud Advisors (Food Fraud Advisors, 2019), FoodAKAI (Agroknow, n.d.)] to cover various elements associated with food fraud that firms and regulators can leverage to combat fraud.

Food fraud mitigation has also become a core element of audit programs. The Global Food Safety Initiative included food fraud mitigation in its benchmark standard, which drove inclusion of food fraud audit requirements in the primary food safety audit programs such as SQF, FSSC22000, and BRC (Safe Food Alliance, n.d.). The benchmark standard required a vulnerability assessment, a food fraud mitigation plan to address vulnerabilities that represent a public health risk, and a Food Safety Management Plan. To assist with the complexity of conducting food fraud assessments and the resulting necessary mitigation strategies, USP developed the Food Fraud Mitigation Guidance (USP, n.d.) to help food companies organize their process of food fraud vulnerability assessment and subsequent implementation of mitigation strategies. This guidance was developed by the USP’s Intentional Adulteration Expert Panel with representatives from across the world and stakeholder community.

2.10 Conclusion

The vast majority of firms do not knowingly engage in food fraud and they are loathe to discover that fraud has impacted them. There are, unfortunately, always those that see the profit opportunity and seek to take advantage of it. Those that seek illicit profit can also be consistently creative. The adulteration of milk has seen a steady progression of approaches, from dilution with water to swill milk adulterated with masking agents to the addition of urea and salts to melamine and then onto hydrolyzed leather, all in attempt to get around increasingly robust testing. This same cat and mouse game is played out across food products and systems. The increased attention from regulatory and law enforcement authorities has not entirely curbed the impetus to commit fraud. In 2019 INTERPOL completed Operation OPSON VIII, its latest in a series of operations to identify fraudulent food products. During the course of the operation, which involved 78 countries, over
€100 million ($110 million) of fraudulent products were confiscated and 672 people were
arrested (Europol, n.d.).

There are several points to mention about food fraud that are unfortunate but appear to
be universal. The first is that the actual extent of food fraud is unknowable as we only
know the events that are caught. The number of successful incidents that avoided detection
will always be an unknown. The second is that the motivation for food fraud is never
going away. Fraud started as soon there were value-added foods in ancient times and it
will continue into the future. The third and most unfortunate point is that there will be
cases where the fraud results in public health harm. While causing illness is not in the best
interest of those committing fraud as it is likely to lead to detection, those who commit
fraud sometimes do not foresee all of the possible negative consequences. This was
sharply illustrated by the illnesses and deaths in infants following the melamine adultera-
tion of milk scandal in China. The data released by USDA and FDA indicated that mela-
mine did not pose a human health risk. However, that was data based on models for a
70-kg male, not an infant. Up to 300,000 infants fell ill in China as a result of the fraud and
it is highly unlikely that the perpetrators anticipated that result. It is also unlikely that
most perpetrators, unless it is a targeted attack, understand the emotional harm caused by
consuming products outside of one’s religion (halal, kosher, etc.) or the health risks posed
by ingredients consumers are trying to avoid (e.g., allergens).

Criminals will continue to perpetrate fraud; some will be successful, some will be
cought, and sometimes there will be public health consequences. Taken together, this illustrates the importance of ongoing vigilance by the food industry, consumer advocacy
groups, and regulatory authorities in combating food fraud. The passage of the Food System Modernization Act illustrated how powerful these groups can be in protecting the consumer when they are aligned. Similar to the fate of a soccer (football) goalkeeper, industry and regulators have to be successful every time to avoid food fraud and its
potential public health consequences. Like a forward in soccer, those committing fraud only have to be successful once to make their profit. That leaves the unfortunate reality
that when they are successful and the system does not catch it, we hope we are lucky
enough that there is no public health harm as a result.

References


3.1 Introduction

Ensuring food integrity has been a challenge throughout history. Adulteration methods and adulterants themselves have evolved based on marketplace pressures, such as the availability of supplies and prices, and also based on the evolution of detection methods.
Over the past 10 years, new regulations have come into effect in the United States and the EU focused on prevention of food fraud. These were prompted in part by two high-profile incidents of food fraud, specifically melamine adulteration of milk in China (Li et al., 2019) and horsemeat adulteration of beef in the EU (Lawrence, 2013).

This chapter will review some of the new regulations in the United States and EU, along with new private (nonregulatory) requirements issued by the Global Food Safety Initiative (GFSI). The chapter will also discuss both standards of identity (SOI) and EU geographical indications (GI) schemes, which have historically been used to ensure both the quality and authenticity of specific foods and food ingredients. In addition, an overview of hazard analyses, vulnerability assessments, and a short discussion of the role of analytical detection strategies will be provided. Finally, tools and data sources that can be used to support the implementation of a food fraud mitigation plan will be summarized.

The incorporation of strategies specific to fraud prevention is still relatively new to industry and regulators. However, the requirements have now been in place for a number of years, and both regulatory investigators and auditing bodies continue to develop their strategies for assessing compliance with these requirements. Large companies may have, by now, developed customized corporate-managed systems for evaluating fraud risk and implementing mitigation plans. Smaller companies and those still coming up to speed with the newer requirements should be able to conduct a straightforward ingredient-by-ingredient assessment using one of the frameworks described in this chapter.

### 3.2 Standards and requirements to prevent food fraud and ensure food authenticity

This section will review the requirements enacted by the US Food and Drug Administration (FDA), the European Commission (EC) and related member state initiatives, and those initiated by GFSI. GFSI requirements are particularly important because they have become the industry standard for facilitating business-to-business relationships based on benchmarked food safety standards. While they are not required from a government regulatory perspective, adherence to the standards of one of the GFSI-recognized auditing bodies is often a de facto requirement to sell ingredients and products for further processing. Finally, this section will describe SOI and other systems such as the EU GI (and other related) quality schemes. These standards have traditionally served as an additional level of oversight and harmonization to ensure both the quality and correct identification of particular foods and ingredients.

#### 3.2.1 US Food and Drug Administration requirements

The Food Safety Modernization Act (FSMA) was passed in 2011 and was the first significant change to food safety regulations in the United States in more than 70 years. It was enacted to strengthen preventive measures for food safety “in response to dramatic changes in the global food system” (Center for Food Safety and Applied Nutrition, 2020a).
FDA has finalized seven rules based on the legislation and has published a proposed rule “Accreditation of Laboratories to Conduct Food Testing.” The seven final rules are:

1. Accredited Third-Party Certification
2. Current Good Manufacturing Practice and Hazard Analysis and Risk-Based Preventive Controls for Human Food (PC Rule)
3. Current Good Manufacturing Practice and Hazard Analysis and Risk-Based Preventive Controls for Food for Animals
4. Foreign Supplier Verification Programs
5. Mitigation Strategies to Protect Food Against Intentional Adulteration (IA Rule)
6. Sanitary Transport of Human and Animal Food
7. Standards for Growing, Harvesting, Packing, and Holding of Produce for Human Consumption

Although one of the rules is focused specifically on “intentional adulteration,” in the view of FDA, intentional adulteration (from a regulatory perspective) does not include food fraud. FDA limited their use of the term “intentional adulteration” within the new rules to “acts intended to cause wide-scale harm to public health, including acts of terrorism targeting the food supply” (Center for Food Safety and Applied Nutrition, 2020b). FDA included requirements related to “economically motivated adulteration” (EMA) of foods as part of the hazard analysis process described in the PC Rules for both human and animal food (Center for Food Safety and Applied Nutrition, 2020b). EMA is not explicitly defined in either the rules or the subsequently issued guidance documents, but FDA did propose a “working definition” at a public meeting in 2009:

...the fraudulent, intentional substitution or addition of a substance in a product for the purpose of increasing the apparent value of the product or reducing the cost of its production, i.e., for economic gain. EMA includes dilution of products with increased quantities of an already-present substance (e.g., increasing inactive ingredients of a drug with a resulting reduction in strength of the finished product, or watering down of juice) to the extent that such dilution poses a known or possible health risk to consumers, as well as the addition or substitution of substances in order to mask dilution. Economically Motivated Adulteration; Public Meeting; Request for Comment (2009).

Based on the previous text, some have inferred that the terms “food fraud” and “EMA” have different meanings. In particular, food fraud is generally viewed as being broader and including acts such as mislabeling, intellectual property infringement (counterfeiting), and stolen goods. It is worthwhile to note, however, the broad use of the term “adulterated” in the Federal Food, Drug, and Cosmetic Act, which includes the following language related to defining adulterated food:

(b) Absence, substitution, or addition of constituents: (1) If any valuable constituent has been in whole or in part omitted or abstracted therefrom; or (2) if any substance has been substituted wholly or in part therefor; or (3) if damage or inferiority has been concealed in any manner; or (4) if any substance has been added thereto or mixed or packed therewith so as to increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater value than it is. U.S. Government (a),(b).

FDA has not explicitly stated in regulation that EMA includes only the addition or substitution of a substance, to the exclusion of other forms of fraud. For simplicity and for the
purposes of this chapter, we will use the terms “EMA” and “food fraud” interchangeably to generally refer to the intentional misrepresentation of foods for economic gain.

Prior to finalization of the FSMA rules, FDA solicited public comments on the question of whether EMA should have been included as part of the IA Rule or included in food safety regulations. Ultimately, FDA included language related to the prevention of EMA in the PC Rule. FDA included similar language in the rule “Current Good Manufacturing Practice and Hazard Analysis and Risk-Based Preventive Controls for Food for Animals,” but for the purposes of this chapter, the focus is on human food (U.S. Food and Drug Administration, 2015). In the Summary of Major Provisions of the Rule, FDA stated the following:

The hazard analysis must consider hazards that may be present in the food because they occur naturally, are unintentionally introduced, or are intentionally introduced for purposes of economic gain. We continue to believe that hazards that may be intentionally introduced for economic gain will need preventive controls in rare circumstances, usually in cases where there has been a pattern of economically motivated adulteration in the past. Economically motivated adulteration that affects product integrity or quality, for example, but not food safety, is out of the scope of this rule.

FDA responded to public comments that indicated disagreement about including EMA provisions in the PC Rule. These comments are useful in illustrating many of the challenges inherent in food fraud prevention. In particular, some of the comments indicated that EMA is an issue of “product integrity and quality,” whereas food safety systems are typically designed around facility-level hazards. Other comments indicated that EMA prevention may be handled at the corporate level since that is where many supply chain management programs are located, whereas food safety programs are often managed at the facility level. Some indicated concern about the additional resources needed to include EMA in a food safety plan without a concurrent increase in food safety. Finally, certain comments expressed the fact that expecting facilities to consider past patterns of adulteration was unduly cumbersome because those may not be relevant to a particular supplier or food product, and that looking at these patterns of adulteration would also be unlikely to inform future risk because fraudsters are aiming to avoid detection.

Excerpts from FDA’s responses include

We agree with the comments stating that the requirement to consider hazards intentionally introduced for purposes of economic gain is narrow... we define hazards to only include those agents that have the potential to cause illness or injury...

We continue to believe that there is benefit in taking this preventive approach to economically motivated adulteration, and not solely on enforcing the preexisting misbranding and adulteration provisions of the FD&C Act after a violation occurs...

It is consistent with the framework for this rule for a facility to address hazards requiring a preventive control that may be intentionally introduced for purposes of economic gain through the facility’s supply-chain program...

The repeated economically motivated adulteration of spices with toxic colorants demonstrates that patterns of economically motivated adulteration can emerge and should be considered as part of a food safety plan... U.S. Food and Drug Administration (2015).
FDA ultimately determined that there are demonstrated patterns of EMA with hazardous substances; while these situations are rare, they are known and reasonably foreseeable to the extent that they should be addressed in the hazard analysis as part of the food safety plan. Therefore the new FDA requirements related to food fraud prevention were fairly limited in scope, focusing only on those adulterants that may be hazards and that have a demonstrated pattern of historical occurrence.

### 3.2.2 European requirements

The 2013 horsemeat scandal in Europe triggered action by legislators both by individual countries and at the level of the EC (European Parliament, 2017). The British Parliament commissioned the Elliott Review into the Integrity and Assurance of Food Supply Networks (Elliott, 2014), which aimed to investigate the underlying criminal structures that facilitate food fraud and food crime and identify gaps in the current control system. The EC set up a food fraud unit, which consists of an information service (European Commission, 2018) and also distributes monthly summary reports of reports on food fraud (European Commission, 2019). Systems that predated the horsemeat incident, such as the Rapid Alert System for Food and Feed (RASFF) (European Commission, 2016), are also used to disseminate information from food safety authorities about possible health risks in the supply chain (RASFF is discussed in more detail next). Both the Food Fraud Summary Reports and the RASFF system are publicly accessible. In addition, the EC established a laboratory unit (Fraud Detection & Prevention) under the EC Joint Research Center which aims to develop and validate food fraud detection methods (European Commission, 2019). The newly introduced regulation on official controls (European Parliament, 2017) not only required establishing a European reference laboratory, but also national counterparts. Also, among the member states, a Food Fraud Network was established with the goal of exchanging information about potential incidents and analytical methods (European Commission, 2017).

In Germany a special center for food authenticity called the Nationale Referenzzentrum für authentische Lebensmittel (National Reference Center for Authentic Food) (Max Rubner-Institut, n.d.) was established by the government. These examples demonstrate the strategic approaches of both the EC and individual member states to combat food fraud. On the legislative side, there have also been significant recent changes. In 2011 the European Consumer Information regulation (EU 1169/2011) (European Parliament, n.d.) was published, which implemented the requirement that consumers not be misled about identity, properties, or ingredients when purchasing food products.

One challenge in Europe has been the informal exchange of information between competent authorities when reports are based on initial observation but are lacking final evidence. To overcome this hurdle a nonpublic system called the Administrative Assistance Corporation system was established. This allows competent authorities to exchange information in the absence of full evidence and facilitates collaboration in investigations and response.

Another major gap identified in Europe was the lack of sufficient inspection and controls of food business operators. To remedy this issue the aforementioned official control
regulation also aimed to ensure the application of food and feed law, as well as rules on animal health and welfare, plant health, and plant protection products. Nonetheless, the number of food inspectors has decreased over recent years, and recent food safety incidents have revealed regulatory “process problems” (Schulz, 2019); therefore it remains to be seen how effectively the new legislation can be implemented.

3.2.3 Global Food Safety Initiative requirements

GFSI is a private organization that benchmarks food safety requirements and approves auditing bodies that meet those criteria (Safe Food Alliance, n.d.). This allows standardization of auditing to support effective supply chain management in food production. GFSI took a fairly broad approach to food fraud mitigation requirements. In 2018 GFSI implemented the requirement for businesses to conduct a documented food fraud vulnerability assessment (FFVA) and put in place a control plan applicable to all products. Unlike the relatively narrow scope of FDA, GFSI recommended companies “be exhaustive in the first steps of the vulnerability assessment analysis and ensure a wide range of hazards are considered...food fraud can cover across all activities of a business and so the scope of the hazard identification step should cover them all” (The Consumer Goods Forum and Global Food Safety Initiative, 2018). Standards subsequently published by GFSI Certification Programme Owners (CPOs) indicated that the criteria used in the vulnerability assessment may include reviewing the history of food fraud incidents, economic drivers, an evaluation of how “easy” fraud would be to perpetrate, supplier and supply chain review, and control measures currently in place (International Featured Standards, n.d.). These will be discussed in more detail in Section 3.3.2.

3.2.4 Standards of identity

SOI are an important tool for defining product quality and can also be used to ensure authenticity. SOI describe what constituents must be present in a certain food, what should not be present, and what may be present (see the US Code of Federal Regulations Title 21, parts 130–169) (U.S. Food and Drug Administration, (c)). For example, in the United States, SOI for raisin bread specify a minimum raisin content (U.S. Food and Drug Administration, (b)). This protects consumers who spend extra for “raisin bread” from the situation of purchasing a loaf of bread with very few raisins. In some cases, SOI specify appropriate manufacturing processes. For example, the United States Department of Agriculture (USDA) published SOI that differentiate among manufacturing and cooking processes for a variety of meat products (United States Government, n.d.).

In the United States the Federal Food, Drug and Cosmetic Act describes SOI as being used to “promote honesty and fair dealing in the interest of consumers” (U.S. Government, n.d. (b)). Further, the FDA has indicated that their priority for creating or updating SOI is to protect consumers from economic adulteration (U.S. Food and Drug Administration, 2018a). SOI have been established in many countries including Canada and Australia/New Zealand for a wide variety of foods (Government of Canada, 2016; Governments of Australia and New Zealand, n.d.). SOI often specify product descriptions and labels that may be used in
the marketplace. Food products labeled as a standardized food that do not meet the requirement of the SOI may be considered mislabeled and potentially fraudulent. Because some foods with SOI (e.g., cheeses) are used as ingredients in further-processed products, manufacturers can use adherence to SOI as part of a supply chain quality control program to ensure both quality and authenticity. The importance of SOI was demonstrated in 2017 when the president of a US-based cheese maker was found guilty of fraud for selling grated cheese products labeled as Parmesan and Romano that contained no Parmesan or Romano cheese. Without FDA SOI for Parmesan (21CFR133.165) and Romano (21CFR133.183) cheeses, it may have been more difficult for prosecutors to demonstrate fraud.

3.2.5 Geographical indication and related EU labeling schemes

The EU has implemented a labeling system for various traditional and geographically specific products that are highly marketable. The system is based on a legal framework provided by the EU Regulation on quality schemes for agricultural products and foodstuffs (Regulation (EU) No 1151/2012 of the European Parliament and of the Council of 21 November 2012 on quality schemes for agricultural products and foodstuffs, n.d.). There are generally four categories of product designations listed by the EC (European Commission, n.d. (c)):

1. Protected Designation of Origin (PDO): The product was produced, manufactured, and processed entirely within one region.
2. Protected GI: At least one stage of production, processing, or preparation occurred in the particular region.
3. GI for spirits and aromatized wines: At least one stage of distillation or preparation occurred in the particular region.
4. Traditional Speciality Guaranteed: Production methods or composition are based on traditional methods, without an assured link to production in a specific geographical area.

Responsibility for ensuring the correct use of these labels is designated to each EU country’s competent national authorities. Product names that are outside of Europe are provided the ability to register as a “GI” if the country of origin of the product has an appropriate agreement in place with the EU. There is a database of registrations that, as of the end of 2019, included more than 1700 product registrations (European Commission, (a)). The countries with the highest number of registered products were Italy (343), France (289), and Spain (231). The estimated sales value of products sold under one of these schemes was almost 75 billion Euro in 2017 (European Commission, n.d. (a)—(c)).

3.3 Hazard analysis and food fraud vulnerability assessment

3.3.1 Hazard analysis

A hazard analysis is required by FDA as part of compliance with the PC Rules. FDA defines a hazard as “any biological, chemical (including radiological), or
physical agent that has the potential to cause illness or injury” (U.S. Food and Drug Administration, n.d. (a)). A hazard analysis is “the process of collecting and evaluating information on hazards and conditions leading to their presence to decide which should be addressed through a preventive control,” which is the procedure or process that would be implemented to minimize the risk of or prevent the hazard (Center for Food Safety and Applied Nutrition, 2020c). A hazard analysis, by definition, is focused on those agents that could cause illness or injury. Given what we know about food fraud, many adulterants used for economic gain would not meet the definition of a hazard because they are, themselves, nonallergenic food products or ingredients and would not be reasonably expected to cause illness or injury (Everstine et al., 2018).

FDA guidance suggests a hazard analysis should begin with a description of the product, its distribution, intended use, and the end user (or consumer) along with a process flow diagram (Center for Food Safety and Applied Nutrition, 2020c). FDA developed an example “Hazard Analysis Worksheet” for organizing a hazard analysis. The identification of EMA-related hazards would be included in Column 2 shown in Fig. 3.1.

Following the identification of potential hazards, FDA recommends evaluating each hazard to determine whether it requires a preventive control based on the likely occurrence and potential severity of the hazard. For evaluating likely occurrence, FDA suggests

reviewing data from foodborne illness outbreaks, recalls, the scientific literature, and “experience and historical information” gathered by a particular facility.

The FDA guidance specifically highlights four examples of foods where there has been “a pattern” of chemical hazards introduced for economic gain: melamine in milk, lead chromate in turmeric, lead oxide in paprika, and Sudan I in chili powder. In Appendix 1 (U.S. Food and Drug Administration, 2018b), FDA lists in detail various biological, chemical, and processed-based hazards for a variety of food commodities. EMA-related hazards are generally classified as “chemical hazards” such as drug residues, heavy metals, industrial chemicals, pesticides, or unapproved colors and additives. For example, “untreated, raw herbs and spices” are associated with potential hazards including heavy metals, mycotoxins/natural toxins, and unapproved colors and additives. The appendix does not directly associate specific spices with particular unapproved colors or heavy metals.

The document further states that both the country of origin and the supplier be considered during the hazard analysis. Using melamine as an example, the guidance indicates “at present, we do not expect you to consider the potential for melamine to be a significant hazard when using domestic milk products, or milk products from other countries when there is no history of melamine adulteration associated with those countries.” Finally, FDA indicates that if the determination is made that an EMA-related hazard requires a preventive control, that hazard can be addressed through a company’s supply chain management program.

3.3.2 Food fraud vulnerability assessment

GFSI and many other organizations around the world have adopted the terminology of a “food fraud vulnerability assessment and mitigation plan” that is generally applicable to all types of fraud involving raw materials, ingredients, products, and packaging (The Consumer Goods Forum and Global Food Safety Initiative, 2018). An FFVA is generally more broad in scope than a hazard analysis and includes identification of the risk of fraud with nonhazardous substances as well as hazards. To date, there is not a universally adopted process for conducting an FFVA, but it is generally acknowledged to include a review of multiple factors that could increase the incentive and susceptibility to fraud (Barrere et al., 2020). These factors include the following:

- supply chain structure and supplier relationships
- auditing and testing protocols in place
- history of fraud and/or history of supplier quality/safety issues
- geopolitical environment
- economic/market environment
- current control measures in place
- potential public health and economic impacts

This assessment can be conducted on an ingredient-by-ingredient or product-by-product basis, or on the basis of groups of related products. For companies with a large portfolio of raw materials and suppliers, conducting a thorough FFVA may be a time-intensive process. There are various tools and resources available to guide the completion of an FFVA which will be discussed in more detail next.
3.4 The role of analytical detection strategies

Analytical detection strategies are an important component of a food fraud prevention program and can confirm what is stated about ingredients in relevant documentation. The application of analytical methods is discussed in more detail in Chapter 4, Analytical detection methods and strategies for food fraud, but it is important to briefly mention them here and their role in food fraud risk mitigation.

One challenge with analytical detection strategies is that the number of potential adulterants tends to increase over time. If the potential adulterant is not known ahead of time, it may take many analyses of a single sample to find out if a product has been adulterated. Fig. 3.2 shows the number of documented potential adulterants for a selection of commonly adulterated food products.

Analyzing individually for each possible adulterant is usually not economically feasible. Therefore analysts have developed a new strategy to cover multiple potential adulterants in a single analysis: so-called nontargeted or untargeted methods. While targeted methods look specifically for one or a small number of possible analytes (adulterants), nontargeted methods evaluate whether the profile of an unknown sample corresponds with a reference profile for a specific product. While such a procedure may not be able to identify all adulterants directly, these types of methods are able to identify that there may be adulteration even with previously unknown adulterants.

How does such a nontargeted method work? First, a reference profile of a material (e.g., olive oil) needs to be established. Variabilities due to seasonal changes, olive varieties, and different growing areas need to be considered, which means that verified authentic samples from a wide variety of regions and production environments need to be sourced to appropriately capture those variabilities. These samples are then analyzed using a nontargeted screening method. Chemometrics (statistical methods) are then used to derive a common profile which is typical for the material. Future unknown samples can then be tested with the same method and evaluated against the verified profile based on

**FIGURE 3.2** Number of documented adulterants for select food products. Source: Based on Decernis Food Fraud Database.
authentic reference samples. If the profile of the unknown sample matches the profile of the reference sample, it can be considered not adulterated. If the sample’s profile differs from the profile of the reference samples, it warrants further investigation (which typically includes the use of targeted methods) (see Fig. 3.3). Nontargeted methods are well suited to the screening of large numbers of samples.

It should be noted that no screening method is currently capable of identifying all possible adulterants. Therefore it is recommended to use a combination of nontargeted screening methods for evaluation (such as a combination of near-infrared spectroscopy, liquid chromatography coupled with two-dimensional mass spectrometry and/or nuclear magnetic resonance methods). The prediction power and quality of any of those methods will depend to a large extent on the quality and number of reference samples as well as how representative they are of a given commodity. To provide information on the development and validation of nontargeted methods, a Food Chemicals Codex (FCC) Expert Panel on Food Adulteration published a guidance document (Xie et al., 2019), and AOAC International is currently developing Standard Method Performance Requirements against which nontargeted methods should be evaluated (AOAC International, n.d.).

While the developments in the analytical field are crucial, neither traceability nor detection methods alone will tackle food fraud. An effective food fraud prevention program requires a holistic approach that combines vulnerability assessment processes, mitigation measures, improved traceability tools, and the strategic application of detection methods to significantly reduce the occurrence of and potential for food fraud.

**FIGURE 3.3** Principle of nontargeted detection using reference sample profiles.
3.5 Data and tools to support hazard analyses and food fraud vulnerability assessments

3.5.1 Data sources

Information relevant to food safety risk, and more specifically food fraud risk, is available from a variety of sources. As noted earlier, FDA suggests a hazard analysis should include a review of data from foodborne illness outbreaks, recalls, the scientific literature, and experience and historical information held at a particular facility. GFSI CPOs recommend a variety of potentially useful data sources to support an FFVA, including subscription-based databases, government and university websites, blogs and media publications, trade and research associations, networking, testing laboratory information, and measures of country risk classification and corruption (BRC, 2017; International Featured Standards, 2018).

One of the challenges related to eliciting data relevant to food fraud risk is the fact that nonhazardous materials or substances that do not result in short-term and identifiable health effects are often used. This makes an understanding of the true scope and scale of food fraud difficult. It also increases the challenge of identifying novel forms of food fraud involving unanticipated adulterants. A review of known occurrences of fraud, government recalls, and publications by media, trade, and research associations is certainly valuable for understanding the history of fraud and identifying ingredients and products with a demonstrated pattern of adulteration. To be more proactive, many organizations recommend reviewing data that helps “scan the horizon” for emerging issues that could result in an increased incentive for fraud. This might include a review of the economics of a particular ingredient or commodity (and/or the general marketplace), tracking the geopolitical situation in the source countries for ingredients, and intelligence gathered through professional networks.

As with foodborne disease surveillance, there is much variability in surveillance and reporting systems for food fraud. There is currently no standardized classification scheme for attributes such as report types, ingredient and adulterant names, and fraud types (or “methods” of fraud). Localized media reports may be difficult or impossible to verify, but they are also important to review for keeping track of possible emerging issues. The remainder of this section will discuss specific data sources in more detail.

3.5.1.1 EU Rapid Alert System for Food and Feed

RASFF is a public database that compiles and makes searchable notifications from the competent authorities of the EU member states about noncompliance with food or feed laws (European Commission, 2016). RASFF notifications related to “adulteration/fraud” have shown an increasing trend in recent years (as shown in Fig. 3.4).

RASFF is useful for tracking official noncompliance notices and, as such, is a critical component to a food safety program. However, it is important to note that the system compiles reports without further curation. The absence of quality control measures for data categorization can result in inconsistent entries, especially for issues that may be fraud related. One example is shown in Fig. 3.5, which reports the detection of melamine in a confectionery product in 2008. Authorities did not categorize the product as...
FIGURE 3.4 Number of notifications per year for the category “adulteration/fraud” in the EU Rapid Alert System for Food and Feed (https://ec.europa.eu/food/safety/rasff_en).

FIGURE 3.5 RASFF notification for the detection of melamine in a confectionery product. RASFF, Rapid Alert System for Food and Feed.
adulterated but as classified the melamine as an industrial contaminant, despite being present at a relatively high level (153–259 mg/kg). A record from Austria during the same timeframe about a milk beverage, however, shows that this was categorized as adulterant (Fig. 3.6) even though the amount of melamine reported (25.6 mg/kg) was significantly lower than in the confectionery product.

The result of this lack of standardization is that searching by category (e.g., adulteration/fraud) would not necessarily list all relevant notifications, since member countries may apply different rules in terms of categorizing their findings. Implementation of a quality control process and curation of the database would help ensure standardization of reporting.

3.5.1.2 US recall notices and noncompliance data

FDA has created a consolidated information resource called the Data Dashboard (U.S. Food and Drug Administration, (d)). This resource allows users to access data on FDA inspections (including firm names and inspection classification), compliance actions (injunctions, seizures, and warning letters), and import refusals (including firm names and product descriptions) in addition to recalls. Each data set can be filtered in multiple ways and the data can be downloaded. Fig. 3.7 shows an example of the data available, specifically the number of import refusals by the country for 2019 through May 2020. There is also a firm/supplier evaluation resource that can be used to search for information about a single entity across multiple data
sets. Although this resource was developed to help firms with the supply chain assessments required under FSMA and the Foreign Supplier Verification Program, the information is also useful for FFVAs.

USDA Food Safety and Inspection Service (FSIS) provides access to several data sets, including a list of regulated establishments that produce meat, poultry, and egg products and a list of import refusals (United States Department of Agriculture, (b)). FSIS also provides access to information on current recalls and alerts for regulated products (United States Department of Agriculture, (a)) and a list of countries and establishments eligible to import regulated products into the United States (United States Department of Agriculture, (c)). The Alcohol and Tobacco Tax and Trade Bureau (TTB) of the Department of Treasury has primary jurisdiction in the United States over beverages containing alcohol. TTB publishes a list of administrative actions taken against firms that have violated alcohol laws (United States Alcohol and Tobacco Tax and Trade Bureau, n.d.).

### 3.5.1.3 Europol operation OPSON

Interpol and Europol have carried out yearly actions aimed at identifying food fraud and removing fraudulent products from the market; these operations are called OPSON (Europol, (b)). Yearly summaries of the findings are a good source of information about food fraud detections, and public versions of the summary reports are available for download (Europol, (a)).

![Figure 3.7](https://www.fda.gov/about-fda/transparency/fda-data-dashboard)
3.5.1.4 Decernis Food Fraud Database

The Food Fraud Database is an online source of information about public documentation of food fraud incidents and other reports that inform food fraud risk. The database was originally developed at USP in collaboration with a panel of experts from government, industry, and academia. It is now a subscription-based tool maintained by Decernis/FoodChain ID (Decernis, n.d.). The database tracks and standardizes historical records of food fraud sourced from public data sources such as peer-reviewed publications, media reports, regulatory sources, and legal documents. The information is curated and standardized and reported as four record types: incidents, inference records, surveillance records, and analytical methods.

3.5.1.5 Food Protection and Defense Institute Food Adulteration Incidents Registry

The Food Adulteration Incidents Registry is another online source of data about historical food adulteration records that is maintained by the Food Protection and Defense Institute at the University of Minnesota (Food Protection and Defense Institute, 2018). The database includes data about food adulteration incidents including terrorism, sabotage, and fraudulent economic gain extracted from public sources. It is a subscription-based tool; records more than 5 years old are available free of charge.

3.5.1.6 FERA HorizonScan

HorizonScan is a compilation of food alerts from government agencies, supplemented with additional information from media reports, that was developed by Fera Science in the United Kingdom (FERA, n.d.). It is a subscription-based service that compiles alerts from governments around the world, including recalls, market withdrawals, and other controls related to both food safety and food fraud. It also includes information about supplier names and the reporting organization.

3.5.1.7 Agroknow FOODAKAI

FoodAkai is another service that compiles alerts about food safety hazards published by national authorities (Agroknow, n.d.). The service includes an assessment of risk level based on the number of recalls and severity of the hazard, as well as the ability to track specific supplier names.

3.5.1.8 SGS DigiComply

DigiComply is a service that provides global regulatory information and can serve as a horizon scanning tool through the creation of alerts for issues involving specific ingredients or product groups (SGS, n.d.). Data are collected from numerous sources, including regulatory documents, trade magazines, and newspaper reports, and the information is verified before it is entered into the system. The system has a Food Fraud Watch service that tracks incidents that are specifically fraud related and can be filtered by country and ingredient.
3.5.1.9 *Estimates of geopolitical risk*

Some vulnerability assessment frameworks recommend incorporating an estimate of country-based risk or corruption levels for ingredient sourcing countries. Two sources for this information include the amfori Country Risk Classification (amfori, n.d.) and the Transparency International Corruptions Perception Index (Transparency International, n.d.).

3.5.1.10 *Considering public, official, and private (subscription-based) sources of data to support a food fraud vulnerability assessment*

There is no perfect source of data to inform food fraud risk. When evaluating data sources, it is important to consider the data collection mechanisms underlying the reporting system. For example, regulatory authorities typically only test a small number of food products, sometimes randomly and sometimes during targeted testing efforts. These regulatory priorities or strategies need to be taken into account when looking at perceived data “trends.” Curated sources of information on food fraud reports usually track only public data and, as such, can only represent a subset of the true occurrence of food fraud. Since fraud is designed not to be detected, it is likely that many fraud incidents are never discovered. However, it is also likely that many fraud issues that are detected within the industry are handled privately and never reported publicly. Protected systems for information sharing are, therefore, critical for food fraud prevention.

It is important to consider a wide range of information sources as part of a comprehensive vulnerability assessment. Personal communication and intelligence gathering, if taken in the correct context of being based on unverified information, can also be helpful to stay ahead of potential emerging issues.

3.5.2 Tools and resources to guide the development of food fraud vulnerability assessment and mitigation plans

3.5.2.1 *USP Food Fraud Vulnerability Assessment and Mitigation Plan Guidance Document*

To facilitate FFVAs the Food Ingredients Expert Committee of the FCC developed the Food Fraud Mitigation Guidance (FFMG) that is available as an appendix to the FCC (USP, n.d.). The FFMG describes a systematic and comprehensive process for assessing vulnerability for each ingredient used by a company and for using this assessment to develop a mitigation strategy. The vulnerability assessment includes evaluation of nine contributing factors (supply chain complexity, audit strategy, supplier relationship, supplier regulatory and quality history, adequacy of test methods, testing frequency, geopolitical considerations, ingredient fraud history, and economic anomalies), impact (both public health and economic impact), and overall vulnerability by integrating these evaluations. The assessment was designed to be carried out for individual ingredients; it provides a clear indication of where a company should prioritize efforts to mitigate fraud as well as information on the most efficacious approaches based on the contributing factor assessments. In the case of companies that source many ingredients and, therefore, may find it difficult to carry out an assessment of each individual ingredient, the guidance also contains information about how to prioritize ingredients for a full evaluation.
3.5.2.2 SSAFE food fraud tool

The SSAFE food fraud tool is an online vulnerability assessment tool that was developed through a collaboration between SSAFE and Wageningen University (SSAFE Food Fraud Vulnerability Assessment Tool). It is available for free as a downloadable spreadsheet and includes a series of 50 questions aimed at assessing the motivation, opportunity, and control measures for food fraud. The tool is not directly linked to sources of data to support the assessment but does recommend sources where applicable. The questions are completed on an ingredient-by-ingredient basis or by ingredient group. The creation of this tool was endorsed by the Board of GFSI.

3.5.2.3 Battelle EMAlert

EMAlert is an online EMA risk analysis tool that was developed by Battelle in collaboration with the US-based Grocery Manufacturers Association (now the Consumer Brands Association) (Battelle, n.d.). This is an online subscription-based tool that enables users to score and rank EMA risk for a set of commodities based both on user knowledge and direct links to external sources of data. The tool currently includes 50 commodities.

3.5.2.4 Food Fraud Advisors Vulnerability Assessment Tools

Food Fraud Advisors developed two downloadable Excel spreadsheets (fee-based) for conducting an in-house vulnerability assessment; one is a general format and the other is based specifically on the requirements of the British Retail Consortium (Food Fraud Advisors, 2019). They can be tailored to ingredients, raw materials, packaging materials, and finished products and do not require the use of an online system.

3.5.2.5 GFSI-recognized certification programme owner guidance documents

Certain CPOs—notably, FSSC22000 (2018) and International Featured Standards (2018)—have created guidance documents to provide information for industry to use in setting up an FFVA process. While these are not tools per se, they do describe factors and/or processes that can be used to implement a vulnerability assessment. For companies interested in creating a tailored system that will meet the requirements of GFSI-recognized CPOs, these documents may provide a helpful starting point.

3.5.2.6 PremiumLab guide to preventing fraud in the food industry

An organization called PremiumLab in Spain published a guide with the support of various universities and the Ministry of Agriculture, Livestock, Fisheries and Food of the Generalitat de Catalunya (Fernandez Sans, 2018). This document was designed to be an adaptable guideline to setting up a fraud control system that is compatible with Hazard Analysis and Critical Control Points (HACCP). It includes examples based on HACCP terminology (such as critical points, critical thresholds, and surveillance) and sample tables for tracking.
3.5.2.7 American Spice Trade Association Guidance—Identification and Prevention of Adulteration

The American Spice Trade Association (ASTA) (n.d.) developed a guidance document targeting the prevention of fraud in the spice industry. This document includes a chart of typical harvest times for herbs and spices by country, which allows stakeholders to anticipate the timing of supply chain disruptions based on extraordinary events.

3.6 Conclusion

Food producers are required to implement food fraud prevention measures to ensure compliance with both government regulations and private (GFSI-based) standards. Although there is no perfect strategy for predicting food fraud risk, there are various tools and data sources available to support an assessment of potential vulnerabilities in specific supply chains. Many large companies have already developed custom vulnerability assessment frameworks and corporate-controlled mitigation plans. Smaller companies or those with resource constraints should be able to conduct a straightforward ingredient-by-ingredient assessment using one of the frameworks described earlier. While food safety is of paramount importance, it is both necessary and possible to build in targeted and effective food fraud controls to enhance food safety and manage brand risk.

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### Analytical detection methods and strategies for food fraud

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4.1 Introduction

An effective analytical testing strategy is a key element in the fight against food fraud and one of the major components of a Food Fraud Vulnerability Mitigation Plan. Its purpose is not just to detect a potential fraud event but also to act as a deterrent and contribute to its prevention. A fraudster is likely to think twice about supplying suspicious product to a company known to operate a comprehensive testing system. Indeed, the same notion could apply to a country that has stringent and regularly enforced regulations in place when compared to one with a lax regulatory system.

A suitable analytical strategy should indicate “where,” “when,” and “how” to test for food fraud. The frequency of testing or “when” to test as well as “where” to test will depend on the product and its current risk status. The latter can be assessed by carrying out a vulnerability assessment on each product or ingredient and using the findings to establish the testing frequency. Testing frequency may range from the systematic analysis of all batches to a random sampling and monitoring scheme.

The “how” element of the strategy relates to the actual analytical methods that are used to assess the possibility of food fraud. The methods currently available and how they fit into an effective strategy are discussed next.

4.2 Getting started—designing an analytical strategy that reduces the food fraud risk

Prior to designing an analytical testing strategy as part of a Food Fraud Vulnerability Mitigation Plan, it is essential to first identify its aim. A series of simple questions can help one to get started:

1. Should the plan look for a specific type of fraud?
2. Based on its food fraud history, has the product or ingredient recently been associated with a specific adulterant?
3. Will the strategy be used on incoming raw materials or does it need to deal with the added complexity of outgoing finished products containing several ingredients?
4. Is the product or ingredient covered by existing labeling or content regulations?
5. Will the results be used by an enforcement agency checking mandatory labeling and compliance with national regulations? Or is the strategy part of a company’s brand protection policy?

Although it may be tempting to dive straight into the use of advanced analyses, it is important when starting out to include some basic common sense to get the best value for money from the strategy. A stepwise approach is recommended, starting from simple detection of blatantly counterfeit or grossly adulterated products to an in-depth forensic approach to uncover sophisticated fraud.

The first step involves carrying out simple visual and organoleptic checks on the integrity of the product container or packaging and on its content. Does the product look, taste, or smell as expected? The best illustrations of using visual inspection to spot suspect product come from
the alcoholic beverage sector, an area where counterfeiting of premium branded products is a serious concern. For example, cheap substitutes for Scotch whisky can be identified in the retail market by checking the color of the liquid in the bottle (is it cloudy or unusual?) or whether the fill level is lower than expected. Fake product is often betrayed by label problems, either where the label itself has not been put on straight, is peeling or creased, or from inconsistencies in the information provided (The Scotch Whisky Research Institute—Personal Communication). Wine provides another good example where spelling mistakes on the label are often an indicator of fraud. One bottle of French wine, for instance, had the word “Chaton” (the French for “kitten”) on its front label, instead of “Château” (a denomination that in France implies compliance with a set of well-defined quality requirements). The error was compounded on the back of the bottle with a map showing a completely wrong wine region!

In the second step, physical and chemical tests are performed on the content of a container or incoming ingredient to check compliance with a set of specifications. Low-cost analyses to test composition in major constituents—alcohol, sugar, fat, and protein—may be enough to highlight a problem and obviate the need for further testing or at least raise suspicion and suggest the need for specialized analytical work.

After those first checks the third step focuses on more sophisticated testing: selecting the analytical techniques able to address the challenge of increasingly complex fraud. In recent years, there has been considerable progress in the development of novel techniques and instrumentation in this area. Given the diversity of potential dishonest practices, multiplied by the number of different products involved, it is obvious that a wide range of methods is required, a major headache for any quality control manager!

4.3 Choosing the right analytical solution—the analytical approaches available

Appropriate analytical techniques for food authentication can be divided into different categories according to the type of fraud to be addressed.

4.3.1 Type (a) methods

These are targeted analytical techniques able to identify minor components normally absent in an authentic product but that may indicate adulteration. These authenticity markers are chemically different species present due to accidental or intentional contamination. An obvious example is the addition of melamine in milk powder. Less evident is the use of D-malic acid as an adulterant to increase acidity and mask sugar addition in apple and other fruit juices where L-malic acid is the naturally present chemical form.

4.3.2 Type (b) methods

These are targeted analytical techniques capable of distinguishing chemically identical analytes or picking up minor differences in the concentration of a molecular species that is normally present. This generally involves analyzing various markers and comparing the results to previously accepted reference values and/or concentration ranges. A good
example is the Food Chemicals Codex Identity Standard for pomegranate juice. This is published by the US Pharmacopeial Convention and was proposed in 2013 after numerous cases of adulterated pomegranate were found in the marketplace. The standard (available from: https://www.foodchemicalscodex.org) provides a list of analytical tests to verify the product’s authenticity. Several other internationally accepted trade standards for the constituents of various foodstuffs are also available, including those provided by Codex Alimentarius for several commodities (www.fao.org/fao-who-codexalimentarius/).

Types (a) and (b) are known as targeted analytical methods as the approach used is directly linked to an authenticity marker (e.g., chemical compound, DNA molecule) or a parameter associated with a chemical compound such as its stable isotope content. These targeted analyses are now well established and widely used in food authentication (Donarski et al., 2019). Major advances in this area have been largely due to technological progress in instrumentation, leading to better precision, improved detection limits, and faster turnaround times.

Food fraud is by nature unpredictable and a targeted approach that sets out to find a specific known adulterant will not always find all potential problems. An example of this is the horse meat crisis in 2013, where existing quality control plans were focusing on turkey or pork as likely adulterants, the addition of horse being undetected. The increasing range of food products that need to be analyzed together with the number of potential adulterants, both known and unknown, has led to the development of a further category of analytical methods to meet this challenge.

4.3.3 Type (c) methods

These are nontargeted or fingerprinting techniques that measure a wide range of analytes or markers, building up an overall picture of the food product. Comparison of this analytical profile with a reference database is then used to spot potential anomalies. Progress in computer technology has been a major driver in the rapid development of these nontargeted techniques.

4.4 Choosing the right analytical solution—an overview of the techniques available

Among the considerable range and diversity of analytical methods available for use in food authentication, this section provides an overview of those that are most frequently encountered, together with a description of their basic principles and main applications. The review is far from exhaustive and the examples provided are there to illustrate how the techniques can be used for food fraud detection. The reader is referred to the individual chapters on specific food commodities for further information.

4.4.1 Separation techniques (gas and liquid chromatography)

Chromatographic techniques are widely used in food authentication as a means of separating and quantifying chemically similar constituents of a foodstuff. The components are
separated between two phases, a stationary and a mobile phase, the separation resulting from the different strengths of adsorption of the different molecules between the two phases. Techniques used in food analysis include gas chromatography (GC) and liquid chromatography (LC) depending on the state—gas or liquid—of the mobile phase. High-performance or high-pressure LC (HPLC) is the most commonly used LC technique, in which the solvent of the mobile phase is pumped through the column. Other variants of chromatography include thin-layer chromatography that uses a solid, planar surface and a liquid mobile phase, and capillary electrophoresis involving electrokinetic separation.

Choosing between GC or HPLC will depend on the type of analyte being investigated. In both cases, sample preparation is an important preliminary step and separation performance is linked to the type of column used.

GC is used to analyze thermally stable volatile substances and is limited to low molecular weight compounds. In food authenticity, it has been used to determine fatty acids, triglycerides, and aroma compounds. Different detectors have been developed to enable detection and quantification of the separated compounds, the most common are flame ionization (FID), electron capture, and atomic emission. For more details on the principles of GC, refer to Ruiz-Matute et al. (2018).

HPLC has a wider range of applications, as it can analyze both volatile and nonvolatile compounds, from low to high molecular weights, that are sufficiently soluble in the solvent used as the mobile phase. In food authenticity, it has been used to determine sugars, amino acids, organic acids, and anthocyanins. The most common detectors are UV absorbance, photodiode array, and refractive index detectors. Other types of LC include ion exchange chromatography, in which ions are separated according to differences in their net surface charge, and affinity chromatography where separation is based on a specific binding interaction between a ligand fixed to the stationary phase and its binding partner (target analyte) in the mobile phase. The latter is especially suited for the separation of active biomolecules. For more details on the principles of LC, refer to Lozano-Sánchez et al. (2018).

The main applications of GC and LC follow both the types (a) and (b) categories described earlier. For example, GC–FID detection of fatty acids is the method of choice for the authentication of both plant and animal oils. It provides information on fatty acids that should not be present in a genuine oil [type (a)] together with a quantitative profile of all the fatty acid components for comparison with accepted ranges [type (b)]. Examples of applications of chromatographic methods in food authentication are given in Table 4.1.

Both types of chromatography have benefitted from the development of mass spectrometric (MS) detectors leading to a greater number of applications and lower detection limits through improved sensitivity and selectivity. In the MS detector, ions or molecules from the sample are ionized to produce additional charged species that are then separated on the basis of their mass-to-charge (m/z) ratio. Several ionization methods can be employed, including electrospray ionization (ESI), chemical ionization (CI), electron impact ionization, atmospheric pressure CI (APCI), and matrix-assisted laser desorption ionization, all of which produce a continuous supply of ions. The most common type of mass spectrometer associated with chromatography is the quadrupole MS.

GC and GC–MS are also suited to the analysis of the characteristic volatile aroma compounds making up the unique flavor profiles of a food product. GC–MS has been applied to detect atypical components indicating the presence of an adulterant and to ensure
### TABLE 4.1 Examples of applications of various analytical methods in food authentication.

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<td>Detection of hazelnut oil</td>
<td>Olive oil</td>
<td>Baeten et al. (2005)</td>
</tr>
<tr>
<td><strong>Nuclear magnetic resonance spectroscopy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^1$H NMR</td>
<td>Syrup additions, quality deviations, mannose, botanical/geographical origin</td>
<td>Honey</td>
<td>Spiteri et al. (2015)</td>
</tr>
<tr>
<td>$^1$H NMR</td>
<td>Authentication</td>
<td>Saffron (<em>Crocus sativus</em> L.)</td>
<td>Schumacher et al. (2016)</td>
</tr>
<tr>
<td>$^1$H NMR</td>
<td>Differentiation of grape variety, geographical origin, vintage</td>
<td>Wine</td>
<td>Godelmann et al. (2013)</td>
</tr>
<tr>
<td>$^1$H NMR</td>
<td>Counterfeit brands</td>
<td>Spirits</td>
<td>Kuballa et al. (2018)</td>
</tr>
<tr>
<td>$^1$H NMR</td>
<td>Fruit type, geographical origin, addition of other fruits</td>
<td>Fruit juice</td>
<td>Spraul et al. (2009)</td>
</tr>
<tr>
<td>$^{13}$C NMR</td>
<td>Authentication</td>
<td>Edible fats and oils</td>
<td>Guyader et al. (2018)</td>
</tr>
<tr>
<td>HR MAS $^1$H NMR</td>
<td>Geographical origin</td>
<td>Cocoa beans</td>
<td>Marseglia et al. (2016)</td>
</tr>
<tr>
<td><strong>DNA-based techniques</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCR–RFLP</td>
<td>Identification of white fish species</td>
<td>Convenience seafood</td>
<td>Ferrito et al. (2016)</td>
</tr>
<tr>
<td>Real-time PCR</td>
<td>Detection of adulteration</td>
<td>Honey</td>
<td>Sobrino-Gregorio et al. (2019)</td>
</tr>
<tr>
<td>Multiplex PCR</td>
<td>Detection of cow, sheep, and goat’s milk</td>
<td>Cheese</td>
<td>Rentsch et al. (2013)</td>
</tr>
<tr>
<td>DNA barcoding</td>
<td>Identification of meat and poultry species</td>
<td>Meat products</td>
<td>Hellberg et al. (2017)</td>
</tr>
<tr>
<td></td>
<td>Identification of fish and seafood species</td>
<td>Fish and seafood</td>
<td>Center for Food Safety and Applied Nutrition (2011)</td>
</tr>
<tr>
<td><strong>ELISA (enzyme-linked immunosorbent assay)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ELISA</td>
<td>Detection of soy proteins</td>
<td>Raw, heat-processed meat</td>
<td>AOAC 988.10.1996</td>
</tr>
<tr>
<td>ELISA $\kappa$-casein</td>
<td>Detection of raw and heat-treated cow and buffalo milk</td>
<td>Milk of other species</td>
<td>Nermin Sajic and Essers (2015)</td>
</tr>
</tbody>
</table>

(Continued)
compliance with legislation governing “natural” claims. Such regulation exists in Europe under Regulation (EC) No 1334/2008. For other countries, guidelines for the definition and use of natural flavorings are provided by Codex Alimentarius (CAC/GL 66-2008). Chiral chromatography uses an enantioselective stationary phase to separate the R and S spatial conformations of chiral compounds. This is used to detect the addition of nature-identical flavor compounds, since most chemically produced flavors are a racemic mixture of both enantiomers (Jamin and Thomas, 2018). The combination of GC or GC/MS with olfactometry (GC-O-MS) in which the volatile constituents are assessed either by an electronic nose (e-nose) or by a specially trained individual (Biniecka and Caroli, 2011) has also been used to authenticate various food products (see Table 4.1).

This coupling of a separation method such as GC or LC with MS is known as hyphenation. It can include more than one MS stage (GC-MS/MS) and/or more than one separation technique LC/LC/MS (Cacciola et al., 2017; Niessen, 2017). The enhanced sensitivity provided by the online coupling of more than one quadrupole mass spectrometers has been shown to improve analysis of highly processed food. For example, ESI LC tandem mass spectrometry (LC-MS/MS) is the standard method for the quantitative determination of melamine and cyanuric acid in milk, powdered milk products, and infant formulae (ISO/TS 15495:2010).

A further example is the use of a triple quadrupole LC-MS system (LC-QQQ) to analyze species-specific peptides to detect the presence of beef and pork in poultry meat products (Fornal and Montowska, 2019). However, the use of these increasingly complex techniques is restricted to specialized laboratories and generally more suited to the analysis of trace contaminants than routine fraud detection.

### 4.4.2 Stable isotope ratio analysis

Stable isotope ratio analyses (SIA or SIRA) have made a major contribution to food authentication and are now official or standard methods used worldwide. These methods are based on the measurement of stable isotope content of the product or of a
specific component such as an ingredient or target molecule of the food product. The basic principle is as follows. The main atoms that make up organic matter exist in several isotopic forms, one of which being largely predominant. For example, carbon is characterized by the natural ratio of its major isotopes $^{13}\text{C}/^{12}\text{C}$ of about $1.1 \times 10^{-2}$, oxygen by the ratio $^{18}\text{O}/^{16}\text{O}$ of around $2 \times 10^{-3}$, and hydrogen by a ratio $^{2}\text{H}/^{1}\text{H}$ of about $1.5 \times 10^{-4}$.

Under the influence of environmental factors, biosynthetic and/or chemical processes, an enrichment or depletion of one of the isotopes with respect to the other—a phenomenon known as fractionation—may occur (Kelly, 2003). This can result in chemically identical molecules with different isotope content and distribution depending on their botanical, chemical, or geographical origin.

The most commonly used technique to measure stable isotope content is isotope ratio mass spectrometry (IRMS), providing both bulk (whole sample) and compound-specific data. Since the measurements are carried out at the natural abundance level, the differences in isotope content are extremely small in absolute terms. For practical purposes, isotopic abundance is normally measured relative to an isotopic standard and expressed using the delta notation ($\delta$) in parts per thousand ($\%$ or per mil). Internationally recognized standards are available for the main isotopes measured.

Providing appropriate sensitivity and precision requires the use of a specialized mass spectrometer in which samples are combusted into a mixture of gases before being introduced into the ionization source. Several sample introduction methods are now available for commercial isotope ratio mass spectrometers, the most common being elemental analyzers (EA-IRMS) suitable for bulk measurements, and GC–IRMS, in which separation of a complex mixture takes place prior to the isotopic measurement (Muccio and Jackson, 2009). More recently, the use of LC–IRMS has become technically feasible (Cabañero et al., 2006).

Food authentication generally concentrates on the isotope ratios of the main light elements: carbon $^{13}\text{C}/^{12}\text{C}$, hydrogen $^{2}\text{H}/^{1}\text{H}$ (or D/H), oxygen $^{18}\text{O}/^{16}\text{O}$, nitrogen $^{15}\text{N}/^{14}\text{N}$, and sulfur $^{34}\text{S}/^{32}\text{S}$. The most well-known application uses carbon isotope measurements ($\delta^{13}\text{C}$) to detect undeclared added sugar in a range of products. In nature, there are three main photosynthetic pathways [$\text{C}_3$, $\text{C}_4$, and crassulacean acid metabolism (CAM)] by which a plant fixes carbon dioxide from the atmosphere resulting in different levels of carbon isotopes in their sugars and other components. This makes it possible, for example, to detect $\text{C}_4$ cane- and corn-derived sugar syrups in $\text{C}_3$ products such as fruit juices, honey, and maple syrup.

$^{18}\text{O}$ and $^{2}\text{H}$ isotopes provide information on geographical origin because of latitude effects on the fractionation of these isotopes in rain and hence groundwater. They are also employed to detect the addition of tap water to beverages such as fruit juices and wines. Local agricultural practices influence $^{15}\text{N}$ and $^{34}\text{S}$ values; $^{13}\text{C}$ and $^{15}\text{N}$ effect animal diet, providing further information on the plant or animal products. See Table 4.1 for examples of the use of SIRA in food authentication.

The combined data from C, H, N, O, and S isotope ratio measurements has the potential to confirm the geographical origin of a food ingredient or raw material. Including data on heavy element isotope ratios such as strontium ($\delta^{87}\text{Sr}$) can improve the assessment. The main requirement when verifying geographical origin is the existence of a comprehensive database of authentic samples. In the current state of the art, even when such a database is available, these methods are not able to determine an unknown origin but rather confirm

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whether the results are consistent with a declared origin. Despite this, there are examples where these methods have been used in court (Camin et al., 2017) for foodstuffs such as grape products, orange juices, olive oil, cheese, butter, and caviar.

Whereas IRMS will provide bulk and compound-specific isotope ratio measurements, obtaining position-specific information requires chemically isolating the position under examination, a process which is complex and not always possible. This problem has been resolved by the development of high-resolution nuclear magnetic resonance (NMR) to measure isotope content, at the natural abundance level, of specific sites in a given molecular species. The technique, known as Specific Natural Isotopic Fractionation (SNIF-NMR) for site-specific natural isotope fractionation studied by NMR, was developed in the early 1980s by Profs. Gerard and Maryvonne Martin, specifically for the detection of the illegal addition of sugar to fermenting wine musts (Jamin and Thomas, 2017).

The first applications of SNIF-NMR used deuterium as its probe to measure site-specific $^{2}H/^{1}H$ ratios in the ethanol obtained from the fermentation of the sugars, providing a means of detecting beet-derived ($C_3$ plants) sugars in wine and fruit juice. Further applications followed, among which is the authentication of flavors such as vanilla, in which the $^{2}H/^{1}H$ ratios measured at specific sites on the vanillin molecule, provide information on its natural or synthetic origin (Guyader et al., 2019).

More recently, the development of $^{13}C$ SNIF-NMR has increased the number of applications making it possible to distinguish for the first time between $C_4$ plant sugars (cane, corn) and CAM plant sugars (pineapple, agave).

Stable isotope analyses, whether by IRMS or SNIF-NMR, fit into the type (b) category described earlier. Interpretation of stable isotope results is usually carried out by comparison with reference data that must be collected beforehand. Improved detection limits can be obtained by measuring the isotope content of several components of the same foodstuff and investigating correlations between them (Jamin et al., 2003). Table 4.1 provides further examples of where these methods may be useful and how they are applied.

### 4.4.3 Vibrational spectroscopy

Infrared spectroscopy is the most commonly used vibrational spectroscopic technique to assess food product quality and authenticity. The main spectral range used in food analysis includes the near-infrared region (NIR) between 750 and 2500 nm ($4000–13,400 \text{ cm}^{-1}$) and the mid-infrared region (MIR) between 2500 and 25,000 nm ($400–4000 \text{ cm}^{-1}$). In these ranges a sample will absorb energy from incoming radiation at frequencies characteristic of the frequency of vibration of the chemical bonds in the molecular species present, leading to a unique fingerprint or spectral signature of the sample. The MIR region of the spectrum relates to the fundamental vibrations of the molecules in the sample providing sharp and well-resolved peaks that can be used to characterize molecular structure. In the NIR region the absorption bands are the overtones of the fundamental bands in the MIR region and as such are relatively weak and poorly delineated. Interpretation of these complex spectra requires the use of multivariate data methods to extract relevant information. Full details of the instrumentation and software available for NIR, MIR, and Fourier transform infrared (FTIR) spectrophotometers are given in Cozzolino (2017).
The main advantage of NIR, MIR, and FTIR is that they require minimal or no sample preparation making them suitable for in-line and online monitoring. No chemicals are normally required and the instruments are robust. Quantification of individual food components is possible, provided suitable calibration models have been established from samples of known composition beforehand. Appropriate data treatment of the overall spectrum can be used for a general assessment of the product’s authenticity. A lot of information can be obtained in a short time without the need for time-consuming chemistry.

A large number of applications of NIR and MIR to food authentication are described in the literature. Their ease-of-use has also made them popular in the food industry. Instrument manufacturers have commercialized dedicated testing solutions based on NIR and FTIR for use both in the laboratory and at-line for a variety of products, including dairy (raw milk, milk powder, yoghurts, and cheese), feed and forage, grains, flour, and wines.

The development of imaging accessories such as light-fiber optics and in-line and online probes has increased the versatility of these techniques. More recently, hyperspectral images have been added. A recent study demonstrated the potential of NIR hyperspectral imaging combined with chemometric data treatment to discriminate between durum and common wheat kernels at the point of entry of the production chain based on morphological criteria, their NIR spectra, protein content, and vitreousness (Vermeulen et al., 2018).

Raman spectroscopy, another vibrational spectroscopic technique, is based on a scattering phenomenon arising due to the difference between incident and scattered radiation frequencies. Analysis of the scattered light provides information on molecular vibrations which, in turn, can be used to elucidate molecular structure.

The application of Raman spectroscopy to food authentication is relatively recent, partly due to the high cost of the early instruments. However, with the development of improved high-energy lasers and greater sensitivity afforded by techniques such as Fourier transform Raman spectroscopy (FT-Raman) and surface-enhanced Raman spectroscopy, this technique is gaining more recognition for food fraud detection. Its potential for miniaturization has also made this technique a suitable candidate as a rapid method (see the next section).

Vibrational spectroscopic techniques fit in with all three categories described earlier being able to detect the presence of an atypical compound, type (a), as in the detection of melamine in milk powder by MIR/NIR spectroscopy (Balabin and Smirnov, 2011). FT-MIR is already used as a type (b) method in milk factories to provide compositional data (e.g., fat, protein, and nonfat solids) and has more recently been shown to be a suitable fingerprinting tool [type (c) method]. In this case a normal milk profile is created using chemometric data treatment enabling potential adulteration to be detected when significant changes in the FT-MIR spectrum arise for an unknown sample (Cavin et al., 2016).

Further examples of the use of vibrational spectroscopy to food authentication are given in Table 4.1.

4.4.4 Nuclear magnetic resonance spectroscopy

There has been increasing interest in the use of NMR spectroscopy, or NMR, as a routine procedure to authenticate food products, especially when used, in conjunction with chemometric data analysis, as a fingerprinting [type (c)] method.
In NMR spectroscopy, a sample is placed in a magnetic field and the NMR signal is produced by excitation of the nuclei in the sample using radio-frequency electromagnetic radiation. Generally speaking, the local environment around a given nucleus in a molecule tends to slightly disturb the local magnetic field exerted on that nucleus and to affect its exact transition energy. This provides information on the electronic structure and the position of a particular atom in a molecule.

The most common types of NMR in food analysis are proton $^1H$ and carbon-13 NMR spectroscopy. In general, if the spectrometer is tuned to the hydrogen frequency, all hydrogen-containing compounds are observed in the NMR spectrum. Similarly, if tuned to carbon, then the peaks present in the spectrum relate to the carbon compounds in the sample. In foodstuffs, NMR is used for the molecular identification of both primary (organic acids, sugars) and secondary (phenolic compounds, sterols) metabolites present. The technique is also quantitative, since the intensity of each NMR peak or signal is proportional to the number of nuclei giving rise to the signal and thus to the molar concentration of the metabolite measured. Other types of NMR include $^{31}P$, $^{15}N$, and deuterium ($^2H$). The latter is used in the SNIF-NMR technique described under the section on stable isotope analysis earlier in this chapter.

Practical details on the use of NMR applied to food authenticity, including NMR instrumentation, experiment setup, sample preparation, acquisition, and spectral analysis, are given in Spyros (2016).

Applications of NMR can be found in various food sectors, such as fish and meat, milk, cheese and other dairy products, fruit juices, coffee, tea, and wine. An area where there has been considerable NMR development is in the authentication of plant and animal oils, where both $^1H$ and $^{13}C$ NMR are used to identify and quantify the fatty acids present. Results obtained on pure or diluted oils show good agreement with the data obtained using classical GC analysis, without the need for lengthy sample preparation (Knothe and Kenar, 2004).

The most recent applications of high resolution $^1H$ NMR are as a profiling technique, combining targeted and nontargeted analyses of a whole food matrix in the same run. In the former, assigned signals in the spectrum are used for quantification and identification [types (a) and (b)], and in the latter the overall spectrum provides a fingerprint of authenticity characteristics [type (c)]. The main advantages of this technique are its rapid execution and the ability to detect unexpected discrepancies. For example, a 20-minute $^1H$ NMR measurement time on a honey sample followed by appropriate data processing provides enough information to quantify major sugar components, identify authenticity markers specific to a botanical source, and give some indication of geographical origin (Spiteri et al., 2015).

As with other type (c) methods, a comprehensive database is required for interpretation, as discussed later in this chapter. A commercial NMR food screener is available on the market for certain food products, where the food company or food analysis provider can send NMR data to a central laboratory for remote interpretation against an up-to-date reference library of authentic compounds. The best example is the $^1H$-NMR screening SGF-Profiling method, in which SGF stands for spin-generated fingerprints, used for the authenticity control of fruit juices (Spraul et al., 2009).

A list illustrating the range of applications of high-resolution NMR is given in Table 4.1.
4.4.5 DNA-based methodology

DNA-based techniques are now used both routinely and officially for food authentication. Indeed, they are the methods of choice for analyzing plant and animal products when the fraud consists of the substitution of one ingredient with another that is a different variety, species, or breed. These techniques make use of the genetic code encrypted in the DNA present in all organisms, exploiting variations in the DNA sequence or code to differentiate species or varieties.

The main starting point for DNA-based methodologies is the availability of enough good-quality DNA. Most procedures use the polymerase chain reaction (PCR) to amplify specific DNA regions. Among the molecular markers used in food authentication are restriction fragment length polymorphisms, random amplified polymorphic DNA, amplified fragment length polymorphisms, microsatellites or simple sequence repeats, and single-nucleotide polymorphisms. In general, these methods use markers from chloroplasts for plant species and from mitochondrial DNA for food products of animal origin. However, nuclear markers are used if a quantified result is required.

Various types of PCR are in use, including real-time PCR, in which the PCR products are continuously detected throughout the amplification providing a reliable means of quantification. Maestri and Marmiroli (2016) highlight the central role that PCR has played in food authentication giving, through a series of case studies, details of the technical aspects required when setting up a PCR method. Examples of applications of PCR in detecting food fraud are given in Table 4.1.

Multiplex and consensus PCR technologies can detect not just one species, but a panel of both known and unexpected species in a mixture. An example is the low-cost and density (LCD) Array, based on DNA biochip technology to simultaneously detect 24 animal species, and that has recently been validated for raw/pasteurized and heated meat and milk matrices (Beltramo et al., 2017).

Current DNA-based approaches are moving toward the concept of DNA barcoding, in which standardized genetic markers are compared with a library of reference DNA sequences. An example of a repository of such sequences is the Barcode of Life Database (available from: http://ibol.org/cbol/) which has the ambitious aim of assembling a reference library of short DNA fragments or barcodes for all plant and animal species (Böhme et al., 2019). DNA barcoding is a reliable method for the authentication of a wide range of foods, as diverse as honey (Soares et al., 2018) and black pepper (Parvathy et al., 2014). Its greatest potential, however, has been demonstrated for species differentiation of both terrestrial and marine animals. The method is used to identify meat and poultry species in food products (Hellberg et al., 2017). The US (FDA) Food and Drug Administration has also adopted DNA barcoding as their regulatory method for the identification of fish species (Center for Food Safety and Applied Nutrition, 2011).

With the considerable technological progress both in instrumentation and in computational capacity, next-generation sequencing or NGS has appeared as a means of simultaneously screening multiple genomic regions in order to identify plant and animal ingredients in a foodstuff (Haynes et al., 2019). The scope of NGS is virtually unlimited as the technique no longer focuses on one or several specific species but on all the species
present. As instrument costs come down, it is likely that NGS will be used by more and more laboratories to test for food authenticity.

### 4.4.6 Immunochemical methods—enzyme immunoassays

Despite the increased acceptance of DNA-based methods for species identification in foods, enzyme immunoassays are still widely used mainly because of their simplicity, speed, and cost-effectiveness. The most common is the enzyme-linked immunosorbent assay (ELISA) that has been developed for numerous applications.

ELISA is a plate-based assay that relies on antibodies to detect a target antigen using highly specific antibody–antigen interactions. The most used variants are direct and sandwich ELISA, details of which are given in Asensio et al. (2008). Different commercial immunoassays kits, both in microtiter plates and immunostick format, are available for use in the food and feed industry. Examples include the detection of soy proteins in meat products, and the rapid identification of milk from various animals in cheese and dairy products (see Table 4.1). A range of test kits is also available for the rapid detection of allergens in foodstuffs.

### 4.4.7 Other methods

It is impossible in this short chapter to review all the analytical methods that are used to detect food fraud. In addition to those detailed earlier, a few others deserve a mention.

Element analysis is used to determine the concentrations of mineral elements in a sample. The most commonly used techniques are atomic absorption spectroscopy, and inductively coupled plasma techniques: inductively coupled plasma (ICP)—optical emission spectroscopy and ICP–MS. Since mineral element composition is characteristic of the soil composition of a particular region of production, these techniques have been used, together with suitable multivariate data treatment, to verify geographical origin (see Table 4.1).

Ambient mass spectrometry is used to record mass spectra on samples with previous treatment or separation by creating the ions outside the instrument. The most commonly used ambient ionization techniques are DESI (desorption electrospray ionization), DART (direct analysis in real time), and ASAP (atmospheric pressure solid analysis probe). These techniques are used both to detect specific adulterants and for fingerprinting purposes. However, despite the number of studies for food authentication (Black et al., 2016), these methods are still largely confined to research laboratories.

### 4.5 Combining different technologies for the most effective outcome

Unless the aim is to look for one specific adulterant, the best results for detecting food fraud may be obtained from a compilation of analytical data. This is the strategy generally adopted for fruit juice authenticity. Rinke and Jamin (2018) provide an example of how an analyst can carry out an authenticity check on a juice sample using a full range of analytical data.
4.6 From targeted to nontargeted analyses

Today there is a distinct move toward the use of nontargeted analyses for the detection of food fraud. These techniques provide a global fingerprint of the food sample through a series of steps:

- analysis of the food sample(s) using the nontargeted technique;
- production of complex two- or three-dimensional data sets;
- data preprocessing (normalization, baseline correction, alignment, etc. depending on the technique and data format);
- data evaluation using multivariate statistics (e.g., principal component analysis, orthogonal partial least square—discriminant analysis, and linear discriminant analysis);
- comparison of results with a previously created database of reference samples;
- classification of the new sample into a group or class of interest;
- and/or identification of characteristic compounds that can be used as authenticity markers in subsequent analyses.

Depending on the intended scope of the analysis, the chemometric model that is built up from the analytical data can be used to predict various attributes of the sample such as its botanical or geographical origin, whether it is organic or not, adulterated or not, and so on. Most importantly, these nontargeted methods that look at an overall picture of the sample also provide early detection of emerging adulterants or food fraud risks.

Spectroscopies (NIR, FTIR, and NMR) are the most commonly and routinely used nontargeted methods for food authentication (see earlier examples). Thanks to the interest in metabolomics (the study of metabolite profiles in a biological cell, tissue, organ, or organism) in clinical medicine there has been rapid progress in both the instrumentation available and the means required for treating huge quantities of data. This, in turn, has led to the increasing availability of solutions based on high-resolution mass spectrometry (HRMS) which have crossed over into the food authentication arena. A review of metabolomics-based technologies in this area is given in Ellis et al. (2016).

The popularity of HRMS for food analysis has increased with the development of benchtop instruments, using time-of-flight and orbitrap technologies. These instruments can be used in full-scan acquisition mode and can provide accurate mass measurements. The current state of the art on nontargeted mass spectrometry in food fraud detection is reviewed in Cavanna et al. (2018).

One of the main stumbling blocks to the routine use of nontargeted methods in food authentication is the lack of standardization and validation procedures able to demonstrate robustness and fitness for purpose. The majority of existing method validation guidelines are applicable to targeted methods only. In addition, the statistical techniques used are complex and the results are not always acceptable in a court of law. Add to this the fact that interpretation is often based on a proprietary database and that the method is only available in one laboratory, and it is easy to see why these techniques are not more widely used.

There have been several recent initiatives to overcome these obstacles. Riedl et al. (2015) have reviewed the reliability of fingerprinting studies and propose a validation scheme for multivariate statistical models, including recommendations on reporting results. This was followed up by an international symposium organized by the German Federal Institute for...
Risk Assessment (BfR) (Horn et al., 2019) that covered the current status quo on validation and standardization of analytical methods and statistical models, including the important aspects of the exchangeability of data between laboratories and quality assurance measures. The US Pharmacopeial Convention has developed a guidance document to address the use of nontargeted methods (Gao et al. 2019). There have also been several approaches to establishing a harmonized workflow for the development and validation of nontargeted methods (Alewijin et al., 2016; Cavanna et al., 2018). And in an aptly named commentary paper “To Target or Not to Target” (Ballin and Laursen, 2019), a set of definitions is proposed as a first step toward the harmonization of these methods.

Establishing the robustness of a nontargeted method is particularly important if it is used to label an unknown sample as fraudulent simply because it fits into to a certain group or class. Further work is required by the international scientific community in this area if these methods are to find their way out of the research laboratories into routine use for food fraud detection. On the other hand, using these methods in a screening approach, in which samples that appear suspect are then subjected to further confirmatory analyses, provides a valid and particularly cost-effective solution.

### 4.7 Rapid methods for food authentication

Whereas most food testing is currently carried out in specialized or factory laboratories, there is a growing demand for suitable instruments that can be used at “point-of-need”—during transport, at the factory gate or just prior to the production chain—and that are able to provide sufficient information to accept or reject a batch.

Although many of the methods developed for food authentication are qualified as “rapid,” because of simple sample preparation or relatively quick measurement time, they are not always suitable for online, at-line, or in-line process and quality control. The move today is toward portable, handheld instruments that can be used wherever there is a need to detect food fraud.

The first systems of this type, based on the spectroscopic methods (NIR, FTIR) described earlier, are now appearing on the market. These miniaturized spectrometers can be controlled via a wireless or Bluetooth connection to a tablet or smart phone and provide information on quality and authenticity parameters by linking up with a previously calibrated chemometric model (Baeten et al., 2016).

A review by Ellis et al. (2015) provides details of rapid quantitative detection methods based on spectroscopic and spectrometric techniques for on-site food fraud analysis that are either commercially available or currently under development. In addition to infrared spectroscopy, handheld Raman devices are being developed. Their main advantage is the ability to analyze samples through glass or plastic containers. Handheld spatially offset Raman spectroscopy, commonly used for security screening in airports worldwide, has been developed for rapid in situ through-container analysis of Scotch whisky and other spirit drinks (Ellis et al., 2017).

The development of various types of chemical and biological sensors is also growing in response to the demand for rapid measuring systems. Most are used for food quality and safety, with limited applications for food fraud (Mustafa and Andreescu, 2018). Future improvements such as the use of nano-fluidic systems leading to miniaturized and portable systems may provide suitable solutions. However, the lengthy sample preparation often required is a significant drawback to genuine “rapid” use.
In general, each of these rapid methods has been developed for a very limited set of applications, a specific fraud in an individual food type. The question therefore needs to be asked whether these bespoke systems will be cost-effective either for the manufacturer or for the end user. In addition, similar concerns of method validation will arise as these testing devices move out of the laboratory for use by less skilled operators (Popping et al., 2018).

### 4.8 Requirements for the analytical detection of food fraud

Confronted with the diversity of analytical methods available, several aspects need to be considered when making one’s choice, the instrumental technique being only one part of the whole picture (Fig. 4.1).

A series of questions can help one to guide the selection process.

1. How reliable is the method in detecting fraud, how sensitive is it to low-level adulteration?
2. What type of answer is required from the method, should it be quantitative or is a qualitative assessment enough? It is commonly thought that any adulteration level below about 10% is not worthwhile for the fraudster. Is this always the case?
3. Do special precautions need to be taken as regards the food product itself? How is the sample collected, handled, and treated prior to analysis? Long-term storage or the physical effects of excess heat or freezing may lead to the deterioration of the sample and erroneous results when analyzed.
4. Is the method fit for purpose? Has it been validated and are details of performance criteria available? Is the method used in official controls, has it been successful in court cases? Is the laboratory carrying out the analysis accredited? Does it have quality control measures in place ensuring consistent results over time?
5. And finally, how are the results reported?

**FIGURE 4.1** Looking at the whole picture when considering an analytical method for food fraud.

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Reporting of the results is the important question of how authenticity data is interpreted. Ideally this should be done by an authenticity expert, who can assess the sample in the light of knowledge of the food product itself (how it is grown, processed, transported, etc.). In addition, types (b) and (c) methods described earlier require a comprehensive reference database for their interpretation. Given the huge variability of food products, establishing a database that is representative of the food being analyzed is one of the biggest challenges facing the authenticity analyst. Reference samples must be authentic or at least authenticated, and the overall database should consider natural variations due to different geographical origins, varieties of plants or breeds of animals, processing methods, climatic and seasonal effects, to name but a few. In most cases, clear sampling guidelines that include reported sample metadata (e.g., number of samples in each category, type of sample whether raw material or processed, sampling location and period, agricultural practices such as feeding regime and use of fertilizers) will ensure that all necessary information on a sample is available. A recently published description of sampling guidelines for building and curating food authenticity databases is an excellent starting point (Donarski et al., 2019).

4.9 Conclusion

Analytical testing provides scientific evidence for food fraud; results can back up paper trails and on-site audits and sometimes are the only proof available.

A stepwise approach as outlined earlier and illustrated in Fig. 4.2 contributes to an efficient analytical strategy to address food fraud. Its efficiency, however, relies on information obtained from a vulnerability assessment, including prior knowledge of potential

![FIGURE 4.2 An analytical strategy to reduce the risk of food fraud.](image-url)
risks. Other mitigating measures, such as supplier audits, establishing clear specifications, and including anticounterfeiting technologies in labels and packaging, are also part of the overall Food Fraud Mitigation Plan and should not be neglected.

Introduction of the latest nontargeted analytical tools is set to revolutionize food fraud testing in the future, once obstacles such as method validation and data sharing have been resolved. These techniques can be applied between steps 2 and 3 as shown in Fig. 4.2 a first screen so that only suspect samples go on to further testing, or directly at step 3 to detect adulteration.

And finally, all the results and information from the testing strategy should be collated and stored. This “food fraud memory” is the best way to learn from past problems and help one to avoid future food fraud incidents.

References


Food fraud
References


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CHAPTER

5

Food fraud criminology

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5.1 Introduction

The focus on food fraud criminology is to analyze and understand the root cause of fraud associated with food products. The root cause is critical because “the goal is not to catch food fraud but to prevent it from occurring in the first place” (Wu et al., 2017). If the biological organism in question were a microbe, it would be most effective to apply the field of microbiology; for food fraud the biological organism in question is a human, so it is most effective to apply the field of social science and, specifically, criminology. Criminology is a vast field, and most applicable is the focus on crime prevention, which is achieved by reducing the incentive for a “motivated offender” by target hardening. Target hardening refers to reducing the vulnerability of the aim of an attack and can be achieved by the application of situational crime prevention theory.

Criminology is one of the fundamental sciences in food fraud prevention. Food fraud prevention encompasses food science and analytical methods (“food authenticity” methods) to
identify the discrepancy, criminology to understand the root cause, regulations and standards to establish a common set of definitions and standardized methods, public policy and public administration to manage the oversight, enterprise risk management to help define “how much is enough” for a given situation, and how to conduct internal risk communication, and finally the overall standard operating procedures that are implemented across a company in supply chain management (Fig. 5.1).

This chapter will present an overview of criminology, specifically with regards to situational crime prevention, and then describe the methods used to gather, assess, and act upon the information. Before reviewing the role of criminology in food fraud prevention, it is helpful to explain how the human adversary is so elusive that traditional food science or food authenticity testing, and even enhanced traceability, are not sufficient to entirely address the risks associated with food fraud.

Those perpetrating food fraud (the “fraudsters”) are generally clandestine, stealthy, intelligent, resilient, well-funded, and/or very creative in evading detection (Spink and Moyer, 2011). The fraudsters often have multiple identities that enable them to escape or stay in business under an alias. They flee when pursued or sued and they may operate behind and through multiple shell companies. Food fraudsters often work through criminal enterprises that use persuasion from bribes, violence, and sabotage (Spink, 2011).

5.2 Criminology overview

When reviewing any new topic, it is essential to start with a clarification of the definitions and the scope. The field of criminology has very specific and long defined foundations.

This will start with an introduction to some of the terminology used in criminology, criminal justice, and crime science (Spink, 2019):

- Traditional criminology is a field that “seeks to improve understanding of the psychological and social forces that cause people to become criminals in the hope of
finding ways to change these causes.” (Romero and Atlas, 2002 in Clarke and Eck, 2005). “Traditional criminology seeks to improve understanding of the psychological and social forces that cause people to become criminals in the hope of finding ways to change these causes. [...] It seeks ways to reduce the opportunities and temptations for crime and increase the risks of detection.”

- **Environmental criminology** is a concept that focuses on “...the immediate situational causes of crime events, including temptations and opportunities and inadequate protection of targets. The problem analysis triangle (also known as the Crime Triangle) comes from one of the main theories of environmental criminology – routine activity theory. This theory, originally formulated by Lawrence Cohen and Marcus Felson, states that predatory crime occurs when a likely offender and suitable target come together in time and place, without a capable guardian present.” (Clarke and Eck, 2005).

- **Criminal justice** is the “Interdisciplinary academic study of the police, criminal courts, correctional institutions (e.g., prisons), and juvenile justice agencies, as well as of the agents who operate within these institutions. Criminal justice is distinct from criminal law, which defines the specific behaviors that are prohibited by and punishable under law, and from criminology, which is the scientific study of the nonlegal aspects of crime and delinquency, including their causes, correction, and prevention.”

- **Crime science** “takes a radically different approach [than criminology]. It focuses not on the reasons why criminals are born or made, but on the act of committing the crime. It seeks ways to reduce the opportunities and temptations for crime and increase the risks of detection. In doing so, it seeks contributions from a wide range of disciplines, including psychology, geography, medicine, to which it helps to reduce crime on our streets, and in our homes and businesses.” (Romero and Atlas, 2002 in Clarke and Eck, 2005).

Next, several fundamental criminology theories that apply to crime prevention and food fraud prevention are presented and reviewed (Spink, 2019). It is efficient for the emerging food fraud field to first seek to build upon current theories and best practices.

- **Situational crime prevention** refers to the “opportunity-reducing measures that (1) are directed at specific forms of crimes, (2) involve management, design, or manipulation of the immediate environment in as a systematic and permanent way as possible, (3) make crime more difficult or risky, or less rewarding and excusable as judged by a wide range of offenders.”

- **Rational choice theory** is the concept that “[e]ssentially, the criminals believe they will not get caught and will benefit from an act.”

- **Routine activities theory** is the concept that “The crime opportunities are most prevalent when and where perpetrators have access to or awareness of the victim or target.”

- **Action research methodology** is “[a] model where “researchers and practitioners work together to analyze and define the problem, to identify and try out possible solutions, to evaluate the results, and, if necessary, repeat the cycle until it is achieved.” (Lewin, 1947).

- **Problem-oriented policing** is a strategy that has a focus on the specific factors of the root cause where “...operational effectiveness... was not through improvements in organization and management but through a detailed analysis of everyday problems... and the devising of tailor-made solutions.”
For food fraud prevention, together these concepts provide a framework for assessing and addressing the root cause, which is a human adversary who is a “motivated offender.”

### 5.3 Types of criminals and criminal organizations

After the foundational definitions and scope are defined, it is important to review the details and organization of the fraudster. Each type of fraudster and fraudster organization has a different level of sophistication, the scope of activities, and some may even be willing to threaten physical harm to employees or retaliatory sabotage against a company. These definitions listed later were first collected in “defining the types of counterfeiters, counterfeiting, and offender organizations,” which built upon a wide range of sources, including INTERPOL and others, and then the types were codified in the International Standards Organization ISO 12931 Performance criteria for authentication solutions used to combat counterfeiting of material goods (Spink et al., 2013; ISO, 2011).

From the overall collection of 13–15 types of criminals extracted from various sources (removing criminals not related to food fraud, such as arsonist), the types of counterfeiters or fraudsters related specifically to food include the following (Spink et al., 2013 in ISO, 2011):

- **Recreational**: for entertainment or amusement. For example, this would be a criminal that steals the product more for excitement or to reduce the cost of personal consumption of these goods.
- **Occasional**: infrequent, opportunistic. A criminal who does not seek to commit the act, but if an incredible opportunity presents itself; therefore they become a motivated offender.
- **Occupational**: incidents perpetrated at a place of employment either as an individual act or in collaboration with the company. An employee, business owner, or agent who actively seeks fraud opportunities in their routine activities.
- **Professional**: crime fully finances their lifestyle. A criminal the fully supports their lifestyle by committing crimes within the food system.

For food fraud, it appears that the most common type of criminal is “occupational” since individuals or individuals acting on behalf of their company seem to conduct their fraudulent act or acts within other legitimate operations and routine activities. The economic gain can be for themselves directly or indirectly through the success of their employer or company. A challenge for the detection of this type of fraud with authenticity testing is that (1) the fraudsters can research the standardized and public test methods to avoid detection and (2) the fraudsters are constantly aware of fraud opportunities that are still there and others that are created as a result of changes in testing protocols.

Another aspect to consider is the type of offender organization (Spink et al., 2013):

- **Individual/small groups**: These are solo or small groups of perpetrators that operate through informal settings and have little structural organization or reporting. There is often little known about these groups because they may be less of a target for law enforcement.
enforcement due to the small operations and difficulty to track haphazard activities. An example could be individuals that handmade counterfeit products in their garage to sell at flea markets.

- **General criminal enterprises**: These are bigger and more structured, organized, and consistent in their target activity. An example could be a group of defendants that are in several countries that coordinate tax avoidance smuggling.

- **Organized crime**: “Organized crime groups are a specialized subset of criminal enterprises that maintain their position through the use of actual or threatened violence, corrupt public officials, graft, or extortion. [...] A challenge of deterring this group is their use of violence and the risk of retaliation to a company or investigators (e.g., physical violence or sabotage)”. Often there are specific laws or regulations—in addition to specific enforcement and prosecution—resources targeting very specific crimes that disrupt markets or influence governments.

- **Terrorist organizations**: While there is not a global agreement on the exact definition, generally, this is a group that has a goal to inflict fear or harm to support an ideology and specifically to coerce the public or governments. As with organized crime, there are often very clearly defined in laws or regulations to address specific actions, including resources for enforcement and prosecution. Supporters of terrorist organizations often use product counterfeiting as a method to raise funds.

- **Gangs**: These are unique types of offenders based on the network organization and activities based on the subtypes such as street gangs, prison gangs, or outlaw motorcycle gangs. Of the three, street gangs most often engage in and profit from IP theft.

- **Foreign government offenders**: These are activities that are coordinated by, or at least sanctioned, by a government. One motivation may be to generate hard currency by any means possible. One activity is violating intellectual property rights such as patents of food products.

To note, there is a key distinction between actions that are conducted by supporters or members of the group and actions that are the main focus and priority of the group. For example, “…the distinction between terrorist supporters who merely provide funding and resources to a terrorist organization versus terrorist organization members who engage in the actual terrorist activities of violence.” (Spink et al., 2013).

Reviewing a list like this is very important to help understand the scope and scale of possible operations, which has an impact on how to organize the countermeasures and control systems and also to be aware of the potential threat of physical violence or other sabotage. The concept of “organized crime” has frequently been casually or informally applied to food fraud, but when considering countermeasures or prosecution, it is very important to clearly understand whether it is “organized crime,” a “general criminal enterprise,” or just “crime that is organized”. The classification is important since an investigator or prosecutor may not have the authority or resources to pursue one type versus the other. For example, enforcement organizations may have very specific definitions or statutory boundaries for the formally defined “organized crime” versus other forms of crime. For example, if the crime only occurs in one state, then a federal prosecutor may be excluded from being able even to take the case—if a state case is brought to a federal
prosecutor, or if an “organized crime” charge is proposed for a “general criminal enterprise” situation, the case may be thrown out, wasting time and jeopardizing getting the prosecutor’s attention in the future.

5.4 Crime prevention

We will now shift to consider the practical crime prevention tasks and organization. In the 1970s there was a new criminology focus on practical application, working closely with practitioners, focusing on prevention or reducing the factors that enable a crime to occur, and a very refreshing practical presentation of the topics. Early leaders include Marcus Felson and Ron Clarke, who conducted research in 1973 on why some students ran away from reform schools and others did not. These concepts were expanded upon in their 1976 book *Crime as Opportunity*. This was followed up with *Crime and Everyday Life* that introduced the crime triangle (Felson, 2002).

Key insights from crime in everyday life (Clarke and Eck, 2005):

- “Don’t get fancy”. In the case of food fraud prevention, this would be a recommendation to start very simple and then increase the complexity of the assessment or selection of countermeasures or control systems only after further review.
- “Don’t worry about academic theories. Just go out and gather facts about crime from nature itself (observation)”. In the case of food fraud prevention, this encourages an initial very simple review of the problem but with an emphasis on seeking insight not only on “what” happened but on “how” and “why”. The emphasis on prevention requires a focus on the factors that influence the root cause which is a “motivated offender”.
- “Focus on very specific slices of crime, such as vandalism against telephones or soccer violence [or, in the case of food fraud, species swapping during the transfer of ownership from supplier to the customer]. Even the crime ‘vandalism’ would be far too broad!” In the case of food fraud prevention, this would be a focus beyond the result back to exactly “how,” “when,” and “where” the fraud act was conducted at a system weakness. This would also emphasize addressing all the unique types of fraud separately, such as adulterant substances, counterfeits, theft, and others.
- “Try to block [prevent] crime in as practical, natural, and simple way, at a low societal and economic cost”. In the case of food fraud prevention, this is a focus on reducing or eliminating the likelihood that the fraud act can occur in the first place. When these key insights are considered together, there is often a very simple and immediately implantable action that can eliminate or vastly reduce the fraud opportunity.

Next, there are many different specific crime prevention results, including an anticipatory benefit, crime displacement, diffusion of benefits, reduction, and dissipation or designing out crime (Spink, 2019).

- Anticipatory benefits of crime prevention are the “[b]enefits from crime prevention that begin prior to initiation of crime prevention treatments” (Clarke and Eck, 2014). Also, “. . . benefits were noted if a pre-initiative drop in a crime measure was observed.”
The criminals reduce their activity in anticipation before the crime prevention countermeasures are implemented.

- Displacement of crime “is the relocation of crime from one place, time, target, offense, or a tactic to another as a result of some crime prevention initiative” (Guerette, 2009). Also, “Overall, displacement is viewed as a negative consequence of crime prevention efforts, but in some cases, it can still provide some benefit” (Guerette, 2009):
  - Temporal—offenders change the time at which they commit a crime
  - Spatial—offenders switch from targets in one location to targets in another location
  - Target—offenders change from one type of target to another
  - Tactical—offenders alter the methods used to carry out a crime
  - Offense—offenders switch from one form of crime to another.”

- Diffusion of benefits of crime “…entails the reduction of crime (or other improvements) in areas or ways that are related to the targeted crime prevention efforts, but not targeted by the response itself.” Though less recognized than displacement, diffusion is recorded in many research evaluations of crime prevention responses. Diffusion effects are referred to in a variety of ways, including the “bonus effect,” the “halo effect,” the “free-rider effect,” and the “multiplier effect.” “The opposite of crime displacement is the diffusion of crime control benefits. Crime diffusion entails the reduction of crime (or other improvements) in areas or ways that are related to the targeted crime prevention efforts, but not targeted by the response itself.” (Guerette, 2009).

The criminals decrease a wide range of their activities, even beyond where the crime prevention countermeasures are implemented.

- Prevention of crime is the concept “is about reducing the risk of occurrence, and the potential seriousness, of crime and disorder events by intervening in their causes. This definition is deliberately inclusive—centering on no particular kinds of causes or theories of crime, and favoring no kinds of intervention over others.” (Ekblom, 2013).

- Reduction of crime “is simply about decreasing the frequency and seriousness of criminal events, by whatever (legitimate) means. […] Most reduction is delivered through prevention, although some involve intervening directly in unfolding events.” (Ekblom, 2013).

- Dissipation or designing out crime is a similar concept within crime reduction because it is focused on opportunity elimination (Newman, 1972).

A full review of the key criminology terms and goals helps provide a foundation for considering crime prevention in the context of food fraud prevention.

The “crime triangle” is a practical and effective way to review the root cause of food fraud because it enables the evaluation of the various factors that could lead to the opportunity and motivation for fraud (Felson, 2002). This application of situational crime prevention includes routine activities theory, rational choice theory, and action research methodology. “The foundational concept is that [Criminals] typically behave like criminals only in certain settings, that is, slices of time and space within which relevant people and things are assembled.” (Spink, 2019 summarizing in Felson, 2002). The crime triangle adapted to food fraud prevention is shown in Fig. 5.2 and includes the following terms (Spink, 2019).

An example of the crime triangle applied to product fraud—and, thus, application to food fraud—can be found in the case study from “Addressing the Risk of Product Fraud: A Case
Study of the Nigerian Combating Counterfeiting and Sub-Standard Medicines Initiatives” (Spink et al., 2016a) (Fig. 5.3). Before this initiative the Nigerian National Agency for Food and Drug Administration and Control identified counterfeit and substandard medicines in their country as a high priority public health and law enforcement priority. Some estimates were that up to 60% of the medicines in certain categories were counterfeit or substandard. The crime triangle figure demonstrates the explanation of how a wide range of countermeasures or control systems reduces the fraud opportunity factors. For example, “Action 1: product authentication” is the implementation of handheld Raman spectroscopy devices to rapidly authenticate the suspicious product at a border or in a marketplace. This evaluation helps select product that is seized for further, more detailed laboratory authentication tests.

The application of situational crime prevention theory to food fraud prevention involves leveraging the existing literature and science to select best practices and also gain

FIGURE 5.2 Crime triangle applied to product fraud. (Copyright permission granted) crime triangle factors include victim—“suitable target,” fraudster—“likely offender,” and guardian and hurdle gaps—“absence of a capable guardian”.

FIGURE 5.3 Application of the crime triangle to the Nigerian Anti-Counterfeit Initiatives—identifying the influence of each action no the fraud opportunity (Spink et al., 2016a). Source: Copyright permission granted.
insights into applying a practical approach. For example, a frequent food fraud assessment focus is on trying to evaluate whether a supplier has a risk of being or becoming a fraudster. Traditional criminology would, rightly, identify that if a person is living beyond their means, there is the risk of them being tempted to engage in fraud or crime. Environmental criminology would acknowledge this but be realistic of “how would you measure this” and regardless, “how would you persuade them not to attack your company.”

“For assessing a food fraud problem, a practical question is how a risk assessor — probably a manufacturing quality control employee in a corporate office in a Western country — would evaluate if a Bangladeshi farmer is living beyond their means? Would the supplier who owns two cows be equivalent to a Westerner owning a Ferrari? Also, if the fraudster were an intelligent adversary, they would not drive their Ferrari/second cow to the business where it could be viewed. Even if this was known, how would the risk assessor conduct an investigation into the lifestyle of the farmer?” (Spink, 2019).

The practical, pragmatic foundation of situational crime prevention provides very simple, direct, and often inexpensive or no cost countermeasures that can be immediately implemented with an instant benefit. The focus on situational crime prevention enables very clear and focused decision-making that identifies the minimum action that achieves the maximum prevention result. This theory shifts the prevention focus from features (what a countermeasure does) to benefits (how it specifically helps to reduce the problem). This will be explained in more detail later in the section on hot products and hot spots.

5.5 How to analyze a crime problem: scanning—analysis—response—assessment

To enable the effective and efficient implementation of the crime prevention concepts, there should be a process to assess the success of the strategies. A major focus of criminology research is on the analysis of the problem and then the intelligence analysis to organize the raw information into actionable forms. Both are such formal types of research that there are specialized graduate programs and even PhD dissertations on the topics.

A commonly adopted concept is the SARA (scanning—analysis—response—assessment) process that is similar to the foundations presented in ISO 9000 Quality Management, ISO 31000 Risk Management, and others. The “plan-do-check-act” quality management concept is similar to this “SARA” (Fig. 5.4) (Clarke and Eck, 2005):

- What is the nature of the problem? (scanning)
- What causes the problem? (analysis)
- What should be done about the problem? (response)
- Has the response brought about a reduction in the problem? (assessment)

A key emphasis for the SARA model is on the application to real-world situations, real problems, and embracing the idea that there is usually very little data and very few resources to conduct the assessment. This is especially applicable to food fraud prevention, for example, when addressing new incidents or suspicious activity with little data, since it can quickly select and evaluate countermeasures and control systems. The SARA model
decision-making process can be supplemented with other detailed assessments, such as in-depth supply chain mapping activities.

5.6 Hot product and hot spot analysis

While it may seem like a casual mention of an idea, the “hot product/hot spot” analysis is a formal type of criminology research (Eck et al., 2005). This is an application of the focus on crime targets (the hot products) and exact vulnerabilities (the hot spots). If the specific hot product, or precise hot spot, is not clearly understood, then the detection, deterrence, and prevention efforts may be inefficient at best.

“If the fraud act is species swapping, then the vulnerability is a lack of specific tests conducted by the receiving company for the correct hot product and at the precise crime hot spot. There could be many species tests conducted but at the wrong spot and for the wrong product. That manufacturing quality control employee could recommend, and almost immediately implement, incoming goods testing for the correct hot product and at the hot spot. Regardless of whether the supplier is a criminal or not, the fraud opportunity would already be vastly reduced to the point that there may not be an opportunity to commit the act—that is, as long as the fraudster and all other suppliers know that new species tests are being conducted.” (Spink, 2019).

Applied to a food fraud incident, horsemeat in beef is a “hot product,” and the manufacturing site where the mislabeling occurred is a “hot spot.” Fig. 5.5 shows examples of three specific hot spots identified in association with the horsemeat in beef food fraud incidents and identifies three specific hot spots (Lam and Spink, 2018). When the vulnerability is defined at those hot spots, there can be a high confidence and specific application of very accurate and precise countermeasures and control systems.

The hot product/hot spot analysis is an excellent way to explain clearly where and how they reveal a vulnerability or system weakness, and also how specific countermeasures reduce that gap. This insight on how and why the hot spots exist in this incident helps prioritize the application of new countermeasures or control systems. It is important to understand that system weaknesses, or vulnerabilities, exist whether they have been exploited or not.
5.7 Intelligence analysis

It is natural that when experts—such as food scientists—address a problem that has emerged from the core area, they create novel approaches. Often, it is difficult or confusing to try to find research from other disciplines that directly applies to a specific problem. This lack of research could lead to “reinventing the wheel,” or the novel approach may face the same potholes or failed paths that the predecessors already overcame. A means to address this is through the use of intelligence analysis and big data/data analytics.

An intelligence analysis tool that can be applied to food fraud is the Product Counterfeiting Incident Clustering Tool (PCICT) (Fig. 5.6) (Spink et al., 2013). This tool was included in the ISO 12931 and presented there as a best practice for organizing information (ISO, 2011).

The PCICT builds upon the concepts that were presented earlier regarding counterfeiting as a type of fraud, types of counterfeitors, and offender organizations. The goal is to simplify the evaluation of all the product fraud incidents or suspicious activity information, data, and reports to identify where the problem is occurring and by what types of organizations. When information is organized, the use of the PCICT often reveals clusters. By reviewing these clusters, the most efficient and effective countermeasures and control systems can be implemented. The example shown in Fig. 5.6 identifies that the most prevalent types of fraud are diversion and also counterfeiting. The model further clarifies that the fraudulent acts were conducted mostly by the occupational type of fraudster. Also, the most common types of offender organizations are individuals and small groups. This reveals that professional and organized crime members are involved, so this would elevate at least the awareness of this risk. To summarize, for this company, diversion and counterfeiting are the two most problematic types of food fraud, it is conducted mostly by an occupational type of criminal, and the offender organization is an individual or small group. With this insight, countermeasures and control systems can be reviewed that focus on these details rather than combating all types of food fraud.
Next, once the information has been gathered and organized, it can now be processed in an intelligence analysis system such as the “4 by 4” method (Table 5.1) (Spink et al., 2019; UNODC, 2010). “Before converting a piece of raw data to information and then to actionable intelligence, Intelligence Analysis methods to evaluate the incoming information include

![Table 5.1](image)

**TABLE 5.1** Conventions for evaluating the source and type of information (UNODC 2010 in Spink, 2019).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Source</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Where there is no doubt of the authenticity, trustworthiness, and competence of the source, or if the information is supplied by a source which, in the past, has provided to be reliable in all instances</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>Sources from whom information received has in most instances proved to be reliable</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>Sources from whom information received has in most instances proved to be unreliable</td>
<td>3</td>
</tr>
<tr>
<td>X</td>
<td>The reliability of the source cannot be assessed</td>
<td>4</td>
</tr>
</tbody>
</table>

*Source: Copyright permission granted.*
organizing by (1) source and (2) type of information.”(Spink et al., 2019). Also, the method presents four levels of “Sources” considered with four levels regarding the “Type of information” (Spink et al., 2019).

5.8 How to use the intelligence analysis data

After the intelligence analysis methods are understood, the food fraud-related raw data can be organized in a standardized way. The further processing of this data in order to achieve “actionable intelligence” requires an understanding of how this intelligence will be used. Before even starting the criminology research or implementing a system, there is a step to identify how the information will be used. For example, gathering information for an “Overview of the problem – General” is very different from “Criminal Prosecution – use as evidence during an investigation or court case.” (Spink et al., 2019).

Before reviewing the types of decision, it is important to review that one of the most important and widely adopted set of guidelines for food fraud compliance is the Global Food Safety Initiative (GFSI) Benchmarking Document. The GFSI membership includes approximately 65% of the world food trade and, especially since many of the requirements are implemented by companies at the end of the supply chain, this is a widely adopted requirement. The food safety management systems such as BRC, IFS, SQF, FSSC 22000, and others are endorsed by GFSI as compliant. The GFSI requirement for a food safety management system includes conducting, implementing, and managing a food fraud vulnerability assessment (FFVA) and a food fraud mitigation strategy. The criminology concepts help in the understanding of the root cause, of processing raw data into actionable intelligence, and in selecting efficient and effective countermeasures or control systems.

There is a range of needs for data related to the many ways that food fraud risk information or incidents may be collected and applied to specific decisions (Spink et al., 2016b):

- Overview of the problem—general
- Overview of the problem—detailed
- Negative list/blacklist (including “early warning system” for known concerns)
- Food fraud vulnerability assessment—current state
- Food fraud vulnerability assessment—fraud opportunity (understanding system weaknesses)
- Product fraud incident clustering (general review of data sets)
- Ongoing suspicious activity scouting/horizon scanning
- Criminal prosecution—use as evidence during an investigation or court case
- Enterprise-wide financial reporting requirements (e.g., Sarbanes–Oxley Act and enterprise risk management)

Based on the wide variety of data needs for decision-making, there are very different needs for the data analysis factors (often referred to as the “5V’s of big data”) such as volume: the amount of data, velocity: the speed of data-collection with big data defined in real time or near real time, variety: a range of text or multimedia forms, veracity: the trust in the thoroughness of the data-collection and ability to represent the entire event, and
value: a rough judgment of the actual usefulness of the data set to address the specific question or the thoroughness recommendation based on this data set (Spink, 2019).

As the value of a countermeasure or control system is judged by the contribution to prevention, the value of intelligence or data is based on how thoroughly it directly addresses a specific question. This section provided a foundation on crime problem and hot spot analysis, the fundamentals of intelligence analysis, and insight on the types of decisions the data is supposed to support. Collectively, these concepts and methods are the application of criminology theory to food fraud prevention.

5.9 Conclusion

The role of criminology in food fraud prevention is to help understand the root cause, which is the motivation of the human adversary, and then to provide a methodologically sound approach to crime prevention. When considering the data-collection needs, the followings are essential:

• Address the entire scope of the crime: address all types of food fraud, not just adulterant substances.
• Assess the problem with a focus on vulnerabilities: conduct an FFVA for all types of fraud and start with a very high-level and simple assessment before confirming there is a compliance or management decision-making–related need for more detail.
• Review all research disciplines that help provide insight or guidance on the countermeasures: consider other enterprise-wide financial or securities assessments that are a nonfood compliance or certification requirement.
• Follow a structured approach to plan-do-check-act: This includes the SARA methodology and to conduct a first FFVA and create a food fraud prevention strategy.
• Consider future needs that will be specified by the needs of the resource-allocation decision-makers.

Food fraud prevention can be more readily addressed once the definition and scope are clearly defined. Also, it is most efficient to apply a wide range of academic disciplines that have been adopted and adapted to the overall focus of preventing the act. Criminology is the key discipline to help understand the root cause of the problem and to evaluate which countermeasures and control system will most efficiently and effectively achieve the maximum prevention impact. The goal is not to catch food fraud but to prevent it from occurring in the first place.

References


Food Fraud


Food Fraud


Chapter 6

Fraud in meat and poultry products

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6.1 Meat and poultry: nutritional value and economic importance

According to the definition provided by the AMSA (American Meat Science Association) (2018), meat corresponds to the “Skeletal muscle and its associated tissues derived from mammalian, avian, reptilian, amphibian, and aquatic species harvested for human consumption. Edible offal consisting of organs and nonskeletal muscle tissues also are considered meat.” Although aquatic species are included in this definition, fish and
other seafood are most commonly viewed as distinct to meat entities, and they will be covered in a separate chapter.

Meat is a significant source of protein of high biological value, B complex vitamins, iron, and other mineral substances, including zinc, selenium, and phosphorus (Baltic and Boscovic, 2015; Biesalski, 2005; Bohrer, 2017; McAfee et al., 2010; Pereira and Vicente, 2013; Wu, 2016). Meat products have high nutritional density, particularly with regard to their content in dietary protein. Indeed, protein (principally essential amino acids) intake is of vital importance in the adult, adolescent, and children diets, supporting body repair, cell regeneration, growth, and development (Bohrer, 2017; Wu, 2016). Moreover, meat and poultry (e.g., lean red meat and meat originating from scavenging birds) may constitute an important dietary source of mono- and/or polyunsaturated fatty acids, well known for their beneficial role in human health (McAfee et al., 2010; Mir et al., 2017). Finally, several feeding strategies and regimes have been evaluated during the last decade as propitious for the improvement of various properties of meat products, including their nutritional value and role in human health, as well as their oxidative stability and sensory characteristics (Bou et al., 2009; Mir et al., 2017; Zotte and Szendrő, 2011).

Based on the Agricultural Outlook 2019–2028, a collaborative effort of the Organization for Economic Co-operation and Development and the Food and Agriculture Organization of the United Nations, a continued expansion in meat supply is foreseen for the next decade. Global meat production is projected to be 13% higher in 2028, with developing countries accounting for the vast majority of the total increase. With regards to trade, meat exports at the global level (excluding live animals and processed products) are projected to be 18% higher in 2028 compared to 2019. The main factors consistently driving the evolution and dynamics in world meat markets are animal disease outbreaks (e.g., African swine fever), sanitary restrictions, and trade policies (OECD/FAO (Organization for Economic Co-operation and Development/Food and Agriculture Organization), 2019). Although there are several factors influencing and collectively delineating meat consumption (e.g., income level, relative prices, religious beliefs, cultural norms, urbanization, and environmental/ethical/health concerns), an overall increase in meat consumption is also expected in the next decade (OECD/FAO (Organization for Economic Co-operation and Development/Food and Agriculture Organization), 2019). Nonetheless, factors such as the increasing consumer focus on animal treatment and meat production practices (such as a preference for free-range, organic, and/or antibiotic-free products) may continue to affect meat consumption in the future.

Meat and poultry products are food commodities of significant nutritional value and major economic importance. In this context, the safety, quality, and integrity of meat and poultry products are food protection issues that affect the entire food supply chain, including manufactures/processors, retailers, regulatory authorities, and consumers.

### 6.2 Meat and poultry fraud: facts, drivers, and vulnerabilities

Meat and poultry are highly vulnerable to fraud due to their high nutritional and market values combined with ample opportunities for fraudulent practices within the supply chain. This was not always the case, since historically (and mainly prior to the industrial
revolution), meat and poultry were marketed as fresh and easily recognizable carcass parts, and as such, they were not as vulnerable to fraud incidents (Nakyinsige et al., 2012). However, this situation has considerably changed nowadays, when processing of meat into various value-added products has increased their susceptibility to fraudulent activities (Vandendriessche, 2008). For example, food processing techniques often applied to meat, such as mixing or grinding, can make it easier to manipulate these products (Esteki et al., 2019; Zhang and Hue, 2016). In this sense, ground and/or processed meat products (e.g., sausages, burger patties, and deli meats) are expected to be especially vulnerable to fraud (Ayaz et al., 2006; Cawthorn et al., 2013; Chuah et al., 2016).

Contemporary advanced data analysis tools have allowed assessment of vulnerabilities across supply chains as well as between chain actors (tiers). Indeed, as reported by van Ruth et al. (2018), exploratory data analysis, utilizing multiple correspondence analysis and agglomerative hierarchical clustering, demonstrated that the vulnerability to food fraud may vary considerably across the food supply chain. In this latter assessment, meat exhibited the third highest overall fraud vulnerability (after spices and olive oil), with the wholesale/traders group being the most vulnerable (van Ruth et al., 2018). Based on a Bayesian network modeling approach, developed from 1393 food fraud cases and 15 different data sources, “meat” showed the second highest probability to be fraudulent (13.4%) after “fish and seafood” (20.6%) (Marvin et al., 2016).

Parameters that may also contribute to the exposure and ultimate vulnerability of meat commodities to fraud include gaps and loopholes potentially existing within certification and enforcement policies. Specifically, meat produced in accordance with religious laws (e.g., Halal meat) may be regulated by different authorities and/or regions (Fuseini et al., 2017). Since consumer choices with regard to meat consumption are driven by lifestyle and health trends, religious aspects, dietary restrictions, and/or ethical and sustainability issues, fraud incidents involving these attributes are emerging food protection issues. Distribution of conventional meat products as organic, adulteration of beef products with other meat species (e.g., pork), or lack of appropriate allergen statements, are a few characteristic examples of fraud incidents that may be encountered in the meat sector (Ballin, 2010).

### 6.3 Incidence of fraud in meat and poultry products

#### 6.3.1 Types of fraud

Various types of fraud have been described for meat and poultry products, either in the form of media reports or as official notifications/alerts from food safety authorities or databases, such as the European Union (EU) Rapid Alert System for Food and Feed (RASFF) (https://ec.europa.eu/food/safety/rasff). Moreover, market survey data reported in the scientific literature (referring mainly to samples collected from retail premises) also provide insight into the incidence (prevalence and types) of fraud in these commodities. These types of reports are valuable for assessing the exposure of the meat industry and consumers to this important food protection issue. A study based in Finland revealed that fraud linked to products of animal origin along with fraud associated with food ingredients make up a large percentage of the reports of food fraud cases (Tähkäpää et al., 2015).
Nonetheless, the observed patterns may vary considerably among reports based on distinct datasets, demonstrating the importance of incorporating different types of data in order for solid conclusions to be drawn. According to the findings of Tähkäpää et al. (2015), who analyzed published food fraud incidents originating from different sources (i.e., RASFF, Finnish Food Safety Authority, and local Finnish cases) in the period 2008–12, the majority of cases in RASFF notifications (50%) and local Finnish cases (88%) concerned food of animal origin from Asia, the Middle East, and South America. Zhang and Hue (2016) investigated food items of animal origin that were identified as being mainly involved in fraud incidents in China, based on an aggregative analysis of 1553 reports on food safety scandals and reports. The fraud incidents involved in this study included (in decreasing order) pork, animal organs and sausages, poultry, meat (mixed), beef, animal blood, and lamb.

The fraud incidents most commonly associated with meat and poultry (and products thereof) include addition (e.g., enhancers, neutralizers, and preservatives), dilution (usually practiced with water addition for volume increase and cost reduction practices), substitution, and mislabeling/misdescription (Chuah et al., 2016; Naaum et al., 2018; Zhang and Hue, 2016). Representative examples of food fraud incidents in meat and poultry commodities recorded in the last two decades are provided in Table 6.1.

Substitution is usually partial and refers to the replacement of high-value ingredients with low-value ingredients for economic gain. The lower value ingredients are either undeclared or above legal limits. Complete species substitution may also be encountered, in which the meat from an animal species is presented and distributed as meat from another species. Partial or full species substitution (as well as others forms of substitution) of high commercial value food commodities, such as meat and meat products, with low-value species (or ingredients) for economic gain has been a well-established fraudulent practice, with the first anecdotal evidence dating as back as 1886 (Walker et al., 2013). Substitution can occur at numerous points in the supply chain, including during meat packing and importation and extending to the retail and food service levels (Premanandh, 2013). In some cases, the presence of undeclared meat species might be unintentional, such as in the case of accidental contamination with another species due to insufficient cleaning of equipment in meat processing plants where more than one species is processed. It has been generally presumed that the presence of a meat species below 0.1% in meat products could be considered accidental contamination in the commercial production line, since substitution at such low levels is not anticipated to have an economic benefit (Al-Kahtani et al., 2017). Indeed, according to the findings of a recent study, incomplete cleaning of grinding equipment typically results in species contamination at levels of <1% (Chung and Hellberg, 2020). On the other hand, when species are deliberately substituted in meat and poultry products for economic gain and commercially packaged, they are also subject to mislabeling/misdescription. In such case, mislabeling is inarguably intentional and, in some cases, may have public health repercussions in addition to economic deception (Everstine et al., 2013). The fraud type referred to as “misbranding” can also be viewed as a subtype of mislabeling/misdescription and, based on the provisions provided by the US Food and Drug Administration (outlined in the Federal Food, Drug, and Cosmetic Act, Title 21, https://www.fda.gov/regulatory-information/laws-enforced-fda/federal-food-drug-and-cosmetic-act-fdca-act), it can include fraudulent practices pertinent,
TABLE 6.1 Examples of food fraud incidents related to meat and poultry commodities.

<table>
<thead>
<tr>
<th>Product</th>
<th>Fraud details</th>
<th>Affected country(ies)</th>
<th>Reference/source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamburger meat; Chorizo</td>
<td>Substitution (undeclared meat species: horse, pork)</td>
<td>Mexico</td>
<td>Flores-Munguia et al. (2000)</td>
</tr>
<tr>
<td>Meat products</td>
<td>Substitution (undeclared meat species: deer, horse, poultry)</td>
<td>Turkey</td>
<td>Ayaz et al. (2006)</td>
</tr>
<tr>
<td>Corned beef</td>
<td>Addition of unfit meat, misdescription as “Halal”</td>
<td>France</td>
<td>Bosley (2007)</td>
</tr>
<tr>
<td>Meat</td>
<td>Distribution of meat unfit for human consumption</td>
<td>Germany</td>
<td>Bosley (2007)</td>
</tr>
<tr>
<td>Mutton meat</td>
<td>Substitution with murine meat</td>
<td>China</td>
<td>Boehler (2013)</td>
</tr>
<tr>
<td>Processed meat products</td>
<td>Substitution (undeclared meat species/plant protein)</td>
<td>South Africa</td>
<td>Cawthorn et al. (2013)</td>
</tr>
<tr>
<td>Meat products</td>
<td>Unauthorized use of colorant (Sudan)</td>
<td>China</td>
<td>Jia and Jukes (2013)</td>
</tr>
<tr>
<td>Beef products</td>
<td>Substitution (undeclared horsemeat)</td>
<td>Several EU member states</td>
<td>O’Mahony (2013), Walker et al. (2013)</td>
</tr>
<tr>
<td>Processed meat/poultry products</td>
<td>Substitution (undeclared meat species)</td>
<td>Italy</td>
<td>Di Pinto et al. (2014)</td>
</tr>
<tr>
<td>Processed meat products</td>
<td>Addition of unfit meat, misdescription as “Halal”</td>
<td>Iran</td>
<td>Dootti et al. (2014)</td>
</tr>
<tr>
<td>Processed meat products</td>
<td>Substitution (undeclared meat species: buffalo, chicken)</td>
<td>Malaysia</td>
<td>Chuah et al. (2016)</td>
</tr>
<tr>
<td>Meat products</td>
<td>Substitution (undeclared meat species: poultry, equine)</td>
<td>Turkey</td>
<td>Keyvan et al. (2017)</td>
</tr>
<tr>
<td>Pork fat (lard)</td>
<td>Addition of recycled cooking oil/animal feed oil</td>
<td>Taiwan</td>
<td>Peng et al. (2017)</td>
</tr>
<tr>
<td>Raw meat sausages</td>
<td>Substitution (undeclared meat species: beef, chicken, horse, pork, turkey)</td>
<td>Canada</td>
<td>Naaum et al. (2018)</td>
</tr>
</tbody>
</table>

among others, to compositional deviations (e.g., fat, protein, and missing or undeclared constituent) or false marketing claims (e.g., health, processing, quality grade, or provenance claims).

Beyond the deception and the resulting mistrust of the food chain, there are frequently ethical issues emerging from such fraudulent activities, related to ideological and/or religious beliefs that consumers may have. For instance, according to the Islamic (Halal) and Jewish (Kashrut) dietary laws, consumption of pork is prohibited, and the same applies for beef consumption for the Hindu (Bonne and Verbeke, 2008; Chuah et al., 2016; Schröder, 2003). Hence, in addition to the economic benefits associated with trading in the
ever-growing food market, many concerns have been expressed by these population groups regarding the slaughter of food animals as well as the subsequent processing or handling of meat and poultry products (Fuseini et al., 2017; Nakyinsige et al., 2012). In this sense, Halal authenticity has evolved as an important food protection issue, and the main food fraud concerns of Muslim consumers include pork substitution, undeclared use of porcine derivatives (e.g., blood plasma, intestine casings, gelatin, collagen, lard, offal, and mechanically recovered meat), non-Halal methods of slaughter, as well as contamination with “Haram” meat species (i.e., pig, cat, dog, monkey, and rat) (Chuah et al., 2016; Nakyinsige et al., 2012). Beyond the cases of direct and specific addition/substitution, prohibited ingredients may be present in Halal meat products indirectly, for example, as a means of masking other fraudulent activities or as a result of accidental contamination during comanufacturing. For example, the addition of water to poultry is a rather common fraudulent practice, and the added water has been found to include proteins of porcine or bovine origin to aid in carcass water retention (Fuseini et al., 2017). Furthermore, given that most of the Halal meat producing facilities in the West also process pork, an increased risk of accidental contamination exists in the case of poor segregation and cleaning (Fuseini et al., 2017). Even in the case of accidental contamination, however, consumer trust in the food supply can be significantly compromised. Therefore good manufacturing practices in conjunction with proper labeling and accurate declaration of meat species and other ingredients in commercial meat and poultry products are of paramount importance if fair trade, freedom of choice, and compliance with regulations are to be ensured (Chuah et al., 2016).

### 6.3.2 Food fraud market surveys

Meat authenticity is a topic of increasing interest among food manufacturers, regulatory agencies, and consumers. Meat authenticity issues that are associated with fraudulent activities include (1) mislabeling of the provenance (e.g., meat cuts, breed, feed intake, age at slaughter, wild vs farmed meat, organic vs conventional meat, and geographic origin), (2) substitution (meat species, fat, and protein), (3) mislabeling of processing treatment (irradiation, fresh vs thawed meat, and meat preparation), and (4) addition of undeclared nonmeat ingredients (Ballin and Lametsch, 2008; Ballin, 2010; Cawthorn et al., 2013). Several market surveys have been conducted on the topic of meat fraud in a range of geographic locations (Table 6.1).

Mislabeled due to false declarations, including the presence of undeclared species in meat and poultry products, has been identified as an area of concern in regions such as South America (Flores-Munguia et al., 2000), Turkey (Ayaz et al., 2006), South Africa (Cawthorn et al., 2013), Italy (Di Pinto et al., 2014), Malaysia (Chuah et al., 2016), China (Zhang and Hue, 2016), the United States (Kane and Hellberg, 2016), and Canada (Naaum et al., 2018). A study conducted in Mexico focused on testing two categories of processed meat products collected from local food stores: hamburger meat and chorizo (Mexican sausage) (Flores-Munguia et al., 2000). Undeclared equine species (i.e., horse) was detected in 39.1% (9/23) of hamburger meat samples, while undeclared equine and porcine species were detected in 29.4% (5/17) of chorizo samples at levels ≥1% and ≥3%, respectively. In a food survey conducted in Turkey, various retail meat products were analyzed for
species determination, and it was reported that 22 of the 100 tested products had authenticity and mislabeling issues. Specifically, 39.2% of fermented sausages, 35.7% of cooked salami, 27.2% of frankfurters, 22.2% of raw meat, and 6.2% of raw ground meat and meatballs, all declared as “beef only,” were found to contain undeclared species. The most commonly detected undeclared species were poultry in processed meat products and horse and deer in raw meat samples (Ayaz et al., 2006). The considerable association of processed meat products with substitution and mislabeling/misdescription was also demonstrated by the findings of Cawthorn et al. (2013), who analyzed products sold in local meat markets (retail outlets and butcheries) in South Africa and found that 68% (95/139) of the samples contained species that were not declared on the product labeling, with the incidence being highest in sausages, burger patties, and deli meats. Pork and chicken were the most commonly detected animal species serving as adulterants (37% and 23%, respectively). Unconventional species such as donkey (in beef sausage), goat (in mutton mince and sausage), and water buffalo (in beef mince, patties, and grillers) were discovered, while soya and gluten also were identified as undeclared plant protein in 31.7% and 28.8% of samples, respectively (Cawthorn et al., 2013). An investigation of various packaged meat products (chicken sausages, pork sausages, meat patties, and pâtés) from Italian dealers, markets, and supermarkets revealed a high substitution rate, demonstrating 41/72 (57%) mislabeling cases (Di Pinto et al., 2014). Specifically, 20/36 chicken sausage samples were positive for pork and bovine, 5/12 pâté samples labeled as pork and bovine were positive for chicken, and the remaining 7/12 meat patties samples labeled as pork were positive for bovine. High mislabeling rates were also identified in processed meat products sampled in Malaysia, with a total of 78.3% (112/143) of samples having false declaration of species and/or presence of undeclared meat species. Common substitution–misdescription issues included the detection of buffalo or chicken DNA in samples labeled as “beef,” as well as of buffalo DNA in samples labeled as “chicken” (Chuah et al., 2016). Testing of a variety of ground meat products sold on the United States commercial market for the presence of potential mislabeling demonstrated that 20.8% (10/48) of the samples were mislabeled, with 9 of the mislabeled samples containing additional meat species and 1 sample being mislabeled in its entirety (Kane and Hellberg, 2016). A similar overall mislabeling rate of 20% (20/100) also was reported in a recent survey of raw meat sausage samples in Canada; animal species recorded as adulterants included chicken in turkey sausages, turkey and beef in chicken sausages, pork in beef sausages, beef in pork sausages, and horsemeat in pork sausages (Naaum et al., 2018).

6.3.3 Meat fraud scandals

With food fraud constituting a highly profitable crime, corrupt operators can be easily tempted to engage in fraudulent activities resulting in enhanced economic vulnerability for food manufacturers and brand owners (Moyer et al., 2017). Although there is still a lot to be ascertained in regard to the motivational and organizational perspectives of the behavior of food fraudsters, it has been acknowledged that food animals are viewed as a source of protein in exchange for financial gain, and that all stages in the meat supply chain (e.g., slaughter, processing, and retail settings) play a distinct role in sustaining such
illicit behaviors (Manning et al., 2016). Despite the fact that information indicating fraud incidents (or suspicion of fraud) can be provided from various sources, fraud in the meat sector has rarely attracted the public attention in the form of major and extensive scandals. Generally, large-scale food fraud incidents, resulting in many products and regions being affected, are perpetrated by highly sophisticated and well-organized criminal networks that take advantage of the complexity of the food supply chain and vulnerabilities at the interface between legitimate and illegitimate business activity (Manning et al., 2016).

The meat fraud incident that has received the most public attention, covered extensively by the media and demonstrating the potentially extensive magnitude of food crime, was the horsemeat scandal reported in January 2013 (Stanciu, 2015; Manning et al., 2016; Walker et al., 2013). This was an incident involving beef substitution with horsemeat and was initiated on January 15, 2013 when the Food Safety Authority of Ireland published a press release on an initially small survey identifying equine and porcine DNA in burger products distributed as “beef products” (Walker et al., 2013). This fraudulent incident evoked a food crisis which, at first appearing to affect mainly the United Kingdom (UK) market, soon expanded to several European countries (O’Mahony, 2013; Walker et al., 2013). In response to this event, an EU-wide investigation was carried out, testing numerous samples of various products (beef burgers, minced beef, beef sausages, meat preparations, and frozen, chilled, or canned beef–based ready meals) for the presence of undeclared equine DNA. This investigation involved the analysis of 4144 samples by the competent authorities in the 27 EU member states, and the results showed that 193 samples were positive for equine DNA (with the reporting limit being 1% of equine DNA in total extracted DNA) (Walker et al., 2013).

The European 2013 horsemeat scandal undoubtedly brought food fraud to the forefront, highlighting the intricate and multifactorial nature of such large-scale food protection issue, stemming mainly from long and correspondingly complex food supply chains. Indeed, the meat supply chain segments involved in that particular food fraud case included a food processor in France, its subsidiary in Luxemburg, a subcontractor in Cyprus, a meat trader in the Netherlands, abattoirs in Romania, and various food businesses across the EU selling the end products (Manning et al., 2016; NAO (National Audit Office), 2013). With horsemeat resembling red meat in beef products, their macroscopic differentiation is not always an easy task. For instance, the organoleptic characteristics and fat content are rather similar in these two species. Moreover, although carcass evaluation would allow for species identification, the commercial cutting of both meats is similar and the lack of bones and head (which are not marketed in the case of horsemeat) makes osteological assessment rather difficult (Stanciu, 2015). In addition to the complexity of the meat supply chain, policy and market factors assumed to have contributed to the horsemeat incident included the 2008 financial crisis and rising food prices (increasing the demand for cheap food), the low risk of detection at the time, and the lack of a strong deterrent such as strict penalties (EPRS (European Parliamentary Research Service), 2014; Manning et al., 2016). In the period 2008–12, beef prices increased 45%, and pricing per ton for beef was estimated at 5300 USD, fourfold higher than the corresponding value for horsemeat which was approximately 1300 USD (EC (European Commission), 2015; Moyer et al., 2017). The “oversupply” of horses facing slaughter, due to the inability of their owners to afford their maintenance, has also been
identified as a side effect of the economic crisis that potentially contributed to this fraud scandal (EPRS (European Parliamentary Research Service), 2014; Manning et al., 2016). Finally, it has been speculated that a 2008 Romanian law banning horses on roads increased the horse availability for processing, creating an additional fraud opportunity in the meat supply chain (Moyer et al., 2017).

As expected, consumers’ trust and confidence in the meat supply chain was seriously compromised by the aforementioned scandal, significantly affecting the EU food sector and leading to a reduction in red meat consumption and beef product boycotting (Stanciu et al., 2013; Stanciu, 2015). Although the European Commission eventually opined that the horsemeat fraud incident had no food safety or public health implications, consumers confronted various uncertainties regarding the safety and nutritional characteristics of horsemeat, while the legality, morality, and ethics of food businesses were also seriously questioned (Stanciu, 2015). Despite the fact that horsemeat is of high nutritional value and already constitutes a part of the traditional diet in many parts in the world (Stanciu, 2015), it is an inarguable consumers’ right to choose and always be aware of the food animal species they consume. However, as will be discussed subsequently (Section 6.5), the 2013 horsemeat scandal constituted a “wake-up call” for regulatory authorities and induced the development of a solid and reliable food fraud prevention network (Premanandh, 2013; Stanciu, 2015).

Food crisis events receiving significant public attention and dissemination via media reports have also been revealed in the context of Interpol/Europol operations. Another example of food fraud in the meat supply chain is the diversion of condemned (waste) meat destined for pet food production back into the human food chain (Manning et al., 2016). This practice was revealed through two operations conducted in the UK. Common features in both of these operations were the involvement of operators from within recognized business structures and the commitment of industry insiders to group-led and conspiracy-driven models, taking advantage of the limited supervision or scrutiny exhibited by the meat industry at the time (Manning and Smith, 2015; Manning et al., 2016). These food fraud incidents, despite their regional character and relatively limited magnitude, prompted the organization of UK authorities against food crime, resulting in the development of the Food Standards Agency National Food Fraud Database (NFFD) in 2006, the National Food Standards Agency Task Force in 2007, and the Food Fraud Advisory Unit in 2009. More recently, in 2015, and after a review of the 2013 horse meat incident, the National Food Crime Unit (NFCU) was established, tasked with the overall protection of consumers and the food industry from food crime within food supply chains.

More recently, specific meat fraud incidents were included in the reports of Operation Opson, which resulted in large-scale seizures of multiple fake (and potentially hazardous) foods at a global level (Interpol, 2016). This joint international Interpol/Europol operation, originally initiated in 2011 and including only 10 EU countries, has expanded to include nearly 60 countries across the world, and seizures due to fraudulent practices in the meat supply chain have been related to (1) monkey meat found at an airport (Belgium), (2) chicken intestines found to be preserved in formalin (Indonesia), and (3) smuggling of meat as well as distribution of buffalo meat unfit for human consumption (Thailand) (Ellis et al., 2016; Interpol, 2016).
6.4 Detection of fraud in meat and poultry commodities

Detecting fraudulent activities in the manufacture and/or distribution of food commodities is of utmost importance for the food industry, regulatory authorities, and consumers. Fraud detection serves various interrelated purposes, including accurate assessment of fraud risks, food law enforcement, and, ultimately, protection of consumer interests and public health. Determining the authenticity of food products, also referred to as “food authentication” or “food forensics,” involves procedures that are anticipated to allow for verification of the products' compliance with label statements and provisions of existing food legislation (Abbas et al., 2018; Primrose et al., 2010). In addition, monitoring of incoming raw materials and timely detection of authenticity issues via appropriate analytical tools is a first-line protection strategy of food manufacturers against fraudulent activities. Food fraud detection and food authentication are not easy tasks, with their efficacy relying largely on the applied methodologies and the latter encountering specific technical challenges with regard to their development and implementation.

Analytical methodologies that are, or have the potential to be, applied for meat fraud detection and product authentication are largely based on immunological, chromatographic, spectroscopic, or molecular techniques (Abbas et al., 2018; Bhat et al., 2015; Danezis et al., 2016; Esteki et al., 2019; Iammarino et al., 2017; Nakyinsige et al., 2012; Primrose et al., 2010).

6.4.1 Immunological techniques

Immunological tests, such as Western blotting and enzyme-linked immunosorbent assay (ELISA), were among the first analytical techniques used for the purpose of fraud detection in meat and poultry commodities (Abbas et al., 2018). Among different immunological assays, ELISA is regarded as the most widely used in food authentication, with various commercial test kits being available for the detection and identification of the species content in raw or thermally processed meat and meat products (Abbas et al., 2018).

Among the earliest relevant research studies, published more than 30 years ago, was the one carried out by Patterson and Spencer (1985), who described the application of three ELISA techniques for meat speciation in domestic animals and reported the detection of donkey meat in horse, goat meat in sheep, and buffalo meat in beef at detection limits of 0.1%, 0.1%, and 1%, respectively. Similarly, Hsieh et al. (1995) reported the successful implementation of ELISA in the identification of poultry and sheep meat in raw meats, and all species in cured raw meats and cooked meats, with the target extraneous species being detected at levels exceeding 1%. In subsequent studies, monoclonal antibody–based ELISA techniques have been also shown to be capable of detecting pork in heat-processed meats (detection limit of 0.5% pork meat in heterologous meat mixtures) (Chen and Hsieh, 2000), as well as of horsemeat (detection limit of 1%) in raw, cooked, and autoclaved ground beef or pork (Hsieh and Ofori, 2014). Furthermore, ELISA-based techniques have been shown to be competent in detecting low contents of animal species (pork, beef, sheep, and poultry) even in highly processed meat products (Giovannacci et al., 2004) and are used by the US Department of Agriculture's Food Safety and Inspection Service for
regulatory testing of meat species (https://www.fsis.usda.gov/wps/wcm/connect/da29aed5-acc4-4715-9b84-443f46961a05/Mlg17.02.pdf?MOD=AJPERES). Additional species that can be detected in meat products using ELISA are proteins of plant origin, such as soy proteins that are often added into some meat products due to their nutritional and functional properties (Macedo-Silva et al., 2001), and specified risk material (e.g., brain and spinal cord) in extracts from meat products or sausages (Asensio et al., 2008).

The rather common use of immunological assays in the field of meat authentication has been largely attributed to their specificity, sensitivity, easy implementation, and low cost (Abbas et al., 2018). On the other hand, the performance of such assays, including ELISA, depends on the antibodies’ specificity to the target proteins(s), with the latter being characteristic of a particular animal species, tissue, or meat adulterant. Thus if antibodies are not highly specific, false-positive results may be recorded resulting from problems associated with cross-reactions, something that is likely to occur in cases of closely related species (Abbas et al., 2018; Sentandreu and Sentandreu, 2014). Another limitation of these techniques is that their discriminatory capacity may be significantly decreased in thermally processed meat and poultry products due to protein denaturation, a limitation that may be overcome via the production of antibodies against heat stable proteins such as osteocalcin, a protein specific to the extracellular bone matrix (Abbas et al., 2018).

6.4.2 Chromatographic techniques

Chromatography in the context of meat fraud detection and authentication is a targeted approach allowing mainly for the determination of specific ingredients or substitution of ingredients (Abbas et al., 2018). Chromatographic analysis provides reliable separation of chemically similar compounds in complex food matrices through unique chemical fingerprints that differentiate and authenticate foods (Danezis et al., 2016). The chromatographic techniques most commonly used are liquid chromatography (LC), including high-performance LC (HPLC), and gas chromatography (GC), with the latter being more suitable for the detection of volatile and semivolatile compounds (Pavlidis et al., 2019). When using these methods, the final results are provided by comparing the generated data to either information stored in databases or analysis results corresponding to specific authentic standards (Abbas et al., 2018; Ballin, 2010). Stemming from the chemical complexity of food commodities in conjunction with increased consumer demand for food safety and quality, high-resolution chromatographic techniques have emerged as food authentication tools, including LC or GC coupled with mass spectrometry (MS) detection (e.g., HPLC–MS, GC–MS) (Danezis et al., 2016).

The specific chromatographic techniques mentioned earlier are capable of separating and thus identifying a large number of compounds. Food authentication can then be addressed based on identification of either minimal analytical differences between patterns or unique marker compounds (Danezis et al., 2016). Both HPLC and GC can be used for the determination of organic or synthetic compounds added to meat products to act as artificial enhancers or neutralizers (masking in some cases fraudulent activities) such as colorants, aromas, preservatives, and stabilizers (Abbas et al., 2018; Ballin, 2010). With regard to the identification of substitution activities, HPLC and HPLC–MS have been
shown to be capable of detecting horse and pork, as well as vegetable proteins and fat in processed meat products (Castro et al., 2007; Nair et al., 2006; von Bargen et al., 2014). Additional meat authentication issues that may be successfully identified using chromatographic techniques, including GC as well as GC–MS, are authentication of meat origin (e.g., animal sex), feed intake, as well as production claims such as “wild versus farmed meat” and “organic versus conventional meat” (Ballín, 2010). Although chromatography-based techniques are time-consuming, costly and require highly trained personnel, their high accuracy, sensitivity, and selectivity still render them methods of choice in many official food control laboratories (Abbas et al., 2018).

6.4.3 Spectroscopic techniques

Spectroscopic techniques have been shown to hold a considerable potential for the purpose of fraud detection in food of animal origin, providing information that could be useful not only for the determination of specific ingredients or substitution but also with reference to the identification of geographical origin (Abbas et al., 2018). Among the various spectral analysis techniques that have been used for meat species identification and other applications, vibrational spectroscopy holds a prominent position (Kumar and Karne, 2017). Indeed, vibrational spectroscopy techniques, which are based on spectral signals associated with molecular vibrations in the infrared region, coupled with chemometrics (i.e., multivariate statistical techniques) have shown a high analytical performance with regard to food authentication (Abbas et al., 2018). The most commonly used spectroscopic techniques under this category are near-infrared (NIR) and Fourier-transform infrared (FTIR).

Potential applications of NIR spectroscopic techniques in the field of meat fraud include assessment of meat adulteration, meat origin authentication as well as meat speciation, as described in detail in the recent reviews by Kumar and Karne (2017) and Abbas et al. (2018). Similarly, FTIR spectroscopy, which focuses on the mid-infrared region (4000–400 cm\(^{-1}\)) of the electromagnetic spectrum, is a very propitious technique for meat authentication purposes, actually providing a higher amount of chemical information than NIR (Abbas et al., 2018). Examples of the promising potential of FTIR in tandem with chemometrics for meat fraud detection include the apparent applicability of this technique for (1) determination of both the presence and the origin of gelatin (Cebi et al., 2016); (2) the quantitative estimation of adulteration of processed bovine meat products via partial substitution with other meat species, namely, pork (or lard) or rat meat (Kurniawati et al., 2014; Rahmania et al., 2015); and (3) the detection of nonmeat ingredients (e.g., NaCl, phosphates, carrageenan, and maltodextrin) in bovine meat, fraudulently applied as injected solutions in order to increase its water-holding capacity (Nunes et al., 2016). Additional spectroscopic techniques that, according to research findings, may constitute valuable meat fraud detection tools, and primarily for meat species differentiation purposes, are Raman spectroscopy (Boyacı et al., 2014; Ellis et al., 2005) and laser-induced breakdown spectroscopy (Bilge et al., 2016).

Hybrid technologies combining spectroscopy and image analysis also exhibit a considerable application potential in meat fraud detection and authentication. Examples of such
technologies are multispectral imaging (MSI) and hyperspectral imaging. Specifically, MSI, which combines spectral and spatial information of the tested food sample, has been evaluated as a promising method for the detection of adulteration of beef and pork in raw meats as well as of minced beef adulteration with horsemeat (Ropodi et al., 2015, 2017). Regarding HIS, this technique has been used for the determination of the water-holding capacity of fresh beef (ElMasry et al., 2011) and the detection of minced lamb adulterated with pork (Kamruzzaman et al., 2013).

The main advantages of the aforementioned spectroscopic techniques are their robustness, simplicity of instrumentation, time-efficiency, relatively low cost, and the fact that they allow for nondestructive analysis of food samples (Abbas et al., 2018; Danezis et al., 2016). With particular reference to infrared spectroscopic methods, the associated techniques are characterized by efficient technical advancements and improved data processing algorithms, justifying their increasing popularity in both qualitative and quantitative analyses (Huck et al., 2016).

### 6.4.4 Molecular techniques

Similarly to chromatographic techniques, molecular techniques are regarded as highly accurate, sensitive, and selective methods, targeting at the determination of specific ingredients or substitution of ingredients when used as a meat fraud detection approach. This methodology category includes DNA- and protein-based techniques, with each one of them being associated with specific applications and demonstrating certain advantages and disadvantages (Abbas et al., 2018; Danezis et al., 2016; Woolfe and Primrose, 2004; Zha et al., 2010).

DNA is a macromolecule containing all genetic information of an organism and it constitutes an excellent target for food analysis. However, since analysis of the entire DNA molecule (containing coding information for numerous genes) is not feasible, only genes that are anticipated to be specific to the tested sample are examined using polymerase chain reaction (PCR) (Abbas et al., 2018; Lee et al., 2017). Genomic approaches for fraud detection appear to be the most extensively studied techniques in meat and poultry. Indeed, various PCR-based methods have been developed for the identification of meat species, with potential application as a detection tool for fraudulent adulteration or substitution of meat and poultry (Abbas et al., 2018; Bhat et al., 2015; Fajardo et al., 2010; Nakyinsige et al., 2012). Examples of such PCR-based techniques, as abundantly described in the scientific literature, include PCR-sequencing (Di Pinto et al., 2014), PCR-restriction fragment length polymorphism (PCR-RFLP) (Amjadi et al., 2012; Doosti et al., 2014; Haider et al., 2012; Stamoulis et al., 2010), PCR using species-specific primers (Abd El-Razik et al., 2009; Amaral et al., 2014, 2015; Naaum et al., 2018), multiplex PCR (Prusakova et al., 2018; Safdar et al., 2014; Soares et al., 2010; Song et al., 2017), real-time PCR (Al-Kahtani et al., 2017; Amaral et al., 2017; Dalsecco et al., 2018; Fang and Zhang, 2016), as well as state-of-the-art integrated tools such as DNA bar coding (Hellberg et al., 2017; Kane and Hellberg, 2016; Naaum et al., 2018; Quinto et al., 2016), and forensically informative nucleotide sequencing (Lago et al., 2011). DNA hybridization techniques have been also commonly used for the identification of DNA species, and levels of detection ranging
from 0.1% to <0.01%, depending on the type of meat, have been reported in the scientific literature (Rahmati et al., 2016).

Due to their high sensitivity and specificity, DNA-based methods are the first choice when two closely related animal species are to be identified and distinguished. This is an issue of great importance when it comes to meat authentication of traditional and regional meat products, since the latter are generally produced via the use of specific animal breeds that are regarded as typical of the producing geographical area (Abbas et al., 2018; Sentandreu and Sentandreu, 2014). An important comparative advantage of DNA-based methods is that DNA is highly heat stable, which means that even in the occurrence of partial degradation during processing, short fragments are generally recoverable. This makes DNA-based testing of great value for processed meat and poultry products (Abbas et al., 2018). Nonetheless, the detectable amount of DNA may be considerably reduced during processing, while other factors that may also influence the results of DNA-based methods, particularly in composite foods, include competitive PCR attributed to matrix effects (Abbas et al., 2018; Primrose et al., 2010). Although both genomic and mitochondrial genes can be targeted in DNA-based methods, the use of mitochondrial DNA has been regarded as a better approach for processed meat products due to its greater stability under different processing conditions (Abbas et al., 2018; Ghovvati et al., 2009; Iammarino et al., 2017).

Each one of the commonly used PCR-based methods has certain advantages and disadvantages that should be taken into account when selecting molecular approaches for the purpose of meat fraud detection. For example, PCR-sequencing results in the highest amount of information and, as such, appears to be the best approach for the inter- and intraspecific identification of DNA in meat products, allowing for the discrimination of even very closely related species (Fajardo et al., 2010). The PCR–RFLP technique is inexpensive and particularly adaptable for routine large-scale investigations (e.g., in the framework of inspection programs), but it might not be applicable in the analysis of meats subjected to DNA destructive processing or admixed meats (Fajardo et al., 2010; Pfeiffer et al., 2004). On the other hand, the molecular technique suggested for the analysis of highly degraded or composite food matrices (e.g., processed, multiingredient meat products) is species-specific PCR, where detection is achieved through either gel electrophoresis or real-time PCR (Fajardo et al., 2010; Stirtzel et al., 2007).

Moving from the DNA-based molecular techniques of value for food fraud detection to protein-based methodologies, the increasingly important role of proteomics should be recognized. Proteomics is a continuously growing field of molecular biology that is concerned with the systematic study of proteins and protein expression. This field has significant potential for application in various food protection issues, including food forensics (Ellis et al., 2016; Primrose et al., 2010). Utilizing high-resolution MS, proteomics technologies are capable of identifying unique proteins or peptides and can thus be used for the differentiation of animal species or tissues based on their specific protein patterns (Abbas et al., 2018; Primrose et al., 2010). Specifically for meat speciation purposes, proteomics techniques demonstrate a discrimination power comparable to that of DNA-based methods, since the biomarkers used are specific for a given animal species peptide sequences (Abbas et al., 2018). Peptides of particular interest as biomarkers in these approaches are sequences of myofibrillar proteins due to the fact that they are not significantly affected by
6.5 Risk mitigation strategies for fraud in meat and poultry

Undoubtedly, the detection of fraudulent activity is of great importance, and the EU’s response to the 2013 horsemeat scandal is a vivid illustration of control strategies triggered by a food scandal (Stanciu, 2015). In this sense, improved detection methodologies, aided by multivariate qualitative analysis and continuous monitoring, are considered valuable for the control of meat/poultry fraud and authentication (Di Pinto et al., 2014; Pilar Callao and Ruisánchez, 2018; Premanandh, 2013). However, the unfeasibility of analyzing all potential substances that can be used as adulterants renders conventional testing per se unsuitable on its own for food fraud control purposes (Everstine et al., 2013; Manning and Soon, 2014). Hence, it has been generally acknowledged that, due to the social and potential public health implications and the high diversity of food fraud opportunities, food fraud should be prevented rather than detected. It has been opined that the most efficient countermeasure is a focus on prevention (or otherwise on reduction of fraud vulnerability), while deterrence and detection should be judged by the impact on prevention (Manning, 2016; Moyer et al., 2017; Spink et al., 2015, 2017; van Ruth et al., 2017).

Given the high complexity of contemporary food systems, safeguarding meat and poultry integrity should be a joined concern for all stakeholders in the supply chain, and development and implementation of management systems can only be sustainable as part of a holistic approach (Esteki et al., 2019; Spink et al., 2016; Spink et al., 2019a). Examples of

6.4.5 Other techniques

Beyond the analytical techniques discussed earlier, there are additional analytical technologies that have been regarded as propitious in the field of food fraud detection, including mass spectroscopy–based techniques (Montowska and Spychaj, 2018; Montowska et al., 2015), enzymatic assays (Boerrigter-Eenling et al., 2017; lammarino et al., 2017), isotope and elemental techniques (Abbas et al., 2018; Franke et al., 2008), impedance techniques (Chen et al., 2016), and biomimetic sensors such as electronic nose (Tian et al., 2019). These analytical techniques have been proposed for various applications, including (but not limited to) determination of the geographic origin of meat and meat products, verification of animal production practices (e.g., corn-fed chicken), differentiation between conventional and organic farming practices, and discrimination of fresh/chilled and frozen/thawed poultry meat. Finally, it should also be noted that very often the best results in meat fraud detection appear to stem from combinations of analytical methods (Ballin and Lametsch, 2008; Ma et al., 2015; Tian et al., 2019) with chemometrics, including multivariate analysis, data fusion strategies, and data mining (Abbas et al., 2018; Esteki et al., 2019; Ropodi et al., 2016; Pilar Callao and Ruisánchez, 2018).

thermal processing (Abbas et al., 2018; Primrose et al., 2010; Sentandreu et al., 2010). Proteomics can also be coupled with other analytical technologies (e.g., labeling of marker peptides with stable isotopes), to provide quantitative information on specific products tested (Primrose et al., 2010).
activities that could compose the role of government authorities in fraud mitigation include auditing of private control bodies, assurance of certain official control tests, adoption of strict control measures through regulation of intermediary labeling, establishment of a legal obligation to report fraudulent activity in the meat and poultry sector, and switching from an essentially administrative approach to a policing one based on risk profiling (Esteki et al., 2019). The meat and poultry industry from its side can also play a significant role in fraud risk mitigation by (1) being more proactive in addressing economically motivated adulteration of meat and poultry products; (2) focusing on process verification rather than product inspection and testing; (3) planning for meat and poultry fraud incidents, reactions, and contingencies; and (4) finding new ways to share information [e.g., through machine-readable devices (bar codes, Quick Response codes, and data matrix) and sharing of electronic data] and, thus, promote collaboration with government authorities, academia, and nongovernment organizations (Esteki et al., 2019; Manning and Soon, 2014; Spink and Moyer, 2011). Other segments of the food supply chain may also aid in the process of fraud control; for instance, retailers can request certification of their meat and poultry suppliers to global good safety standards such as the Global Food Safety Initiative schemes (Esteki et al., 2019).

Data acquisition, management, and analysis have been evaluated as significant components in Food Fraud Vulnerability Assessment (FFVA) and Food Fraud Prevention Strategy. In this sense, fraud control in the meat and poultry sector should be benefited by the integration of different data sources (Tähkäpää et al., 2015), while aggregative analyses of fraud incidents based on official notifications and/or media reports are expected to be very useful in prioritizing target areas in policy-making and regulations’ enforcement (Zhang and Hue, 2016). In this context the ongoing development of data centralization systems, ensuring that distinct databases can be coordinated so that collective data analysis is feasible for specific food commodities, including meat and poultry, is of utter importance. As well, sophisticated data mining and analysis approaches have been identified as important action options at global meat supply chain and organizational levels (Manning, 2016; Ropodi et al., 2016). Advanced applications of statistical analysis and computer science disciplines have paved the way for the development of food fraud monitoring systems, which are based on text mining and allow for the collection, processing, and presentation of food fraud incidence data published worldwide (Agroknow, 2019; Bouzembrak et al., 2018). Indeed, software applications based on such monitoring systems may provide a timely and credible briefing on food fraud prevalence (and relative contribution of specific fraud types) for specific food commodities such as meat and poultry (Fig. 6.1). In this manner, such applications constitute useful decision-making tools for quality control managers (e.g., selection of raw materials/suppliers) and risk assessors/managers (e.g., deciding which fraud type to check in recalls or border inspections of imported products). Additional valuable tools at the disposal of risk managers, assisting them in the comprehension of meat/poultry fraud influencing parameters and their interrelation, are modeling approaches (e.g., Bayesian network modeling) based on fraud incidence data. These data are pivotal in providing predictions of fraud types and probability of specific product categories to be associated with fraudulent activity (Bouzembrak and Marvin, 2016; Marvin et al., 2016). In the same context, screening tools aiming at monitoring of changes in specific drivers for the emergence of meat/poultry fraud issues (e.g., volume, origin,
FIGURE 6.1 Number of incidents (i.e., recalls/border rejections) pertinent to meat and poultry and associated with (A) different food protection issues (N = 72000) and (B) specific fraud types (N = 3988). Data were compiled from records in the FOODAKAI system (Agroknow, 2019) based on notifications by national authorities and international organizations in 20 countries in the period from 1980 as of November 2019, whereas the associated meat and poultry products refer to 65 countries of origin (accessed September 15, 2019).
and prices of imported products) are also anticipated to be useful in allowing for automated data analysis for the systematic detection of unexpected changes (Verhaelen et al., 2018).

As acknowledged by scientists and food safety authorities, various macro- and micro-level factors must be addressed simultaneously if food fraud prevention is to be achieved in the years to come (Moyer et al., 2017). Understanding the methods used by defaulters, and more specifically of the organizational ability of food criminals in terms of their modus operandi in the meat supply chain, has been identified as an important parameter to be taken into account in FFVA countermeasures and control systems’ development (Esteki et al., 2019; Manning et al., 2016; van Ruth et al., 2017). Similarly, comprehension of the economic influences of fraud opportunity for meat and poultry, including commodity flows and prices, as well as of the impact of market environments are also key factors in vulnerability assessment and the basis for increased risk anticipation (Manning et al., 2016; Moyer et al., 2017; Verhaelen et al., 2018). Furthermore, food science and technology research should expand to include social science, criminology, supply chain management, and business decision-making (Spink and Moyer, 2011; Spink et al., 2017). Additional parameter of major significance is the faith of the meat and poultry industry in the value of FFVA, and thus its commitment to its efficient implementation. Although promising FFVA tools are being developed (van Ruth et al., 2017), and in-house (or other) FFVA tools may be used, the impact of conducting FFVA as viewed by food manufacturers is not always positive, since negative views, mainly related with cost and concerns for brand reputation, or even uncertainties are frequently expressed (Soon et al., 2019).

6.6 Conclusion and outlook

The nutritional value and economic significance of meat and poultry products render them very appealing commodities for economically motivated and fraudulent activities. Moreover, the increasing globalization of the meat supply chain is expected to increase the fraud likelihood in these commodities. The 2013 horsemeat scandal triggered the development of a food fraud prevention network, the materialization of which has been a gradual and ongoing process. Certainly, the adoption of FFVA is still at its early stages, with full impact of its implementation remaining to be seen. Nevertheless, with time and continual diligence by the food industry, FFVA is expected to benefit the food, including meat and poultry, supply chain in terms of both safety and integrity ( Soon et al., 2019).

With the prediction of food fraud risks resting upon data availability (with high volumes and different data sources being required), use of robust predictive tools, and expert knowledge (Manning and Soon, 2014; Marvin et al., 2016), progress made in any of these areas in the future will bolster and further expand the existing risk mitigation strategies. Indeed, there are several applications, including analytical techniques, sensors, and new algorithms and pattern recognition techniques that remain to be explored and validated in the future, allowing for the development of robust food forensics methodologies (Esteki et al., 2019; Primrose et al., 2010; Ropodi et al., 2016). Specifically, “omics” approaches in tandem with future technological and computational advancements hold a great deal of promise for the detection of authenticity and integrity of meat and poultry.
Future research should also assess the specifics of data collection needs and expand to other stakeholders, beyond food manufacturers and brand owner companies, such as regulators and enforcement bodies (Spink et al., 2019b). Further improvement of current modeling approaches into dynamic models that take into account temporal variations in food fraud drivers is awaited to allow for a stochastic and thus more realistic prediction of fraud in meat and poultry (Marvin et al., 2016). Finally, it has been presumed that a holistic view of meat production, expanding beyond the classical “farm-to-fork” principle and taking into account factors and developments both inside and outside the meat supply chain, should be pursued and integrated into future fraud risk mitigation strategies (Verhaelen et al., 2018).

Overall, and although significant progress is still to be made, efficient food fraud mitigation systems are aspired to constitute an integral part of food standards control programs, similarly to the place that Hazard Analysis and Critical Control Points holds in food safety management systems (Manning and Soon, 2014). In this sense, and with all the aforementioned research and action needs being progressively addressed in the future, the global combat of food fraud, including the meat and poultry sector, should be an unambiguous and attainable goal.

Note: FOODAKAI is collecting global food protection incidents announced by national authorities and international organizations in 26 countries. An incident in the FOODAKAI system is a food recall or a border rejection (import refusal). In the case of food recalls, incidents refer to one or more product brands with specific LOT (i.e. batch) and UPC (Universal Product Code) numbers, while in the case of border rejections, incidents correspond to specific imported product brands or ingredients/raw materials. The data in FOODAKAI cover 196 countries of origin for the recalled or rejected products, and the time frame is 1980 until today, with the majority of the data coming after 2000.

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7.1 Introduction

Seafood is a staple of the global food supply, with an estimated 177.7 million tonnes of fish and shellfish produced in 2018 (FAO, 2019). Worldwide consumption of seafood in 2018
averaged 20.4 kg per person: 9.5 kg from capture fisheries and 10.9 kg from aquaculture production (FAO, 2019). The top species produced through capture fisheries in 2016 were walleye pollock, Peruvian anchovy, skipjack tuna, Sardinella spp., and mackerel, while the top species produced through aquaculture were carp, tilapia, shrimp, and oysters (FAO, 2018b). Seafood is one of the most traded food items worldwide, with exports of fish and fish products totaling 60 million tonnes in 2016 (FAO, 2018a). The main global exporter of seafood in 2016 was China, followed by Norway, Vietnam, and Thailand. The largest market for seafood products in 2016 was the European Union (EU), followed by the United States and Japan.

Production from capture fisheries has remained relatively unchanged since the late 1980s; however, aquaculture production has continued to grow (FAO, 2018b). Indeed, aquaculture is the fastest growing of the major global food production sectors, with production in 2016 reaching approximately 80 million tonnes of food fish. Specifically, 54.1 million tonnes of finfish, 17.1 million tonnes of mollusks, and 7.9 million tonnes of crustaceans were produced from aquaculture globally (FAO, 2018b). Seafood is produced for human consumption in a variety of forms, with the most common being live, fresh, or chilled products (45%) and frozen products (31%) (FAO, 2018a). A smaller portion of seafood is sold in a prepared or preserved form (12%) or as a cured (dried, salted, in brine, fermented, or smoked) product (12%). Live and fresh fish are widely utilized in Eastern and Southeastern Asia, while the majority of seafood consumption in Europe and North America involves frozen, prepared, and preserved forms of fish (FAO, 2019).

Seafood is considered a high-quality protein food, accounting for 17% of the total animal protein consumed by humans (Domingo, 2016). Seafood also contains several essential nutrients, including retinol, vitamin D, vitamin E, as well as the essential omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Jacobs et al., 2015). EPA and/or DHA have been associated with a number of health benefits, including reduced risk of cardiovascular disease, improved visual and cognitive development, alleviation of certain inflammatory conditions, and reduction in specific mental disorders (Hellberg et al., 2012).

Seafood is highly vulnerable to fraud for a number of reasons, including the similar appearance of many species, increasing global trade, complex supply chains, volatile prices, and fluctuations in quality, supply, and demand of specific seafood products (Berrini et al., 2006). The results of an INTERPOL–Europol investigation in 2015 revealed that internationally traded fish was the third-highest risk category of foods on the basis of fraud potential (FAO, 2018a). International trade of fish often involves highly complex supply chains with numerous points at which fraud may occur (Fig. 7.1). Furthermore, the trade of processed fish that lack morphological indicators makes it difficult to visually determine when a fish has been fraudulently labeled (Naaum and Hanner, 2016).

In addition to intentional mislabeling, there are also concerns with regard to inconsistencies in global seafood labeling requirements. These can vary from country to country and further complicate international trade of seafood. For example, the EU requires both the commercial and scientific names on all seafood labels, yet the regulatory agencies for seafood in the United States and Canada just require the commercial name (Roebuck et al., 2017). In addition, the acceptable commercial names assigned to a particular species can vary depending on the country (Shehata et al., 2019). These differences can lead to improper labeling of seafood and confusion over the actual identity of the fish. Global
inconsistencies in labeling requirements and market names also leave the seafood industry susceptible to fraudsters that may take advantage of the confusion to intentionally mislabel fish for economic gain.

There are a range of potential consequences associated with seafood fraud and mislabeling, including exposure to allergens and toxins that can be life threatening, religious infringement, environmental impacts, and economic deception. Mitigating seafood fraud requires a concerted effort from industry, trade organizations, researchers, and government agencies in areas such as developing standards and test methods, enforcing and following regulations, and educating seafood purchasers. This chapter will discuss common types of seafood fraud, the main analytical methods used to detect seafood fraud, and risk mitigation strategies.

7.2 Types of seafood fraud

Various forms of seafood fraud are known to occur, including species substitution, illegal transshipment, mislabeling country of origin and/or production method, overtreatment, undercounting, and short-weighting. These forms of fraud are conducted globally and have serious consequences for consumers, the seafood industry, international trade, and protected species.

7.2.1 Species substitution

Substitution of seafood species occurs when a highly valued species is substituted with an inexpensive alternative without the purchaser’s knowledge, resulting in a mislabeled product. For instance, red snapper (*Lutjanus campechanus*) is often substituted with less expensive species, such as other snappers, tilapia, rockfish, or pollock (*Warner et al., 2013*). Seafood species have also been substituted for the purpose of avoiding taxation or concealing illegally harvested seafood (*FAO, 2018b*). For example, in 2010 the CEO of the US company Sterling Seafood Corporation was sentenced to prison for falsely labeling *Pangasius*...
spp. from Vietnam as grouper to evade over US $60 million in federal tariffs (DOJ, 2010). In another US court case, two seafood wholesaler owners were sentenced to 2–3 years in prison for selling falsely labeled fish and smuggling and misbranding of seafood products (DOJ, 2011). Among other offenses, the wholesalers evaded close to US $150K in taxes by importing *Pangasius* spp. that was falsely declared as wild-caught sole.

Seafood substitution can be difficult to recognize due to similarities among various species, including taste, appearance, and texture (FAO, 2018b). As seafood is processed, visual identification of species becomes increasingly challenging without the use of analytical methods (Fig. 7.2). In addition to economic deception, substitution of seafood species can lead to myriad health, religious, and conservation concerns (see Section 7.3). Another form of seafood species mislabeling occurs as a result of noncompliance with regulatory guidelines for species labeling; however, this section is primarily focused on the intentional substitution of one seafood species for another.

Numerous independent studies have demonstrated the reason for concern over seafood substitution throughout the global seafood supply chain (Armani et al., 2015; Carvalho et al., 2017b; Cawthorn et al., 2015; Hanner et al., 2011; Nedunoori et al., 2017; Pardo et al., 2016; Shehata et al., 2019; Tinacci et al., 2018). A summary of commonly substituted species is given in Table 7.1. Seafood species substitution studies conducted in North America have reported mislabeling rates of 9%–61%, depending on the products targeted and the geographic region (Bosko et al., 2018; FDA, 2013; Hanner et al., 2011; Oceana, 2019; Shehata et al., 2018, 2019; Willette et al., 2017; Wong and Hanner, 2008). Interestingly, a study conducted in Canada found that seafood mislabeling rates increased at each point in the supply chain, from 17.6% at import, to 27.3% at wholesale, to 38.1% at retail, thus demonstrating a cumulative effect of seafood mislabeling throughout the country’s supply chain (Shehata et al., 2019). In another Canadian study, Oceana analyzed over 400 seafood samples from various grocery stores and restaurants between 2017 and 2019, identifying

![FIGURE 7.2 Examples of the similar appearances of various fish species.](image)

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### TABLE 7.1 Examples of commonly substituted seafood.

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<thead>
<tr>
<th>Fish species on label</th>
<th>Regions</th>
<th>Substituted with</th>
<th>References</th>
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61% of those samples to be either substituted or failing to meet Canadian Food Inspection Agency labeling requirements (Oceana, 2019). Species that were commonly substituted or mislabeled included snapper (100%), yellowtail (100%), and tuna (94%).

In 2012–13 the US Food and Drug Administration (FDA) conducted a seafood mislabeling survey that analyzed 174 fish product lots collected primarily from wholesalers, with a limited amount of samples collected at the point of import (FDA, 2013). Overall, 15% of the samples were mislabeled, with the highest rates involving grouper, snapper, and *Pangasius* spp. Other studies conducted in the United States have reported relatively high rates of mislabeling among sushi products. For example, Willette et al. (2017) reported 47% mislabeling among fish from sushi restaurants in Los Angeles, California. As well, a nationwide market study was conducted by Oceana, in which sushi venues revealed the highest mislabeling rates (74%), followed by restaurants (38%), and grocery stores (18%) (Warner et al., 2013). The common species mislabeled in this study included snapper (100%) and white tuna (89%), with DNA tests finding 33% of the 1215 samples to be mislabeled. Other common substitutes within the United States include Asian catfish and Lake Victoria perch sold as grouper and aquacultured shrimp sold as wild-caught shrimp (Warner et al., 2013).

Several studies have been conducted in South America investigating the prevalence of seafood mislabeling (Carvalho et al., 2017a,b; Staffen et al., 2017). For example, Carvalho et al. (2017b) investigated 255 fish products from Brazilian supermarkets and found an average mislabeling rate of 17%. The most commonly mislabeled fish species in the study included hake, *Sorubim* spp., and whitemouth croaker. Studies conducted in South America

### TABLE 7.1 (Continued)

<table>
<thead>
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<th>Fish species on label</th>
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<tbody>
<tr>
<td><strong>Flounder</strong></td>
<td>Brazil, North America</td>
<td>Northern rock sole (<em>Lepidopsetta polyxystra</em>), <em>Pangasiondon</em> sp., Alaska plaice (<em>Pleuronectes quadrituberculatus</em>), Indian Ocean spiny halibut (<em>Psettodes erumei</em>)</td>
<td>Carvalho et al. (2017b), Shehata et al. (2018), Warner et al. (2019)</td>
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**Food Fraud**
have reported mislabeling rates of 9%–50% for fish collected from wholesalers/distributors, restaurants, and retailers (Cawthorn et al., 2012, 2015; von der Heyden et al., 2010).

In Asia, various studies have identified fraudulent activity related to seafood, especially due to consumers’ desire for various high-quality marine fish (Chang et al., 2016; Chin et al., 2016; Xiong et al., 2016a,b,c). For example, Xiong et al. (2016b) identified the highly priced sablefish to be substituted with Patagonian and Antarctic toothfish in 36 of 42 samples collected in the Chinese marketplace. As well, another study assessing various seafood product labels in China reported a lack of origin declarations for salmon, cod, and tuna products (63%, 31.5%, and 81.3%, respectively) (Xiong et al., 2016c). In Taiwan, DNA testing of imported fish revealed that 70% of samples were mislabeled, including mackerel, anchovy, and black marlin (Chang et al., 2016). In Malaysia, 8 of 62 seafood products tested were reported to be mislabeled, including walleye pollock, red bigeye, and threadfin bream (Chin et al., 2016).

Throughout Europe, various studies have reported the occurrence of seafood mislabeling (Armani et al., 2015; Crego-Prieto et al., 2012; Cutarelli et al., 2014; Di Pinto et al., 2013; Filonzi et al., 2010; Nedunoori et al., 2017; Tinacci et al., 2018). In one study, Pardo et al. (2018) investigated seafood mass catering markets in 23 European countries, revealing that one of every three mass caterers served mislabeled products. Overall mislabeling rates were 26%, with grouper, perch, and yellowfin tuna being the most common species substituted. Commonly mislabeled fish identified in various European studies include cod, halibut, Atlantic cod, catfish, and tilapia, with rates of mislabeling ranging from 17% to 66% (Cutarelli et al., 2014; Filonzi et al., 2010; Nedunoori et al., 2017; Tinacci et al., 2018).

Another area of concern for mislabeling is processed seafood products, such as fish cakes, fish balls, and surimi. In a study conducted in Brazil, Carvalho et al. (2017a) reported a 41% mislabeling rate of processed cod products, including some products that were substituted with multiple species. Giusti et al. (2017) investigated surimi products in Italy and Spain and detected multiple species in all 16 products tested, with a reported mislabeling rate of 37.5%. Mislabeling included declaration of a species that was not detected in the product and the identification of undeclared mollusks. The presence of undeclared mollusks is especially concerning due to the health risk it presents to consumers with allergies.

### 7.2.2 Illegal transshipment

Transshipment involves the transport of goods to an intermediate location before arriving at the final destination. During transshipment a container may be off-loaded from the original vessel and transferred to a different vessel at an intermediate port. While transshipment is a common procedure in international trade, it is considered illegal if the purpose is to circumvent duties and other trade restrictions. For example, transshipment may be used to avoid antidumping duties, which are applied to foreign manufacturers who sell goods in another country for less than fair value (Upton, 2015). A specific example of this occurred between 2016 and 2018, when shrimp was shipped from China to the United States through Cambodia and Malaysia, likely in order to avoid antidumping duties (Upton, 2015).

Transshipment is also exploited for the international trade of illegally caught or unre-ported fish (Naaum and Hanner, 2016). This practice is considered one of the most
difficult challenges in the elimination of illegal, unreported, and unregulated (IUU) fishing (FAO, 2017). Annual global losses from illegal and unreported (IU) fishing have been estimated to be between US $9 and $23 billion (Ewell et al., 2017; Sumaila et al., 2020). In the United States in 2011, IU catches accounted for an estimated 20%–32% by weight of total imported wild-caught seafood for human consumption (Pramod et al., 2014). An investigation into likely transshipment events involving commercial fishing vessels and refrigerated cargo vessels between 2012 and 2016 found that almost 40% of likely transshipment events were conducted on the high seas, outside of country boundaries (Malarky and Lowell, 2017). Suspected transshipping hotspots included the following: “(1) Russia’s Sea of Okhotsk; (2) Outside the Exclusive Economic Zone (EEZ) of Argentina; (3) outside the EEZ of Peru; (4) Barents Sea Loophole, a high-seas region surrounded by the EEZs of Norway and Russia; and (5) National waters of Guinea-Bissau.”

In a study into global transshipment encounters, Boerder et al. (2018) observed over 10,000 transshipment events off the coasts of Russia and West Africa, in the South Indian Ocean, and in the equatorial Pacific Ocean. In Russia, regulations require all vessels that catch within the Russian water zone to report to customs, yet this is believed to be done on an inconsistent basis (Miller et al., 2018). In areas of the South Atlantic Sea, transshipment behaviors are still taking place even though regional fisheries management organizations banned at-sea transshipments over 15 years ago. These illegal acts lead to economic losses and consumer concerns over unknowingly purchasing IUU seafood (Miller et al., 2018).

### 7.2.3 Country of origin and production method mislabeling

Many countries require that seafood products be labeled with the country of origin and/or country of last substantial transformation, as well as the method of production (farm-raised or wild-caught). For example, in the United States, Country of Origin Labeling (COOL) regulations require that certain retailers provide the country of origin and production method for fresh and frozen fish and shellfish. However, seafood that is harvested in the United States and then processed in another country must be labeled with the foreign country as the country of origin. European regulations require that consumers are provided with the production method, the fishing gear used, and the geographical area in which the product was caught or farmed [Regulation (EU) No. 1379/2013]. While misreporting the country of origin and/or production method could be associated with a lack of knowledge regarding proper labeling at the retail level, it could also be conducted in a fraudulent manner for reasons such as falsifying product information for economic gain, selling IUU seafood, and/or covering up illegal transshipment. Differences in regulations with regards to labeling the country of origin versus the country of last substantial transformation can further complicate the issue and make it difficult to verify the country of origin using analytical testing.

Compliance with COOL regulations has been assessed in various studies in the United States. For example, Lagasse et al. (2014) analyzed over 600 fresh and frozen seafood products from 14 different stores in Baltimore, MD, and identified 3.8% of products to be noncompliant with COOL. A study conducted in Southern California reported 59% of 32 catfish samples to be noncompliant with the regulations (Bosko et al., 2018). Another study in Southern California investigated 120 fresh or thawed fish samples from
30 different grocery stores and reported that 23% of products were noncompliant with COOL (Liou et al., 2020).

A study into the traceability of seafood products sold in Belgium reported difficulties in determining information on the origin of seafood based on the combined data from four sources (Sioen et al., 2007). Specifically, multiple unrelated databases had to be searched for information; countries of import did not necessarily specify the origin of the seafood based on internationally defined fishing grounds; and there was no available information on whether the seafood had been transited through multiple countries. Furthermore, a study conducted in Bulgarian seafood markets reported that over 85% of sample labels contained incomplete references to catch areas, 34% lacked a scientific name, and 55% did not report the fishing gear used (Tinacci et al., 2018).

While several studies have identified noncompliance with country of origin and production method labeling requirements, it is not clear whether any of these acts were intentional. Further investigation is needed to examine the traceability information for these products and to verify not only the declared species but also the country of origin and production method. This information could then be used to help one to determine whether the seafood product was marketed in a fraudulent manner. Overall, appropriate labeling of country of origin and production method is necessary and needs to be further addressed for traceability purposes along with protecting consumer health and safety (Leal et al., 2015).

### 7.2.4 Overtreatment and short-weighting

Overtreatment and short-weighting are important concerns for the seafood industry because they artificially inflate the weight of seafood in a product and can be a major source of economic deception. Short-weighting occurs when the net weight of the seafood content in a processed seafood product is misrepresented due to overtreatment with glazing, breading, or soaking (Santos et al., 2010). The US FDA requires a minimum of 50% shrimp in breaded shrimp products, thereby preventing consumers from paying for excess breading (FDA, 2018a). Glazing is a common practice for preserving seafood and preventing freezer burn that involves the addition of an ice layer to the product. According to the US FDA, the net weight of the frozen seafood should not include the weight of glazing and violations of this kind may be criminally prosecuted as felonies (FDA, 2009a).

Overglazing is sometimes carried out by processors for the purpose of increasing economic gains on a product. For example, in 2009, the US FDA sent a warning letter to a seafood company stating that it was overglazing its shrimp products with ice and/or marinade to increase product weight, resulting in an adulterated product (FDA, 2009b). A market survey conducted by Peterson et al. (2020) found that 10 out of 111 fish fillets acquired from various grocery stores in Southern California were short-weighted based on the National Institute of Standards and Technologies (NIST) standards for the maximum allowed weight variance. Seven of the short-weighted samples had >10% glaze, exceeding recommendations from the National Oceanic and Atmospheric Administration (NOAA) fisheries of 5%—10% glaze for prepackaged frozen fish (NOC, 2014).

Certain additives, such as polyphosphates, are used to improve water retention in seafood proteins and reduce drip loss during thawing. Polyphosphates are legally allowed to
be added to frozen and deep-frozen mollusks and crustaceans up to a maximum level of 5 g/kg (0.5%) in the EU, yet the United States has no limit on their use (SEAFISH, 2012). Polyphosphates are often used with seafood products such as scallops or shrimp. When these polyphosphate-treated products are soaked for a prolonged period, they absorb excess water, resulting in an artificial increase in weight. A study by Wang et al. (2015) assessed phosphate content in several fish and shrimp products purchased in China and reported that frozen peeled shrimp and frozen shrimp were the most common products treated with polyphosphates. The levels of polyphosphates reported in these products ranged from nondetectable up to a maximum of 3.95 mg/g (pyrophosphate + tripolyphosphate), which is below the EU legal limit. The majority of fish samples tested did not contain detectable levels of polyphosphates, with the exception of a fish sausage that contained 1.14 mg/g of tripolyphosphate.

Another common preservation practice is the addition of carbon monoxide to seafood, which allows for color enhancement by preventing oxidation of the fish fillet. The use of carbon monoxide is prohibited in certain countries, such as Canada, Japan, Singapore, and the EU because it is difficult for consumers to discern the degree of spoilage (Djenane and Roncales, 2018; Marrone et al., 2015). The US FDA has considered tuna, for example, to be misbranded if businesses do not signify that a “preservative” was added if treated with carbon monoxide (Upton, 2015). Minimal evidence has been found for carbon monoxide being used in a fraudulent manner; however, there is a concern regarding the use of carbon monoxide to mask deterioration of fish fillets. This could affect consumer health due to the food safety risks of consuming fish that is past its shelf life and/or has been stored at an unsuitable temperature.

7.3 Consequences of seafood fraud

7.3.1 Economic concerns

While there are no overall estimates available for the economic losses associated with seafood fraud, they are thought to be significant (Upton, 2015). With the total first sale value of fisheries and aquaculture production estimated at US $362 billion globally for 2016 (FAO, 2018b), this market is highly susceptible to fraud. For example, in 2011, it was estimated that if 2% of the declared weight of seafood purchased annually by consumers in the United States was ice, the annual loss to consumers would amount to about US $1.6 billion per year (Sefcik, 2011). The substitution of a lower valued fish for a higher valued one can have significant economic consequences for the seafood industry and consumers (Xiong et al., 2016b). For example, Filonzi et al. (2010) investigated various seafood products in Italy and identified the commercial value of the declared species to be in the range of 19.90–40 Euros/kg, compared to 8.90–11.20 Euros/kg for the substitute species. In Canada, Oceana identified 74% of mislabeled seafood products to be listed as a more expensive variety than the fish that was being sold, including whiting (CND $7.33/kg) sold as Atlantic cod (CND $33.33/kg), Atlantic salmon (CND $37.66/kg) sold as Sockeye salmon (CND $101.69/kg), and catfish (CND $11.64/kg) sold as sea bass (CND $113.88/kg) (Levin, 2018). Reports of seafood substitution can also harm the reputation of the seafood industry.
7.3 Consequences of seafood fraud

7.3.2 Health concerns

Although the main incentive of food fraud is economic profit, there are various health implications that can be life threatening, including exposure to toxins, environmental contaminants, banned veterinary drugs, and antibiotic residues (Naaum and Hanner, 2016). Globally, various market surveys have revealed seafood fraud events that have the potential to impact human health, including studies conducted in countries such as Italy, Bulgaria, Brazil, and the United States (Armani et al., 2015; Carvalho et al., 2017b; Tinacci et al., 2018; Willette et al., 2017). For example, documented species mislabeling of tilefish as red snapper can pose a health concern for at-risk groups such as pregnant women and young children due to the relatively high levels of mercury in tilefish (Warner, 2012). Allergies to various seafood products, such as crab and other shellfish, are common and can leave consumers at risk if not aware of these items within the products they consume (Khora, 2016). Common fish species that the human population is allergic to include salmon, tuna, and halibut.

Substitution of certain fish species can also introduce harmful contaminants or toxins that can cause serious illness or even death if consumed. For example, in 2007, pufferfish was mislabeled as monkfish, which caused severe illness in the United States due to the ingestion of tetrodotoxin, a potentially fatal neurotoxin (Cohen et al., 2009). As well, market surveys have revealed that the majority of sushi products labeled as white tuna in the United States are actually escolar, which can cause serious digestive problems (Warner et al., 2013). Certain scombroid species, such as tuna, are a concern for histamine poisoning, which causes an allergy-like reaction (FAO, 2018b). The substitution of a non-scombroid fish with a scombroid fish could be an issue for consumers who are sensitive to histamine. As well, ciguatera fish poisoning is caused by the consumption of specific reef fish containing ciguatoxins. A commonly consumed reef fish is grouper, which has been studied in depth for the presence of ciguatera poisoning (Schoelinck et al., 2014). In Australia, four different cases of ciguatera fish poisoning have been identified due to consumption of grouper, red throat emperor, green jobfish, and purple rock cod (Edwards et al., 2019). Another major health hazard is antimicrobial residues, which are used in aquaculture to treat or prevent infections and disease. The presence of antimicrobial residues in aquaculture production constitutes a health hazard for consumers, yet not all countries conform to strict regulations on the use of these antimicrobials (Okocha et al., 2018). The illegal use of certain antimicrobials or other veterinary drugs may lead fraudsters to mislabel a certain fish to avoid testing for these substances at import.

In addition to the examples provided earlier, improper labeling of seafood species can lead to safety and quality concerns associated with the handling of the product. For example, a fraudster who mislabels seafood may also compromise the cold storage
temperatures required along the supply chain and/or not follow proper sanitation guidelines. Along these lines, INTERPOL and Europol operations have reported the discovery of numerous seafood fraud events that have public health concerns. For example, Operation Opson VI uncovered over 300,000 tin cans of sardines in Portugal that were produced without proper safety procedures and standards (INTERPOL, 2017). As well, various manufacturers of mollusks and clams sold in Spain were found to be uncooperative with sanitation procedures, ultimately deceiving consumers with false labels of treatment. More recently, Operation Opson VII led to over 90 seafood seizures in 15 different countries, with health concerns, including bivalve mollusks unsuitable for human consumption in Italy, 15 t of fish without sanitary authorization in Brazil, and over 460 pieces of canned mackerel in tomato sauce infested with parasites (INTERPOL, 2018b).

7.3.3 Religious concerns

The mislabeling of certain fish can infringe on religious practices, specifically for individuals on a kosher diet. According to kosher law, kosher fish are those that have scales and fins. These fish must be properly labeled with the kosher symbol in the marketplace. Common nonkosher fish in the seafood supply include *Pangasius* spp., catfish, freshwater cod, swordfish, and billfishes (Atz, 2017). The substitution of kosher fish with nonkosher alternatives is concerning for individuals following a kosher diet. There have been a couple of US court cases involving the mislabeling of *Pangasius* spp. (nonkosher) as other species that are considered kosher, such as grouper or sole (DOJ, 2010, 2011). In addition, a market survey conducted in 2012 reported the mislabeling of *Pangasius* spp. as Pacific cod (kosher) in New York City restaurants (Warner, 2012).

7.3.4 Environmental concerns

Numerous seafood species are severely impacted by issues pertaining to overfishing, leading to endangerment concerns and overharvesting. Some of these issues are associated with varying and unclear labeling regulations on a global level. For example, under previous US FDA regulations, 13 species of Pacific rockfish were allowed to be sold in interstate commerce under the market name Pacific red snapper (Logan et al., 2008). However, in a retail survey of fish sold as Pacific red snapper, over half of the rockfish samples identified belonged to species listed as overfished (Logan et al., 2008).

Other species that have been investigated and identified for improper labeling of endangered or vulnerable species include skates, rays, and sharks (Asis et al., 2016; Barbuto et al., 2010; Cardeñoso et al., 2017; Fields et al., 2015; Griffiths et al., 2013; Hellberg et al., 2019; Holmes et al., 2009; Jabado et al., 2015; Liu et al., 2013; Moore et al., 2014; Naaum and Hanner, 2015; Sembiring et al., 2015; Steinke et al., 2017). For example, Steinke et al. (2017) investigated 134 dried shark fin and ray gill plate samples originating from Vancouver, Hong Kong, and Sri-Lanka. Overall, 71% of all the fins and gill plates sampled came from species of high conservation concerns. Similar results were found in an analysis.
of the shark trade in the United Arab Emirates, in which 45.3% of species traded were considered to be at high risk of global extinction (Jabado et al., 2015).

Although many studies provide evidence for ineffective regulation and prevention, various countries have provided results that are showing effective surveillance and detection. In particular, Griffiths et al. (2013) investigated various skate and ray products sold in Ireland and the United Kingdom and found that none of the species identified were considered vulnerable according to the International Union for Conservation of Nature Red List of Threatened Species. The authors also did not detect any species with a zero total allowable catch as set by the EU. Although the sample collection in this study was relatively modest (n = 98 products), considerable efforts across Britain are believed to be enhancing awareness and conservation efforts.

### 7.4 Global efforts to combat seafood fraud

#### 7.4.1 Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization (FAO) Fisheries and Aquaculture department oversees information on international fish trade and provides statistical information for marketers and consumers (FAO, 2018b). For example, the FAO publishes the State of the World Fisheries and Aquaculture on an annual basis that provides global fishery and aquaculture data (FAO, 2018b). In June 2016 the FAO created an agreement on Port State Measures to prevent, deter, and eliminate IUU fishing (FAO, 2016). The focus of this agreement is to eliminate IUU fishing by stopping IUU vessels from using ports and docks to sell catches. This foundational set of standard measures promotes awareness among port states and puts them on high alert for foreign vessels seeking entry that may be associated with IUU fishing.

#### 7.4.2 European Commission

The European Commission is an advisory organization that, among other things, oversees regulation and policy for the seafood industry in Europe. In addition to requiring that consumers are provided with the specific area where the product was caught or farmed, the production method, and the fishing gear used, Regulation (EU) No. 1379/2013 requires seafood labels to include the commercial designation, the scientific name, and whether the product was defrosted. The inclusion of the scientific names instead of common names on seafood products throughout the supply chain can ultimately allow for appropriate tariffs to be applied to specific items and promote traceability for regulatory compliance and fraud prevention. It can also facilitate border inspections by allowing for easy identification of products that are covered by the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

In 2014 the European Commission updated a management policy for European fishing fleets called the Common Fisheries Policy, giving all fleets equal access to EU waters and fishing grounds and allowing for equal opportunity for fishers (European Union, 2018b). As well, this policy promotes fishing and aquaculture production, focusing on fostering an
economically and socially sustainable source of seafood. According to the European Commission, the EU accounts for about 5% of total fisheries production worldwide, with about 1.3 million tonnes in volume produced from aquaculture (European Commission, 2018). To combat concerns with IUU fishing, the European Commission has created a system called CATCH that brings all certification paperwork to an online platform (European Union, 2018a).

7.4.3 INTERPOL

With a global mission to enhance international crime surveillance, INTERPOL is engaged with over 170 countries to protect the health and safety of individuals on a global scale. Counter-terrorism and crime prevention are implemented through various operations throughout the global food supply (INTERPOL, 2018a). In 2018 Operation 30 Days at Sea was conducted to assess marine crime activity, including illegal discharge from vessels, dumping, and unregulated ship emissions. Over 1500 violations were identified, leading to about 700 investigations and implementation of fines and prosecutions. Operation Opson is a joint Europol and INTERPOL effort with participation from numerous countries around the world that targets fake and substandard foods and beverages. Eight operations have been completed since 2011. Operation Opson has repeatedly identified seafood as a major global concern for fraudulent activity and as a target for poor food safety regulation.

7.4.4 United States

The United States has a number of organizations that are associated with seafood fraud detection and mitigation. Customs and Border Protection (CBP) implements port of entry regulations, including labeling requirements, such as country of origin, and enforcement of antidumping or countervailing duties. CBP also reviews seafood import documentation to detect illegal transshipment. The US FDA has an active role in preventing seafood mislabeling. This organization provides consumers and industry with guidance on combating seafood mislabeling, including an official Seafood List of acceptable market names for over 1800 seafood species and groups sold in interstate commerce (FDA, 2018a). As well, a Regulatory Fish Encyclopedia provides detailed taxonomic features of fish to assist with accurate identification of species (FDA, 2018b). FDA conducts regulatory testing for seafood species substitution using a technique called DNA barcoding, which involves DNA sequencing of the cytochrome c oxidase subunit I (COI) mitochondrial gene (Handy et al., 2011; Yancy et al., 2008). The FDA’s Reference Standard Sequence Library contains over 1040 DNA barcode sequences for seafood species, including vertebrates and invertebrates (Deeds et al., 2014).

NOAA Fisheries, also known as the National Marine Fisheries Service, provides various seafood safety and sanitation programs (Johnson, 2014). NOAA Fisheries inspects approximately 20% of the seafood consumed in the United States as part of a voluntary seafood inspection program. This includes inspection of loading docks, fishing vessels, and processing sites to confirm that all standards are within FDA regulations (Johnson, 2014). With
respect to imports, the US Seafood Import Monitoring Program was published by NOAA Fisheries in 2016 as part of an action plan overseen by the National Ocean Council’s Committee on IUU Fishing and Seafood Fraud (NOC, 2014). The Seafood Import Monitoring Program is a risk-based traceability program that requires the importer of record to keep records from the point of harvest to the point of entry into US commerce for seafood species identified as being particularly vulnerable to IUU fishing and/or seafood fraud.

Nongovernmental organizations and the seafood industry have also been working together to draft industry-led standards on seafood traceability. Specifically, the Institute of Food Technologists’ Global Food Traceability Center and the World Wildlife Fund initiated the Global Dialogue on Seafood Traceability (GDST) in 2017. The goal of this program is to provide traceability tools and standards to fishermen, food companies, and other seafood stakeholders to meet regulatory demands in a complex seafood supply chain (Garcia, 2020). Over 60 companies and nongovernmental agencies from across the world have participated in this dialogue, including retailers, wholesalers, mid-supply chain processors and distributors, producers, and primary processors. In March 2020 the GDST released their first set of industry-wide global traceability standards for tracking seafood from the point of origin to the point of sale: GDST Standards and Guidelines for Interoperable Seafood Traceability Systems, Version 1.0.

7.5 Detection methods for seafood fraud

7.5.1 Detection methods for species substitution

Morphological characteristics have traditionally been used to identify various seafood species (Teletchea, 2009). Species-specific features, such as size, color, and texture, can be used for differentiation, but this often requires individuals with expert training. In processed seafood products, many of the identifying features are missing and it can be nearly impossible to properly identify a specific seafood product (Pardo et al., 2018). Fortunately, numerous analytical test methods are available for species-specific identification of seafood, with the most common being DNA and protein-based methods. This section will provide a brief overview of some of the most commonly used methods for seafood species identification. Additional information on this topic can be found in previous works (Hellberg and Morrissey, 2011; Lago et al., 2014; Naaum and Hanner, 2016).

7.5.1.1 Protein-based methods

7.5.1.1.1 Isoelectric focusing

Isoelectric focusing (IEF) has been historically used for seafood species identification due to its cost-effectiveness and overall simplicity (Gangar et al., 1996). This method involves the separation of water-soluble sarcoplasmic proteins in a polyacrylamide gel that has a pH range of 3–10 and is connected to an electrical field (Verrez-Bagnis et al., 2018). Due to the difference in amino acid content of proteins, the overall charge of each molecule varies, allowing for separation of various proteins.
correlating to each specific species. The protein-specific positions, defined as isoelectric points (pI), produce protein patterns that are similar to a barcode. The pI values of the identified bands are calculated using a known marker protein and the use of a visualization system with data analysis capabilities. Several studies have effectively used IEF as a species-specific identification technique (Berrini et al., 2006; Chen et al., 2003; Ortea et al., 2010; Renon et al., 2001; Schiefenhovel and Rehbein, 2013). However, various processing methods, such as heating, frying, or smoking, can denature proteins and result in inefficient bands for species identification (Verrez-Bagnis et al., 2018). Other electrophoresis-based techniques have been deemed effective for species identification under these conditions, including sodium dodecyl sulfate polyacrylamide gel electrophoresis and denaturing urea IEF. The combination of these three techniques is recommended for protein-based identification of seafood species.

7.5.1.1.2 Chip-based capillary electrophoresis

A protein-based method for seafood species identification using chip-based capillary electrophoresis combined with protein pattern analysis was developed by scientists at NOAA Fisheries (Walker et al., 2017). The method analyzes water-soluble sarcoplastic proteins from seafood using microfluidic electrophoresis to identify species-specific protein patterns. Protein pattern-matching algorithms are used to identify species based on comparison with a database. Walker et al. (2017) effectively identified over 300 fish samples using this protein-based technique. The downside of this technique is the complex data analysis and algorithms required for species identification, yet it is effective in differentiating frequently reported substitution, including catfish and tilapia (Walker et al., 2017). As well, the authors reported that this technique is applicable in conjunction with DNA-based species identification methods by providing a low cost, high throughput, and cost-effective tool for seafood authentication.

7.5.1.1.3 Immunoassays (enzyme-linked immunosorbent assay)

The use of antigen–antibody reactions can be used for seafood species identification, in which muscle protein antigens and poly/monoclonal antibodies (pAbs/mAbs) are used. Surimi-based products have been tested for possible species substitution with dot-blot methods, including Atlantic salmon, yellowfin tuna, and tilapia (McNulty and Klesius, 2005). Enzyme-linked immunosorbent assay has also been effective in quantifying walleye pollock surimi in crabsticks using pAbs (Verrez-Bagnis and Escricheroberto, 1993). Concerns with using pAbs include the low specificity and cross-reactivity issues that can develop with this assay. To prevent these issues, mAbs have been developed for high throughput testing of fish species such as red snapper and catfish with no cross-reactivity (Verrez-Bagnis et al., 2018). The overall use of immunoassays for species identification is limited due to the need for analysis from parallel reference samples to identify cross-reactivity and inefficient identification of processed products due to protein modification and degradation.
7.5.1.2 DNA-based methods

7.5.1.2.1 Sanger sequencing

The two main sequencing-based methods used for seafood species identification are DNA barcoding and forensically informative nucleotide sequencing (FINS) (Hellberg et al., 2016). Both the techniques rely on Sanger sequencing of a standardized gene target that shows low divergence within species and high variation between species. These methods utilize reference databases containing sequences from authenticated specimens that can be compared to the sequence from an unknown specimen to enable species identification. These methods are highly informative, reliable, and widely used (Espineira et al., 2009; Shehata et al., 2018; Wong and Hanner, 2008). In 2011 the US FDA published and implemented a DNA barcoding protocol for the regulatory identification of fish species (Handy et al., 2011).

The main genetic targets utilized by sequencing-based methods are the mitochondrial genes cytochrome b (FINS) and COI (DNA barcoding) (Hellberg et al., 2016). The use of mitochondrial DNA (mtDNA) for seafood species identification is preferred due to high mutation rates and the presence of multiple copies. On the other hand, nuclear DNA is a recognized species identification marker that is used instead of, or in conjunction with, mtDNA when hybridization and introgression occur within specific fish populations. For example, the intronless nuclear rhodopsin gene has been effective in combination with mtDNA for targeting tuna imported into Indonesia (Abdullah and Rehbein, 2014).

Sequencing-based methods for seafood species identification traditionally target regions of DNA, or barcodes, that are 400–700 base pairs (bp) in length. However, the integrity of DNA is reduced in processed seafood products, which can present challenges for species identification. In these instances, shorter regions of DNA (~150–350 bp), often termed “mini-barcodes,” can be targeted (Shokralla et al., 2015; Sultana et al., 2018). Mini-barcoding techniques have been demonstrated to be successful for various fish species and cooking methods (Pollack et al., 2018). Despite the success with DNA sequencing techniques, a continued limitation has been the inability to simultaneously identify multiple species in a seafood product, unless an expensive and time-consuming cloning step is added. In cases where analysis of species mixtures is required, alternative methods such as real-time polymerase chain reaction (PCR) and high throughput sequencing (HTS) may be employed. A limiting factor for DNA-based techniques is the reliance on a reference database for sequence information. While public databases contain a large amount of sequence information, there are sometimes incomplete reference libraries for a given species and errors such as misidentification of a specimen. Curated databases, such as the FDA’s Reference Standard Sequence Library, which contains sequences linked to authenticated specimens, provide a reliable source of sequence information and are essential for regulatory purposes.

7.5.1.2.2 Real-time PCR

Real-time PCR is a rapid approach for seafood species identification that records data in real time using fluorescence-based technology (Hulley et al., 2019). This high-throughput method is effective with the use of specific primers and fluorescent probes that detect a target region of DNA in either a single-species or multiplex approach.
Various fluorescent technologies are used for this application, the simplest being the SYBR green I, which binds to small grooves of double-stranded DNA (dsDNA) (Hellberg and Morrissey, 2011; Luekasemsuk et al., 2015; Pappalardo et al., 2019). Highly specific probes, such as TaqMan, that bind to the target region of DNA are also widely used (Feng et al., 2017; Herrero et al., 2012). Real-time PCR generally targets short fragments (<300 bp) of DNA and numerous studies have demonstrated this technique to be effective in the identification of seafood species in processed products (Feng et al., 2017; Liu et al., 2016; Trotta et al., 2005). Due to the increasing portability of real-time PCR instruments combined with the development of prepackaged species identification kits, there is high potential for widespread implementation of these methods throughout the supply chain (Naaum et al., 2019). However, there are still some challenges associated with real-time PCR, including reduced amplification efficiency of target regions in complex matrices, nonspecific amplification, and limited capabilities for multiplexing.

7.5.1.2.3 PCR-restriction fragment length polymorphism

PCR-restriction fragment length polymorphism (RFLP) is a technique that includes amplification of a specific DNA fragment with universal primers, digestion with restriction endonucleases and separation using gel electrophoresis (Verrez-Bagnis et al., 2018). This method is inexpensive and well established for seafood species identification (Dooley et al., 2005; Mueller et al., 2015; Xu et al., 2016). Various studies have used this technique in combination with DNA barcoding for species authentication of seafood (Panprommin et al., 2019; Xu et al., 2016). Similar to real-time PCR, PCR-RFLP is a targeted method that requires reference sequencing information in order to design a species-specific assay (Lago et al., 2014). While PCR-RFLP does not require expensive equipment, it does have the drawback of requiring multiple post-PCR steps, making it more time-consuming as compared to real-time PCR.

7.5.1.2.4 High-resolution melting

High-resolution melting (HRM) is a rapid technique that is applied following PCR in which small variations in the melting properties of dsDNA are assessed using real-time-PCR instrumentation (Druml and Cichna-Markl, 2014). The melting temperature is defined as the point at which half of the dsDNA is denatured and it is related to the amount of guanine and cytosine present in the sequence as well as the overall length (Angers, 2017). Using specific data analysis software, subtle variations in melting curves associated with a specific DNA sequence are examined and used to identify the species of an unknown sample. HRM analysis of DNA barcode regions has been proposed as a high throughput, cost-effective screening tool for differentiation of various fish species, including codfish, hake, and Macrourus spp. (Fernandes et al., 2017, 2018; Fitzcharles, 2012). Advantages of HRM include high accuracy, low price, and reduced time for analysis (Verrez-Bagnis et al., 2018).

7.5.1.2.5 High throughput sequencing

Next-generation sequencing and other HTS platforms involve analysis of multiple DNA sequences in parallel (Goodwin et al., 2016). HTS is advantageous over traditional Sanger sequencing because it allows for the simultaneous identification of multiple species in a
mixture. Several studies have been carried out examining the effectiveness of HTS for seafood species identification. For example, one study reported that pyrosequencing targeting COI and 16S ribosomal DNA were effective for detecting various species of bivalve mollusks (Abbadi et al., 2017). Another study reported successful use of the MiSeq platform (Illumina) to identify tuna species in prepared mixtures using two short cytochrome b segments (Kappel et al., 2017). The Ion Torrent Personal Genome Machine (Life Technologies) has also been used for authentication of Brazilian cod products (Carvalho et al., 2017a).

Despite the general success that HTS has shown thus far with identification of fish species, the technique has not yet been widely adopted in part due to high costs, complex data analysis, and an incomplete reference library. In addition, there are concerns with primer bias and incomplete universal primers that have thus far limited the efficacy of these HTS platforms. Currently, researchers are looking to combine droplet PCR with HTS techniques for seafood authentication in mixtures to prevent primer bias concerns (Verrez-Bagnis et al., 2018).

7.5.2 Overtreatment and short-weighting

Seafood products are considered to be short-weighted if they exceed the maximum allowable variation standards published by NIST. The maximum allowable variation is based on labeled quantity, for example, packages labeled as containing a net weight of 426–489 g of product have a maximum allowable variation of 19.9 g (National Institute of Standards and Technology, 2011). Official methods for determining the net weight of seafood are published by the Association of Official Analytical Collaboration (AOAC) International and include AOAC 963.26 (Net Contents of Frozen Food Containers), AOAC 963.18 (Net Contents of Frozen Seafoods Drained Weight Procedure), AOAC 967.13 (Drained Weight of Frozen Shrimp and Crabmeat), and AOAC 970.60 (Drained Weight of Frozen Crabmeat). These methods provide detailed procedures for removing the glaze from frozen seafood prior to determination of net weight.

Identification of phosphates in seafood products can be accomplished with various methods, from more classical techniques involving phosphate ratios to more advanced methods, including chromatographic and capillary-based techniques. Spectrophotometric methods for total phosphorus quantification are unable to differentiate and quantify various types of phosphates added to foods (SEAFISH, 2012). As well, added phosphates can only be estimated by calculating the ratio of free-phosphate to protein-bound phosphate (Dušek et al., 2003). To overcome these issues, more advanced methods, such as chromatography and capillary electrophoresis, are advantageous for quantifying and differentiating various types of phosphates (SEAFISH, 2012). For example, ion chromatography analysis of various fish species, including cod and tilapia, was effective at identification of protein-bound pyrophosphates and triphosphates (Kaufmann et al., 2005). Capillary electrophoresis is advantageous and effective for phosphate detection in seafood due to its ability to simultaneously identify orthophosphates, pyrophosphates, and tripolyphosphates in a given sample (Jastrzebska, 2011). Although these methods can assist with measuring “added” phosphates and/or total phosphates, no official methods have been implemented for regulation of seafood products (SEAFISH, 2012).
7.5.3 Country of origin and production method mislabeling

There are several analytical methods available for the identification of the geographical origin and/or production method of seafood products. These include the analysis of stable isotope ratios, DNA markers, fatty acids, elements, and/or trace elements (Morin and Lees, 2018). Stable isotope ratio analysis is a widely used method that involves the correlation between isotope availability and geo/climatic environment of a specific fish (Morin and Lees, 2018). For example, isotope ratios of \( ^{18}O/^{16}O \) and \( ^{15}N/^{14}N \) have been used to distinguish wild and aquacultured salmon from both unknown market samples and known origins (Thomas et al., 2008).

A novel approach to identifying the origin of seafood involves the use of DNA-based techniques to assess the microbiome of seafood species. In a study investigating the origin of Manila clams, HTS-generated microbiome data were more effective at identifying the geographic origin compared to single nucleotide polymorphisms (Milan et al., 2019). Another study reported discrimination of the geographic origin of aquacultured sea bass based on an analysis of the bacterial communities found in the sea bass skin mucus (Pimentel et al., 2017). While these studies provide encouraging results regarding the use of the microbiome to determine origin of seafood, additional investigation is needed, including research into the effects of processing environments and transshipment.

7.6 Conclusion and future direction

The global seafood industry is highly vulnerable to fraudulent activity, in part due to the extensive international trade of seafood, complex supply chains, similar appearance of many seafood species, fluctuations in supply and demand, and increased trade of processed seafood products. While seafood fraud is inherently motivated by economic factors, there are serious public health risks that can occur when seafood containing certain toxins or allergens is sold under a false or misleading name. In addition, poor sanitation practices associated with some fraudulent events present a health risk to consumers. Important advances have been made to the analytical methods available for detection of fraud, especially with regards to species substitution. These advances have enhanced the capability of regulatory agencies in the monitoring and detection of seafood fraud. Major seafood scandals and market surveys have highlighted the need for increased scrutiny and enforcement of regulations surrounding seafood fraud. The use of different market names from country to country further complicates proper labeling of seafood. While government action to address seafood fraud has been limited, recent progress focused on combating seafood fraud and IUU fishing is encouraging. Regulations should be updated on a global scale to require the use of scientific names along the entire seafood supply chain. Furthermore, regularly inspecting seafood for fraud at multiple points throughout the supply chain is recommended, including at the point of import as well as at the wholesale and retail levels. Inspections should include testing for short-weighting and species, as well as examination of traceability documents to verify the country of origin and identify instances of illegal transshipment. Taken together, these actions would be expected to enhance traceability, authenticity, and safety of seafood globally.
References


7. Seafood fraud


Food Fraud


References

Food Fraud


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CHAPTER 8

Coffee and tea fraud

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8.1 Introduction

Coffee (\textit{Coffea arabica}, commonly called Arabica coffee, and \textit{Coffea canephora}, commonly called Robusta coffee) and tea (\textit{Camellia sinensis}) both have a long history of consumption around the world. Tea has its roots in China and slowly spread from there, while coffee primarily originated in Ethiopia and expanded to the Middle East before being introduced to Europe. While the Spanish and Portuguese were the first to utilize the sea link to East Asia for trade, their primary goals were trade of pepper and other spices (not coffee or tea). The United (Dutch) East India Company (founded in 1602) and the (British) East...
India Company (founded in 1600) also imported spices, but their larger focus was on tea. To varying degrees, expanding tea production and trade had the unique secondary historical responsibility of advancing the colonization of Asia. By the late 1700s the East India Company held over 300,000 mi² of land in India, with a sizable military force to assert its authority over the 40 million people who lived under the Company’s administration (Walker, 1826). From inception to 1826 the East India Company imported over 1.27 billion pounds of tea to Britain and others such as China and Holland.

Tea has presented a unique series of food fraud challenges for as long as it has been an international commodity. Tea is susceptible to substitution with inferior ingredients, addition of undeclared colors or flavors, and mislabeling of geographical origin and processing methods. It is a natural product made from an infusion of water with the leaves and/or leaf buds of the *C. sinensis* plant. Therefore some level of inclusion of twigs and other plant materials is expected. While the process varies somewhat by supply chain or firm, tea production includes the basic steps of withering, crushing, oxidizing, and drying. These steps can occur at a single point of production or may be spread out across the supply chain, with the individual stages being completed by separate processors. With each stage of processing, the appearance of the tea changes, increasing the vulnerability to fraud. The quality of the end tea product is affected by every step of the production process. First flush teas are picked from the earliest spring growth of the tea plant and are considered to be the most exclusive and, therefore, expensive. Second flush teas are more mature and are harvested a few months after a brief period of dormancy during the rainy season. Monsoon flush and autumnal flush teas are picked in the succeeding months depending on the variety of tea plant (Heiss and Heiss, 2007). Immediately after picking, the fresh tea leaves are carefully withered to remove the majority of the water in the leaf; the rate of withering also affects the flavor compounds, the bioavailability of caffeine, and breakdown of amino acids in tea (Jabeen et al., 2019).

After withering the leaves are torn and bruised by kneading or tearing to begin the oxidation step. This breaks down the leaf cell structures and allows enzymes to interact with substrates, jumpstarting oxidation, and changing the flavor profile of the tea (Wu et al., 2019). The amount of time the tea is allowed to oxidize further determines the flavor, color, and aroma: little to no oxidation produces white and green teas, moderate levels of oxidation yield yellow and oolong teas, and high oxidation creates black tea (Lin et al., 2013). The tea producer halts the oxidation process by fixation, heating the leaves to destroy the oxidative enzymes. Afterward, the tea leaves are rolled into the desired shapes and dried to prepare for sale (Wu et al., 2019). Some teas, such as Pu-erh teas or flavored teas, are further processed after drying by an aging or curing process (Wang et al., 2018).

Coffee has a somewhat different history from tea. For the most part the coffee trade did not expand due to a strategic colonization plan. The history of coffee is instead one of expansion of the growing regions through an uncoordinated mix of official and unofficial travelers conveying seedlings or seeds to far-flung parts of the world. Coffee growing originated in Ethiopia, then expanded to the Arabian Peninsula and surrounding countries, with eventual expansion to globally distributed growing regions in subtropical and equatorial regions (“the coffee band”) (National Coffee Association, n.d.). Like other high-value crops or products, coffee has been the target of food fraud from the very early days of the coffee trade.
Whole coffee beans have some inherent advantages when it comes to the prevention of fraud, since they can be more easily visually identified than ground beans. However, they are still a target for fraud, often through the partial or complete substitution of Robusta beans for Arabica beans. A trained buyer can visually differentiate between Robusta and Arabica beans. If substitution is not detected during the visual inspection, it can often be identified during the roasting process. Robusta beans are denser and, therefore, take longer to roast to achieve the same desired color profile compared to Arabica beans. The process from field to consumer and the different methods of distribution across the supply chain increase the potential for fraud in coffee. Ripe coffee “cherries” are generally handpicked by either stripping the cherries off of the stem or selectively picking only the ripest cherries on a stem. They are typically dried at the point of harvest, sometimes with a prior wet processing stage to remove outer layers. Milling usually occurs in the growing region or country and consists of a two-step process of hulling and polishing. The beans are then ready to enter into trade, but there can be many intermediate stops along the way before a cup of coffee reaches the consumer, with each stop an additional opportunity for fraud (NCAUSA, n.d.).

Ground Arabica and Robusta coffee beans, on the other hand, are visually indistinguishable from each other and substitution of one for the other can only be detected by certain analytical techniques or experienced tasters (individuals trained for their ability to evaluate the organoleptic profile of coffee). Numerous adulterants have been associated with ground coffee; those committing fraud with ground coffee are looking for anything that will dilute the coffee with minimal likelihood of detection. A series of papers exposing food fraud in England in 1851–54 illustrated this through the reporting of adulterants including chicory, roasted wheat, corn, acorns, burnt beans, iron oxide, roasted mangelwurzel (a root vegetable), and coconut shells (HART, FL, 1952). Tea was also reported to have been adulterated, with substances including copperas (copper ferrous sulfate) and vitriol (copper sulfate). These reports of fraud associated with coffee and tea combined with a public outcry led to the formation of a British Committee to investigate the issue. The driver of this effort was Mr. Twining, who would go on to build a family tea empire (Walker, 1826). This was the first step in an ongoing effort to counter coffee and tea fraud.

8.2 Breadth of commodity consumption

Consumer preference for coffee or tea is dependent upon the initial introduction to the product and income. In general, tea is preferred in Central European countries, British colonies, and most of Asia and Africa (where data exists), while coffee is preferred in North America, Latin America, and Southern Europe (Pew Research Center, n.d.). Tea costs significantly less than coffee, enabling a greater percentage of the global population to purchase it. It only takes 2 oz of tea leaves to brew a cup of finished product versus 10 oz of ground coffee beans. As economic growth in developing nations, such as China and India, increases the disposable income, coffee and tea consumption will likely continue to increase.

According to the International Coffee Federation, in the 2018/19 growing year coffee exporting countries produced approximately 10 million metric tons of coffee beans.
The top producing countries included Brazil, Vietnam, Indonesia, and Colombia, which accounted for over 68% of total production.

Tea production in the 2018 growing year was 6.3 million metric tons or over 110 trillion servings, illustrating just how popular tea is globally (FAOSTAT, n.d.). In fact, tea is the second-most consumed beverage in the world after water (FAO, n.d.). From 2013 to 2018, global tea consumption rose from 30 to 36 billion liters (Technavio, 2019), with the top exporters being China, India, and Sri Lanka (Workman, 2020). Current (2018) tea production is dominated by China (41%) and India (21%) (FAOSTAT, n.d.). While these countries retain a large portion for domestic consumption, tea is also a big export commodity for both countries ($1.78 billion in Chinese exports in 2018) (UN, n.d.). The projected growth of the global tea market is an additional $12.6 billion for 2019–23 on top of its current worth of $7.8 billion (Bolton, 2019).

8.3 Fraud in coffee and tea in current times

As is the case with all fraudulent foods, the absolute rate of coffee and tea adulteration for profit is unknown. However, we can make inferences about the types of fraud based on the data that is available.

8.3.1 Incidents of coffee fraud

The main types of fraud associated with coffee are the substitution of Robusta for Arabica (whole or ground coffee beans) and the use of inexpensive fillers in ground coffee. An inquiry of the Decernis Food Fraud Database conducted on March 8, 2020 (Decernis, n.d.) showed that the preponderance of coffee fraud records was related to dilution with many of the materials cited earlier (e.g., chicory and corn), as well as materials such as barley and spent coffee grounds. For example, in 2018, a coffee manufacturer in Cambodia demonstrated a wide range of adulterants currently in use when the facility was raided by officials, including raw and roasted corn, soybeans, and other materials, as well as adulterated coffee (Khmer Times, 2018). Materials that have more recently been detected as adulterants in coffee include soybean, magnesium dioxide, maltodextrin, and others. While adulteration with these materials has only recently been discovered, it is possible that those committing fraud have been using them as adulterants for some time. The wide variety of potential adulterants in ground coffee presents analytical challenges that will be discussed in the next section.

The second-largest category of fraud associated with coffee records in the Food Fraud Database was the substitution of Robusta beans or ground Robusta beans for Arabica beans or ground Arabica beans. While the substitution of whole beans can be identified by a skilled taster or roaster, there are also new and emerging analytical techniques available (discussed in the next section) that can be used with whole beans or ground coffee. In addition to the dilution and substitution records mentioned, there were also a few cases of nonorganic coffee represented as organic coffee. Given the higher value placed on organic products, this is a problem across food commodities (see Chapter 16: Fraud in Organic Foods). As long as supply chain certifications are in
place and no pesticide residues are found on the beans, there is little else that can be
done to uncover this type of mislabeling, as the organic beans look and taste the same
as conventional beans.

Mislabeling of coffee origin has also been reported. For example, in 2014, a product
labeled as 100% Jamaican Blue Mountain Coffee was found to contain substandard beans
and be falsely labeled with regards to the product origin. Jamaican Blue Mountain Coffee
is a highly valued commodity; this contributes to its vulnerability to fraud (Jamaica
Observer, 2014). Kona coffee from Hawaii has also been prone to fraud over the years. In
2019 three Kona coffee farmers proposed a class action lawsuit against retailers and whole-
salers for selling non-Kona coffee labeled as Kona coffee. The suit alleged that 2.7 million
pounds of Kona coffee were produced each year, while more than 20 million pounds of
coffee labeled as “Kona” were sold at retail (Rizzi, 2019). Coffee has also been the target of
counterfeiting and label tampering. One example occurred in 2008, in which instant coffee
granules from an unreported origin were imported into Western Europe with a false
Nescafe label that contained incorrect manufacturer information (Liverpool Echo, 2008). In
a case of label tampering, judicial police in Colombia seized instant coffee packets with
expiration dates that had been removed or changed (Fiscalía General de la Nación, 2014).

8.3.2 Incidents of tea fraud

Tea is susceptible to substitution with inferior ingredients, addition of undeclared colors
or flavors, and mislabeling of geographical origin and processing. One of the earliest
records of tea fraud in the modern era dates back to 1818 with the fake tea scandals in
Britain (Wilson, 2008). Tea merchants were found to be creating fake tea leaves from sloe,
elder, and ash leaves, through a complicated and almost artistic process involving boiling,
baking, curling, drying, and coloring until the leaves appeared almost exactly like green
tea from China. One of the colorants used to make fake black tea was logwood that can
cause gastroenteritis in large doses. To create fraudulent green tea, the leaves were boiled
in copper acetate and painted with “Dutch pink” dye and more copper acetate after the
leaves were dried (Wilson, 2008). Selling adulterated tea has historically been very profit-
able, especially when taxes/tariffs are high. At one point, Britain taxed tea imports from
China at nearly 100% of the declared value. The Adulteration of Food and Drugs Act was
enacted in 1872 in Britain, which helped to address these fraudulent practices. In the same
year a market survey reported that 36 out of 41 tea samples were adulterated with
Prussian blue, fake leaves, clay, and sand; by the end of the following decade, tea was
reported to be far less adulterated (Wilson, 2008).

A recent inquiry of the Decernis Food Fraud Database records for tea identified a wide
range of adulterants. The adulterants included some common to coffee, such as chicory
and nut husks, but the vast majority of the adulterants involved dyes/pigments and other
coloring agents used to improve the appearance of tea or “spent” tea leaves. The Sri Lanka
Tea Board in 2018 surveyed 80 tea factories and 53 were found to be adding undeclared
sugar and glucose to their Ceylon tea products in order to improve the flavor and brewing
color of the tea (Wettasinghe, 2018). Sugar additives are not permitted according to Sri
Lanka Tea Board standards. Also, fraud erodes buyers’ confidence in the quality of
Ceylon tea, which is a black tea exclusively grown in Sri Lanka and is the country’s second-largest export. Similar adulteration was found in teas in Brazil, as the undeclared presence of sucrose, soil, and sand was detected in tea. These contaminants were purposefully added to teas in order to increase the product weight so manufacturers could increase their profits (Tibola et al., 2018). To increase volume and weight, manufacturers have also added fillers such as ground cashew nut husks, dried apple skin, sand, and gravel, making the product unsuitable to sell as tea (Tibola et al., 2018; Xu et al., 2015). For example, the Tea Board of India discovered that 44 of 47 samples sent by an Indian tea company for testing had over 20% crude fiber content when the acceptable level is only 16.5%; this indicated that the company was likely adding tea waste to a product sold as Assam tea (Sentinel Digital Desk, 2019). Assam tea is exclusively grown in the Assam region in India and is known for its strong flavor and high grade. Substituting such a high-quality tea with tea waste such as tea sweepings, stalks, or fluff threatens to negatively affect the global reputation of Assam tea.

There have been many reports of the addition of undeclared and potentially dangerous coloring agents such as coal tar dye and Prussian blue to improve the apparent appearance and flavor of the tea. For example, eateries in India were found adding banned artificial colorants and chemicals to enhance the appearance and flavor of teas (OnManorama, 2019; Nadu, 2012). These adulterants included carmoisine, sunset yellow, tartrazine, coal tar dye, Prussian blue, indigo, soapstone, and gypsum, all of which are illegal to add to tea per India’s safety standards. A study of 12 local and packaged teas in West Bengal found that half of the local tea samples and about a third of the packaged teas were adulterated with undeclared dyes, such as coal tar dye, azo dye, and chicory (Pal and Das, 2018), likely to improve the visual appearance and flavor of old or poor-quality tea leaves and to allow them to produce a higher volume of brewed tea. According to the Tea Board of India, genuine tea leaves yield approximately 400 cups of tea per kilogram, while adulterated tea can yield up to 800–1000 cups (Nadu, 2012). In August 2019 the Food Safety and Standards Authority of India seized 1.5 tonnes of tea dust with high concentrations of colorants (Raja, 2019). Also in 2019, China authorities raided a business that had been selling fake tea online since 2017 and seized 40 tonnes of fake material adulterated with coloring agents (Huizhi, 2019).

Mislabeling of geographical origin, picking season, and processing type also occurs, as all of these are value-added attributes to the perceived quality of the tea. Tea grown in the high mountains of Darjeeling, India is a prime example of fraud by geographic mislabeling (Firmani et al., 2019). Darjeeling tea is renowned worldwide and is registered under the protected designations of origin and protected geographical indications labels, as it is a very rare and expensive tea. The quantity of Darjeeling tea marketed for international sale greatly exceeds the reported amount of Darjeeling tea actually produced by the Darjeeling region, illustrating the extent of fraud (Burslem and Wainwright, 2019). Unexpected shocks in production, such as the 70% loss of Darjeeling production in 2017, may also provide opportunities for others to fill that void, in some cases taking advantage of free trade agreements (Siliguri, n.d.).

Tea is sold not only as whole tea leaves, but as flavored tea powders and processed tea drinks for consumers. This adds another opportunity for fraud, as these tea products can be further adulterated during later stages of processing with additives that may...
themselves be contaminated. One example involved Lipton milk tea powder that was recalled in Hong Kong due to the contamination of the tea powder with melamine; this was a result of widespread adulteration of milk supplies in China with melamine in 2008 (Hong Kong Centre for Food Safety, 2008). In 2011 tea drinks in Taiwan were found to be tainted with clouding agents adulterated with plasticizers di(2-ethylhexyl) phthalate and di-isononyl phthalate (Yang et al., 2013).

8.4 Prevention and mitigation

8.4.1 Supply chain controls

The complexity and natural variability of coffee and tea combined with the range of potential adulterants make the application of analytical strategies as preventive controls difficult. Therefore, supply chain mitigation strategies are essential for both coffee and tea. Vertical integration or, at least, direct oversight at the point of harvest, can help one to ensure both the quality and the authenticity of both coffee and tea. It is also not uncommon to have strong, long-standing relationships within coffee and tea supply chains to help one to mitigate the potential for fraud. This is reinforced by regulatory and international standards authorities that require preventive controls if there is a risk to human health. In the case of coffee and tea, oversight at the point of harvest is only one of the many supply chain preventive controls that firms may choose to use. It is important to note that for supply chain preventive controls to be at all useful, they must be more than a paper exercise. There must be an understanding and awareness of practices and procedures that the firm is counting on their suppliers to have in place to protect their customers.

8.4.2 Qualification/acceptance testing

Once supply chain controls are in place, it is useful to differentiate between qualification/acceptance testing and operational testing to prevent fraud. For example, the highly trained coffee taster is of significant importance when qualifying a new supplier or new product line. Due to the characteristics of the beans, such tasters are readily able to distinguish between Arabica and Robusta. Green (unroasted) Arabica and Robusta coffee beans have distinct color differences. Green Arabica beans are oval in shape, almost twice as large as Robusta, and have a variant underside crease. Green Robusta coffee beans are round in shape, half the size of Arabica, and have a straight underside crease (Coffee Chemistry, 2015). After roasting the beans may look more alike, but a trained taster can differentiate between the fruity and sweet notes of Arabica versus the harsher, grain-like notes of Robusta. Unless it is a boutique mill, however, it may be unrealistic to expect the coffee taster to be part of the operational support for fraud mitigation.

8.4.3 Physical examination, microscopy, and agricultural sorting machines

For whole coffee beans and tea, there are some long-standing fraud mitigation strategies that still have merit, but they are labor intensive and, as a result, may only be used for
spot checks. Furthermore, they can be highly dependent on the skill of the analyst and may not be well suited for all types of fraud. For tea, physical examination and microscopy (by trained technicians) are well-established approaches for detecting foreign material. However, this is not a reliable approach for detecting colorants. In the last decades, new agricultural sorting machines have become available that can not only sort among types of tea (CSG, n.d.; Sortex Group, n.d.) or coffee (ASA, TS, n.d.; Satake, n.d.), but they can also sort out physical contamination and detect color differences and other variations that might indicate quality or fraud problems. This has the dual benefit of in-line adulteration detection while enabling more focused examination of suspect samples using microscopy or other methods.

8.4.4 DNA-based methods

There are options for including DNA testing (such as whole genome sequencing or other DNA-based methods) to automated color sorting or visual inspection processes. These methods can be used on coffee beans to determine whether the beans are Arabica or Robusta. In the case of tea, they can be used for determining the presence of *C. sinensis*, as well as other plant species. However, tea analysis may have a lot of “background noise” (i.e., low-level detection of other species) due to the method of picking. If the tea is hand plucked, there will be less unintentional inclusion of other plant species than if it is mechanically harvested. However, hand-plucking tea is an arduous job. The harvesters are tasked with ensuring only the new growth is plucked. Typically, the industry considers the new growth to be the last three leaves and a bud at the end of each twig on the bush. In mechanical harvesting a trimmer runs down the bush clipping off all the new growth, including anything wild growing up through the bush. The clipped leaves are commingled, fermented, dried, and then cut close to the harvesting location and there is the potential for a non-insignificant amount of non-*C. sinensis* material in the clippings. While DNA-based methods can be used to help ensure the integrity of the finished product by detecting the presence of non-*C. sinensis* plant species, they do not allow one for quantification of these foreign materials. This makes it difficult to determine whether their presence is due to fraud or is a result of the harvesting process. For this reason, microscopic examination for foreign materials, including a determination of the amount of foreign material in a blend, remains an important method in the industry. Microscopic examination is sometimes used in a complementary manner with DNA-based testing. A trained technician can determine the purity of a sample and estimate how much foreign material is in a sample. If the foreign material is found at a significant amount, which is usually predetermined in specifications set by the customer and the laboratory, the technician can separate the material out and run DNA testing on the sample to determine the identity of the foreign material.

8.4.5 Chromatography

While DNA-based methods can be used to identify foreign plant materials, they are not suitable for detection of colorants, which is a major concern for tea fraud. The preferred
approach for detection of colorants is the use of chromatography-based techniques, such as liquid chromatography or high-performance liquid chromatography (HPLC), potentially paired with mass spectrometry if needed. Chromatography-based techniques have been used to verify the authenticity of ingredients and geographic origin of tea. Chromatography is a simple analytical method that involves the separation of mixtures into individual components for identification and quantification (Juvet, 2019). In gas chromatography, volatile components are separated based on their boiling points, whereas liquid chromatography uses a liquid solvent to separate mixtures based on their basic physiochemical properties and chemical interactions, such as polarity. (Dorsey, 2018; Juvet, 2019). Both methods measure retention time that reflects the rate at which the individual components separate through the column. Documented retention times for components in an authentic sample of tea can be used to evaluate the retention times for a potentially adulterated or mislabeled tea sample in order to confirm its authenticity and geographic origin. The advantage of using these methods is that, even if the specific colorant is not in the reference library, it will be flagged as being out of context for tea. This is a significant advantage over other methods, since one of the greatest challenges is trying to guess which fraudulent additive might occur next.

For coffee the challenges increase significantly when a firm moves from sourcing beans, where there are reasonable and cost-effective options for fraud detection, to sourcing ground coffee, where the analytical requirements become much more challenging. For analytical testing of ground coffee, chromatographic techniques and/or spectroscopy-based methods (discussed later) are generally applied (Toci et al., 2016). From mass spectrometry (direct infusion) HPLC, HPLC–UV–vis, to gas chromatography techniques, a wide range of related methods has been explored both to identify adulterants and to confirm Arabica versus Robusta. All these techniques have demonstrated clear potential to be useful, but they are also likely to require a third-party laboratory for testing.

8.4.6 Spectroscopy

Spectroscopic techniques provide qualitative and quantitative analysis regarding the chemical composition and chemical structure of the components in coffee and tea (Bursey, 2019). Spectroscopy measures the relationship between matter and the electromagnetic spectrum. The spectral data generated is commonly coupled with chemometrics for mathematical and statistical analysis. Within spectroscopy, there is an array of specific techniques that have been used with coffee and tea, including near-infrared (NIR) spectroscopy, Fourier-transform infrared spectroscopy (FT-IR), and nuclear magnetic resonance (NMR) spectroscopy.

NIR spectroscopy uses the NIR portion of the electromagnetic spectrum to stimulate molecular vibrations and the low-energy electronic transitions that are present in the molecules of coffee and tea (McDowell, 2018). In FT-IR an interferometer is used rather than a spectrometer because it can simultaneously irradiate smaller samples with varying wavelengths. Spectral data is generated based on the intensity of recombined and interfering beams that are then utilized in Fourier transform, a mathematical procedure that converts the raw data into a spectrum (McDowell, 2018). NIR and FT-IR are useful in identifying
adulterants in coffee or tea, such as glucose, starch, chicory, husks, corn, and corn husks. The complexity of the method and the expertise required, however, suggests that most processors would send samples out to a third-party laboratory for such testing, thereby reducing the utility.

NMR characterizes the molecular structure of a material based on the absorption of radio-frequency radiation by atomic nuclei in a static magnetic field (Larive, 2019). NMR can reveal the presence of specific chemical markers in a spectrum and, by extension, ones that should not be there. NMR is highly specific and can be used to indicate the presence of substances in coffee and tea such as theanine, catechin, caffeine, trigonelline, total caffeoylquinic acids, sucrose, fatty acids, and/or quinic acids. It could be run in-house by larger processors but is more commonly outsourced to third-party laboratories. Recently, a certification program for coffee and tea was developed that uses a combination of NMR- and DNA-based methods for authentication (TRU-ID, n.d.). Certification programs such as this allow supply chain verification and provide consulting services to the industry to put in place quality control programs and reduce the potential for fraud.

8.5 Conclusion

Coffee and tea are very popular beverages globally. However, their high value, complex supply chains, and wide range of potential adulterants leave these commodities vulnerable to food fraud. In addition to the potential health risks of fraud, these practices can negatively impact consumer confidence around the globe, as coffee and tea are important to many cultures. While there are numerous approaches and analytical methods available to detect fraud that should be used when appropriate, the foundation for food fraud mitigation for coffee and tea lies in supplier qualification/verification and active supply chain management. For the United States and Europe, nearly all coffees and teas are imported, meaning that firms must follow the relevant foreign supplier verification programs in addition to corporate programs. Firms should focus on the visibility and control of their supply chain, with the ability to identify and exchange information with all intermediaries in their supply chain from farm to final sale. If they do not manage their supply chain back to the point of harvest, they should ensure that those they source from can trace the product back to the farm. Customers and regulators now expect this level of supply chain oversight. Companies and consumers should also keep in mind that very low prices may be a sign of an inauthentic product.

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CHAPTER 9

Fraud in fats and oils

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9.1 Introduction

Food oils are a tempting target for adulteration and fraud since, in many cases, one food oil looks much like another. There is a general understanding that fraud is committed for economic gain. Food oil fraud has been a problem as long as these oils have been food for human beings, which is millennia in the case of olive oil (Mueller, 2012).

Food oils are regularly described as one of the categories of foods most at risk for fraud (European Parliament, 2013; Johnson, 2014; Tsimidou et al., 2016). Food oils are an interesting topic for the discussion of food fraud as there are two easily discernable groups: (1) fats and oils that fall into the commodity group (e.g., soy, palm, canola/rape, corn, peanut, sunflower, and cottonseed) which are also potential adulterants and (2) specialty oils such as argan, camellia, olive, tree nut, grapeseed, and fruit seed oils that may be the subject of adulteration. Commodity oils are by far the largest sector, whereas olive oil, the most
highly traded specialty oil, commands only 1.5% of world trade, as predicted by the USDA for 2018/19 (USDA, 2019) (Fig. 9.1).

Industry experience with olive oil suggests that the cost of fraud since 2000 for high-value food oils can be valued in terms of many millions if not billions of dollars. Product value has been eroded in a retail “race to the bottom” (Miller, 2016), particularly noticeable for olive oil in the period from 2004 to 2014.

Since 2016 there has been increased interest from regulators and authorities in fraud in food oils, in particular in the European Union (EU), the United States, and China. There is also an increased media interest, and the numbers of both media and scientific reports have been used to reflect the level of food fraud that is likely happening for various foods, including food oils (Johnson, 2014). Such analysis of food fraud problems is perhaps the most effective indication of their importance as by its nature food fraud is secretive. It may never be possible to accurately analyze the volumes of fraudulent foods in global supply chains and therefore the true costs of the problem.

Against this background of increasing concern and interest, the nature of the problems for food oils is described and examined in this chapter, and some strategies for mitigating these problems are suggested.

### 9.2 Commodity fats and oils

The worldwide production of vegetable oils was estimated to be over 200 million MT in 2018/19 (USDA, 2019), and the value of these commodity oils was in the region of US$100 billion. Since commodity oils are significantly lower in price (around $500/t) than specialty oils [for instance, extra-virgin olive oil (EVOO) may sell for $2–$8000/t, and argan oil may cost over $45/kg] and generally visually indistinguishable, they provide a readily available source of possible adulterants. In the food industry, various refined vegetable oils, and blends thereof, are used for their functional qualities, including product stability. These characteristics are a property of their individual fatty acid and triglyceride composition. As can be seen from the nutritional information panel on a packaged food, any number of vegetable oils or blends may be used in a finished food.
9.3 Examples of fraud in edible oils

Three high-value food oils are selected as examples regarding fraud in food oils—argin oil, camellia oil, and olive oil. There will be a particular focus on olive oil regarding the regulatory, technical, and global trade context of this well-researched food.

Reports of such fraudulent events in English language databases and reporting services are more frequent for olive oil than for argan and camellia oils. A search of the Food Fraud Database (www.foodfraud.org) from 2014 to 2019 found 84 distinct records of reporting or discussion of fraud regarding these products; 70 records for olive oil, 10 records for camellia oil, and 4 records for argan oil. The EC Food Fraud Monthly Reports (www.ec.europa.eu) that have been published since September 2016 make no mention of argan oil or camellia oil while there are 32 records of reports of food fraud in olive oil (Joint Research Center).

The main evidence of the importance of food fraud in argan and camellia oils is the level of research into methods of detection of fraud and reports in some specific publications by authors who work with these industries. The apparent lack of media attention to such problems does not necessarily indicate any difference in levels of food fraud compared with other foods or oils since food fraud is generally performed without publicity.

9.4 Argan oil

Argan oil is extracted from the kernels of the fruit of the argan tree—Argania spinosa (L.) Skeels. This species is almost exclusively found in Morocco, and the 870,000–1,000,000 ha of native argan trees in southern Morocco is known as the “argan forest” (Guillaume et al., 2019). It is also described as the last barrier against the encroaching Sahara Desert (Huang, 2017).

Argan oil has been used for centuries (since the time of the Phoenicians) by the people of Morocco as an important and highly nutritious food, for medicinal purposes and as a cosmetic (Charrouf and Guillaume, 2014). The production and, notably, the export of argan oil from Morocco has increased in recent years with exports reported at 1000 MT in 2014 and projected to rise to 20,000 t by 2022 (Guillaume et al., 2019).

In Morocco, for cultural and ancestral reasons, women are the exclusive traditional producers of argan oil. “The argan oil project” that began in the 1980s is one that sought to modernize the production and technology of argan oil as well as prioritizing the development and welfare of the local women-managed cooperatives (Guillaume et al., 2019; Charrouf and Guillaume, 2014). This ambitious undertaking has had its successes and failures, but it has raised the profile of argan oil as an important product and this has contributed to increasing demand and associated production and export of argan oil as a high-value product (Guillaume et al., 2019).

The significant cultural importance of the argan trees and argan oil to the people of Morocco, its cultivation and care by women and family cooperatives, the reported health and cosmetic attributes of the oil, its particular origins, and its ancient history make it a special and unique product. It is now selling for high prices in certain markets, for example, 150 Euros per liter in Europe in 2017 (Guillaume et al., 2019).
Unsurprisingly such an oil is the subject of fraudulent practices (Guillaume et al., 2019; Momchilova et al., 2014).

The food fraud associated with argan oil encompasses deceptive practices, including:

- mixing of argan oil with oils of another botanical origin and lesser value while the product claims to be exclusively argan oil,
- false label quality statements—selling lower grade products than as labeled, and
- false geographic origin claims.

In relation to the false geographic origin claims of argan oil, these include the marketing of products from a country devoid of traditional culture toward this product (Guillaume et al., 2019). This is a very interesting form of fraud that reflects the high value of the cultural aspects of argan oil in its country of origin.

The identification of the geographic origin of argan oil within Morocco is also being studied, including the use of UV–visible fingerprinting recently reported as discriminating argan oils from five Moroccan argan forests and also the extraction process/kernel type (Kharbach et al., 2017, 2018). Such work indicates that the origin of argan oil from different parts of Morocco is of value to the supply chain and increases the risk of food fraud.

Vegetable oils have long been described in standards according to quality and composition factors (Codex Alimentarius, 1999). Both are important when seeking to authenticate food oils. Argan oil quality and composition were standardized in Morocco in 2003 [Service de Normalisation Industrielle (Snima), 2003].

Codex Alimentarius (1999, 1981) has standards for named vegetable oils and olive oils that are instructive. These documents demonstrate the wide variations in fatty acid and phytosterol compositions exhibited by different food oils. The compositional makeup of such oils is clearly influenced by the species from which the oil is sourced. The selective breeding of the main oilseeds has given rise to newer varieties that have ranges of chemical and physical parameters that are purposely different from the traditional oils of the same species. For example, data for three sunflowerseed oil varieties, “high-oleic” and “mid-oleic” and traditional are listed in Codex Standard-210 (Codex Alimentarius, 1999). These oils have different amounts of oleic acid than traditional sunflowers oils though they are derived from the same species. In many cases the aim of the modification of the chemistry of the oil has been better stability (lesser amounts of polyunsaturated fatty acids) or perceived health benefits such as having an oleic acid content similar to olive oil.

Argan oil appears to have compositional ranges of fatty acids and phytosterols that are narrower than for most other oils [Service de Normalisation Industrielle (Snima), 2003]. This may be because argan oil comes from seeds of trees that are only grown in a specified geographical area of Morocco. This may assist the determination of the authenticity of argan oil products in comparison with other food oils that could be used to adulterate argan oil.

Notwithstanding the current restricted origin of argan oils, the ranges of composition of other food oils overlap some of the compositional ranges for argan oils, and this should be taken into account in work to authenticate and specify argan oil products. The detection of mixtures of argan oil with other oils and the detection of the origin of argan oils is the subject of diverse and extensive research. Examples of such work are given in Table 9.1.
TABLE 9.1  Research into argan oil characteristics and authenticity.

<table>
<thead>
<tr>
<th>Test</th>
<th>Details</th>
<th>References</th>
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<tbody>
<tr>
<td>Compositional parameters</td>
<td>A retail survey of the argan oils in the Bulgarian market, analyzed fatty acid profile, triacylglycerol composition, phytosterols, and indicators of oxidative stability.</td>
<td>Momchilova et al. (2014)</td>
</tr>
<tr>
<td>Phytosterols</td>
<td>Argan oil has a minimal content of campesterol (≤0.4% of total phytosterols) compared with other oils—all oils in the Codex standard for named vegetable oils have levels of campesterol that are significantly higher than argan oil. This characteristic has been proposed as a factor in the detection of adulteration with other vegetable oils.</td>
<td>Service de Normalisation Industrielle (Snima) (2003), Codex Alimentarius (1999), Hilali et al. (2007)</td>
</tr>
<tr>
<td>Fingerprinting approach using multiple technologies to detect multiple parameters</td>
<td>A range of analyses and chemometrics to characterize and authenticate the geographical origin and quality of argan oils parameters measured included free acidity, peroxide value, spectrophotometric indices, fatty acid profiles, phytosterols, and some phenolic compounds. In addition, fingerprinting using UV-visible and FTIR spectroscopic analyses, UPLC-MS, and selected ion mass spectrometry were used. Extensive chemometric analysis of the data was used.</td>
<td>Kharbach et al. (2017)</td>
</tr>
<tr>
<td>Fatty acid profiling and UV-visible spectroscopy</td>
<td>Fatty acid profiling and UV-visible spectroscopy to discriminate the origin of argan oils within Morocco.</td>
<td>Kharbach et al. (2018)</td>
</tr>
<tr>
<td>Elemental analysis</td>
<td>Elemental analysis of vegetable oils to detect adulteration oil argan oil with other vegetable oils. Argan oil contains higher levels of tin than any of the other oils that were studied.</td>
<td>Mohammed et al. (2019)</td>
</tr>
<tr>
<td>Visible and near infra-red spectroscopy</td>
<td>The combination has been used to discriminate between argan oils and blends of argan oils with other vegetable oils. Reported capability to detect less than 1% of the adulterant.</td>
<td>Farres et al. (2019)</td>
</tr>
<tr>
<td>Sensory analysis</td>
<td>Sensory analysis is important for argan oil. Oils were assessed according to the classification of olive oils. Defects in argan oil, such as for olive oil, include fusty, rancid, and burnt. In addition, a defect descriptor for argan oil is “Roquefort cheese.”</td>
<td>Kharbach et al. (2018), Matthäus (2013)</td>
</tr>
</tbody>
</table>
The range of methods and approaches to analyzing argan oil intended to be used as tools to prevent food fraud indicates that this research is complex and ongoing. The use of sensory analysis to detect defective argan oils that may be labeled as oils without defects may best be used in combination with other analyses to deter food fraud. Recent descriptions of fraud in argan oil highlight the use of several analytical techniques to resolve the various problems (Guillaume et al., 2019; Kharbach et al., 2018). The particular importance of geographic origin as part of the high value of this product may support additional strategic analytic approaches such as the use of stable isotope fingerprinting (Epova et al., 2019) combined with elemental analyses (Mohammed et al., 2019).

9.5 Camellia oil

Camellia oil (camellia seed oil, tea seed oil) is extracted from the seeds of plants of the *Camellia* genus. There are more than 100 species of *Camellia* and more than 20 of these are used to extract oil (Liang et al., 2016). Camellia oil is an important food and cosmetic product in China and to a lesser degree in Japan, the oil has been known in China for more than 1000 years (Robards et al., 2009; Liang et al., 2016; Xue, 2014). The main species used for camellia oil production is *Camellia oleifera* and the oil extracted from the seeds of this species accounts for most of the world’s camellia oil. *C. oleifera* has been reported to cover 98% of the cultivated area for oil production in China, with China producing more than 90% of the world’s camellia oil (Liang et al., 2016).

It is estimated that more than 3.8 million ha are planted with *Camellia* species for oil in 14 provinces of China and that most of this is in hilly or mountainous terrain, not competing with conventional arable lands (Liang et al., 2016; Yang et al., 2016). Much of this area has been recently planted and the production of camellia oil in China has been increasing with the total annual production of oil expected to reach between 500,000 MT and more than 2 million MT in 2020 (Xue, 2014).

There are more than 260 varieties of *C. oleifera* that are cultivated for oil production (Xue, 2014). Though these varieties exhibit individual ranges of fatty acid composition, the major characteristic of camellia oil is the high level of oleic acid (about 80% of the fatty acids) (Liang et al., 2016; Xue, 2014; Yang et al., 2016). The high level of oleic acid (C18:1) in camellia oil is seen as a valuable characteristic of this oil, and camellia oil is considered to have the highest average natural levels of this monounsaturated fat of the major fruit oils—higher than olive or avocado oils (Liang et al., 2016; Robards et al., 2009; Yang et al., 2016).

Most camellia oil is refined in the same way as other commodity seed oils, and its sensory characteristics are much less intense and diverse than typical unrefined (virgin) food oils such as extra virgin olive oil (Robards et al., 2009).

There is ongoing research into new varieties of *C. oleifera* for oil content and also other species such as *Camellia osmantha*. This research is seeking higher production efficiency and oil percentages in the seeds while maintaining the unique fatty acid profile of camellia oil (Liang et al., 2016; Yang et al., 2016). It has also been reported that transgenic camellia oils have been developed (Liu et al., 2019).
Increasing production of camellia oil, its promotion as an ancient healthy food oil, its use in cosmetics, and its premium price over other oils has led to problems with food fraud (Wang et al., 2019; Robards et al., 2009). In English language literature and media searches of camellia oil, discussions are mostly in research papers examining ways to detect and prevent fraud caused by adulteration with cheaper seed oils (see Decernis, www.foodfraud.org). In comparison with olive oil or argan oil, fraud related to quality or origins of camellia oil seems to be rarely discussed.

The natural complexity of camellia oil and the variety of possible adulterant oils means that the detection and prevention of such problems is also a complex topic. Examples of research examining methods to detect and help prevent camellia oil fraud are summarized in Table 9.2.

The characteristic fatty acids and triacylglycerol patterns of camellia oil—notably, high levels of both oleic acid (C18:1) and triolein (OOO)—could assist to distinguish it from other oils (Robards et al., 2009; Zhu et al., 2018). However, the compositions of new high-oleic seed oils (Codex Alimentarius, 1999) may provide criminals with further alternatives for the adulteration of camellia oil that are harder to detect.

The ongoing search for a variety of solutions to camellia oil adulteration reflects the extent of the problem and its complexity. This problem of adulteration of camellia oil should be considered in the context of the adulteration of many food oils in the marketplace. In China, many techniques are being investigated with the aim of selecting a suite of analyses for each specific purpose (Zhang and Li, 2016a). This approach is consistent with those used in other nations. In the case of the virgin flavorful oils such as virgin olive oils, sensory/volatile analysis is often proposed as part of the suit of analyses. However, with the other food oils such as camellia oil, it is worth noting that refined oils also have volatile compounds that contribute to their sensory characteristics. The detection of these compounds either by a sensory panel or by the use of headspace gas chromatography or an artificial neural network known as an electronic nose may be useful to authenticate products as well as to detect the presence of other types of oils (Robards et al., 2009).

The increase in the production of camellia oil, its reputation as an oil with naturally high levels of monounsaturated fats and its promotion by China, is starting to generate interest in the consumption and production of this oil in nontraditional countries (Liang et al., 2016). The supply chain and new producer countries should follow the extensive work in China on the development of suites of techniques to authenticate this product and detect adulteration of camellia oil with other oils (Zhang and Li, 2016a).

9.6 Olive oil

Olive oil originated in the east of the Mediterranean thousands of years ago and for many years was produced and consumed almost exclusively in countries around the Mediterranean. The olive tree (Olea europaea) is an evergreen plant naturally suited to the climates and conditions in many areas of this region.

Olive oil is consumed traditionally as both a food and a food ingredient; however, it also has potential health benefits. Since olive oil contains high levels of the monounsaturated
TABLE 9.2 Research into camellia oil characteristics and authenticity.

<table>
<thead>
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<th>Test</th>
<th>Details</th>
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<tbody>
<tr>
<td>Triacylglycerol patterns</td>
<td>Triacylglycerol patterns of fruit oils such as camellia and olive oils were compared as a means of discrimination between such oils. In particular, levels of triolein (OOO) were examined.</td>
<td>Xue (2014)</td>
</tr>
<tr>
<td>DSC/gas chromatography</td>
<td>DSC (thermal analysis) was compared with gas chromatographic analyses of fatty acids to verify adulteration of camellia oil with sesame oil, sunflower oil, peanut oil, corn oil, and canola oil. DSC was proposed as more effective tool than the analysis of fatty acid patterns.</td>
<td>Li et al. (2016)</td>
</tr>
<tr>
<td>LC−MS/MS</td>
<td>Adulteration of camellia oil with other oils using four isoflavones, trans-resveratrol, and sinapic acid to detect soybean, peanut, and rapeseed oils mixtures. The methods used LC−MS/MS in combination with solid-phase extraction.</td>
<td>Dou et al. (2018)</td>
</tr>
<tr>
<td>Terahertz spectroscopy</td>
<td>Discrimination of transgenic from nontransgenic camellia oil using terahertz spectroscopy and different chemometrics. Terahertz spectroscopy coupled with chemometrics could effectively discriminate various types of transgenic edible oils.</td>
<td>Liu et al. (2019)</td>
</tr>
<tr>
<td>NIR spectroscopy and subwindow permutation analysis</td>
<td>Adulteration of camellia oil with soybean oil, rapeseed oil, peanut oil, and complex mixed oils. This study compared different types of chemometrics highlighting that the chemometrics are a major factor in the effectiveness of nontargeted technologies such as NIR.</td>
<td>Sun et al. (2015)</td>
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<tr>
<td>Proton nuclear magnetic resonance spectroscopy (1H NMR)</td>
<td>The effectiveness of the detection of the adulteration of camellia oil with corn oil, sunflower oil, and rapeseed oil using was shown to be dependent on the particular chemometrics used and the selection of parameters from particular adulterant oils to verify the 1H NMR analysis.</td>
<td>Shi et al. (2018)</td>
</tr>
<tr>
<td>Chemometrics</td>
<td>The importance of effective chemometrics and the potential pitfalls of this aspect of the science of detection and discrimination of cases of food fraud have been discussed.</td>
<td>Brereton (2016a,b)</td>
</tr>
<tr>
<td>Excitation-emission matrix fluorescence spectroscopy combined with chemometrics</td>
<td>Excitation-emission matrix fluorescence spectroscopy combined with chemometric methods has been proposed for the rapid identification and quantification of camellia oil adulteration with other cheaper vegetable oils.</td>
<td>Wang et al. (2019)</td>
</tr>
<tr>
<td>TRES</td>
<td>TRES combined with chemometrics has been proposed for the detection of adulteration of camellia oil with cheaper oils, e.g., peanut oil and sunflower oil.</td>
<td>Chen et al. (2018)</td>
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(Continued)
fatty acid oleic acid, it meets an EFSA-approved health claim on the unsaturated fatty acids (European Union, 2012):

- “Replacing saturated fats in the diet with unsaturated fats contributes to the maintenance of normal blood cholesterol levels. The claim may be used only for food which is high in unsaturated fatty acids, as referred to in the claim HIGH UNSATURATED FAT as listed in the Annex to European Union, 2006.”

Among the minor components of olive oil, hydrocarbons, particularly squalene, phytosterols, and phenolic compounds also known as biophenols (phenols) also have potential health benefits. There is an EFSA-approved health claim for olive oil phenols (European Union, 2012):

- “Olive oil phenols contribute to the protection of blood lipids from oxidative stress. The claim may be used only for olive oil, containing at least 5 mg of hydroxytyrosol and its derivatives (e.g. oleuropein complex and tyrosol) per 20 g of olive oil. In order to bear the claim information shall be given to the consumer that the beneficial effect is obtained with a daily intake of 20 g of olive oil.”

Squalene and phytosterols have also been shown to exert possible beneficial effects, including anticarcinogenic effects for both squalene and β-sitosterol. Considering the possibility of additional synergistic effects among hydrocarbons, phytosterols, phenols, toco-pherols, flavor compounds, and the favorable fatty acid composition, the health benefits of the oil as a whole might even be higher than the sum of the single beneficial effects.

Olive oil production and consumption has spread globally and olive oil is now produced and consumed increasingly outside the traditional production countries of the Mediterranean, according to data collected by the International Olive Council. The global nature of the modern olive oil trade is well described in the US International Trade Commission (USITC) report of 2013 (United States International Trade Commission, 2013).

Notwithstanding the natural origins of olive trees, they are now cultivated on every arable continent where farmers and technologists have adapted practices to deal with a wider variety of climates and conditions.

The global production of olive oil now averages about 3 million MT/year. Production varies from year to year depending on weather conditions and the natural tendency of the

TABLE 9.2 (Continued)

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<th>Test</th>
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<tr>
<td>Immunoassays</td>
<td>Adulteration of vegetable oils with waste frying oil is a significant</td>
<td>Zhang and Li (2016a,b)</td>
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<td></td>
<td>problem in China and therefore could be a problem for camellia oil.</td>
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<td></td>
<td>Such waste oils can contain traces of foods, and this has led to the</td>
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<td>use of immunoassays for their detection.</td>
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<tr>
<td>Phytosterols</td>
<td>Spinasterol was reported as unique to camellia oil and this may be</td>
<td>Robards et al. (2009)</td>
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<td></td>
<td>one component that is useful along with others in authenticating</td>
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<td>camellia oil.</td>
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DSC, Differential scanning calorimetry; LC–MS/MS, Liquid chromatography tandem mass spectrometry; NIR, near infrared; TRES, time-resolved emission fluorescence.
olive tree to bear fruit biennially or more irregularly under harsh drought conditions. In the period from 2011/12 to 2018/19 the International Olive Council reported that total world olive oil production varied between 2.4 and 3.3 million MT (Fig. 9.2).

Spain is by far the largest producer of olive oil, averaging 44% of global production as reported by the International Olive Council. Its share of production varied between 26% and 55% during the period 2010–19, further demonstrating the annual variability of olive oil production.

Despite its global presence, olive oil is still only a minor oil compared with the major seed oils and the total world production and consumption of vegetable oil that reached about 204 million MT annually in 2018/19 (USDA, 2019). Olive oil accounts for about 1.5% of total vegetable oil production and consumption.

Olive oil is subject to a range of standards of identity (which are generally voluntary) and regulations depending on the country of production and consumption. These standards describe quality and purity parameters in a similar format to standards for other food oils (Codex Alimentarius, 1981; Codex Alimentarius, 1999). Most standards split olive oil into two broad categories and then divide them into a total of eight subcategories for the supply chain (AS 5264-2011, 2011; Codex Alimentarius, 1981; Miller, 2016), as shown in Fig. 9.3.

The first category, virgin olive oil, is subdivided into two edible categories, extra-virgin and virgin olive oils, plus a category that is not fit for human consumption termed

![Supply chain categories of olive oil](image)

**FIGURE 9.2** World production of olive oil in 1000 MT.

![Categories of olive oil found in the commercial supply chain](image)

**FIGURE 9.3** Categories of olive oil found in the commercial supply chain.
lampante. The edible virgin olive oils are considered to be of higher quality than other categories because of the presence of various additional components in addition to triacylglycerols. These oils are unrefined and subjected only to the mechanical process of extraction. Therefore they contain additional components (including biophenols and other fat-soluble substances) that are from the olive paste. These extra components give the oil its unique flavors, enhance its culinary qualities, and are considered to be part of the health benefits of olive oil in the human diet. As discussed in more detail later, extra virgin olive oil is defined as having no sensory defects, while virgin olive oil exhibits some sensory defects and is defined in trade standards as having less restrictive chemical and sensory limits.

Lampante olive oil is considered to be not fit for consumption without refining, as it exceeds permitted quality limits in all olive oil standards. Olive oils are judged on their attributes from a culinary perspective. The refining process leads to the production of refined olive oil and olive oil (subcategories 4 and 5 within the refined olive oil category shown in Fig. 9.3). Standards and regulations allow the addition of extra-virgin (or virgin) olive oil as part of the composition of the official category of olive oil to give color and flavor. Crude olive pomace oil (subcategory 6) is oil extracted from the leftover olive paste after the separation of the olive oils in subcategories 1–3. The oil is extracted using a solvent-based process that is used to extract most seed oils. Refined olive pomace oil (subcategory 7) is similar in chemistry and characteristics to refined olive oil. Standards and regulations allow the addition of extra-virgin (or virgin) olive oil as part of the composition of the official category of olive pomace oil to provide color and flavor attributes.

By their nature, olive oil subcategories 4–8 have lower levels of the components that give extra-virgin and virgin olive oils their additional quality and culinary characteristics and so are considered lower grade products.

An additional feature of olive oil regulations and standards is the requirement for sensory (organoleptic) testing against specific parameters and limits. Extra virgin olive oil in particular is defined as having no sensory defects according to the official trade standard of the International Olive Council (2018). This particular definition is important because it also defines an important part of a suite of quality attributes that relates not only to the quality and grade of the oil when it is made, but also to its viability (shelf life) at this grade before it degrades beyond the defined quality limits for extra virgin olive oil and begins to exhibit some sensory defects. Once it exhibits these sensory defects, it should be classified as virgin olive oil (Mueller, 2012; Miller, 2016; Codex Alimentarius, 1981; AS 5264-2011, 2011; Gertz and Fiebig, 2005; Gertz and Fiebig, 2006; Guillaume et al., 2014; Guillaume and Ravetti, 2016). Sensory defects are indicators of poor handling of the olives before and during processing or/and poor handling of the oil after processing/storage and are associated with some chemical measures of quality (Guillaume and Ravetti, 2016; Matthäus, 2016b). Sensory quality by itself is also important in a food ingredient that has such culinary value (Mueller, 2012; Oberg, 2016).

Vegetable oil refining processes are continually being developed, and in recent years the advent of “soft refining” or “soft deodorization” has led to the ability to temporarily eliminate some of the sensory defects of virgin and lampante olive oil so that such lower grade oils can be (falsely) mixed with or labeled as extra virgin and then sold as such (Tsimidou et al., 2016; Guillaume et al., 2014; European Commission, 2013b; Conte et al., 2019).
The annual production of the various grades of olive oil is not well documented, though, in the industry, it is accepted that the largest proportion of olive oil made each year is of lampante quality and therefore requires refining to make it edible. Olive oil, considered as EVOO at the time of production, is estimated to be about 25%–35% of the annual global supply of olive oil. (Note that all food oils degrade over time at a rate depending on initial oil quality, composition and storage conditions.)

Extra virgin olive oil attracts premium prices over the other grades of olive oil because of its perceived and measurable qualities and as a category commands a significant retail premium over the major refined seed oils (Mueller, 2012; United States International Trade Commission, 2013). The global trend in many olive oil markets is toward EVOO over other olive oil grades. This is readily apparent in the United States market where olive oil consumption is increasing. The United States has been by far the largest non-EU market since at least 1990/91 according to the data of the International Olive Council.

Fig. 9.4 shows the data from the USDA Foreign Agriculture Service for annual imports into the United States of all olive oil declared as the categories virgin (including extra virgin) and refined from 1990 to 2018, and for the category declared as extra virgin from 2014 to 2018 (since 2014 separate records were kept for olive oil declared as extra virgin).

Prior to 2014, olive oil was declared as virgin whether it was extra virgin or virgin grade. It is likely that most of what was imported in the virgin category prior to this time was labeled on the packaging as EVOO. Since 2014, when separate data collection began, it is clear that the expansion in the United States olive oil market has been largely accomplished by increased imports of olive oil declared as extra virgin. This is consistent with other reports (United States International Trade Commission, 2013).

Note that while domestic US production of olive oil is increasing, it currently represents less than 2% of US consumption according to International Olive Council data. According to industry sources, nearly all of the olive oil produced in the United States is extra virgin in response to the clear consumer trends and the premium for extra virgin olive oil in this market. According to the USITC report of 2013, consumers in the United States will pay an additional premium for locally produced extra virgin olive oil (United States International Trade Commission, 2013). Similarly, in Europe, consumers pay a premium for olive oils from specific geographical locations (Testu, 2010) and standards and regulations for olive oil often take this into account (International Olive Council, 2018).
Premium wholesale prices for extra-virgin and virgin olive oils are also apparent for the imports to the United States in data from the USDA Foreign Agriculture Service shown in Fig. 9.5.

These data and the discussion above identify several factors that may typically drive food fraud:

1. Olive oil is a food product that commands a premium over other products that look similar to it and may be indistinguishable to an untrained person.
2. Within the olive oil trade, there are grades and origins of olive oils that command premium prices while such products may appear exactly the same as others.
3. This is a product that lends itself to the packages being labeled to attract price premiums while containing something of lesser quality and cheaper (Mueller, 2012; Tsimidou et al., 2016; European Parliament, 2013; Johnson, 2014).
4. This is a product with complex modern global supply chains (United States International Trade Commission, 2013).

The globalization of olive oil production and consumption is an example of how modern global food systems make the problem of food fraud increasingly complex. In the 2016 publication Food Law in the United States (Roberts, 2016), the consequences of such food systems for economically motivated adulteration (EMA), compared with food safety, for regulators and the legal system are outlined as follows:

Although the problem of EMA has been surpassed in the twentieth century as a regulatory priority by food safety and nutrition, a new paradigm for EMA—a modern global food system marked by the trade flow of a variety of food products and ingredients from multiple locations in the world—increases the level of EMA, especially for imported premium products, and has positioned this form of adulteration once again as a priority for regulators and as a challenge for the legal system. (Roberts, 2016).

9.6.1 Recent examples of food fraud in olive oil

Olive oil food fraud can involve the following:

- Adulteration with oil of a different botanical origin.
• Adulteration with olive oil of a lesser grade.
• Addition of coloring agents such as copper chlorophyll or beta carotene.
• Sales of oil that is not from the declared country or region.
• Sales of oil for which the quality does not match that indicated on the label; this is typically oil that is old and may once have been extra virgin but is now virgin or lampante grade.
• Adulteration with previously defective olive oil that has been temporarily cleaned up by “soft refining.”

A search of the EC Food Fraud Monthly Reports (www.ec.europa.eu) that have been published since September 2016 reveal 32 records of reports of food fraud in olive oil. Of these 32 records, 15 involved adulteration with oil of a different botanical origin, 11 were of false origin, and 12 were of mislabeling the quality of the oil (Joint Research Center). Two of the records of adulteration with other oils included the addition of artificial coloring.

A search of the Food Fraud Database (foodfraud.org) from 2014 to 2019 found 84 distinct records of reporting or discussion of fraud regarding these products. Of these records, 18 were specific reported incidents involving food fraud of olive oil, the rest were inferences about the fraud mainly from technical journal papers or books. Of the 18 incidents, 4 involved adulteration with oils of a different botanical origin and 3 included the addition of artificial coloring. Eight involved false origin declarations and 10 involved adulteration of olive oil of a stated grade with olive oil of lower grades.

Olive oil fraud is sometimes reported in high-profile media such as the CBS 60 Minutes reporting of the problem in Italy and the vigorous efforts of Italian authorities to overcome the problem, including criminal prosecutions of fraudsters for adulteration and false labeling of the origin of Italian olive oils (CBS News).

The Canadian Food Inspection Agency (CFIA) has long been active in monitoring olive oil authenticity in the Canadian market (Sheridan, 2008; Sheridan et al., 2013). The CFIA has reported the detection of olive oil adulterated with sunflower, canola, and soybean oils along with extra virgin olive oil being adulterated with refined olive oil and olive pomace oil. In 2008 the agency reported that from 1998 to 2004, it had laid 22 charges in relation to olive oil fraud and that from 2005 to 2007, there were 22 active cases regarding olive oil and allegations of breaches of Canadian food authenticity laws (Sheridan, 2008).

In Spain, it was reported that of 770 inspections by Spanish authorities of olive oil products, 23% were noncompliant with the EU regulations concerning authenticity and purity of olive oil products. Of these violations, 48% were related to quality and purity and 33% were mislabeled (Izquierdo, 2013).

In 2013 the USITC noted that the US Food and Drug Administration (FDA) could develop a standard of identity for olive oil to assist it in enforcement actions against economic adulteration (United States International Trade Commission, 2013), but to date, this has not occurred. Scientists of the FDA Center for Food Safety and Applied Nutrition have recently undertaken extensive research to develop rapid methods for the determination of olive oil authenticity and quality (Mossoba et al., 2018; Karunathilaka et al., 2017; Karunathilaka et al., 2016).

There has also been discussion at conferences and in reports about the specific problem of adulteration of extra virgin olive oil with soft refined olive oil (European Commission, 2013b;
Conte et al., 2019; Izquierdo, 2013). A recent development that highlights the concern about olive oil fraud has been the initiation and funding by the EU, under the Horizon 2020 initiative, of a major cooperative research project involving scientists from the EU and other countries. This project is called the OLEUM Project and it commenced in September 2016 (www.oleumproject.eu). The expected outcomes of this project include the following:

- at least eight new in-house validated methods to control olive oil quality and to detect fraud;
- at least four revised in-house validated methods to control olive oil quality and to detect fraud;
- at least four validated standard operating procedures, along with two associated quality control materials, to deal with the main challenges of olive oil authentication:
  - method for the assessment of the organoleptic characteristics (Quantitative Panel Test), including two reference materials,
  - method to detect blends of EVOOs with soft-deodorized olive oil,
  - method to detect illegal blends of olive oils with other vegetable oils, and
  - method to be selected during the OLEUM Project development;
- identification of additional methods and markers for the olive oil quality control and to detect fraud;
- development of an OLEUM Databank of analytical information that will improve the implementation and the harmonization of methods of analysis; and
- establishment of an OLEUM Network for technology transfer of new methods and procedures and to foster laboratory proficiency and harmonization on a global scale.

This major undertaking will hopefully reduce olive oil food fraud and benefit olive oil consumers and the entire olive oil supply chain.

9.6.2 Olive oil standards and regulations

There are numerous standards and regulations relating to olive oil. Such standards usually contain considerations of characteristics that relate to the determination of quality and purity, including limits for particular contaminants. Because states or regions, countries, and groups of countries may have different laws relating to foods and food safety, most olive oil standards also defer to the jurisdiction in which the olive oil is sold for these aspects of the products.

Olive oil standards are developed and released by both governments and private organizations. Olive oil standards are voluntary unless they are incorporated into government regulations; however, voluntary standards may be used as the basis for government surveillance and prosecutions of food fraud (Sheridan, 2008; Sheridan et al., 2013). All olive oil standards for quality and authenticity contain references to methods of analysis, and these methods are developed and released by governments, professional, and private organizations.

The complexity of the numerous standards and methods was the subject of discussion at the European Commission workshop on olive oil authentication in 2013 (European Commission 2013b). Fig. 9.6 is adapted from a presentation at this meeting (Valentin, 2013), and it depicts the global relationship among various standards, methods of analysis, and regulations existing for olive oil in 2019.
There are multinational standards for olive oil, including the EU (European Union, 1991; European Commission, 2013a; European Commission, 2012), the Codex Alimentarius (1981) standard for olive oil, and the International Olive Council (2018) standard for olive oil. European standards are also regulations and apply under European law in all EU member states and therefore cover most of the olive oil produced and traded in the world. Codex Alimentarius standards are referred to in the World Trade Organization matters. IOC standards are voluntary although IOC member signatories undertake to apply the IOC standards when they export olive oil. Member signatories may apply their own different national standards for domestic olive oil trade. There are many individual national standards; although most are voluntary, some are compulsory. As a further complication, some countries such as the United States have different regulations and standards in different states.

Though all olive oil standards have similar structures, differences can be found in the ranges for some of the purity criteria, especially the composition of fatty acids and phytosterols. Olive oil has been well studied in regard to its quality and composition, and the expansion of the production of this oil into areas far from the Mediterranean and with different growing conditions for the trees has resulted in expanded ranges of composition for fatty acids and phytosterols. This is evident in standards such as the Australian and South African standards for olive oil [AS 5264-2011, 2011; South African National Standard (SANS) 1377, 2015].

The natural variations in olive oil composition are known to be influenced by variety, climate, and fruit maturity. The climatic conditions are in turn influenced by the geographic latitude and elevation of olive farms (Mailer, 2007; Carelli, 2008; Ceci and Carelli, 2008).
While these studies show that there are broad ranges of composition for olive oils, they also show that oils from a specific region have much narrower and more consistent makeup of components such as fatty acids and phytosterols than those that are necessarily shown in standards that have to encompass the natural variations that occur from broad geographical origins. As a result of the submission of more regional data, changes to fatty acid and phytosterol composition are being considered in the current review of the Codex Alimentarius, Rep 19/FO (2019) standard for olive oil.

Work by the German Society for Fat Research (DGF) since about 2003 has highlighted the role of the consumer and the quality of olive oils at the point of retail purchase (Gertz and Fiebig, 2005). Consumer preference and the availability of different olive oils have moved the market toward higher sales of EVOO and the development of a greater number of specialty outlets. Additional research associated with this trend has led to important developments in the olive oil trade regarding the assurance of quality and authenticity (Guillaume et al., 2014; Guillaume and Ravetti, 2016). Some recently developed standards and regulations include additional quality parameters that can better describe and monitor the quality over time of EVOO [CDFA, 2015; AS 5264-2011, 2011; South African National Standard (SANS) 1377, 2015]. These parameters enable better control and monitoring of product specifications during its shelf life (Gertz and Fiebig, 2005) and have been in use by the trade in northern Europe since at least 2007. In the review and updating of its olive oil standard, Codex Alimentarius, Rep 19/FO (2019) has also directed the relevant working group to study ways that these parameters and their associated methods could be taken into account in the revised standard.

There are also bodies that develop methods of analysis as shown in Fig. 9.6. These standards development organizations (SDOs) include IOC, AOCS, ISO, and DGF. In addition, from time to time, consortia are formed that are relevant to olive oil, and it is hoped that the work arising from the OLEUM project will generate additional methods of analysis that could be adopted by one or more SDO for use in the prevention of food fraud in olive oil. Ongoing efforts to harmonize and improve standards through the work of OLEUM, and also by bodies such as Codex Alimentarius, should yield significant improvements in global olive oil standards and regulations.

From the perspective of the olive oil supply chain, it is also possible to develop specific criteria and product specifications to severely limit the possibilities of food fraud in olive oil products. Technologies that are not in current standards may also be necessary in product specifications to assure origin, authenticity, and quality (European Commission, 2013b; Epova et al., 2019; Gertz, 2016). Whatever the approach, a suite of parameters and a product traceability system are essential in efforts to prevent olive oil fraud. A final consideration will be the authenticity of retail products sampled in random off-the-shelf verification and enforcement actions.

9.6.3 Progress in analysis and identification of fraudulent practices in extra virgin olive oil

It has been documented that extra virgin olive oil is one of the most commonly adulterated foods in the world (Moore et al., 2012). Research studies from several countries have
concluded that very old oils, poorly stored oils, and/or deodorized oils are the most common mislabeling practices (Gertz and Fiebig, 2006; Gertz, 2008; European Commission, 2013b; Psomiadou et al., 2003; Gutierrez and Fernandez, 2002; Frankel et al., 2011; Guillaume and Ravetti, 2012).

It is commonly accepted that extra virgin olive oils are obtained from sound olives using mechanical extraction processes that produce minimal changes in oil composition (Tsimidou, 2006). However, it is technically possible to reduce the acidity, peroxides, and undesirable odors of poor-quality virgin oils to obtain a mildly refined oil that can be blended with extra virgin olive oil without detection. This mild refining process, also known as soft deodorization or soft refining, essentially consists of neutralizing and washing the oils followed by deodorizing at low temperature under vacuum. It is extremely important to highlight that blends of extra virgin olive oil with soft refined olive oils are undetectable using the tests included in the IOC standard or Codex regulations (Conte, 2009; Gertz and Fiebig, 2006; Guillaume and Ravetti, 2012). The IOC states, in its Decision No. DEC-18/96-V/2008, the urgency to adopt methodology to control this widespread adulteration practice. Australia, South Africa, and California (United States) have introduced in their standards tests such as the determination of the degradation products of chlorophylls a and a' [pheophytins a, a' and pyropheophytins (PPP)] and the determination of relative amounts of 1,2- and 1,3-diacylglycerols (DAGs) as tools for the detection of the presence of deodorized, extremely old, and/or poorly stored EVOOs (Gertz and Fiebig, 2006; Gertz, 2008; Guillaume and Ravetti, 2012).

The olive oil industry is experiencing two further issues. First, based on health considerations, consumers are demanding more information when deciding which oil to purchase. Minor constituents such as squalene, phytosterols, biophenols, and vitamin E may play a vital role when considering healthy aspects of olive oil. Certain health claims are permitted by the EU and other authorities, but consensus methods of analysis may not be available. The extra virgin olive oil producer may also be able to use such information to allow product differentiation. Second, there is a need for new methods, technologies, and approaches to address the problem of adulteration. Olives are grown all around the world far away from their origins, in places where there is no historical background or reference. If good practices are implemented, this does not mean that these olive oils are of a lower quality or grade than those from the countries in the Mediterranean basin. However, there remains an urgency to document the effects of agronomic practices and the environment on the variability of olive oils.

**9.6.3.1 Degradation of chlorophyll as a marker for olive oil quality**

The determination of the degradation products of chlorophylls a and a' (pheophytins a, a' and PPPs) is described in ISO 29841:2009 (2009). This method (known as PPP or PPP content) determines the proportions of PPP a and pheophytins a and a' in olive oils. An argument commonly used against this method is that the PPP content is affected by storage time, storage temperature, and light. Previous research showed that PPP can increase between 2% and 8% per year, depending on storage temperature and light exposure (Gertz and Fiebig, 2006; Gallardo-Guerrero et al., 2005, Mailer et al., 2010; Ayton et al., 2012; Guillaume et al., 2014). The level of PPP in samples stored at 20°C in dark containers (glass and plastic) remained below 17% at 25 months, whereas in clear glass containers the
PPP content was above 17% after 15 months, showing oil susceptibility to degradation under illumination. When the samples were stored in the dark at 30°C, the PPP content reached 17% in under 10 months. This project also showed that PPP is not influenced by the initial quality of the oil, cultivars used, and climatic conditions under which the olives were grown. The studies emphasize that PPP does increase with storage time and its formation is accelerated when oils are exposed to higher than normal storage temperatures and/or under light for a period of time (Guillaume et al., 2014).

### 9.6.3.2 Isomerization of diacylglycerols as a marker of olive oil quality

The determination of the amounts of 1,2-DAGs is described in ISO 29822:2009 (2009). In virgin olive oils, isomeric DAGs are present in a range of 1%–3% and they are found as 1,2-isomers. Two independent enzymatic reactions contribute to DAG content: (1) while the fruit is still on the tree, enzymatic formation of 1,2-diacylglycerols is an intermediate in triacylglycerol synthesis and (2) during fruit storage and oil extraction, lipolytic enzymes react with triacylglycerols to produce 1,3-DAGs and free fatty acids (FFAs) (Amelotti et al., 1989). Finally, during storage, further isomerization of 1,2-DAGs to 1,3-DAGs occurs. This reaction is acid-catalyzed and is accelerated at elevated temperatures (Spyros et al., 2004). Consequently, freshly made olive oils from healthy olive fruit contain almost solely 1,2-DAGs (>95%), whereas oils extracted from poor-quality fruit show a significant level of 1,3-isomers and FFAs (Guillaume et al.; 2014).

The 1,2-DAGs method is not intended to be used to detect deodorized oils. The 1,2-DAG content depends mostly on initial fruit quality and on storage time, but it is not an indicator of thermal treatment nor the presence of neutralized olive oil (Gertz and Fiebig, 2006). Nevertheless, the amount of 1,2-DAG is a valuable tool in the determination of aging of olive oils and complements, but does not replace, the utility of the PPP parameter described earlier. As with the PPP parameter, the most widely used argument against this method is the fact that the 1,2-DAG% can decrease between 10 and 30%/year, depending on storage time, temperature, and initial oil quality (Gertz and Fiebig, 2006; Gertz, 2008; Guillaume et al., 2014; Ayton et al., 2012). The decrease in 1,2-DAG was approximately 20% after 12 months storage at 20°C (in dark containers) and double that in the same time period at 30°C.

There is no evidence that the initial variety or other environmental factors have influence on these tests (Ayton et al., 2012; Guillaume et al., 2014). PPP and 1,2-DAGs showed very good performance as indicators of overall olive oil quality and freshness as well as highlighting problems occurring during the storage of the product. The evolution of these values is highly predictable if storage conditions are known (Guillaume et al., 2014).

### 9.6.3.3 A novel approach to determine extra-virgin olive oil shelf life

Extra virgin olive oil shelf life could be defined as the length of time under normal storage conditions within which no defects are developed and quality parameters remain within accepted limits for this commercial category. Prediction of shelf life is a desirable goal in the food industry. Even when extra virgin olive oil shelf life should be one of the most important quality markers for extra virgin olive oil, it is not recognized as a legal parameter in most regulations and standards around the world (Psomiadou et al., 2003; Coutelieris and...
An innovative method to predict shelf life was proposed by Guillaume and Ravetti (2016). This approach uses values obtained from determining PPP, DAGs, FFA (free acidity), and oxidative stability (Induction Time by Rancimat) to predict extra virgin olive oil shelf life. The induction time test provides strong correlation over time depending on the fatty acid profile of the oils and their antioxidant content. These factors are well known to be influenced by the variety, environmental conditions, and management practices. The PPP test provides strong correlation over time with light exposure and storage temperature without being influenced by oil quality or the oil’s chemical composition. Finally, the DAGs test provides a strong correlation over time with temperature of storage and initial oil quality expressed through its FFA content. FFA content affects directly the rate of DAG isomerization; the higher the FFA content, the higher rate of conversion of 1,2-DAG to 1,3-DAG. The particular FFA ranges and factors were chosen based on the quality of extra virgin olive oil (extra virgin olive oil with FFA lower than 0.4% is often considered high quality, extra virgin olive oil with FFA between 0.4% and 0.6% is considered average quality, and extra virgin olive oil with FFA greater than 0.6% can be considered low quality). The factors associated with each of these levels of FFA were demonstrated experimentally (Guillaume et al., 2014). Results obtained with retention samples indicate that shelf life can be reasonably predicted by measuring these key values even though these individual parameters are influenced by different factors in their evolution over time (Guillaume and Ravetti, 2016).

Using the background information gained in the study of these testing methods (Guillaume et al., 2014) and using the value limits set down in AS 5264-2011 and other standards, the best before date (BBD) can be reasonably accurately predicted by the lowest of the following three estimates:

- Induction time at 110°C (hours) = expected shelf life (in months)
- \((17.0 - \text{PPP})/0.6\) = expected shelf life (in months)
- \((\text{DAG} - 35.0)/\text{FFA factor}\) = expected shelf life (in months)

  FFA factor = 1.7 (if FFA < 0.4%); 2.1 (if 0.4% < FFA < 0.6%); or 2.5 (if FFA > 0.6%)

When those oils were also randomly tested from retail shelves under real-life conditions, a slightly larger proportion of oils failed one or more chemical and/or organoleptic limits for extra virgin olive oil according to most common international standards. Hence, data collected from off-the-shelf testing would indicate that an additional time of 1–2 months may have to be subtracted from the initial formula in order to compensate for the potential exposure of the oils to less than ideal storage conditions during transport, handling and while present on the shelves.

9.7 Concluding comments

As highlighted in this Chapter, vegetable oils are very similar in characteristics and appearance. The existence of both commodity oils, which are mainly refined in nature,
and higher value oils that are rarer, in short supply, and have positive health attributes, provides a perfect opportunity to produce fraudulent product by mixing the two classes to the detriment of the unsuspecting consumer. It is clear from the discussions of the three specialty oils that there might be various motivations to dilute the higher priced product and different substrates available to do so. However, analytical testing (both chemical and organoleptic) is seen as the only possible way to sort the fraudulent from the genuine article. It is also clear that this is not an easy problem to solve as can be seen for extra virgin olive oil where numerous regulations and recommended tests have to be applied to ensure the product is as claimed or labeled. In addition, many specialty oils have changing characteristics that may be accelerated by poor handling and storage conditions. Again, the consumer may not be aware of this and assume that a Best Before Date accurately indicates when the product will start to deteriorate.

To implement a system to accurately determine the shelf life of extra virgin olive oil requires not only laboratory facilities and testing prowess but also the will of the consumer to demand it and the will of the producer and regulator to adopt such measures. To meet some of these requirements, consumer organizations have carried out their own surveillance, utilizing respected laboratories to perform the testing. Intergovernmental organizations such as Codex Alimentarius are also considering the value of new approaches as it revises its olive oil standards. Proficiency testing providers (such as AOCS) have incorporated PPP ratio and DAG ratio determinations in their regular assessments of laboratories performing olive oil testing.

The use of multiple analyses, including organoleptic, chemical, and physical tests, has been proposed as the most effective approach to authenticate olive, argan, and virgin canola oils purity and quality (Gertz and Fiebig, 2005; Matthäus, 2016a,b). Such an approach has been successful in separating extra virgin olive oil from lower quality olive oils and in predicting the shelf life of EVOO (Guillaume and Ravetti, 2016). Development and implementation of automated testing to augment the work of sensory panels should help in the future and allow the swift identification of correctly classified oils. The high value of certain vegetable oils will ensure that their authenticity and susceptibility to food fraud will be an ongoing problem for which novel analytical solutions for authentication will need to be devised in the future.

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Further reading


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Spice and herb fraud

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10.1 Introduction

Spices and herbs are highly valued for the flavors and colors they add to foods. Grown in various parts of the world, spices and herbs have been a valuable traded commodity since ancient times. The spice and herb trade supports a global market of consumers that seek out these plant-based ingredients for the purpose of adding flavor to foods, providing health benefits, and preserving food. Many spices and herbs that are associated with health claims are also taken as dietary supplements, as well as used in the pharmaceutical and cosmetic industries. According to the 2018 FAO data, over 2.8 million tonnes of various spices were produced around the world [FAO (Food and Agriculture Organization of the United Nations), 2018a], with $2.69 billion in global trade (OEC, 2018).

Spices and herbs are obtained from various parts of plants. Herbs, such as oregano, parsley, and mint, are leaves that are harvested from their respective plants. Common spices represent various plant parts, including the seeds, stems, berries, fruit, roots, and bark. For example, cinnamon is obtained from the bark of Cinnamomum trees, while cloves are the flower buds of the clove tree (Syzygium aromaticum).

Herbs and spices are vulnerable to fraud for a number of reasons, including complex global supply chains, high demand, limited supply, and high value. Spices begin their journey through the supply chain in various places around the world and are dependent upon specific growing conditions that dictate how many (or how few) locations can support enough crop growth to supply the global demand. The source locations and growing regions are conducive to small crop farmers, for whom a small amount of land can produce a marketable and highly valued yield of spices or herbs (FAO, 2011). In many cases, spices are grown in economically underdeveloped countries, which creates additional complexities. Spice growers must choose the crops that provide the best opportunity to making a living wage. In addition, many areas where specific spices thrive are in countries or regions that are challenged with political and economic instability, which leads to corruption and other factors that can create the conditions conducive to fraudulent activity. Once grown, the crop can travel through various transfers until it gets to the intended market. Spices and herbs may traverse through a series of collectors, brokers, traders, agents, exporters, and processors before they reach their final destination with the consumer.

The value of herbs and spices is based on various inherent characteristics that dictate taste, flavor, and/or color. The quality or grade of those characteristics, along with the weight of the product, will help determine the price of the herb or spice. Common characteristics that define the flavor or quality of the spice or herb include volatile oils, piperine levels, size, color, and other defining compounds. These characteristics are measured to ensure that the spice or herb is of the quality that will impart the desired flavors and colors for which it is known. The higher the grade of the characteristic, the more certain it is that the taste, flavor, and color will be what is expected, resulting in a higher value herb or spice.

When assessing an herb or spice’s vulnerability to fraud, it is helpful to understand the flow of the product through the supply chain. Herb and spice grading is done early in the supply chain. Because there are many points in the supply chain where adulteration can
occur, which we will discuss later in this chapter, it is possible that the adulteration of herbs and spices can occur after the initial grading of the product. Another challenge for herbs and spices is that, ultimately, many whole spices and herbs will be ground into finer particles for use. Ground herbs and spices generally have an increased vulnerability to fraud because mixing in foreign or inferior materials could easily go undetected by the naked eye.

10.2 Historical fraud and incidents involving herbs and spices

Adulteration of herbs and spices is not a new concept. Documented fraudulent commercial activity for economic gain dates back centuries. For example, in the Middle Ages, imported spices were quite valuable and often traded in place of currency. Due to high prices and limited supplies, merchants often adulterated spices with numerous cheap substitutes such as ground nutshells, pits, seeds, juniper berries, stones, or dust (Stone, 1964). In fact, in 1444 adulteration was so serious that any merchant caught selling adulterated high-value products such as saffron was burned alive.

Over the years, fraud has occurred across the herb and spice categories, with various events drawing focus to particular herbs and spices. Examples of the types of adulterants detected in various herbs and spices can be found in Table 10.1. Although adulteration can occur in any of the herbs and spices available on the market, some spices and herbs have been implicated in widespread and/or frequent fraud incidents. These include black pepper, vanilla, saffron, oregano, and others (Table 10.2). Some of the commonly occurring fraud incidents and major events associated with these herbs and spices will be covered here.

10.2.1 Black pepper

There are several varieties of pepper that include black pepper, white pepper, and green pepper. These varieties are produced from the same plant (Piper nigrum) but differ due to processing techniques. The portion of the plant utilized as a spice is the berry, known as the peppercorn, which is picked and dried in whole form. Once dried, the pepper can then be graded and sold as whole dried berries. Black pepper is made from cooked and dried unripe peppercorns, white pepper is made from ripe peppercorn seeds, and green pepper is made from dried unripe peppercorns. Globally, black pepper is the most common variety and it is widely grown, produced, and traded. Pepper is grown in various countries around the world, with Vietnam growing the largest quantities for trade, totaling almost 263,000 tonnes of the total pepper produced globally [FAO (Food and Agriculture Organization of the United Nations), 2018b]. Black pepper attributes that contribute to its value as an edible spice include the piperine values and the volatile oil levels. Piperine is a substance responsible for the pungency or spiciness of the black pepper and the volatile oil imparts the pepper flavor.
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TABLE 10.1  (Continued)

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<td>Sicklefruit fenugreek (Trigonella foenum-graecum), puncturevine (Tribulus terrestris), damiana (Turnera diffusa), Chinese ginseng (Panax ginseng), withania (Withania somnifera)</td>
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<td>Herbs and spices</td>
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<td>Oregano (Origanum vulgare) and pot marjoram (Origanum onites)</td>
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<td><em>Akebia</em></td>
<td>Botanical product (Akebiae Caulis)</td>
<td><em>A. manshuriensis</em></td>
<td>LAMP</td>
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<td><em>‘ilima</em> (<em>Sida cordifolia</em>)</td>
<td>Botanical product</td>
<td><em>Abutilon indicum</em>, <em>Sida rhombifolia</em></td>
<td>DNA barcoding</td>
<td>Vassou et al. (2015)</td>
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<td><em>Sida acuta</em>, <em>Sida spinosa</em>, <em>Sida alnifolia</em>, <em>Sida scabrida</em>, <em>Sida ravii</em>, <em>Abutilon sp</em>, <em>Ixonanthes sp.</em></td>
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<td>Vassou et al. (2015)</td>
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<td>'ilima (S. cordifolia), S. rhombifolia, monkeybush (A. indicum)</td>
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<td><em>S. acuta</em> and <em>S. alnifolia</em></td>
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<td><strong>Cissampelos pareira</strong></td>
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<td>Other species (<em>Cyclea peltata, Stephania japonica</em>)</td>
<td>RAPD</td>
<td>Vijayan et al. (2014)</td>
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<td><strong>Moldavian dragonhead (Dracocephalum moldavica L.)</strong></td>
<td>Botanical product</td>
<td>Other species (<em>M. officinalis, Nepeta cataria L.</em>)</td>
<td>RFLP</td>
<td>Horn et al. (2014)</td>
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<td><strong>Podophyllum hexandrum Royle</strong></td>
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<td><em>Podophyllum peltatum L.</em></td>
<td>RAPD–SCAR</td>
<td>Al-Shaqha et al. (2014)</td>
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<td><strong>Bulbus fritillariae cirrhosae</strong></td>
<td>Botanical product</td>
<td>Other <em>Bulbus</em> subspecies (<em>B. fritillariae pallidiflorae, B. fritillariae thunbergii, B. fritillariae hupehensis, and B. fritillariae ussuriensis</em>)</td>
<td>PCR–RFLP</td>
<td>Wang et al. (2007)</td>
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<td><strong>Peucedanum praeruptorum L.</strong></td>
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<td><em>Anthriscus sylvestris</em></td>
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<td><strong>Gingko biloba</strong></td>
<td>Botanical product</td>
<td><em>Oryza sativa, Juglans nigra L.</em></td>
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<td>Little (2014)</td>
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<td><strong>Date palm (Phoenix dactylifera L.)</strong></td>
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<td><strong>Schisandra chinensis</strong></td>
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<td><em>Schisandra sphenanthera</em></td>
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<td><strong>Japanese honeysuckle (Lonicera japonica)</strong></td>
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<td><em>L. japonica var. chinensis, Lonicera similis, and Lonicera acuminate</em></td>
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<td><strong>Gentiana species</strong> <em>(G. scabra, G. triflora, G. manshurica, and G. rigescens)</em></td>
<td>Herbal tea or alcoholic extract (gentian)</td>
<td><em>Gentiana rhodantha</em> and <em>P. hexandrum</em></td>
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<td><strong>Convolvulus pluricaulis</strong></td>
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<td><em>Ansicora decussata</em>, <em>Clitoria ternatea</em>, <em>Evolvulus alsinoides</em></td>
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<td><strong>Fallopia multiflora</strong></td>
<td>Botanical product</td>
<td><em>Cynanchum auriculatum</em>, <em>Pteroxygonum giraldii</em> and <em>C. auriculatum</em></td>
<td>PCR-RFLP</td>
<td>Zheng et al. (2012)</td>
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<td><strong>Madagascar periwinkle (Catharanthus roseus L. Don)</strong></td>
<td>Botanical product (periwinkle)</td>
<td><em>Solanum melongena</em>, <em>Lycopersicon esculentum</em></td>
<td>RT-SCAR</td>
<td>Chaudhary et al. (2012)</td>
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<td><strong>Asparagus racemosus Willd.</strong></td>
<td>Botanical product</td>
<td><em>Asparagus gonoaclados</em> Baker, Other <em>Asparagus</em> species</td>
<td>PCR–RFLP</td>
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<td><strong>Chinese ginseng (P. ginseng)</strong></td>
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<td><em>Panax quinquefolius</em>, <em>Panax notoginseng</em> <em>Platycodon grandiflorum</em>, <em>Codonopsis lanceolata</em>, and <em>Pueraria lobata</em></td>
<td>RAPD–SCAR</td>
<td>Jiang et al. (2018b)</td>
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<td><strong>Siberian ginseng (Eleutherococcus senticosus)</strong></td>
<td>Botanical product</td>
<td><em>Periploca septum</em> and <em>Eleutherococcus sessiliflorus</em></td>
<td>PCR–RFLP</td>
<td>Zhu et al. (2011)</td>
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<td><strong>Ipomoea mauritiana</strong></td>
<td>Botanical product</td>
<td><em>Pueraria tuberosa</em> (Roxb. ex Willd.) DC, <em>Adenia hondala</em> IGaertn. deWilde, and pith of <em>Cycas circinalis</em> L.</td>
<td>Nested PCR and DNA sequencing methods, nested PCR and RFLP</td>
<td>Lu et al. (2010b)</td>
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<td><strong>Scutellaria baicalensis</strong></td>
<td>Botanical product</td>
<td><em>Scutellaria amoena</em>, <em>Scutellaria rehderiana</em>, and <em>Scutellaria viscidula</em></td>
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<td>Guo et al. (2011)</td>
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<tr>
<td><em>Swertia chirayita</em></td>
<td>Botanical product</td>
<td><em>Andrographis paniculata, Exacum tetragonum, Exacum pedunculatum, Slevoglia orientalis, Sarracenia alata, Senna angustifolia, S. wertia bimaculata, Shorea ciliata, Swertia densifolia, Sanorhabditis elegans, Swertia lawii, Swertia minor, Saxifraga paniculata, Schelhammera multiflora, Swertia cordata</em></td>
<td><strong>AFLP</strong></td>
<td>Misra et al. (2010a)</td>
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<td><em>Aconitum heterophyllum</em></td>
<td>Botanical product</td>
<td><em>Cyperus rotundus</em></td>
<td><strong>AFLP</strong></td>
<td>Misra et al. (2010b)</td>
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<td><em>Curcuma comosa</em></td>
<td>Botanical product</td>
<td><em>Curcuma latifolia</em></td>
<td><strong>AFLP</strong></td>
<td>Keeratinijakal et al. (2010)</td>
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<td><em>Cynanchum wilfordii, C. auriculatum, and tuber fleeceflower (Polygonum multiflorum)</em></td>
<td>Botanical products</td>
<td><em>C. auriculatum</em> is the substitute of <em>C. wilfordii</em> and <em>C. auriculatum</em> are the substitutes of <em>P. multiflorum</em></td>
<td><strong>RAPD–SCAR</strong></td>
<td>Moon et al. (2010)</td>
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<td><em>Taxillus chinensis</em></td>
<td>Botanical product</td>
<td><em>Thuja sutchuenensis, Scurrula parasitica, and S. parasitica var. graciliflora</em></td>
<td><strong>DNA barcoding</strong></td>
<td>Li et al. (2010)</td>
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<td>Indian frankincense (<em>Boswellia serrata</em>)</td>
<td>Botanical product</td>
<td><em>Boswellia frereana, Boswellia sacra</em> <em>Pinaceae</em> sp., <em>Boswellia</em> sp., <em>B. sacra, Boswellia rivae, Boswellia neglecta, Boswellia papyrifera, Boswellia frereana</em></td>
<td><strong>LC–MS</strong></td>
<td>Meins et al. (2016)</td>
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<td><strong>DNA barcoding</strong></td>
<td>Shanmughanandhan et al. (2016), McCutcheon (2018)</td>
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<td>Alexandrian senna (<em>S. angustifolia</em>)</td>
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<td>Other <em>Senna</em> species (<em>S. tara, S. sophera, and S. acutifolia</em>).</td>
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<td>Khan et al. (2011)</td>
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<td><em>Xeranthemum</em>, meadow rue (<em>Thalictrum</em>), valerianaan (<em>Valeriana</em>)</td>
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<td><em>Medicago, Convolvulus, Elymus, Trifolium</em>, and <em>Rorippa</em></td>
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<td>Omelchenko et al. (2019)</td>
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<td>All heal (<em>Valeriana officinalis</em>)</td>
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<td><em>Veratrum album</em></td>
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<td><em>Eurycoma longifolia</em></td>
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<td>Orthosiphon stamineus</td>
<td>Herbal tea (Java tea)</td>
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<td><em>Olea europea</em></td>
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<td><em>Dendrobium sp.</em></td>
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<td>Xu et al. (2012)</td>
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<td><em>Hipppophae species</em></td>
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<td><em>Nitraria tangutorum, Cynomorium songaricum</em></td>
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<td>Hanbury’s garcinia (<em>Garcinia cambogia</em>)</td>
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<td>Jamila et al. (2016)</td>
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<td><em>Baliospermum montanum</em></td>
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<td><em>Plumbago zeylanica</em></td>
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<td><em>Commiphora wightii</em></td>
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<td>Bitter oleander <em>(Holarrhena pubescens)</em></td>
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<td>Olive tree <em>(O. europaea)</em></td>
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<td>Goldenseal <em>(Hydrastis canadensis L.)</em></td>
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<td><em>Berberis vulgarris L., Coptis chinensis, Mahonia aquifolium</em></td>
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<td>Pinkhead smartweed <em>(Polygonum capitatum)</em></td>
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<td><em>Polygonum nepalense</em></td>
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<td><em>Actaea pachypoda, Actaea podocarpa</em></td>
<td>TLC and TLC-bioluminescence</td>
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<td><em>Actaea rubra and Actaea cordifolia, Actaea cimicifuga, Actaea dahurica, and Actaea heracleifolia</em></td>
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<td>Masada-Atsumi et al. (2013)</td>
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<td>Other <em>Cimicifuga</em> species <em>(C. foetida, C. heracleifolia, and C. dahurica, C. americana)</em></td>
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<td>Ankli et al. (2008)</td>
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<td>LC–MS/MS</td>
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<td>Saw palmetto (Serenoa repens)</td>
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<td><em>Cordyceps pruinosa or Isaria cicae</em></td>
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<td><em>Belamcanda chinensis, Paeonia albiflora Pall, and Peucedanum japonicum</em></td>
<td>Multiplex PCR</td>
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<td><em>Hedyotis diffusa</em></td>
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<td><em>Hedyotis corymbosa</em></td>
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<td><em>Apocynum pictum</em></td>
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<td>Botanical and food products (ladybells)</td>
<td><em>C. lanceolata, Codonopsis pilosula, and Glehnia littoralis</em></td>
<td>Multiplexed ITS sequence-based SCAR markers</td>
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<td><em>P. sepium, E. senticosus, Eleutherococcus giraldis, E. sessiliflorus, and Eleutherococcus Trifoliatus</em></td>
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<td>Botanical product (Kadsurae Caulis)</td>
<td><em>Spatholobus suberectus Dunn</em></td>
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<td><em>Solanum lyratum</em></td>
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<td><em>Aristolochia mollissima</em></td>
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<td><em>Oldenlandia diffusa, Scutellaria barbata, Polygala tenuifolia, Artemisia annua, Digitaria sanguinalis</em></td>
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<td>Matrimony vine (<em>Lycium barbarum</em>)</td>
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<td><em>Lycium chinense and Lycium ruthenicum</em></td>
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<td><em>Pulsatilla chinensis</em></td>
<td>Botanical product</td>
<td><em>Pulsatilla cernua, Potentilla species, Gossypium, and Astragalus species</em></td>
<td>PCR–RFLP</td>
<td>Shi et al. (2017)</td>
</tr>
<tr>
<td><em>Artemisia species (A. argyi, A. annua, A. lavandulaefolia, A. indica, and A. atrovirens)</em></td>
<td>Botanical products</td>
<td><em>Crotalaria spectabilis</em></td>
<td>HRM</td>
<td>Song et al. (2016)</td>
</tr>
<tr>
<td><em>Marsdenia tenacissima</em></td>
<td>Botanical product</td>
<td><em>Telosma cordata and Fissistigma polyanthum</em></td>
<td>DNA barcoding, TLC and HPLC</td>
<td>Yu et al. (2018)</td>
</tr>
<tr>
<td>Roseroot stonecrop (<em>Rhodiola rosea</em>)</td>
<td>Botanical product</td>
<td>Other <em>Rhodiola</em> species (R. crenulata, R. serrata, R. gelida)</td>
<td>DNA barcoding</td>
<td>Xin et al. (2015)</td>
</tr>
<tr>
<td><em>Mitragyna speciosa</em></td>
<td>Botanical product (kratom)</td>
<td>Closely related species</td>
<td>PCR–RFLP</td>
<td>Maruyama et al. (2009)</td>
</tr>
<tr>
<td>Common name (scientific name)¹</td>
<td>Main commercial use</td>
<td>Adulterants detected</td>
<td>Discriminant technique²</td>
<td>References</td>
</tr>
<tr>
<td>-------------------------------</td>
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<tr>
<td>Chinese chaste-tree (Vitex negundo L.)</td>
<td>Botanical product</td>
<td>Moringa olifeira Lam. and Mormodica charantia L.</td>
<td>DNA barcoding</td>
<td>Olivar et al. (2016)</td>
</tr>
<tr>
<td>Tangerine (Citrus reticulata Blanco), Citrus unshiu</td>
<td>Botanical products (Pericarpium Citri Reticulatae and Citri Unshius Pericarpium)</td>
<td>Other Citrus species (C. japonica, C. maxima, and C. trifoliata)</td>
<td>SNP markers</td>
<td>Wang et al. (2012)</td>
</tr>
<tr>
<td>Shrubby sophora (Sophora flavescens)</td>
<td>Botanical product (Ku Shen)</td>
<td>Sophora tomentosa L., S. japonica L., and G. uralensis</td>
<td>PCR–RFLP</td>
<td>Lin et al. (2012)</td>
</tr>
<tr>
<td>Ophiocordyceps sinensis</td>
<td>Botanical product</td>
<td>Ophiocordyceps militaris</td>
<td>Bar-HRM</td>
<td>Osathanunkul et al. (2018b)</td>
</tr>
<tr>
<td>Climbing palas (Butea superba)</td>
<td>Botanical product</td>
<td>Mucuna colletti</td>
<td>PCR–RFLP</td>
<td>Wiriyakarun et al. (2013)</td>
</tr>
<tr>
<td>Soursop (Annona muricata)</td>
<td>Botanical and food product</td>
<td>Annona squamosa</td>
<td>Bar-HRM</td>
<td>Osathanunkul (2018a)</td>
</tr>
<tr>
<td>Common speedwell (Veronica officinalis L.)</td>
<td>Botanical product</td>
<td>Veronica chamaedrys</td>
<td>DNA meta barcoding, HPLC–MS</td>
<td>Raclariu et al. (2017)</td>
</tr>
<tr>
<td>Zornia latifolia</td>
<td>Botanical product</td>
<td>Stylosanthes guianensis</td>
<td>DNA barcoding</td>
<td>Cornara et al. (2018)</td>
</tr>
<tr>
<td>Pomegranate (Punica granatum L.)</td>
<td>Botanical and food product</td>
<td>Aristotelia chilensis, Aronia melanocarpa, Dioscorea alata, Euterpe oleracea, Malus × domestica, Morus nigra, Sambucus nigra, Vaccinium macrocarpon, Vaccinium myrtillus, and Vitis vinifera</td>
<td>SCAR</td>
<td>Marieschi et al. (2016)</td>
</tr>
<tr>
<td>Egletes viscosa chemotype A</td>
<td>Botanical product</td>
<td>E. viscosa chemotype B</td>
<td>Molecular identification and phylogenetic analysis</td>
<td>Batista et al. (2012)</td>
</tr>
</tbody>
</table>

¹ Continued

10.2 Historical fraud and incidents involving herbs and spices

Food Fraud
There have been multiple incidents of fraud involving black pepper. The incidents span across the various types of food crime. In many cases, pepper is adulterated by combining low-quality pepper with higher quality product or by using fillers, such as
spent material from other commodities. Some common and known adulterants for pepper include papaya seeds (Table 10.1), mineral oils, and olive pomace.

In 2018 an incident involving black pepper was uncovered in Vietnam. The perpetrators utilized a homemade black dye created from the contents of batteries. The substances from the batteries, which were determined to be manganese dioxide, zinc chloride, and ammonium chloride, were not authorized for use in food. The dye was then used to color spent materials such as coffee bean skins and gravel mixed into black pepper to increase the weight, and therefore increase the potential profit (Son, 2018). This is a clear example of how an economically motivated act of fraud could lead to a food safety/public health problem.

10.2.2 Vanilla

Multiple incidents involving vanilla fraud have occurred over the years. Authentic vanilla is obtained from *Vanilla planifolia*, which is a species of vanilla orchid plant. The species *Vanilla tahitensis* is also used in the vanilla trade, but in lesser quantities. Because of vanilla’s high value, substitution or dilution incidents are conventional means of creating fraudulent vanilla extract. Those purchasing vanilla extract depend on analytical testing to detect fraud. In many cases, vanilla fraud occurs by using synthetic vanillin or ethyl vanillin as a substitute for natural vanilla extract, as they are significantly cheaper than natural vanilla extract (de Guzman and Zara, 2012). Organic vanilla has also become vulnerable to labeling fraud, which is usually conducted through the creation of fraudulent “organic” certificates.

In 2008 a court case in the United States addressed the mercury contamination of vanilla beans from Indonesia (U.S. District Court and D. New Jersey, 2008). The court case details that an Indonesian supplier likely injected vanilla beans with mercury to increase the weight of the product, thus increasing the perceived yield of beans that translated into more money for the supplier.

The use of plants that are not *V. planifolia* is another way that vanilla is substituted. Other plants that have been used in place of *V. planifolia* include *Dipteryx odorata* (a flowering tree that produces seeds called tonka beans), *Vanilla pompona* (an inferior vanilla plant), and other plants closely related to the vanilla orchid plant (de Guzman and Zara, 2012). The tonka bean is native to Central America and northern South America. Tonka beans are substantially less expensive than vanilla beans and have a flavor similar to vanilla due to the presence of coumarin, which contains compounds that impart a vanilla-like scent. Coumarin is a natural substance found in the tonka bean but not in authentic vanilla, and its presence can be identified through analytical testing. Coumarin has been reported to exhibit hepatotoxic effects and, in 1954 the U.S. Food and Drug Administration (FDA) (1989) banned the use of coumarin as a food additive, including as the use of tonka beans or tonka extract. However, Mexico does not have strict regulations that outline standards of identity for vanilla extract or vanilla extract labeling, which also loosens oversight on how it is made and what is utilized. These “Mexican vanillas” often contain tonka bean extract and tout claims of unique flavors driven by the product’s origin and growing region.
10.2.3 Saffron

Saffron (*Crocus sativus*) is known as the most expensive spice in the world and is a significant target for adulteration (Table 10.1). The saffron threads are the stigmas of the *Crocus* flower, and only three are typically produced per flower. The low number of threads per flower combined with labor-intensive hand harvesting acts to drive the high cost of saffron. Saffron adulteration has occurred with both the whole and powdered form of the spice. Historically, saffron adulteration incidents show a variety of methods used, but most involve utilizing plant fibers and colorants to replace authentic saffron threads. Examples of other plant parts that are mixed with genuine saffron include root hairs, stamens, and styles or stigmas from other *Crocus* varieties (Alonso et al., 2012). The addition of dried fibers of meats and/or gelatin has also been reported. Coloring agents are utilized to mimic the yellow coloring of the saffron. Dyes such as tartrazine, erythrocine, azorubine, cochineal, red, orange-yellow, and naphthol yellow have all been used to add color as a means of defrauding the buyer (Koocheki and Melani, 2020). Another common type of saffron adulteration includes partial substitution with older, degraded saffron. Degradation of saffron impacts the flavor, aroma, and color, which are the attributes of importance when assessing the quality. Weight additions occur by increasing humidity or soaking the saffron in substances such as honey, olive oil, or glycerin.

Incidents involving saffron adulteration continue to occur frequently. For example, in 2019, samples of saffron on the retail market in the United Kingdom were found to be laced with other, cheaper plant fibers. The adulteration was uncovered as officers collected and tested multiple bottles of saffron. After investigating the incident the source of the adulterated saffron was found to be a factory in Spain (Addy, 2019).

10.2.4 Oregano

Oregano has made headlines in recent years due to market surveys and research publications attempting to quantify how much adulteration exists in the oregano market. Deriving from the genus *Oreganum*, oregano is an important culinary herb, with the most critical volatile oils that impart its distinct flavor found in the leaves of the plant. Bulking is a known means of defrauding oregano in the market. Common adulterants found to be used as bulking agents for oregano are leaves of similar plants, usually myrtle, sumac, and olive leaves (Drabova et al., 2019).

Research published by Black et al. (2016a) indicated around 25% of oregano sample was adulterated with parts of other plants, with myrtle and olive being the most predominant. The level of adulteration ranged from 30% to 78% within each product. The results of this study and the exposure it received across Europe and other regions have brought oregano under greater scrutiny for authenticity.

10.2.5 Other notable spice adulteration incidents

Over the last decade, spice adulteration incidents have made regional and global headlines. These incidents have garnered attention due to the widespread distribution and usage of the adulterated products. In addition, food safety and health concerns were
created by the adulterants used to commit these acts of economically motivated adulteration. These incidents of food fraud had lasting impacts due to the nature of the adulterants used. Some examples are discussed here.

10.2.5.1 Peanuts in cumin

Cumin (*Cuminum cyminum*) is a flowering plant, the seeds of which are dried and used as a spice. At the end of 2014 and into 2015, numerous cumin products were recalled globally as peanut residues (*Arachis hypogaea*) were found in the cumin-based products. The US FDA issued a nationwide advisory to peanut-allergic consumers to avoid consuming products containing cumin, noting the presence of undeclared peanut protein in numerous products (*CFSAN, 2015*). Although the source of peanut inclusion as well as a motive has not been confirmed to date, there are several theories about the cause (*Agres, 2015*). Some suggest that either ground peanut shells or possibly dried peanut meal (after oil extraction) was added as a bulking agent to adjust for a bad cumin crop in India that year.

10.2.5.2 Sudan dyes

Sudan dyes (Sudan I–IV), along with other dyes falling into a broader family called Azo dyes, continue to be known adulterants in spices. Sudan dyes are typically found as adulterants in brightly colored red and orange spices, such as chili powders, curries, and paprika (*Rebane et al., 2010*). Sudan dyes have been banned as additives in both the United States and the EU. These dyes are considered potentially carcinogenic as well as genotoxic.

In 2005, a massive recall occurred in the United Kingdom, with chili powder contaminated with Sudan 1 as the root cause of recall (*Meikle, 2005*). The recall was actually for Worcestershire sauce, in which the adulterated chili powder was an ingredient. The recall was greatly expanded due to the multiple uses of the Worcestershire sauce as an ingredient in many foods.

10.2.5.3 Lead in turmeric

Turmeric is a commonly used spice made from the roots of the turmeric plant (*Curcuma longa*). Lead chromate, used to enhance the spice’s favorable yellow hue, is a common adulterant in turmeric. For example, in 2016, numerous products in the US market were recalled due to high levels of lead found in a routine sampling of turmeric by state regulators (*Addady, 2016*). Lead consumption is of concern due to the potential adverse health effects from both short- and long-term exposure.

A study of lead chromate adulteration in turmeric by *Forsyth et al. (2019)* exposed the rampant contamination of turmeric in the Bangladeshi market. The study confirmed that, due to the consumer desire for colorful yellow curries, manufacturers of turmeric utilized old “polishing” techniques of adding lead chromate to enhance the root’s yellow color. In many cases, these polishers were unaware of the adverse public health effects of this practice. This study also confirmed that the lead levels tested in many of the turmeric samples exceeded the national threshold by 500 times.

10.2.5.4 Fraud in organic herbs and spices

Organic certification of many herbs and spices provides price premiums on top of an already high value-to-weight ratio. The demand for herbs and spices that meet organic
standards is growing, which creates an opportunity for fraud to occur. Because an organically produced herb or spice demands a price premium, it can become a target of fraudulent organic claims that misrepresent the conditions under which the herb or spice was produced. Organic fraud in herbs and spices mostly occurs through document fraud, with fraudulent certifications accompanying lots of material. The result is the consumer is defrauded by purchasing a product that is represented as organic, but in reality, it was not produced under a certified organic program and may not have been produced using organic farming practices.

### 10.3 Herbs and spices used in natural health products

Fraud among herbs and spices used as botanical ingredients in natural health products (NHPs) is a considerable concern. The recent movement toward authentic NHPs requires pharmacovigilance throughout the supply chain of botanical ingredients. There are millions of botanical products registered by the health regulatory authorities throughout the world, and the demand for these botanical ingredient-based products from 60% of the global population is increasing (compound annual growth rate; 8%–10%). There is immense pressure on the supply of botanical ingredients, which may cause further increases in adulteration and product substitution (Cheng et al., 2015; Gao et al., 2017; Newmaster et al., 2013; Raclariu et al., 2017; Shanmughanandhan et al., 2016). Economically motivated adulteration could adversely impact the trade of medicinal plant products in the global market (Cammà et al., 2012; Claros et al., 2012; Downey, 2016; Mishra et al., 2016). This has raised environmental concerns that some uncommon or rare species of plants are being harvested for commercial use as NHPs (Chen et al., 2016). In certain areas of the world the supply of botanical ingredients is being depleted, which has raised concerns from global organizations such as the Convention on Biodiversity and the World Health Organization (WHO). The WHO has concerns for developing countries, where 80% of the populations use NHPs almost entirely based on traditional medicine practices as their primary health care. The WHO (2004) deemed the safety of NHPs due to product adulteration a concern; with increasing use and reports of adverse reactions, regulatory standards need to be reviewed to consider proper due diligence in quality assurance. There is an immediate need for more adequate quality assurance tools to authenticate botanical supply chains for commercial use in the herbal industry.

A study published in 2013 identified considerable adulteration of botanical ingredients in NHPs (Newmaster et al., 2013). As a result of this research, cease and desist orders were sent to specific corporations being accused of adulteration of botanical ingredients in their products. This paper utilized an innovative approach that exposed botanical ingredient adulteration using disruptive molecular diagnostic biotechnology. The exposure of botanical ingredient adulteration resulted in brand damage and lack of consumer confidence, costing unknown billions of dollars within the industry. Although this was very damaging for the industry, it prompted many stakeholders to ask critical questions about methods of quality assurance and supply chain management.
10.4 Common analytical methods used to detect herb and spice adulteration

Because culinary spices and aromatic herbs represent a highly heterogenous botanical family, analyzing them for authenticity is a challenging task that generally requires multiple methods (Table 10.1). Most of the authenticity issues come from mislabeling the provenance, the addition of adulterant(s) or the substitution by another species. The range of adulterants that has been used with these food products is extensive and includes:

- artificial and natural dyes to enhance color;
- plant bulking agents, whether they are endogenous (any parts of the plant the spice or herb belongs to, processed or not) or exogenous (added starch, sawdust, coffee husk); and
- mineral bulking agents (dust, talc, chalk, sand, etc.).

Unlike some other natural products, the development of analytical methods to authenticate herbs and spices is still in its relatively early stages because in-depth and specific knowledge is needed for each of these niche food products. Their supply chain is long and complex with many steps where adulteration can occur. The supply chain nodes range from the producing countries, which are primarily tropical countries, to the consuming countries, resulting in a diversity of fraud methods and a range of potential adulterants.

The first basic and inescapable step to authenticate herbs and spices is the visual inspection. The spice expert can detect many abnormalities or deceptions with the naked eye, especially when the spice is in its whole form. The International Organization for Standardization (ISO) provides detailed specifications for most of the herbs and spices known in the Americas and Europe as well as methodologies to test their quality attributes, which are spice dependent. The American Spice Trade Association (ASTA) and the Association of Analytical Communities also offer methods dedicated to testing the quality of herbs and spices. Noncompliant quality attributes might reveal fraud, at which point further techniques must be used to investigate the authenticity.

Conventional microscopy remains the reference method for spice authentication (ASTA, 2016; BRC-FDF-SSA, 2016). Microscopists are highly trained analysts, but the analysis can take a long time. Technologies are emerging that are easier to use once implemented. From 1980 to 2010 the top two methods used for detecting adulteration were liquid chromatography (LC) and infrared spectroscopy (Moore et al., 2012). These techniques are targeted methods that enable screening of herbs and spices for one or multiple components. The best example is the LC with tandem mass spectrometry (LC–MS/MS) method to detect the presence of illegal dyes, such as the Sudan dyes and other artificial or natural dyes, in yellowish and reddish spices. Such screenings can detect up to 58 added dyes with limits of detection down to 0.1 mg/kg (Bessaire et al., 2019). However, if a dye is added that is not in the list of target compounds, it will not be detected with this method. With targeted methods, one only detects what one is looking for and perpetrators can devise clever, new ways to beat these tests. This can become an endless cycle as criminals find new methods to commit fraud.

Currently, there is a move toward fast and reliable analytical techniques to confirm the authenticity of food. While standard techniques involve the use of benchtop instruments, researchers are working on the development of methods that can be used at-line, in-line, or...
handheld in the field, at the farm, or in the factory. Since the beginning of 2010, there has also been a boom of the so-called nontargeted methodologies applied to food authenticity. Although targeted testing is the determination of known adulterants and requires their prior identification, nontargeted testing serves to answer the question, “Is there anything in the spice that doesn’t belong?” with a binary “yes” or “no” answer. In other words, is the food product “typical” or “atypical” compared to the large population of authentic samples describing all-natural variations? This question implies a statistical approach to the problem. Nontargeted methods are often referred to as fingerprinting or profiling methods and offer considerable advantages in terms of efficiency and cost-effectiveness. These methods are developed in combination with chemometrics (statistics-based) tools to produce models. However, validation procedures for nontargeted methods have not been standardized, which can reduce consistency between laboratories. There is guidance from the US Pharmacopeia related to one-class, nontargeted classification methods for the detection of economically motivated adulterants in food, independent of the analytical technology used (USP, 2018).

Nontargeted approaches are very important in the field of herb and spice authentication, whether it is to prove the country of origin or to detect adulteration. The development of nontargeted methods is generally time-consuming because many authentic and adulterated samples must be analyzed, and statistical approaches must be tested. However, the final methodology is meant to be rapid and easy to use, faster than wet chemistry, microscopy, or regular targeted chromatography analyses. An immediate problem of nontargeted technique development is the need for a large number of authentic representatives of all the possible natural variations. Intense collaboration between the spice industry and research centers is thus needed.

10.4.1 Spectroscopy

Vibrational spectroscopies combined with chemometrics have become one of the most attractive and widely used methods in the detection of adulteration/authentication in the food industry. They are rapid, nondestructive, fingerprinting techniques, and are valuable screening tools. The range of vibrational spectroscopic analytical techniques includes near infrared (NIR), Fourier-transform middle infrared, and Raman (Lohumi et al., 2015). Infrared radiation is the region of the electromagnetic spectrum between the visible and the microwave wavelength. In comparison to the mid-infrared region, where only fundamental vibrations can be observed, overtones and combinations can be found in the NIR region containing a manifold of information. For example, all the numerous bulking agents (plant-related and mineral adulterants) that are known to potentially adulterate black pepper absorb in the infrared spectral region (Lafeuille et al., 2020). This is also true for main bulking agents used in other culinary dried aromatic herbs and spices. Raman spectroscopy, relying upon the inelastic scattering of photons, combined with chemometrics has also been used to detect cornstarch in ginger, garlic, and onion powder (Lee et al., 2014, 2015).

Spectroscopy can also be utilized in the imaging mode giving a supplementary spatial dimension to the detection. Multispectral and hyperspectral imaging instruments integrate traditional nondestructive spectroscopy and regular imaging systems, which simultaneously analyze and extract detailed spectral information for every single pixel in the image of the tested sample. Visible and IR spectroscopy can be used in hyperspectral imaging, thereby
enabling a large number of dried herbs or spices to be analyzed and avoiding problems associated with representative sampling. Hyperspectral imaging has been reported to be capable of detecting foreign leaf addition in cut oregano (Damiani et al., 2018), shell and spent material in nutmeg (Kiani et al., 2019), and papaya seed in black peppercorn (Orrillo et al., 2019). Fourier-transform infrared (FTIR) spectroscopy coupled to a microscope in the imaging mode (micro-FTIR imaging) has been validated for the detection of numerous types of adulterants in black pepper (Lafeuille et al., 2020), especially in its ground form. However, there are some limitations of vibrational spectroscopy applied to herbs and spices that must not be overlooked. They are used as rapid techniques and, therefore, generally must be followed up with confirmatory techniques that require more expertise and time, such as microscopy, mass spectrometry, or DNA analyses.

Nuclear magnetic resonance (NMR) is a spectroscopic technique that examines local magnetic fields around atomic nuclei. Hydrogen (proton) and carbon are the most common atoms observed in NMR. The use of proton NMR ($^1$H-NMR) combined with chemometrics is an efficient technique to assess the authenticity of saffron (Petrakis et al., 2015) and many other spices (Portaluri et al., 2018). However, it requires expensive instruments and experienced analysts. Even more sophisticated is the site-specific natural isotopic fractionation by NMR or SNIF–NMR. This technique determines, to a high level of accuracy, the isotopic ratios for each of the atom sites of the molecule of interest, which enables better discrimination. The combination of $^{13}$C and $^2$H SNIF–NMR enables the identification of the presence of artificial vanillin fraudulently added to vanilla pods or extracts from diverse precursors such as guaiacol from oil derivatives, ferulic acid from rice, eugenol from cloves, and curcumin from turmeric or lignin (Guyader et al., 2019).

### 10.4.2 Mass spectrometry

MS is often considered as the gold standard technique in the food industry and is an exciting tool in the fight against herb and spice fraud. Molecules in a sample are ionized, but not necessarily fragmented, before their mass-to-charge analysis. MS combined with a chromatographical separation step such as gas chromatography (GC–MS) or LC (LC–MS) is frequently used. These techniques require sample preparation (e.g., extraction, purification, and derivatization) before injection. The most advanced use of these methods is to develop nontargeted metabolomic-like approaches to prove herb and spice authenticity. In that case, high-resolution mass spectroscopy (HRMS) coupled to GC or LC is preferred. The objective is to use a nontargeted fingerprinting approach as the first step before a final targeted method. In other words, plant biomarker compounds of interest are selected through metabolomic profiling and used subsequently to develop a more cost-effective targeted-acquisition method for routine control purposes. Indeed, patterns of metabolomic changes are informative about either environmental factors that can verify provenance or the presence of foreign plant material to prove the addition of adulterants. As examples, LC–HRMS was used to determine the geographic origin of a saffron sample (Rubert et al., 2016) and to detect foreign leaf additions in oregano (Black et al., 2016a). GC–MS has been used when investigating detection methods for known adulterants in fennel seed (Ma et al., 2015).
Essential oils of fennel seed and two adulterants (cumin and dill seeds) were profiled, and distinct differences were observed.

Upgrades in mass spectrometry involve the use of real-time analysis by directly introducing the samples to the mass spectrometer. These direct- or ambient-MS analyses consist of over 30 different techniques. The molecules are desorbed/extracted from the sample via a spray, heat, or a laser, and molecule ionization happens in the open air directly on the surface of the sample. Ions are generated without significant fragmentation to avoid too much complexity in the final spectrum. Ambient mass spectrometry is a relatively new analytical technique that gives comparable results to conventional techniques without complex sample preparation. There is growing interest in using direct-MS with the nontargeted acquisition. Desorption ElectroSpray Ionization (DESI-MS), Atmospheric Solids Analysis Probe (ASAP-MS), Direct Analysis Real-Time (DART–MS), and Paper Spray (PS-MS) have been recently used to authenticate herbs and spices (Black et al., 2016b).

Other MS technologies such as isotope ratio (IR)–MS and inductively coupled plasma (ICP)–MS are involved in the assessment of spice geographic origin. Both were used to measure trace concentrations of 42 elements and stable isotopic ratios of $^2$H, $^{13}$C, and $^{15}$N to assess saffron provenance (Wakefield et al., 2019). Gas chromatography–combustion–IR mass chromatography is also commonly used to analyze vanillin and associated aromatic components to authenticate vanilla pods and extracts (Scharrer and Mosandi, 2002).

Similar to spectroscopy, the validation procedure for nontargeted methods in mass spectrometry has not been standardized. Not-targeted approaches require the use of chemometrics to improve the chemical data obtained from analytical instruments and to correlate the properties of samples with the use of mathematics and statistical methods. The most common algorithms used for the determination of authenticity are the classification/discrimination algorithms such as the unsupervised principal component analysis, the supervised partial least squares discriminant analysis, and its improvement known as orthogonal projections to latent structures discriminant analysis, as well as soft independent modeling by class analogy. Further to chemometrics, machine learning classifications such as random forest classifiers are emerging to improve classification accuracy (Jiménez-Carvelo et al., 2019).

### 10.4.3 DNA-based techniques

DNA analysis plays an important role in the detection of plant species addition or substitution in herbs and spices. Sequence characterized amplified region–polymerase chain reaction (SCAR–PCR) was used to detect bulking agents in saffron by screening large batches with a fast, reliable, sensitive, and low-cost method (Marieschi et al., 2012). In 2015, several cumin and paprika products were subject to a costly recall from the international market because of the suspected unlabeled presence of almond, a known allergen from the *Prunus* genus. Current allergen detection techniques, such as immunoassays, typically had difficulties distinguishing between closely related *Prunus* species due to cross-reactivity. In isolation, none of the applied techniques could adequately answer whether almond or mahaleb (or both) was present in the samples. The DNA approach was crucial in the correct identification of the adulterants. Specifically, real-time PCR was successfully used to prove mahaleb was fraudulently added to the cumin sample (Burns et al., 2010).
DNA melt-curve analysis confirmed that both almond and another *Prunus* species were present in the paprika sample (Nixon et al., 2016). For DNA melt-curve analysis, the point at which the DNA “melts” (dissociation of the double-stranded DNA) is dependent upon the nucleotide composition and it was demonstrated as useful to detect DNA from specific *Prunus* species.

PCR testing is limited by the number of targets that can be simultaneously identified and differentiated and requires knowledge about which species to search for. For these reasons, next-generation sequencing (NGS) has recently emerged as a new nontargeted DNA technique with rapid success. NGS is a high-throughput method used to determine a portion of the nucleotide sequence of an individual’s genome. This technique utilizes DNA sequencing technologies that are capable of processing multiple DNA sequences in parallel. For plant material, a single unique barcode region of the plant DNA is used for universal tests that amplify a few hundred base pairs. This region is meant to be extremely variable among plant species and should reliably differentiate plants down to the genus or species level. In other words, NGS is capable of detecting the DNA from any plant material in a sample after an important bioinformatical data evaluation process and a comparison of the sequences to the nucleotide sequence collection of the available databases. The quality and accuracy of the databases used are of importance. Any species detected should have clear and well-defined sequence entries available in the database. If additional specificity is needed, it can be coupled with specific tests using other regions for particular plant groups. However, when used as a plant DNA technique to authenticate aromatic herbs and spices, several shortcomings have been described elsewhere (ESA, 2019). Endogenous material sharing the same DNA or mineral adulterants containing no DNA can, of course, not be detected. Highly processed plant material is also difficult to accurately detect because it contains degraded DNA. As a result, and for the time being, it is recommended that NGS is used as a powerful secondary tool to confirm or/and identify additions of exogenous plant materials containing DNA when detected by reference methods. NGS quantitation of different vegetal components of a sample is also an issue in the field of spice and herb authentication. Indeed, concentrations are expressed in DNA sequence read percentages, which tightly depend on both the quantity of DNA in the components (which can be highly variable) and the DNA recovery rate of the analysis extraction step for the considered plant. For herbs and spices, NGS quantitation does not clearly differentiate between the addition of vegetal bulking agents and low natural contamination by foreign plant material during cultivation/harvest. It is important to note that NGS good practices are on the way to be standardized at the international level (ISO) to decrease lab result discrepancies.

### 10.5 Risk mitigation strategies for herb and spice fraud

#### 10.5.1 Supply chain risk mitigation

Knowledge of the supply chain for a procured spice or herb is essential to determining the fraud vulnerability. A supply chain with many touchpoints and transactions creates more complexity and introduces more opportunities for fraud to occur. To combat these
complexities, companies should seek to have a thorough understanding of all touchpoints for the spice or herb they are sourcing. It is important to know where it originates at the farm, and, subsequently, all points through the supply chain until it reaches the consumer. Herbs and spices can travel through multiple transaction points, including brokers, agents, shippers, and processors. At each step, there are specific types of fraud that could occur. Companies can work to shorten their supply chains by cutting out several of the intermediaries, but where this is not possible, companies must become knowledgeable of all vulnerabilities at these touchpoints and discuss mitigation options where there is a significant risk.

10.5.2 Supplier relationships

To reduce fraud opportunities, companies can adopt a more proactive relationship with source suppliers. Building a partnership with the source supplier provides additional oversight to ensure that both parties understand the concerns of food crime that may be specific to the commodity grown. Sometimes, oversight alone serves as a deterrent if the supplier is considering committing fraud or does not have sufficient measures in place to prevent fraud. Companies that source spices benefit from close relationships along their supply chain. If they can engage at the farm level, the ability to have oversight of practices in farming techniques and direct awareness of challenges can assist the company in having a better understanding of what vulnerabilities may exist regarding potential food crime. Intimate knowledge of the farming economy and other crops nearby can also be useful information when identifying vulnerabilities such as substitution and bulking.

10.5.3 Forensic auditing

Building on the supplier relationships, companies can choose to initiate deeper dives into a supplier’s financial health. Audits of a supplier’s finances can reveal vulnerabilities that could indicate a potential fraud event. Financial audits can also pair with mass balance activities (discussed later), to understand if the prices paid for inputs match up with what the supplier shows as throughput. An auditor can also review purchases of raw materials for the supplier. This review can reveal if there have been any materials purchased that are suspicious or that do not go into any of the supplier’s documented formulas or product offerings.

10.5.4 Mass balance activities

A mass balance review is an accounting of the material entering and leaving a system. This activity can also be conducted with a supplier to determine if the amount of input materials equals what would be expected of output products. Where there is an indication of any significant imbalances, such as a much higher output yield versus a much lower input, further investigation can take place to determine the reason(s) for these imbalances. On a macrolevel, it is possible to understand mass balance by studying economic reports that are published by countries. Sociopolitical economics can create situations where trade
restrictions are imposed on countries that provide significant sources of an ingredient. In these types of cases the sanctioned country may move its exports through other countries. These activities have the goal of altering the origin designation so that the penalized country can still move and sell their goods (sometimes called “transshipment”). The masking of the exact origin location is a form of manipulation whereby that the end customer is not provided with the true origin. These types of imbalances occur on a large scale and must be studied to understand where the import and export balances indicate there is a misstatement of origin.

10.5.5 Review of certifications and documentation

Detailed reviews of documentation can be valuable in detecting fraud. This is particularly relevant in areas of certificate fraud for varying types of certification. Checking issued certificates for certain product claims, such as an organic claim, against certification databases can help mitigate the risk of fraud in this area. Buyers of organic herbs and spices, specifically, can verify organic certificate status by checking issued certificates against the organic certification databases such as the US Department of Agriculture Organic Integrity Database. This online database allows the user to search by vendor name to verify which products are certified and that they are current on their certification status. Certifying bodies for organic status also have their own searchable databases that can be utilized as well. Audits can also help verify organic practices and certificate authenticity.

10.6 Relevant standards for herbs and spices

Spices and herbs can be measured against standards that have been established across various organizations. Currently, most standards have been created by spice industry trade associations. These trade associations vary by region and by country. Each spice commodity has its grading criteria, so there are not necessarily standard grading criteria that can be applied across all spices and herbs equitably. The published standards, where available, contain information on analytical attributes that are important for spice characterization but also for quality. Many of the same organizations that publish the quality standards also publish methods for evaluation of the quality specifications for the various types of herbs and spices.

When searching for reference standards for spices and herbs, the sources are varied and information may not be comprehensive for each spice when comparing across the different standards. In addition, most of the standards must be purchased and are not available to the general public. The standards and references available are heavily focused on analytical characteristics important for the spice/herb. There is currently a lack of published standards that focus on adulterants, identification of adulterants, and acceptable methods for identification in the spice and herb commodities. However, there are bodies of work and research methods available that address analytical testing specific to adulterant detection.
across spice and herb categories. In many cases, methods of adulterant detection are still being actively explored to bring robust testing to the industry.

Spices and herbs often have standards of identity associated with them and as defined by various publications. These standards can be utilized as a benchmark for what constitute the critical attributes of the spice or herb. Beyond that, one could assume that deviations could indicate possible fraud or adulteration. The US FDA has basic information that outlines the main components of various spices and herbs. This can be found in the Compliance Policy Guide, CPG Sec 525.750 Spices—Definitions (Office of Regulatory Affairs, 1980). These fall short of being an exact specification for the commodity but can assist with ensuring labeling accuracy for the herb or spice. In addition, the US FDA has also provided more specific information on items such as extracts, specifically vanilla extract, which (as noted earlier) is a primary product produced from the vanilla bean and is highly vulnerable to fraud. The Code of Federal Regulations outlines very specific criteria for a product to be labeled as vanilla extract (21 CFR §169.175).

10.6.1 American Spice Trade Association standards

The ASTA is a US-based trade association that represents the interests of the US spice industry. ASTA has created publications available to members and nonmember companies that outline the quality specifications for various herbs and spices. ASTA has also provided private standards for the spice industry. Currently, ASTA has published several documents that assist with standardizing how spices and herbs are analyzed and by what methods. These are important to the industry as they add a layer of detail in assessing herbs and spices for potential adulterants through a set of standard methods and protocols.

10.6.1.1 Microscopic identification of spices

This document is a reference text for the microscopic or histological identification of pure spices (ASTA, n.d.). This document provides information for the spice industry that helps to determine adulterants or contaminants in various spice products, and it enables companies to ensure they have a pure product.

10.6.1.2 Analytical methods manual

This document provides standardized methods for the analytical evaluation of spices for the industry (ASTA, 1997). Analytical methods included in this manual range from standard tests such as moisture, total ash, and crude fiber to more specific analysis methods for spice attributes such as cinnamic aldehyde in cassia oils and foreign leaves in oregano. There are a handful of methods included in this document that focus on spice or herb adulterants.

In addition, ASTA has published a guidance document titled “Identification and Prevention of Adulteration” (ASTA, 2016). This guidance document details specifics for the prevention of adulteration along the spice supply chain and lays out a decision matrix to identify potential vulnerabilities based on some basic questions known to be impactful in assessing fraud vulnerability in the sector.
10.6.2 International Organization for Standardization standards

ISO has published standards for many dried herbs and spices. These standards are publicly available for a fee and are used as global standards for a variety of quality parameters. ISO standards cover aspects of herbs and spices such as the botanical nomenclature and physical description; some product requirements such as flavor, color, and cleanliness; and, in some cases, some of the chemical attributes essential to the herb/spice such as volatile oils and moisture (Schaarschmidt, 2016). These standards capture relevant information that serves as a standard of identity for the individual spices. Information on known adulterants is not provided in the ISO standards, as they include only basic identifying information and parameters that define the herb/spice. These standards do assist with maintaining an aligned definition of what can be classified as a particular herb or spice.

10.6.3 Codex standards

The Codex Alimentarius Commission has developed the Codex Committee on Spices and Culinary Herbs to create standards specific to herbs and spices. This committee is charged with (1) to elaborate worldwide standards for spices and culinary herbs in their dried and dehydrated state in whole, ground, and cracked or crushed form and (2) to consult, as necessary, with other international organizations in the standards development process to avoid duplication (CCSCH, n.d.). To date, the committee has published standards for black, white, and green pepper as well as standards for cumin and dried thyme. There are many draft standards in development under this committee that are not yet published. The Codex standards cover elements such as how the spice or herb is offered, quality characteristics, chemical characteristics, spice grading classes, physical characteristics, and generic references for contaminants, hygiene, and labeling. Similar to ISO standards, the Codex standards for spices and herbs aid in accurately setting parameters for spice and herb characterization to set minimum standards for the trade.

10.7 Conclusion

This chapter covers various factors that make the spice and herb market susceptible to food fraud. The types of fraud may be specific to a particular spice or herb and need to be consistently monitored. The industry must also be vigilant in combatting the new and creative ways that criminals are seeking to defraud herbs and spices. Analytical testing is a critical component for monitoring for adulteration of spices, but there are other mitigating factors that can assist with reducing the vulnerability of the supply chain. Supplier relationships as well as intimate knowledge of the supply chain are valuable in identifying vulnerabilities and applying appropriate mitigation activities. Ongoing advances in fraud detection should continue to be pursued and leveraged in this space to deter and detect instances of fraud in herb and spice supply chains.
References


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11

Fraud in nonalcoholic ready to drink products

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11.1 Introduction

Food fraud remains an ever-increasing threat to the fast-moving consumer goods sector and can occur at any point along the supply chain. The consequences of food fraud can vary and include financial and reputational damage to those companies directly affected by the criminal enterprises. The impacts can also affect actors across the supply chain together with other stakeholders such as national authorities and industries when public trust is lost as a result of a serious incident. In a worst case scenario, food fraud can impact consumer health and well-being (Yang et al., 2019). Food fraud encompasses acts committed for economic gain, such as mislabeling, misrepresentation (e.g., counterfeiting), and in
some definitions also theft, tampering, diversion, tax evasion, gray market, and overrun (Van Ruth et al., 2017). Lord et al. (2017) build on this theme by conceptualizing “food fraud as relating to the abuse or misuse of an otherwise legitimate business transaction and an otherwise legitimate social/economic relationship in the food system in which one or more actors undertake acts or omissions of deception or dishonesty to avoid legally prescribed procedures (process) with the intent to gain personal or organizational advantage or cause loss/harm (outcome).” This is the interpretation that we have aligned on for this chapter.

Ultimately, no product or brand is safe, since the threat transcends industry sectors. This chapter examines the threat as it pertains to the nonalcoholic ready to drink (NARTD) category that captures products, including soft drinks, juice drinks, juices, energy drinks, water, and functional drinks. Functional drinks are a rapidly growing beverage subsector and include products with enriched vitamins, minerals, isotonic and a variety of sports drinks, wellness, and nutraceutical products. Many functional drinks have been developed with consumer health claims in mind. Due to the increased economic value and profit margins often associated with premium retail positions, these enhanced functional drinks—in addition to the shift of the larger NARTD sector toward “natural” products—represent increased exposure to food fraud risk. Ultimately, food fraud mitigation in the case of NARTDs is critically important due to the risk to consumer health and well-being which is linked to the speed of production and beverage consumption. If there is an undeclared allergen due to labeling issues, or an error in production that results in the inclusion of an excessive amount of a substance (such as a stimulant), the impact can be swift with potential health consequences.

### 11.2 Nonalcoholic ready to drinks and their economic importance

The NARTD market has strong global economic importance. The diverse range of products encompasses a variety of categories which, despite their tight margins, contribute both directly and indirectly to the value chain. The size of the commodity stream is illustrated by the fact that the “soft drinks” market worldwide is projected to grow at a compound annual growth rate (CAGR) of 5.8%. This is despite shifting market dynamics and consumer sentiment, with the market poised to attain revenues over US$695.6 billion (bn) by 2025 (Reportlinker, 2019) and the United States is projected to maintain a 4.9% growth momentum. In Europe the market attained total revenues of US$160.7 bn in 2017 representing a CAGR of 3.2% between 2013 and 2017 (Marketline, 2018), and in Japan the market is projected to reach US$37.6 bn in the near future. Lastly, “as the world’s second largest economy and the new game changer in global markets, China exhibits the potential to grow at 8.5% over the next couple of years and add approximately US$121.9 bn in terms of addressable opportunity” within the soft drinks market (Reportlinker, 2019).

As it is among the top performing food and beverage industries, the NARTD sector plays a key role in the global economy across all types of markets (including developed, emerging, and developing). Due to its long-range growth potential, it is considered an attractive business sector for the coming decades. According to the American Beverage Association (2019) (www.ameribev.org), the direct impact of the industry in the United
States accounts for 182.6 bn dollars. Distilling the economic importance further and to illustrate the contribution to the value chain, we turn to an example of the direct and indirect economic benefits of the NARTD sector to a country’s economy. Coca-Cola HBC Greece in 2016, as part of their internal operations, commissioned a study conducted by consultancy firm Steward Redqueen. The purpose of the study was to analyze market data from 2014 to evaluate the contribution of the Coca-Cola Greece system\textsuperscript{1} NARTD activities to the Greek economy. In their evaluation of value chain contributions, the study authors (Kapstein et al., 2016) made the following conclusions with respect to the Greek operations:

- The total added value to the economy from the operations was €924M and this equaled 0.5\% of Greek GDP.
- The operation’s total direct and indirect tax contribution amounted to 1\% of the total Greek tax revenue.
- A total of 21,300 direct and indirect jobs (0.6\% of total employment in Greece) were created across the supply chain from the operational activities of the Coca-Cola system, enhancing the income of 54,000 people.
- Every €1 of added value created by the Coca-Cola system contributed €7 to the Greek economy.

11.3 Vulnerability to food fraud

A study by the online global food safety system, Foodakai (2019), into the various types of food fraud committed with NARTD beverages enables us to illustrate the level of vulnerability within this commodity group. The vulnerability of the product category is multifaceted and can include counterfeit production; adulteration through the insertion of illegal dyes, inclusion of undeclared pharmaceuticals in energy drinks, adulteration of raw materials such as milk powder, adulteration of juice concentrates by adding high-fructose corn syrup and/or a variety of lower economic value juice blends, and the sale of product after the “best before” period with the dates being manipulated. The FOODAKAI study was based on published information on food safety and fraud incidents from numerous relevant, globally known food safety agencies and networks. The sources include the European Commission’s Rapid Alert System for Food and Feed (RASFF) database, regulatory and statutory authorities such as the US Food and Drug Administration (US FDA); the Japanese Ministry of Health and Food Standards Australia New Zealand (FSANZ); as well as various professional portals such as “Food Safety News” and “Food Safety Tech.” These data sources can be used to identify critical food protection trends, including food safety and authenticity, for different food and beverage products.

In the period between 2008 and 2018, fraud was identified as being in the top three food safety incident categories associated with NARTD beverages, as shown in Fig. 11.1.

\textsuperscript{1} The Coca-Cola Company in Greece and Coca-Cola Tria Epsilon, plus the activities of the local subsidiaries of the Coca-Cola HBC AG Group (Coca-Cola HBC) in Greece, namely, Coca-Cola HBC Services M.E.P.E and TSAKIRIS.
During 2017–18 the NARTD industry faced a sharp increase of reported beverage product fraud incidents. Specifically, there was a 200% increase in the number of reported incidents compared to 2008. In 2017–18 the majority (almost 40%) of hazardous incidents reported for NARTD beverages involved fraud (Fig. 11.2), and, for the first time in the FOODAKAI report, fraud was ranked as the top incident category, being linked to 94 cases on a global level.

In distilling the data further, some specific examples include the following:

- Two factories were closed in Punjab, India, after it was identified that they had produced substandard artificial flavors. The fruit flavors were produced without using fruit and were chemically contaminated (JRC, May 2018).
- Incorrect labeling [best before date (BBD) not legible and possibly expired] on fruit juices from the United Arab Emirates, dispatched from Egypt (RASFF, 2018).
- Misbranding and absence of labeling; missing required nutrition information; incorrect labeling of preservatives in fruit juice and vegetable juice by JC Snacks Mexico De Rl from Mexico (FDA, 2018).
- Misbranding and unauthorized color and food additives in fruit juice and vegetable juice by Pharma Green S.r.l. from Italy (FDA, 2018).
- False marketing claims in bottled water by 8 Knot from Japan (FDA, 2019).
- A popular energy drink in Zambia was banned after it was found to contain an undeclared pharmaceutical, sildenafil citrate, the active ingredient in Viagra (BBC, 2019).
Violation by intentional overdosing of zinc sulfate outside of beyond the legally permitted specification in a juice drink resulted in border rejection in Spain. Inspection conducted by certified personnel from Ministry of Health, Labour and Welfare, Japan (Foodakai, 2019).

The extent of the vulnerability of NARTD beverages to fraud was discussed by Lord et al. (2017) in their study of the tampering of the BBDs in Europe of Sporty Pop, a popular sports drink, where they aimed to better understand the range of the crime, the perpetrators and the skills, resources, and knowledge involved. They concluded that the fraudsters in the market were able to engage in the abuse and misuse “of an otherwise legitimate business transaction and an otherwise legitimate social/economic relationship in the food system” (Lord et al., 2017) due to their awareness of the ability to avoid legally prescribed procedures with the intent to gain personal and/or organizational advantage. The lack of a regulatory structure and oversight associated with NARTD beverage fraud, plus the lack of contractual obligations and industry self-regulation in this area of the market, provided ample opportunities for the fraud to occur with little risk of detection.

11.4 Detecting and responding to nonalcoholic ready to drink beverage fraud

The detection and response to food fraud requires a multifaceted approach that encompasses technical knowledge and effective quality assurance and food safety management.
systems (FSMSs); an understanding of the fraud risk and the role of risk management programs in understanding the context of the threat; effective crisis management; and an underpinning relationship with law enforcement, government stakeholders, and industry bodies.

This section discusses the technical elements of detecting and responding to NARTD beverage fraud, the role played by effective risk and crisis management programs, and mechanisms to enhance industry and government stakeholder collaboration. Collaboration throughout this process is critical to enable businesses to collectively prepare in a consistent and uniform way for the unexpected, through system-level thinking and activate partnerships with stakeholders (Prezelj and Doerfel, 2017).

11.4.1 Technical and food safety/quality assurance systems

Science, technology, and FSMSs together play a key role in the reduction of the NARTD fraud exposure in the marketplace. It is important to shift from the traditional quality and FSMS approach, which is not specifically designed to integrate with food fraud control and mitigation plans, to specific standards where fraud prevention and vulnerability reduction is a fundamental part of the management system. Some of the specific control measures to be considered are listed next:

- integration of the food defense program as standard part of the FSMS;
- regular validation of the entire food safety and defense management system with the aim to enhance the system robustness, to reduce the likelihood and the severity of food fraud;
- monitoring of the marketplace, introduction of trade sampling programs;
- efficient utilization of global food safety fraud information and trends;
- identification and mitigation of emerging risks across the supply chain; and
- close monitoring of raw and packaging material pricing and other economic drivers.

An example of implementation of the abovementioned control measures can be provided within the context of fruit juice. The European Fruit Juice Directive clearly defines fruit juice standards and processing requirements. However, due to price volatility within the market, the prevention of fruit juice adulteration requires specific analytical tests and effective end-to-end quality assurance systems in place. Juice is considered adulterated if a concentrate or not from concentrate juice contains an added substance (e.g., adulteration of pineapple juice concentrate with added apple juice or glucose syrup). Procurement and quality assurance departments can be trained and empowered to set up juice authenticity programs covering the entire scope from raw materials through finished product monitoring with a special focus on tracking the causes and frequency of substandard raw materials.

Some of the recommended preventive control measures for NARTD products against food fraud include:

- supplier quality management with a special focus on critical to quality performance tracking and data analysis;
• application of emerging risk models (e.g., for juice concentrates, flavors, or other NARTD ingredients);
• increased traceability compliance checks, verification within the routine and/or elevated supplier auditing schemes;
• external laboratory analysis of preshipped samples and comparison tests;
• enhanced incoming goods inspection as per supplier/commodity risk assessment;
• authenticity, trade quality monitoring programs; and
• application of enhanced analytics.

One of the analytical applications is the determination of the main isotopic and compositional parameters for authenticity and quality control of fruit juices, purees, and concentrates, flavors, and other NARTD ingredients. This process includes the analysis to check the authenticity and restoration of flavors lost during processing. These analyses can be completed by an analysis for pesticide or heavy metal residues.

Detection of adulterants is a complex and challenging aspect of food safety/quality assurance management systems for NARTD products. In most cases of analytical testing, the volatile compounds are first extracted and then the principle molecules present are identified and quantified using gas chromatography—mass spectrometry (GC–MS). GC–MS is an analytical method that combines the features of gas chromatography and mass spectrometry to identify multiple substances within a test sample. The resulting profile is compared to a reference database established from authentic samples. Certain target molecules are also analyzed by chiral chromatography. Chiral column chromatography is a variant of column chromatography that is employed for the separation of optical isomers (with mass spectrometry detection) in order to determine whether their enantiomeric distribution is consistent with data obtained on authentic fruit juice or flavor samples or whether synthetic compounds are present.

Nuclear magnetic resonance—based screening method can be used for evaluating the quality and authenticity of fruit juices by the measurement of a single data set (Sure Global Fair—SGF profiling). In contrast to other methods such as GC–MS, it is a rapid method that allows screening for several types of adulteration (including falsely declared origin) within one measurement. This analytical method has the potential to be used on a routine basis for raw juice products testing by substituting some of the conventional analysis. Instead of performing the full range of methods, it can be combined with additional techniques to reduce cost and time to detection. The disadvantage is that as a screening method it may have an elevated detection limit for certain adulterants in comparison with most of the conventional methods. Therefore it is recommended for first screen analysis, followed by additional testing of suspect samples.

In addition to the challenges of detection, another area of concern for NARTD beverage fraud is in the design of tamper-evident packaging. Due to the incremental pressure on economic profitability margins and the evolution of sustainability requirements, such as reduction of end-to-end carbon footprint, the demand for manufacturing best-in-class lightweight packaging materials has significantly increased. At the same time, the design of robust (1) tamper-resistant and (2) tamper-evident packaging solutions, such as tamper-evident plastic closures (PCO), has not developed significantly since the late 1980s. As a result, it is becoming increasingly technologically challenging to meet the lightweight packaging goals and at the same time meet the incremental tamper-evident robustness
standards. These dynamics in parallel with the increasing trend of food fraud pose a con-
tinued challenge for food and beverage engineers and quality assurance specialists. An example of the above is illustrated with the comparison of the plastic closures used frequently used across the beverage industry (Table 11.1). PCO, metal crowns, and screw caps are also frequently subject to counterfeit associated with NARTD products, where copies of popular beverage products are filled and capped with lower quality or insufficient materials (Table 11.2).

<table>
<thead>
<tr>
<th>Beverage type</th>
<th>Sparkling soft drink</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plastic closure system</strong></td>
<td>“Old generation” PCO 1810</td>
<td>“New generation” PCO 1881</td>
</tr>
<tr>
<td><strong>Closure weight (g)</strong></td>
<td>≥ 3.0</td>
<td>≤ 2.0</td>
</tr>
<tr>
<td><strong>Tamper-evident feature</strong></td>
<td>The closures are positioned mechanically and a seal through plastic bridges needs to be broken in order to open them, which leaves an obvious visual indication that the bottle has been opened. Same concept in the 1980s versus current.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>PCO 1810</strong></th>
<th><strong>PCO 1881</strong></th>
<th><strong>Old generation PCO</strong></th>
<th><strong>New generation PCO, e.g., 2925</strong></th>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Recommended preventive control measures</th>
</tr>
</thead>
</table>
| Plastic closures, metal crowns, screw caps, and labels | • Monitor marketplace  
• Tamper-evident (TE) performance assessment validated by frequent ring tests  
• Review of TE standards and calibrate technical expert group  
• Trademark identifiable (print, embossment)  
• Critical to apply and trace controlled disposal of trademarked materials  
• Consistent focus on consumer/customer education, call–lines  
• Radio-frequency identification (RFID) technology application on labels and/or primary packaging is expected to play a dominant role in the future food defense technical solutions |
11.4.2 Risk management’s role in NARTD food fraud response

Globally, the business operating environment is complex, and the ability to understand exposures, including those relating to food fraud in the non-alcoholic-ready-to-drink (NARTD) category, is critical for managers at all levels of an organization. Risk management is a process that assists in navigating ambiguity, volatility, and uncertainty, with an objective of minimizing the downside of an uncertain event while leveraging potential growth elements that might exist. The process assists us in understanding threats to the business, enabling management to implement programs that raise awareness of a specific risk (e.g., counterfeiting of NARTD products) and then implement strategies to minimize the occurrence or impact of the risk. A risk management program, as an element of a company’s business resilience strategy, must be supported by a robust crisis management program that, when activated effectively, minimizes the financial and reputational damage to a business should an incident of food fraud occur with a NARTD product.

Risk management is a pivotal component of business resilience. It resides within a three-dimensional model that encompasses the following elements of a business: (1) risks in the operating environment and processes to manage risk, (2) governance and accountability structures, and (3) best practices for crisis preparedness and response (Gius et al., 2018). Enterprise risk management (ERM) is the program that enhances the traditional approaches to risk management by bringing them out of functional silos, thereby enhancing the visibility not only of the risks themselves but also of the controls and management actions applied to manage those risks. It is argued that ERM leads to enhanced business management, organizational effectiveness, improved business performance, and increased business value and assists in the identification of potential crisis scenarios (Gates et al., 2012; Gorzeń-Mitka, 2013). By way of example, improved business performance and value can be attained by understanding our own vulnerabilities with respect to food fraud risk in the NARTD sector, as well as the opportunities observed by those entities and actors wishing to manipulate systems in order to achieve economic gain at the expense of the consumer (e.g., substituting ingredients to reduce cost and increase profit).

It is critical to note that risk is neither static nor objective, but is constantly constructed and negotiated (Gephart et al., 2009). The integration of a risk management process across business streams assists in ensuring that managers have a system that guides them in the management of uncertainty and “predictable surprises.” The process addresses an issue observed by Watkins and Bazerker (2003) whereby “lapses in recognition occur when leaders remain oblivious to an emerging threat or problem—a lack of attention that can plague even the most skilled executive.”

The reality is that food fraud in the NARTD sector is a specific risk category that may not be either visible or understood by management within a business without a program that raises the risk dialog. As discussed in the vulnerability section, the risks can be varied and range from counterfeiting to intentional use of substandard ingredients during production. In addition, the visibility of the nature of the risks and the appropriate mitigation strategies are dependent on adhering to sound risk methodologies.

Generically, a successful ERM program requires documented frameworks and structure which in process management terms are the ostensive routines which when performed correctly (the performative aspect of the routine), guide business leaders in their understanding
and response to risk. This requires a prevailing cultural mindset shift from one that sees management purely considering potential losses to thinking about the potential gains that can be attained from an effective risk response. This requires the processes and routines that imbed ERM into all areas of the business resulting in timely discussions within the operations and in specialized functional streams. Effective routine utilization enables us to catalog risks against the underlying risk parameters. In the area of food fraud in NARTD, this requires us to ensure that the dialog of the risk extends across the business streams, for the response will be driven by the nature of the exposure and point of occurrence. The overall challenge is to raise awareness of the NARTD risk, with the relevant internal stakeholders, who may not otherwise understand either the scale or complexity of food fraud in this product category. The process provides us with the capability to enhance through risk dialog management understanding of the multiple dynamics driving the NARTD food fraud threat. The threats in many instances are externally driven through the activities of suppliers, wholesalers, customers, and criminal gangs with the risk analysis providing an understanding of the potential enablers and the interrelationships that support the manifestation of the risk.

Ultimately, when applied correctly ERM enhances management awareness though casting a focus on risk visibility which is then supported by the implementation of effective early warning mechanisms that create the linkage with crisis management. An example of an early warning mechanism is the utilization of customer care centers for NARTD products. These provide the consumer with the ability to escalate concerns relating to quality directly to the company. This information is analyzed against risk criteria to identify the nature of the issue and category of risk within which the concern resides (e.g., a general quality issue or food fraud related), and this determines the nature of the response. Through the understanding of risks, the early warning mechanisms aid the identification of unexpected events that can become a threat to organizational survival if they exceed a certain temporal and spatial scale (Linnenluecke and Griffiths, 2010). “Effective threat recognition is, however, often inhibited by paradigm blindness, where decision makers deny the plausibility of particular threats and fail to develop appropriate mitigation strategies” (Fischbacher-Smith, 2014). ERM enables risk identification and mitigation to occur and assist in responding to paradigm blindness, particularly as it relates to food fraud with NARTD products.

11.4.3 The role of crisis management in responding to food fraud

Businesses in the NARTD sector cannot eliminate all risks, and there will invariably be occasions when an incident will occur that has the potential to damage the business both reputationally and financially. Food fraud, be it counterfeiting or the use of adulterated raw materials that cause illness to consumers, can all create a business crisis. This is where robust crisis management processes and capabilities provide a critical response element. Indeed, Watkins and Bazerman (2003) confirmed the linkage between risk management and crisis management as there is a need to be cognizant of the sequence that involves “recognizing the threat, to making it a priority in the organization, to actually mobilizing the resources required to stop it” and this awareness of potential crisis situations through ERM is a critical first step.
Research has confirmed (Knight, 2019) the critical role of a crisis team, the importance of the ostensive routines, and the need to minimize process deviation. The research confirmed that core contributors to process deviation from the ostensive routines included weakness in the crisis management team’s construction and cohesion, their level of experience, and the capabilities of the crisis leader. The ostensive routines and the associated artifacts used in a business context were evaluated as appropriate and value adding and confirmed that human intervention, interpretation, and behavior create the deviations. The importance of routines is illustrated by the fact that when a stakeholder raises a health concern about the integrity of a NARTD product, it is imperative that the correct analysis occurs. If process is not followed, the risk is that the crisis team will fail to identify the correct issue, which complicates the response, and potentially exposes other consumers to risk. Therefore the routines and the associated artifacts create a foundation for the crisis response. The artifacts linked to an ostensive routine enable a crisis team to avoid pitfalls by providing the guidance, framework, and lens on which to base informed action.

According to the research conducted by Knight (2019), crisis response deficiencies in a business crisis team’s structure and the capabilities of the crisis leader can lead to process deviation. It confirmed that the composition of the crisis management team and the skills that they possess need to be leveraged in order to minimize process deviation to ensure that the correct problem is solved. This included ensuring that the selection of crisis team members be based not on a model that focuses position/role held and seniority, but rather the skill sets and the demonstrated ability of an individual during a crisis.

Leadership and construct of crisis teams is an important aspect of crisis management. In respect to team construct, King (2002) concluded that not all teams are effective, and cohesion can be influenced by factors, including time, information resources, procedural conflict, poor leadership, and prior interactions. It is also important to consider the attributes of the managers who will comprise the team and when we look at who should be a member. Smits and Ezzat (2003) argued that members of a crisis team must be dependable, calm, self-confident, and assertive, with personalities that have the ability to influence perception and decision-making. Further, Crandall et al (2014) argue that the members must have the ability to work as a team; be able to work under pressure; have a tolerance for ambiguity; and possess good listening and verbal skills, which, when present and combined, strengthen the team’s capability.

Building on team construct is the importance of team leadership. Numerous authors noted that it is difficult to dispute the impact of weak leadership and its translation to ineffective team performance within a crisis context (Owen, 2008; Smith, 1990, 2000; Turner, 1976). This deficiency and its adverse impact on the response have been observed by the authors in several NARTD crisis responses. Therefore it is a necessity for businesses to formalize the process of the identification and selection of the crisis team leader. This critical position cannot be based on position or seniority but rather on experience and exposure to crisis situations. It is important to note that “successful management” of a crisis may not necessarily equate to successful resolution, for this can often be outside a crisis leader’s control. Instead, the focus should be on the way the crisis leader approaches the crisis response and the strategies applied to minimize process deviation.

Within elements of the NARTD sector, we are observing changes in the approach to team structure and leadership. Consideration of the skills and attributes required, together
with the role that personality plays, can help in building an effective crisis team. It is also important to utilize a team selection model that is not based purely on role and seniority. Then, through the provision of ongoing training together with exposure to real-life experience, enhanced capabilities can be developed. Capabilities of the crisis team and its leader can be built through rehearsals, with a central requirement being that simulated rehearsals are realistic and occur on a regular basis. Ultimately, training is paramount in building a team’s capability in the use of the artifacts and confidence in their contribution to the crisis response.

Why is crisis management of specific importance to the NARTD sector? It arises from the fact that the industry produces significant volumes that reach a consumer relatively quickly. An issue with a brand that has been manipulated through food fraud has the potential to impact the health of consumers. In cases where a brand responds poorly to the issue, damage to public health, reputation, and finances can be significant, with brand trust and loyalty impacted. By understanding what constitutes an effective crisis team, we can build understanding of the risks and strengthen our crisis response. This ultimately contributes to an organization’s resilience and ongoing viability.

11.4.4 Law enforcement and industry collaboration

Stakeholder collaboration is a central mitigation pillar within an effective risk management program. This includes partnerships and collaborations across industry sectors and governments. One of the challenges facing businesses is the fact that food fraud is a concept that has traditionally been poorly conceptualized and failed to gain currency as a major global policy issue (Lord et al., 2017). In more recent times a shift in this position is starting to occur and this has been driven by effective stakeholder engagement with law enforcement, governments, and policy makers. To be successful in this space, businesses that understand the risk have a proactive strategy to engage individually and collectively with stakeholders, particularly local and international law enforcement, together with key policy makers. This section outlines an approach that is being leveraged to enhance conceptualization and understanding.

Globally, an example of a law enforcement response toward food fraud is Operation Opson (Interpol, 2020), which is a program coordinated by Interpol with local implementation by law enforcement agencies, such as police and customs, within jurisdictions. As reported by Interpol, the legal scope and framework encompasses both counterfeit and substandard food and beverages. In respect to beverages, they are defined as drinkable liquids, which are liquids intended or reasonably expected to be ingested by humans or animals. A counterfeit food/beverage product is a product infringing on an Intellectual Property Right as defined under national and European law and a substandard food/beverage product as a product that does not meet the criteria required by European and national laws regarding its production, packaging, storage, and distribution.

Operation Opson, which was first conducted jointly in 2012 by Europol and Interpol, established the framework for what is now a regular investigative event. The results from Operation Opson VIII conducted between December 1, 2018 and the end of April 2019, covered 78 countries and resulted in the seizure of €100 million of potentially dangerous
food and drinks. This included 16,000 tonnes and 33 million litres (L) of products and the arrest of 672 individuals (Europol, 2019). Illustrating the NARTD risk, Opson VIII resulted in Zimbabwean authorities seizing nearly 14,000 L of soft drinks that were for sale, with these products containing high levels of an active ingredient used in erectile dysfunction medication, a situation that created a significant health risk to unsuspecting consumers (Interpol, 2019). In addition, the law enforcement analysis from the previous operation OPSON VII indicated that 85,261.9 L of NARTD beverages were seized during those investigations (Interpol, 2018). Law enforcement, however, cannot do this alone, and effective collaboration with business at the global and local levels is a critical component. Understanding the importance of this dynamic, companies and industry bodies have been actively engaged with Interpol in the training of law enforcement investigators to build awareness and enhance collaboration in the management of the risk. On a local level, business also engages with law enforcement to assist in identification of fraudulent goods and support specialized investigations into offenses such as counterfeiting.

Another example of stakeholder’s collaboration to combat counterfeiting, which is a specific subset of food fraud, is the industry alliance Together Against Counterfeiting. This alliance, based in Europe, brings together over 90 companies across many industrial sectors (including beverages, chemicals, toys, and pharmaceuticals) and is supported by over twenty trade associations and NGOs. The objective of the alliance is to raise awareness among European decision and policy makers as to the dangers of counterfeiting and to encourage the adoption of legislative measures that help curb the proliferation of fake goods. Counterfeiting in NARTD is particularly dangerous due to the health and safety risks to the consumer from the consumption of products that are of inferior quality or manufactured in a way that makes their consumption harmful to the end user. The establishment of collaborative bodies such as these, that draw together diverse industry stakeholders, creates momentum and scale. When combined with the high-profile work of law enforcement, the NARTD industry can enhance the political awareness of food fraud as a major global issue.

11.5 Conclusion

In conclusion, food fraud within the NARTD category will continue to proliferate in the coming years as fraudsters attempt to take advantage of vulnerabilities in this economically important sector. The vulnerabilities are multifaceted in nature and cover a spectrum that incorporates counterfeiting, adulteration of the raw materials, and selling products after their “best before” dates. As the risk is multifaceted, the detection and response to NARTD food fraud needs to be dynamic, flexible, and risk based. There is no one-size-fits-all approach and it is critical that those engaged in the fight leverage technical know-how, implement effective quality assurance, and food safety system systems, as well as develop underpinning risk management protocols that enable stakeholders to understand and respond to the risks proactively. Ultimately, none of us can approach this issue in isolation and industry and government collaboration remains a critical pillar in the fight against food fraud, which at the end of the day, is a battle to protect the health and well-being of consumers.
11. Fraud in nonalcoholic ready to drink products

References


Interpol, 2019. I illicit Food and Drink Seized in Global Operation.

Interpol, 2020. Operation Opson Removes Counterfeit and Substandard Food and Drinks From the Market.


12

Fraud in wine and other alcoholic beverages

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12.1 Introduction

Wine is an alcoholic beverage that is made by fermenting grapes or other fruits (Prakitchaiwattana and Tananuwong, 2012). Many different grape varieties grown in various regions of the world are used in wine production, resulting in a wide range of wines available for consumers. Some of the most popular wines consumed worldwide include Cabernet Sauvignon, Merlot, and Chardonnay (Wine Folly, 2019). The flavor and aroma of wines is influenced by a number of factors, including the way in which the grapes are grown, the
climate and region in which they are grown, the fermentation process, and the aging process (Prakitchaiwattana and Tananuwong, 2012). The European Union (EU) is a major global producer of wine, with about 15 billion L of wine produced in 2018 (Eurostat, 2019). In 2018, 28 countries within the EU imported €13.4 billion of wine and exported €22.7 billion (Eurostat, 2019). The top wine-producing countries in the EU are France, Italy, and Spain. While the EU accounts for 60% of the world’s wine production, other countries, including the United States, Argentina, Australia, and Chile, are major wine producers as well (Forbes, 2019). The United States ranks fourth globally among wine-producing countries, with approximately 3.4 billion L of wine produced in 2017 (Wine America, 2019). The top wine-consuming countries worldwide include the United States, France, and Italy (OIV, 2019).

Wine and other alcoholic beverages are susceptible to fraud due to several factors, including their complex nature, global supply chains, high market value, and variability in pricing (Magnusdottir et al., 2010; Alañón et al., 2015). For example, wine is a major target for fraud due to the high prices at which it can be sold (Alañón et al., 2015). Fraud can occur during many points of the wine making process and throughout the supply chain. Wine can be adulterated in terms of the type of grapes used, the ageing process, mixing of ingredients, and even the labeling of the bottle. Due to consumer demand for fine wines and extensive global trade of this commodity, the exact point of adulteration may be difficult to detect. It is also often difficult to detect adulteration in wine because there are so many factors that can influence the composition. Searching for a possible adulterant may be time consuming and can be expensive if many different tests are required (Alañón et al., 2015).

Other types of alcoholic beverages susceptible to adulteration include vodka, rum, and whiskey (Kuballa et al., 2018). These alcoholic beverages are largely susceptible to adulteration due to their high profit margins. Vodka is one of the most susceptible alcoholic beverages to fraud (Food Standards Agency, 2017). Its colorless and odorless nature makes it susceptible to substitution with harmful ingredients such as those used to make antifreeze, disinfectants, and fuel (Lord et al., 2017). Vodka is often consumed with mixers that can mask the taste or odor of a fraudulent substance.

The focus of this chapter will be on wine fraud, with some discussion of fraud associated with other alcoholic beverages. The objectives of this review are to discuss the history of fraud associated with wine and other alcoholic beverages, factors that make wine and other alcoholic beverages susceptible to adulteration, explain the various forms of fraud, and discuss the main adulterant detection methods.

### 12.2 History of fraud

Wine adulteration dates back thousands of years to the Roman Empire (Eisinger, 1982). As the production of wine increased to meet consumer demands, Roman winemakers started using a preservative known as sapa to keep the wine from spoiling (Eisinger, 1982). Sapa was made by boiling unfermented grape juice in a lead pot until the remaining volume was measured to be one-third of the original volume of unfermented grape juice (Eisinger, 1982). The sapa preserved the wine because of its high lead content (Eisinger, 1982). Not only was the sapa found to be an effective preservative, but consumers liked the taste because it was sweet, enhanced the color of the wine, and had an
appealing fragrance (Eisinger, 1982). However, sapa caused chronic lead poisoning and led to an illness known as colic (Holmberg, 2010). The effects of developing colic included interference with the central nervous system and, in severe cases, paralysis (Eisinger, 1982). It has been estimated that the wines the Romans were consuming contained up to 80 mg/L of lead, while chronic lead poisoning can be caused by exposure to 0.5 mg/day (Eisinger, 1982; Holmberg, 2010).

Another type of historically common adulteration was inconspicuously mixing different wines together, whether they are outdated or unacceptable for consumption, and selling them to consumers for the same price as pure wine (Holmberg, 2010). This type of fraud was common in England in the 14th century. The mixing of wines was done in such a way that the consumer could not see the taverner pouring the wine, so they did not know if the wine was fresh or mixed. King Edward III became aware of this adulteration and required the taverners to serve the wine in such a way that consumers would have clear visibility of the wine being dispensed directly from wine barrels (Holmberg, 2010).

Early history also showed that beer was being adulterated by brewers (Downey, 2016). Brewers were manufacturing batches of beer with inexpensive ingredients such as poisonous plants and oat malt. Ingredients such as aloe, wormwood, and picrotoxin were used as substitutes for hops. In 1516 the German beer law was instituted which required brewers to use only water, barley malt, hops, and yeast in the beer making process (Downey, 2016). This law was created to ensure the safety and integrity of the beer made in the future.

Fraud in other alcoholic beverages has also occurred historically due to excessive taxing or federal restrictions. During the prohibition on alcoholic beverages in the United States (1920–33), counterfeit alcohol was the only available option for consumers and it often contained industrial chemicals not fit for consumption (Tobiassen, 2014). China has historically placed high taxes on alcohol with the goal of increasing funds for the country. In 1984 grain spirits were taxed 50% and potato spirits were taxed 40% (Xu and Yong-guang, 2015). Instead of paying these excessive taxes, consumers would purchase counterfeit alcohol sold on black markets.

### 12.3 Forms of adulteration

An estimated 5% of the wine that is sold through the secondary market is adulterated (Fahrni et al., 2015). The supply chain of wine is complex and there are many points in the supply chain in which adulteration can happen. Adulteration of wine can occur through the addition of additives such as sweeteners, blending different wines or grapes, or by mislabeling the product (Holmberg, 2010). Adulterating wine is illegal and can have consequences for the company or winery performing the adulteration, can result in consumer mistrust of the industry, and can have harmful effects on the health of the public. Other alcoholic beverages may be adulterated by mislabeling, using ingredients from different origins, and the addition of ethanol and methanol (Kamiloglu, 2018).
12.3.1 Use of additives

Additives have been used in the past to enhance or improve the flavor of the wine or to mask the presence of other adulterants. Historical incidents show the addition of lead as a preservative and sugar to increase the sweetness of the wine (Holmberg, 2010). Additives such as diethylene glycol have been used to disguise the addition of sugars to a wine so that it is difficult to detect the adulteration with analytical methods (Moore et al., 2012). Diethylene glycol is an industrial chemical often used in manufacturing plasticizers and can result in poor health outcomes if ingested (Moore et al., 2012). An example of a large impact that diethylene glycol had in the wine industry occurred in Austria in 1985 (Moore et al., 2012). Over 70 winemakers were found to be adulterating their wines with diethylene glycol (Holmberg, 2010). The adulterant was added because it was easily available and allowed for winemakers to mask the addition of sugars to their wine. The impact of this incident expanded over 10 countries and diminished Austrian wine exports (Moore et al., 2012). Health effects of ingesting diethylene glycol include gastrointestinal pain, injury to the kidneys, nervous system impairment, and, in some cases, death (Schep et al., 2009). After the adulterant was found in Austrian wines, other wines also tested positive for diethylene glycol leading to the conclusion that other wines had been mixed with the Austrian wine (Holmberg, 2010). The diethylene glycol made it possible for winemakers to conceal their acts of adulteration from consumers, but once the industry was made aware of the adulterant, analytical methods could be targeted specifically toward diethylene glycol. Following this adulteration event, regulations within the Austrian wine industry were severely tightened.

In 2009 Her Majesty’s Revenue and Customs (HMRC) in the United Kingdom carried out raids and seized 9000 bottles of fake vodka that was branded as Glen’s Vodka (Independent, 2011). These bottles were distributed to independent shops throughout Britain. In addition to containing counterfeit labels, the vodka was also found to have high levels of methanol. Consumption of high amounts of methanol can cause headaches, muscle pain, blindness, and even death (OEHHA, 2012). When HMRC raided the unit, they found 25,000 L of methylated spirits (Independent, 2011). Due to the purple color of methylated spirits, bleach was used. This only increased health hazards since bleach is poisonous when ingested. The revenue loss for this raid was £1.5 million (Independent, 2011).

12.3.2 Blending of varieties

Illegal blending of wines can take the form of mixing wines that have already been made by other companies or blending of undeclared grape varieties. Counterfeitors have often adulterated wine by mixing less expensive wines and selling them as more valuable wines with popular brand names. In 2008 wine made by the Consorzio del Vino Brunello di Montalcino in Italy was found to be adulterated by mixing grape varieties (Cavicchi et al., 2010). In this region of Italy, there were 250 wine producers producing Brunello wines. If a wine producer chooses to produce Brunello wines, they must produce them with Brunello grapes. The adulterated wines were suspected to be produced from a mixture of grapes such as Merlot, Cabernet Sauvignon, and Petit Verdot (Cavicchi et al., 2010). The Brunello wines were so high in demand and price that wine producers saw it as an
opportunity to make an extra profit. The adulteration was detected by an investigation conducted by the Italian authorities. Unfortunately, this adulteration event led to a loss of consumer trust in the Brunello wine industry.

12.3.3 Mislabling

Mislabling is the most common type of fraud associated with wine. Labeling of wine in the United States is regulated by the Alcohol and Tobacco Tax and Trade Bureau (TTB, 2015). Wine labels must include information such as the brand name, the percentage of alcohol content, and the place of origin (TTB, 2015). Wine mislabeling is common among counterfeiters because the labels can be manipulated to reflect popular brands, rare vintages, or origin.

In 2014 a man named Rudy Kurniawan was arrested in the United States for producing counterfeit wine in his own home (USAO-New York Southern, 2015). Kurniawan was popular among the collectors of rare wine so when he presented rare vintages for sale, collectors did not hesitate to claim the product for their collection. After suspicions from winemakers and collectors of the vintages he was selling, the Federal Bureau of Investigation (FBI) (2014) led an investigation into his suspicious behavior and raided his home. The FBI found lower quality wines that Kurniawan had been mixing to imitate the flavor of expensive and rare wines. Kurniawan had made his own labels with well-known brands, popular origins, rare vintages, and even vintages that were never made by winemakers. His knowledge of rare wines allowed him to produce his own labels and earn over $30 million through defrauding buyers. Kurniawan was sentenced to a 10-year prison term, had to forfeit $20 million, and paid $28.4 million to his victims (L.A. Times, 2014).

Counterfeiters have become highly skilled at creating labels that look almost indistinguishable from the real products. Often, counterfeit bottles may go undetected because the labels and craftsmanship of the bottle look so similar to that of the real product. In 2015 Italian police discovered over 9200 bottles of counterfeit sparkling table wine labeled as Moet & Chandon champagne. The fraud became apparent as an official was investigating a different case and noticed that the label on one of the bottles did not have a serial number (Miller and Lavanga, 2016). The resulting investigation led them to a shed which contained counterfeit champagne bottles worth $380,000 and 40,000 labels which, if sold, would have amounted to $1.9 million dollars.

Mislabling is not only unique to wine, instances of counterfeit products can be found in other types of alcohol. Counterfeiters often find success in mislabeling fine alcohols that are limited in supply and in high demand, such as Pappy Van Winkle, a bourbon whiskey. This whiskey has been found to sell for $100 an ounce and counterfeiters have realized that they can buy empty bottles of Pappy Van Winkle on sites such as eBay and fill it with another whiskey such as Old Fitzgerald to profit as much as $1500 per bottle (Lyons, 2016). This whiskey is so sought after because it involves an aging process of up to 15–23 years. The supply is difficult to gauge because producers cannot foresee how the inventory will sell two decades from when the production process begins. The limited supply increases the value of the product and consumer demand.
12.4 Summary of database entries

The Decernis Food Fraud Database and Food Protection and Defense Institute (FPDI) (Foodshield) Food Adulteration Incidents Registry were reviewed to observe the occurrence of adulteration in alcoholic beverages over recent years (Table 12.1). Among the 354 incidents of alcoholic beverage fraud between 1980 and 2019 recorded in the Decernis Food Fraud Database, the top three adulterated beverages were vodka, whiskey, and wine. The top countries with reported cases of adulteration were China, India, Italy, the United Kingdom, and France.

<table>
<thead>
<tr>
<th>Geographic location</th>
<th>Year(s)</th>
<th>Type of fraud committed</th>
<th>Brief description of incident</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Italy</td>
<td>2020</td>
<td>Geographic origin misrepresentation, artificial enhancement with colors</td>
<td>Large quantities of sugar and additives were used to make fake Oltrepo Pavese DOC (PDO) and PGI wines. Lower quality wines were sold as premium Italian wines.</td>
<td>Meininger’s Wine Business International, 2020. Italian police uncover major wine fraud. Accessible from: <a href="https://www.wine-business-international.com/wine/news/italian-police-uncover-major-wine-fraud">https://www.wine-business-international.com/wine/news/italian-police-uncover-major-wine-fraud</a> (accessed 03.12.20.)</td>
</tr>
<tr>
<td>Taiwan</td>
<td>2010–15</td>
<td>Counterfeit</td>
<td>A company in Taiwan rebottled bulk wines from Spain and Chile and labeled them as French with replicated labels.</td>
<td>The Drinks Business, 2015. 30,000 bottles of fake wine seized in Taiwan. Accessible from: <a href="https://www.thedrinksbusiness.com/2015/03/30000-bottles-of-fake-wine-seized-in-taiwan/">https://www.thedrinksbusiness.com/2015/03/30000-bottles-of-fake-wine-seized-in-taiwan/</a> (accessed 03.08.20.)</td>
</tr>
<tr>
<td>East Asia, China</td>
<td>2007–10</td>
<td>Counterfeit, Substitution</td>
<td>Counterfeit Mont Tauch Fitou AOC wine was made with low-quality wine from South America. Authorities were alerted because the price of the wine was low.</td>
<td>Decanter, 2010. Mont Tauch targeted by Chinese counterfeiters. Accessible from: <a href="http://www.decanter.com/wine-news/mont-tauch-targeted-by-chinese-counterfeiters-59943/">http://www.decanter.com/wine-news/mont-tauch-targeted-by-chinese-counterfeiters-59943/</a> (accessed 03.08.20.)</td>
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<tr>
<th>Geographic location</th>
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<th>Type of fraud committed</th>
<th>Brief description of incident</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Oceania, Australia</td>
<td>2003–10</td>
<td>Substitution</td>
<td>Less expensive grapes were used to make Chardonnay</td>
<td>Decanter, 2010. Six arrested in Australian wine fraud. Accessible from: <a href="https://www.decanter.com/wine-news/six-arrested-in-australian-wine-fraud-59499/">https://www.decanter.com/wine-news/six-arrested-in-australian-wine-fraud-59499/</a> (accessed 03.08.20.)</td>
</tr>
<tr>
<td>Western Europe, Denmark</td>
<td>2007–09</td>
<td>Counterfeit, Dilution</td>
<td>Castello Venezi Amarone wine was diluted with up to 60% inexpensive French table wine.</td>
<td>NRK, 2009. Discovered fake Amarone in the wine shelves. Accessible from: <a href="https://www.nrk.no/urix/oppdaget-falsk-amarone-i-vinhyllene-1.6855178">https://www.nrk.no/urix/oppdaget-falsk-amarone-i-vinhyllene-1.6855178</a> (accessed 03.08.20.)</td>
</tr>
<tr>
<td>Western Europe, Italy</td>
<td>2008</td>
<td>Dilution</td>
<td>Tuscan wine and wine from other regions were blended and sold with false public documents of production, wine standards, and tax bills.</td>
<td>Decanter, 2009. Adulteration scandal surfaces in Tuscany. Accessible from: <a href="https://www.decanter.com/wine-news/adulteration-scandal-surfaces-in-tuscany-62442/">https://www.decanter.com/wine-news/adulteration-scandal-surfaces-in-tuscany-62442/</a> (accessed 03.08.20.)</td>
</tr>
<tr>
<td>Western Europe, Italy</td>
<td>2008</td>
<td>Artificial enhancement</td>
<td>Wine was adulterated with sugar, sulfuric acid, and hydrochloric acid to adjust pH and sweetness. Only 1/5 of the wine originated from grapes.</td>
<td>Italy Magazine, 2008. Italian wine safe to drink, Brussels says. Accessible from: <a href="https://www.italymagazine.com/italy/food-drink/italian-wine-safe-drink-brussels-says">https://www.italymagazine.com/italy/food-drink/italian-wine-safe-drink-brussels-says</a> (accessed 03.08.20.)</td>
</tr>
<tr>
<td>Western Europe, France; Western Europe, Belgium</td>
<td>Unknown–2002</td>
<td>Counterfeit, Dilution</td>
<td>Bordeaux wine was diluted with other vintages and geographic origins.</td>
<td>The Guardian, 2002. Top French wine diluted and sold with fake labels. Accessible from: <a href="https://www.theguardian.com/world/2002/feb/24/paulwebster.theobserver1">https://www.theguardian.com/world/2002/feb/24/paulwebster.theobserver1</a> (accessed 03.08.20.)</td>
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(Continued)
Common types of alcoholic beverage fraud found through the reviewed cases were substitution, dilution, and counterfeiting. In many cases, cheaper ingredients were used to make alcoholic beverages and the fraudulent beverages were sold as popular and expensive brands. Oftentimes, the less expensive ingredients also presented a threat to public health. For example, methanol was used as an adulterant in numerous reported incidents of fraud.

### 12.5 Regulations

Regulations on alcoholic beverages are necessary to help protect the public from fraud and the risk to public health (TTB, 2015). These include regulations on labeling of wine and other alcoholic beverages, as well as imports and exports (TTB, 2015).

#### 12.5.1 United States Regulations

The Code of Federal Regulations (CFR) Title 27 Subchapter A addresses the labeling and advertising of alcoholic beverages, including standards of identity (CFR, 2019). These
include sections on the labeling and advertising of wine (27 CFR § 4), distilled spirits (27 CFR § 5), and malt beverages (27 CFR § 7). With regards to wine the percent alcohol by volume is set at 7%–24% by the Revenue Act of 1918 (27 CFR § 4). Multiple grape varieties can be used in the name as long as the origin of grape is included in the wine label. The name of a single grape variety can be used if the wine is composed of 75% or more of that variety of grape. The entire 75% must be grown in the origin named on the wine label. Laws can differ for each state. For example, Oregon requires the declared grape variety to be present at a concentration of at least 90%, except for Cabernet Sauvignon which is 75%. All wines produced in the United States must also contain the Surgeon General’s warning about dangers associated with alcohol consumption and a warning about sulfites (CFR, 2019).

The TTB can take action against any alcoholic product that they find fraudulent. Noncompliance can result in a payment of penalties or a felony under a law of the United States (CFR, 2019). The TTB oversees alcoholic beverage laws, regulations, and imports and exports. For example, the facility where wine will be produced needs to be approved by a TTB officer to ensure that the operations are suitable for the intended purpose. The tanks used to process or store wine need to have the contents marked on the tank, barrel, or bulk container used. At the beginning of the fermentation process, only water, sugar, concentrated fruit juice, malo-lactic bacteria, yeast, sterilizing agents, and precipitating agents can be added (CFR, 2019). This is to ensure a natural wine production. If the natural grape wine has a low sugar content, pure dry sugar or a concentrated grape juice can be added to develop the alcohol. The quantity of the sugar or concentrated juice should not increase the original density above 25 degrees Brix (CFR, 2019).

With regards to distilled spirits, 27 CFR § 5.23 states that addition of any coloring or blending material to any of the distilled spirits alters the class of the beverage and therefore it must be redesignated. Formula requirements are also listed for the various distilled spirits in 27 CFR § 5.27 as well as labeling requirements in 27 CFR §§ 5.31–5.32.

### 12.5.2 European Union Regulations

The member states of the EU account for nearly two-thirds of the world’s wine production (USDA-FAS, 2015). There are many regulations for wine produced in the EU surrounding its composition and labeling requirements. The Commission Implementing Regulation 1185/2012 is a labeling regulation that details rules on Protected Designations of Origin and Geographical Indications. Food Information to Consumers (FIC) Regulation 1169/2011 states that any mandatory information on the wine label must be printed using a minimum font size of 1.2 millimeters. An allergen label must also be printed at a minimum of 1.2 mm. If a wine has any allergens, the word “contains” must be listed before the product. According to the Single Market Regulation 1308/2013, mandatory information must be listed in one or more of the official languages of the EU. This language must be easily understood by the consumers where the wine will be marketed (USDA-FAS, 2015).

The EU regulates grape varieties that are used in wine. If the label indicates a single variety of wine, there must be a minimum of 85% of that variety (USDA-FAS, 2015). Some members of the EU have stricter regulations. According to the France Appellation d’Origine Controlee,
Riesling must contain 100% Riesling grapes. Geographical indication (GI) links products to where they are made (European Union, 2020). Product names containing a GI allow consumers to distinguish specific quality attributes of products. Three EU quality indicators include protected designation of origin (PDO), protected GI (PGI), and traditional speciality guaranteed (TSG). For a product to be labeled PDO, the product must be entirely manufactured within the specific region. For example, a wine with a PDO label means that the grapes came exclusively from the same geographical area where the wine was made. For a PGI label the product must have had at least one stage of production, processing, or preparation from that geographical region. This means that 85% of the grapes used for a wine must have come from the geographical area where the wine was made. A TSG label does not link a product to a specific geographical area, but rather it indicates that the product was produced or processed using traditional methods.

12.6 Methods of detection

There are numerous analytical detection methods available for the authentication of wine and other alcoholic beverages (Geana et al., 2016). These generally involve the use of specific marker compounds, measurement of stable isotope ratios, calorimetry, and/or chromatography (Geana et al., 2016; Li and Suslick, 2017). With regards to wine, many aspects of the product can be evaluated with detection methods, including origin, variety, and production method.

12.6.1 Stable isotope analysis

Stable isotope analysis can be used to identify various factors, including geographical origin, replacement, and dilution. For example, Geana et al. (2016) used stable isotope ratio data for carbon and oxygen to detect the addition of water and/or sugar. Carbon-13 analysis was done in ethanol and the oxygen-18 analysis was done in water. The addition of sugars can be detected using the carbon-13 analysis because grapes are C3 plants. Both sets of stable isotope data were compared with reference data from a wine databank consisting wine from the same geographical area. From the wine databank, authentic wines were characterized by $\delta^{13}C$ in the range of $-29.19\%$ to $-25.19\%$ and $\delta^{18}O$ between $0.71\%$ and $4.38\%$. Using the wine databank, 23 samples of authentic wine were compared with the 29 red wine samples in the study. Out of the 29 samples, 8 table wines were found to be adulterated, 7 wines contained added water, and 6 contained added sugar (Geana et al., 2016).

The use of stable isotope analysis is becoming increasingly important for the authentication of wine and other foods (Rossmann, 2001). This analysis can be done on grape juice before the wine making process and can also be used after the ageing process. Rossmann (2001) used the oxygen-18 value to analyze water in wine. Authentic juices have elevated oxygen-18 values compared to water from rediluted products because the rediluted products are made using tap water that has depleted oxygen isotopes. The levels of oxygen-18 and carbon-13 were compared with a wine databank from a specific German region and vintage. The results of the study found that at least half of the samples were mislabeled, with commercial wines...
found to contain mixtures of the authentic wines and less expensive southern European wines (Rossmann, 2001).

Stable isotope analysis is also used with alcoholic beverages, such as Scotch whiskey (Meier-Augenstein et al., 2012). Scotch whiskey must be produced in Scotland using Scottish water throughout production. This includes water that is added to the barley and water used to dilute the distilled alcohol. Therefore bulk $^2$H and $^{18}$O isotope analysis can be used to detect adulteration of Scotch whiskey by determining the geographical origin (Meier-Augenstein et al., 2012).

### 12.6.2 Chromatography

Chromatography is an analytical method that separates chemical compounds to find a unique composition (Cserhati et al., 2005). This method is used to authenticate high-quality products that may contain less expensive ingredients. For example, sweeteners and red dyes are sometimes used in adulterated wine to adjust the taste and color of the wine, respectively, after dilution with water (Geana et al., 2016). A study conducted by Geana et al. (2016) analyzed red wine samples for synthetic sweeteners and synthetic red dyes using chromatography. The sweeteners [acesulfame K, aspartame, saccharin, and 5-(hydroxymethyl)-2-furaldehyde] and red dyes (azorubine, erythrosine, and amaranth) were analyzed through chromatographic separation using a high-performance liquid chromatography system. Acesulfame K was detected in seven out of the eight adulterated table wine samples, while the other sweeteners were only found in one sample. One wine sample contained azorubine.

Chromatography can also be used to detect adulteration in other alcoholic beverages, including rum and vodka (Lachenmeier et al., 2003). Ion chromatography separates polar molecules and ions based on their affinity to the ion exchanger. In a study conducted by Lachenmeier et al. (2003), ion chromatography was used to analyze samples of vodka and white rum for adulteration. The anions of suspicious alcohol samples were compared to reference samples. The results of the study showed that four suspicious rums that were sold as Bacardi brand and three suspicious vodkas sold as Smirnoff brand were not authentic products. The anions of the suspicious samples for both vodka and rum samples were significantly higher than the anions of authentic Smirnoff vodka and Bacardi rum and showed greater similarity to a German vodka (Lachenmeier et al., 2003).

### 12.6.3 Trace metals

Some wines contain trace metals, such as manganese, copper, and iron (Vystavna et al., 2014). These trace metals may contaminate the wine during vine-growing steps, application of agricultural chemicals, or even during the wine making process. During winemaking the wine is in contact with equipment made of aluminum, brass, and other materials. Through extended contact, trace amounts can get into the wine. Vystavna et al. (2014) carried out a study to look at the Cu, Zn, Pb, Cr, and Ni accumulation in the soil, leaves, grapes, and irrigation water in Ukraine. Atomic adsorption spectroscopy and plasma atomic emission spectroscopy were used to analyze the samples. Cu, Pb, and Zn were found to accumulate at higher levels in the leaves than in the grapes. The pattern of trace
metals accumulation also differed among wines. Therefore, the presence of a trace element and its concentration can be used to determine the composition of the soil and grapevine (Vystavna et al., 2014).

Xiao-Hua et al. (2014) used lanthanides as chemical markers to determine geographical origin and traceability information for imported wines of different countries of origin. There are 15 lanthanide earth elements with atomic numbers 57 through 71. Inductively coupled plasma mass spectrometry was used to test the samples and the results were statistically analyzed. The authors of the study could not distinguish the characteristic elements in wine from Australia and Chile; however, they were able to identify the geographic origins of wine from Italy, Spain, France, and Argentina (Xiao-Hua et al., 2014).

12.6.4 Nuclear magnetic resonance

Proton nuclear magnetic resonance (¹H NMR) spectroscopy is an analytical method based on protons that provides a unique metabolic profile for a molecular compound (Versari et al., 2014). ¹H NMR can reveal characteristics of wine, including its grape variety and origin. Specific regions of the ¹H NMR spectra are compared between blended wines and monovarietal wines. This method is a precise and quick way to determine if a specific wine has been adulterated (Versari et al., 2014).

Spraul et al. (2015) used fully automated ¹H NMR spectroscopy to analyze various characteristics of wine, including the amount of anthocyanins, country, and vintage of the wine, by comparing data to base spectra from a wine databank. Classification analysis was done on three different wine samples: Bordeaux, Silvaner Gruner, and Tempranillo. The Bordeaux and Silvaner Gruner samples had spectra that were consistent with the classification results, showing proper labeling of these wines. The Tempranillo analysis found that the sample was mostly consistent with classification results. While Syrah was detected in the sample, the amount of Syrah detected was lower than the limit of assignment (Spraul et al., 2015).

12.6.5 Calorimetry

Calorimetry can be used to distinguish among several types of liquors, including vodka, bourbon, and whiskey (Li and Suslick, 2017). By testing vapor analysis of alcoholic beverages, a calorimetric sensor array made up of chemically responsive links can support quality assurance of liquors. The sensor spots change colors before and after exposure to the liquor vapors. The calorimetric sensor array also shows dilution of the liquors which can aid in the detection of adulteration (Li and Suslick, 2017).

12.7 Conclusion

Wine and other alcoholic beverages, such as vodka, rum, and whiskey, are susceptible to adulteration due to their extensive global supply chains, high market values, and
complex natures. Adulteration can take place at any point in the production or distribution process, making fraud difficult to trace. Some common types of fraud observed with alcoholic beverages include mislabeling, counterfeiting, dilution with water, and addition of inexpensive ingredients, such as sweeteners. There are numerous regulations in place globally to promote proper labeling of alcoholic beverages, including standards of identity and geographical origin designations. Detection methods, such as stable isotope analysis, have been developed to assist in detecting geographic origin, as well as the addition of sugar and water. Further research is needed into noninvasive methods for the authentication of rare and expensive wines. With advances in technology, sophisticated labeling methods may be used to prevent counterfeiting. For example, labels can be marked with ink visible only in UV light, making it more difficult to make counterfeit labels through scanning. Along with these advancements, stricter enforcement of regulations can assist in protecting the public against harmful substances and economic losses attributed to adulteration of alcoholic beverages. Due to the complex global supply chain of alcoholic beverages, it is essential that countries and agencies combine their efforts and resources to combat fraudulent activities.

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13.1 Introduction

Dairy products are consumed globally and are an important source of nutrition. Studies, however, have also found that relative to other foods, dairy products are rather susceptible to fraud. Dairy products broadly include milk and products derived...
While a majority of dairy products are produced from the milk of farm animals such as cows, buffaloes, goats, and sheep, in some geographic locations, milk from other species of animals such as camels, reindeer, moose, yaks, and mares can also be used. Dairy products include milk (liquid and concentrated milk) and products derived from milk such as milk powders, milk beverages, fermented dairy products such as cheese and yogurt, butter, cream, and ice cream (Burke et al., 2018; Papademas and Bintsis, 2010).

This chapter considers the issue of fraud in dairy products. We begin this discussion by considering features of the dairy industry, as well as the nutritional and economic value of dairy products. Taken together, these product and industry characteristics both provide incentive, and in some cases, opportunity for dairy fraud. In Section 13.2, an overview of the methods, causes, and consequences of dairy product fraud is presented. As part of this discussion, a study of the case of melamine adulteration of milk in China is presented. In Section 13.3 the analytical techniques and approaches that can be used to detect fraud in dairy products are summarized. Strategies that can be undertaken to reduce the risk of dairy fraud are presented in Section 13.4 and Section 13.5 concludes the chapter.

13.1 A brief overview of the dairy sector

Several features distinguish the production, processing, and distribution of dairy products from other agrifood sectors. First, the form and characteristics of milk set it apart from many other agrifood products. In its natural form, raw milk is a bulky commodity that will spoil quickly without cooling and requires high-cost, refrigerated storage. It is also an extremely valuable and expensive raw material that is used to make a variety of higher value products. The perishable nature of milk combined with its limited shelf-life necessitates that milk typically be shipped and processed daily.

Second, the channels used to market fluid milk are also uniquely shaped by the product’s form. Due to its perishability, there is limited opportunity for dairy producers to delay marketing their product in order to (potentially) obtain a higher price. Consequently, dairy producers in many countries work collectively through cooperatives that pool the interests and production of dairy farmers, thereby strengthening their bargaining power toward dairy processors and other buyers. Some cooperatives may opt to collectively run their own processing plants to further minimize their price and marketing risks (Knips, 2005).

Third, this sector fills a unique and important role in human health, rural labor, and farm income. Milk and dairy products offer an important source of dietary energy and macronutrients and are of crucial importance in the diets of infants and young children. Further, as milk production is relatively labor-intensive and the product is relatively perishable, this sector provides employment opportunities on the farm, in the transportation and processing of milk, and in the agricultural supplies and services sectors (Douphrate et al., 2013). Due to its

1 The Codex General Standard for the Use of Dairy Terms defines milk as the “normal mammary secretion of milking animals obtained from one or more milkings without either addition to it or extraction from it, intended for consumption as liquid milk or for further processing.” A milk product is defined as a “product obtained by any processing of milk, which may contain food additives, and other ingredients functionally necessary for the processing.” (Codex Alimentarius, 2011).
important health and economic linkages, the dairy industry enjoys a high degree of economic protection in many countries. This has implications for both innovation and the industrial organization of this industry; in general, it is thought that this protection has slowed the pace of the industry’s adjustment to market and technology changes.

13.1.2 Nutritional benefits of dairy products

Dairy products are commonly divided into three groups: (1) basic milk products (e.g., yogurt and cheese); (2) added-value products (e.g., milk enriched with calcium and vitamins); and (3) functional dairy foods (e.g., products with added probiotics, omega-3 oils) (Özer and Kirmaci, 2010; Papademas and Bintsis, 2010; Saxelin et al., 2003). These products are consumed both as a final product by consumers as well as intermediary inputs by the food manufacturing industry (such as cheese and milk powder).

Milk and dairy products are a major source of dietary energy and macronutrients such as proteins, fats, and carbohydrates. In addition, these products contain essential micronutrients, including minerals such as calcium, magnesium, selenium, riboflavin, and several fat- and water-soluble vitamins (Burke et al., 2018; FAO, 2016). By way of example, cow’s milk is composed of approximately 87% water and 13% total solids, including fat (~3.3%), lactose that is the main carbohydrate (~4.7%), proteins such as caseins and whey (~3.3%), and various vitamins and minerals (Burke et al., 2018; Muehlhoff et al., 2013).

In addition, dairy products are rich, wholesome, and nutrient-dense foods that play a crucial role in reducing hunger and malnutrition, particularly among vulnerable populations such as pregnant women, nursing women, children, and the elderly. Milk proteins contain the nine essential amino acids necessary for child development and maintenance of tissues in adults (Burke et al., 2018; Kabariya and Ramani, 2018). Due to these qualities, dairy proteins are often viewed by consumers as the “gold standard” of proteins (DeLoitte, 2017). Further, milk is the sole natural food for infants (Kabariya and Ramani, 2018), because it is relatively well assimilated. Given these qualities, milk is a valuable component in a balanced diet as recommended by dietary guidelines of most countries (FAO, 2016).

13.1.3 The economic value of dairy products

Between 2010 and 2018, global milk production increased by 17.6% from about 712.45 to 837.97 million tonnes. Among the milk produced in 2018, the majority came from cows (81%) and buffalo (15%); the milk of goats, sheep, and camels combined comprised the remaining 4% of global production (OECD-FAO, 2019a). Between 2016 and 2018, the top milk-producing regions or countries in the world were India, the European Union, the United States, Pakistan, Africa, Brazil, China, the Russian Federation, New Zealand, and Turkey (OECD-FAO, 2019a).

The global production of dairy products other than milk also experienced a significant increase in recent years. Between 2010 and 2018, production increased by 17.7% from 400.46 to 471.22 million tonnes (OECD-FAO, 2019b). These dairy products include

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2 In addition, in many countries, dairy farming also plays an important role in environmental conservation and agritourism (Douphrate et al., 2013).

3 Data used to generate these estimates was obtained from OECD-FAO (2019b).
butter, cheese, skim milk powder (SMP), whole milk powder, whey powder, casein, and other fresh dairy products. In terms of their volume of processed milk, the top countries in 2011 were the United States, Germany, China, France, and India (Douphrate et al., 2013). Moving forward, India is anticipated to have the largest growth in dairy production and is expected to be the world’s largest milk producer within the next decade (OECD-FAO, 2019a).

A majority of dairy products are consumed as fresh dairy products. Per-capita consumption of fresh and processed dairy products varies significantly by country and region. Using data from 2016 to 2018, it is estimated that those living in Pakistan (46.3 kg/capital per year), the European Union (25.7 kg/capital per year), the United States (24.1 kg/capital per year), and India (20.3 kg/capital per year) were among the largest consumers of these products (OECD-FAO, 2019a). Consumption in Latin America (12.9 kg/capital per year), China (3.8 kg/capital per year), and sub-Saharan Africa (3.5 kg/capital per year) was notably lower during this time period. Driven by increasing per-capita income, the demand for fresh dairy products is expected to grow by 1.0%/year over the next decade (OECD-FAO, 2019a). The demand for cheese stems mainly from consumers in Europe and North America; per-capita consumption of cheese products in these regions is expected to continue to increase.

The total value of global agricultural trade topped 2.7 trillion USD in 2019. Milk and dairy products accounted for about 0.3% of global agricultural trade, at 8.95 billion USD. Dairy products have experienced consistent increases in the volume of their trade; traded volumes increased 2.9% to 75 million tonnes from 2017 to 2018 (measured in milk equivalents; FAO, 2019a). Trade of dairy products, particularly cheese and milk powders, is projected to continue to increase over the next decade (through 2018; OECD-FAO, 2019a).

On average, approximately 8% of world milk production is internationally traded. Due to difficulty in transporting and storing fresh dairy products, less than 1% of the global production of these products is internationally traded (OECD-FAO, 2019b). The longer shelf-life afforded by processing permits more extensive trade of other dairy products. Milk powders are the most frequently traded agricultural commodities; in recent years, more than 40% of whole and SMP production was traded (OECD-FAO, 2019a). New Zealand, the European Union, the United States, and Australia together account for more than 75% of world exports of cheese, butter, and milk powders. Countries in the Middle East and North Africa, South East Asia, China, and other developed countries are the largest importers of dairy products (OECD-FAO, 2019a).

### 13.2 Food fraud in the dairy sector

Food fraud involves the intentional and illegal deception of consumers for economic gain. Typically this is achieved by either increasing the perceived value or decreasing the cost of producing a food product through (1) replacement in whole or in part, of a food ingredient or its valuable authentic constituent with a less expensive substitute through addition, dilution, or extension of an authentic ingredient with an adulterant; (2) addition

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4 Authors’ calculations using data from the UN Comtrade Database.
of small amounts of a nonauthentic substance to mask inferior quality ingredient; or (3) removing or intentional omission of an authentic and valuable constituent without the purchasers’ knowledge (Johnson, 2014). Indeed, several studies report that dairy products, and particularly milk, rank among the top 10 food categories with the most reported instances of food fraud (Everstine et al., 2013; Johnson, 2014; Moore et al., 2012). Dairy products also account for a large number of cases of illness outbreaks, and hospitalizations, and deaths attributed to foodborne illness outbreaks.\(^5\) Importantly, while it is not the direct intent of food fraud to harm consumers, the tactics used to commit fraud may result in products being improperly handled or stored, or allergens or other harmful contaminants being introduced into food products. Given the perishability of milk and dairy products, and the relatively high incidence of food allergies and sensitivities to these products, the economic and health impacts of dairy product fraud can be substantial.

Among the most common types of fraud affecting milk is adulteration that is the intentional addition of a substance that should not be present in a product. Historically, milk has been one of the most adulterated foods, with the earliest cases caused by diluting milk with water to increase its weight and volume (Tola, 2018). More recently, starch, flour, skimmed milk powder, whey powder, and other thickening agents are being added to enhance its solid contents (Chauhan et al., 2019; Reddy et al., 2017). An increase in fat, carbohydrate, and apparent protein content in diluted milk is achieved by adding vegetable or refined oil, sugarcane, and urea or melamine, respectively (Sharma et al., 2012, as cited in Poonia et al., 2017). Melamine, which is an industrial chemical compound used in the production of glues, laminates, dinnerware, and flame retardants has been found to have significant negative effects on health (Box 13.1; Liu et al., 2012; WHO, 2017). Due to its high nitrogen content, melamine has been used to artificially increase the apparent protein content of milk. Chemicals such as hydrogen peroxide, carbonates, bicarbonates, antibiotics, caustic soda, and formalin have also been used to increase the shelf-life of milk. Detergents have also been used to cosmetically enhance milk by giving it a foamy appearance and white color (Chauhan et al., 2019).\(^6\)\(^7\)

As milk is the primary ingredient in processed dairy products, these products face similar types of fraud risk. Adulterated milk can be used to produce other milk-based products and infant formulas. Milk powders can be adulterated with starch, whey, sucrose, urea, soap, and melamine (Tola, 2018). Fatty milk products such as butter and ghee (clarified butter) have been adulterated with other nonmilk fats and oils such as animal fats (cow tallow and pork lard) and vegetable oils (soybean oil, palm oil, etc.). Cheese derives

\(^5\) Using data from outbreak-associated illnesses between 1998 and 2008, a study by the US Centers for Disease Control and Prevention found that in the United States dairy products annually accounted for 1.3 million cases of foodborne illnesses (second after leafy vegetables), 9284 hospitalizations (the highest among the commodities) and 140 deaths (Painter et al., 2013).

\(^6\) Indeed, sometimes “synthetic milk” produced from urea, caustic soda, refined oil, and common detergents is sold under the false label of natural milk (Reddy et al., 2017). One study notes the prevalent consumption of synthetic milk among preschool and school age children in Uttar Pradesh, India (Bhatt et al., 2008).

\(^7\) Food adulteration, and particularly which has food safety and health implications, has contributed to the United States and other nations making efforts to strengthen their food safety laws and dairy industry oversight. As a result, the risk of dairy product adulteration in these countries is now greatly reduced.
The Chinese Melamine Scandal, 2008

In September 2008, Chinese official media carried news reports about kidney stones and renal failure among infants. The source of the illness was traced to the contamination of infant formula with melamine, a chemical compound that has a number of industrial uses, including the production of laminates, adhesives, and flame retardants. Melamine is nitrogen-rich and, given commonly used testing methods, can be added to foods to increase their apparent protein content.

Sanlu Dairy Company, which at the time was one of four major milk processing firms in China, was responsible for the tainted milk and milk products. Subsequent investigation into the causes of the fraud revealed vulnerabilities in the dairy supply chain and government policy in China. The surge in domestic and international demand for dairy products in the previous decade had led to the expansion of the Chinese dairy sector and milk supply. As a majority of the dairy farmers in China were small-scale operators and there were few major buyers, this market shock caused the farm price of milk to decrease at the same time milk production costs were increasing. To reduce cost and increase their sales and profits, stakeholders along the raw milk supply chain, including dairy farmers, milk collection station owners, and top executives of milk processors, were engaged in milk adulteration and contamination. The use of a decentralized raw milk procurement model that entailed obtaining raw milk from small-scale suppliers meant poor-quality supervision, contributing to inadequate sanitary conditions and a lack of quality/safety awareness (Chen et al., 2014; Xiu and Klein, 2010). Furthermore, improper use of detection methods, and not specifically listing melamine as an illegal additive further exacerbated the situation.

Complicating matters, many leading dairy companies in China, including Sanlu, were exempted from mandatory government inspections and official controls (Pei et al., 2011). Also, as China is the largest manufacturer of melamine, excess production found an easy outlet in the milk industry (Keck, 2009).

The consequences of this incident were devastating and had global repercussions. In China alone, more than 290,000 people suffered from poisoning and renal complications, most of them being infant children. At least six babies died consuming contaminated milk powder (Xiu and Klein, 2010). Since the tainted infant formula had been distributed to a large number of countries, the UN issued a worldwide alert and more than 60 countries banned or recalled Chinese dairy and other affected products (GMA, 2010).

Within the Chinese dairy industry, more than 30 local and milk brands were affected. The total cost to the dairy industry was estimated to be approximately $10 billion (Chan et al., 2008). Sanlu filed for bankruptcy in December 2008. Further, harsh penalties were imposed on individuals directly involved with this scandal; two death sentences and five life imprisonment sentences were handed down by the Chinese courts (Xiu and Klein, 2010).

This event was an important trigger point that drew international attention to the issue of food fraud in the global food supply chain. Following this event, a new Food Law was enacted in China in 2009 that focused on increasing coordination between authorities, and increasing institutional and monitoring capacity through certified laboratories. The law also required enforcement agencies to conduct periodic or random food safety checks from which no companies were granted exemptions (Pei et al., 2011).
its value from its inherent characteristics that are attributable to the composition and type of milk used, the microorganisms and processes used in its production, and the geographic place of origin (FAO, 2019b). Some examples of cheese fraud include mislabeling the type of cheese and its place of origin and adding excess cellulose in grated cheese to increase the product weight (Harper, 2016; Tola, 2018).

Certain high-quality cheeses are produced in areas with protected designation of origin (PDO) status, meaning that they have distinct characteristics related to the geographical area of their production, the materials, and/or the technologies used in the production process (De la Fuente and Juarez, 2005). These characteristics give the products a higher market value, leading to increased economic incentives for fraud, especially through the replacement of PDO milk or milk products with those produced elsewhere or using different production techniques (De la Fuente and Juarez, 2005). Other forms of milk fraud include the addition of cheaper, lower quality milk from nonbovine animals (false declaration of origin and/or species), or selling milk with recombinant bovine somatotropin (rbST) as rbST-free milk (faulty documentation, false declaration of production process) (Agrimonti et al., 2015; Cunha and Domingues, 2017; Lamas et al., 2019).

Also worth noting is the particular risk of fraud of organic milk and dairy products. In the US marketplace, dairy and eggs together make up the second largest organic food category, valued at $6.5 billion in 2018 (OTA, 2019). This market continues to flourish internationally as well; it is anticipated that global sales of organic dairy products will experience double-digit annual growth rates and that the global market will be valued at 54.4 billion USD by 2025 (Renub Research, 2020). Given the high demand for organic dairy products and the price margins between conventionally and organically produced dairy, these products offer a particularly high incentive for fraud (Garfield, 2017).

13.2.1 Global incidence of fraud in dairy products

In order to gain a more complete understanding of the nature and prevalence of dairy fraud, it is instructive to consider global trends in identified fraud cases across countries, products, and time. To do so, we consider food fraud cases reported in HorizonScan. Among the 5890 cases of food fraud reported in this database between 2000 and 2018, 4% (245) report cases of dairy product fraud. Fig. 13.1 shows the distribution of cases by the type of dairy product across time. While there has been a general trend of increase in the number of dairy fraud cases over time, reported incidents were particularly high in

8 rbST is a genetically modified version of a growth hormone that occurs naturally in cows and is injected to enhance milk production by 10%–15% (Kiesel and Villas-Boas, 2007).

9 HorizonScan is a global database developed by FERA (Food and Environmental Research Agency, the United Kingdom) and its partner Leatherhead Food Research in order to build a consolidated resource of food recalls, alerts, and food safety information (NSF, 2014). HorizonScan uses official sources [such as Rapid Alert System for Food and Feed (RASFF), US FDA] as well as other sources such as local newspaper reports to identify food hazards, food safety issues, and emerging threats in food supply chains.
Cheese, followed by milk\textsuperscript{10} and cream, yogurt, and butter and ghee have the highest reported number of cases in this dataset. “Other dairy products” category, which encompasses milk-based beverages and other dairy-based products, saw a significant rise in the number of reported dairy fraud incidents in 2008 due to the Chinese melamine incident (discussed in Box 13.1).

While there were several notable cases of dairy fraud during this period, aside from the melamine incident, no specific fraud incidents are directly responsible for this increase. Rather, it appears that a general increase in reported food fraud cases (de Lange, 2013), awareness of food fraud, as well as improved testing and detection capacities of dairy fraud account for the increase (EU, 2017; Handford et al., 2016; IDF, 2016). A notable example is that of the Czech Republic which, in response to several damaging cases of food adulteration, increased the number and intensity of on-site retailer and other inspections and laboratory testing (CAFIA, 2013). In addition, in 2015, the scope of authority of the Czech Agricultural and Food Inspection Authority was expanded to also include mass caterers (Koubová et al., 2018). Perhaps not surprisingly, studies reported a notable increase in the detection of food fraud during the period examined in this study (between 2009 and 2018; Koubová et al., 2018).

The top 10 reported countries of origin of fraudulent dairy products from 2000 to 2018 in HorizonScan were Poland (16%), the Czech Republic (11%), the United Kingdom (9%),

\textsuperscript{10} Milk includes bovine (cow), caprine (goat), and ovine (sheep) milk.
China (7%), Germany (7%), India (7%), the Netherlands (5%), France (4%), the United States (3%), and New Zealand (3%). An additional 5% of the reported dairy cases do not have known country of origin. Together, they represent approximately 77% of the total reported dairy fraud cases in the database. The countries that notified the most cases of dairy fraud over the same time period were the Czech Republic (42%), the United Kingdom (11%), Italy (7%), India (5%), the United States (4%), Cyprus (3%), Germany (3%), the Russian Federation (3%), Brazil (3%), Greece (2%), and Belgium (2%). Collectively these countries account for approximately 83% of dairy fraud notifications.

It is also useful to characterize these cases by the type of fraud; Fig. 13.2 presents this information considering the number of global cases between 2000 and 2018. Over this period a majority of dairy fraud cases were due to fraudulent documentation (51% of cases). Examples of fraudulent documentation include mislabeling (product contents do not match those specified on the labels) or insufficient labeling, the absence of health certificates, and incorrect or fraudulent documentation at the port of entry. Fraudulent documentation primarily affects cheese and cheese products, yogurt, and other milk-based dairy products.

Adulteration or substitution of dairy products or their ingredients is the second most prevalent type of dairy fraud (32% of cases), followed by incidents of dairy products being processed or produced on unapproved premises (11% of cases). “Unapproved premises” refers to the production and manufacturing of a dairy product without approval or adequate licensing. This also includes operators supplying milk and dairy products without authorization from the state authority. Fig. 13.2 also reports number of fraud cases disaggregated by the type of affected product. Here we see that most of the dairy-related adulteration/substitution cases were due to fraud in cheese, milk and cream, and butter and ghee products. Also, cheese, milk and whey powders, and ice cream are the products most commonly found to have been produced at unapproved premises or by unauthorized operators.

It is important to acknowledge that these cases of dairy fraud indicate only the cases that were detected; the full scope of dairy fraud is, of course, not precisely known. Datasets that compile cases of fraud each draw upon and differently weight reports of fraud from different sources. The dataset used in this analysis, HorizonScan, was developed by FERA, draws upon over 100 sources, including the EU’s RASFF. Relative to other datasets, HorizonScan includes more fraud notifications from European countries. Further, while this information identifies the number of fraud events, it does not provide details regarding the magnitude of these incidents in terms of the quantity or volume of affected products, or their economic or potential health impacts. Nonetheless, taken together, these trends offer important insights into the specific countries and dairy products that are particularly vulnerable to fraud. In doing so, this information offers timely guidance as to which settings it would be particularly beneficial to direct additional fraud mitigation surveillance and detection efforts.

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11 A notifying country is a country that issues an alert that a fraudulent food product is being sold in their country.

12 In particular, it has been observed that the Czech Republic and Poland have a larger number of observations than fraud other datasets.
FIGURE 13.2  Number of cases by type of fraud, as reported in HorizonScan from 2000 to 2018.
13.2.2 Causes and consequences of dairy fraud

An important exercise in comprehending the full extent of dairy fraud is to look at its underlying motivations and the resultant consequences. Since the key motivating factor behind food fraud is economic gain, changes in economic factors and market characteristics are bound to have a significant effect on dairy fraud. A price gap between the authentic and adulterated products may increase the likelihood of fraud, as seen in the case of synthetic milk sold as natural milk (Kandpal et al., 2012). Similarly, high profit margins may also encourage dairy fraud, as is the case in high-value dairy products such as cheese, butter, and ghee. Large gaps in demand and supply of milk, along with its perishable nature and detection techniques that require a sophisticated laboratory apparatus, may further promote unethical practices leading to dairy fraud (Jalili, 2017; Kamthania et al., 2014; Reddy et al., 2017). Also, the unique nature of dairy farming, which in many countries involves many small-scale dairy farmers, may exacerbate the issue of dairy fraud in the absence of oversight and quality checks and controls. From the consumer perspective, a lack of general awareness of dairy fraud coupled with low purchasing capability of consumers may further inspire fraudsters to commit dairy fraud (Chauhan et al., 2019; Reddy et al., 2017).

One of the most important concerns of dairy fraud is its potentially significant impact on public health. While some fraudulent activities carried out for economic profits may pose minimal health risk to consumers, such as substituting expensive milk fat with cheaper vegetable fat or refined oil, or adding water or milk powders to boost the volume of milk (Jalili, 2017; Reddy et al., 2017), activities such as adding hazardous chemicals may have long-term or even fatal health consequences on consumers. For example, urea in milk can cause renal failure, starch and detergent in milk are responsible for diarrhea and other gastrointestinal problems (Chauhan et al., 2019), and harmful chemicals such as formalin and melamine in milk and milk products can lead to death in vulnerable populations such as infants and young children (Chauhan et al., 2019; Singh and Gandhi, 2015). Individuals allergic to cow’s milk may suffer from serious health consequences by consuming milk from other species like goats and sheep that is adulterated with cow’s milk. While instances of food fraud lead to a loss of consumer trust in the food industry and supply chain (Esteki et al., 2019), the companies involved in these losses also suffer from economic and social losses due to recalls and reputation damage, thus impacting the overall industry (van Ruth et al., 2018). This is best illustrated by the melamine scandal highlighted next (Box 13.1).

13.3 Analytical methods for identifying adulterated dairy products

As discussed in the previous section, second to fraudulent documentation, adulteration is the most common cause of fraud in dairy products. Further, in most cases, adulteration poses a larger potential health risk than other forms of dairy fraud. For this reason the approaches used to identify adulteration of dairy products are the focus of the following discussion. The extent of adulteration (quantity of adulterants) can vary due to biological, climatic, and agronomic factors and can be further altered as a result of common processing techniques (Poonia et al., 2017). Complicating detection, adulterators can have a positive impact...
on quality measures of dairy products. As with all forms of laboratory testing, it is important that the methods used to detect dairy adulterants be as precise and rapid as possible, without being so restrictive that the method yields false positives (Azad and Ahmed, 2016; Poonia et al., 2017). The remainder of this section introduces the analytical methods used to detect each of the common types of adulterants in dairy products.

13.3.1 Qualitative methods

Qualitative methods to detect adulterants in milk products consist of simple, rapid, and often color-based chemical reactions (Azad and Ahmed, 2016). These include tests for color changes or other reactions evaluated using, for example, methylene blue reduction, $p$-dimethyl aminobenzaldehyde, phenol, iodine, Barfoed’s test, Seliwanoff’s test, Leach’s test, picric acid, rosole acid, and iodometric titration (Aparnathi et al., 2019). These tests have advantages in that they are typically quick, easy to perform, and relatively cost effective (Aparnathi et al., 2019; Azad and Ahmed, 2016). As such, they may be particularly important for fraud detection in developing countries (Aparnathi et al., 2019). The Food Safety and Standards Authority of India has disseminated the Detect Adulteration with Rapid Test manual that describes common qualitative tests to detect adulteration of milk and dairy products (and other foods) for use in household settings (FSSAI, 2017).

These simple analytical methods can be particularly useful for the detection of certain edible compounds used to improve the taste of adulterated products such as sugar, starch, glucose, salt, and buffalo milk. These methods can also be used to detect certain hazardous chemicals, including hydrogen peroxide, formalin, ammonium sulfate, urea, nitrate, benzoic and salicylic acid, borax and boric acid, detergents, soaps, and colorants, all of which are used to improve the physical appearance and/or shelf-life of the product (Azad and Ahmed, 2016; Reddy et al., 2017).

Despite their advantages, however, qualitative methods do have important shortcomings. In particular, these methods are not highly precise and are limited in their ability to detect lower concentration levels of adulterants (Azad and Ahmed, 2016). Another limitation of these methods is that common dairy processing techniques, such as sterilization, can affect test performance and results (Aparnathi et al., 2019).

13.3.2 Quantitative methods

Quantitative methods are more complex analyses that offer higher rates of precision and the ability to detect a more diverse range of adulterants (Azad and Ahmed, 2016). For this reason, quantitative methods are typically preferred for the detection of hazardous compounds, although they are commonly used to detect a variety of less harmful compounds as well (Azad and Ahmed, 2016). Broadly, a variety of chromatographic, spectroscopic, DNA-based, or

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13 For example, melamine increases the nitrogen content of milk; through standard testing this appears to increase the protein content of milk (WHO, 2015b).

14 These methods are cited and described in reviews published by Azad and Ahmed (2016) and Reddy et al. (2017).
immunological methods can be used to detect dairy adulterants. In addition, there are a number of emerging methods such as automated instruments that may be potentially useful; however, they are still limited in their development and further research is needed to confirm their validity in detecting adulterants (De la Fuente and Juarez, 2005; Poonia et al., 2017).

The best type of quantitative method to use is highly dependent upon the type of adulterant (Azad and Ahmed, 2016). Specific methods used to identify and quantify adulteration of dairy products have been reviewed by Azad and Ahmed (2016), Das et al. (2016), De la Fuente and Juarez (2005), Nascimento et al. (2017), and Poonia et al. (2017), among others. This section highlights the several common current and emerging quantitative methods used to detect common types of adulterants in dairy products. These approaches, and the particular type(s) of dairy products they can be used to assess, are summarized in Table 13.1.15

### TABLE 13.1 Summary of common quantitative analytical methods used to detect adulteration in dairy products as referenced in review articles published between 2005 and 2017.

<table>
<thead>
<tr>
<th>Type of adulteration</th>
<th>Type of analysis</th>
<th>Specific method</th>
<th>Dairy product(s)</th>
<th>References</th>
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<tr>
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</tr>
<tr>
<td></td>
<td>PCR–LCR–EIA</td>
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<tr>
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15 For ease of exposition, references that describe the application of specific tests to detecting each type of adulteration are included in Table 13.1.
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Food Fraud
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### TABLE 13.1 (Continued)

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**Dairy Products:** M, Milk; MP, milk powder; Ch, cheese; Y, yogurt; F, other fermented product; MF, milk fat; B, butter; G, ghee; Cr, cream; IF, infant formula.

**Methodologies:** CE, Capillary electrophoresis; CEMS, capillary electrophoresis mass spectrometry; CZE, capillary zone electrophoresis; ELISA, enzyme-linked immunosorbent assay; EIA, enzyme immunoassay; ESI, electrospray ionization; FP, freezing point; FTIR, Fourier transform infrared; GC, gas chromatography; HIC, hydrophobic interactive chromatography; HPLC, high-performance liquid chromatography; HPTLC, high-performance thin-layer chromatography; ICP-OES, inductively coupled plasma emission spectroscopy; IDMS, isotope dilution mass spectrometry; IEF, isoelectric focusing; IRMS, isotope ratio mass spectrometry; LC, liquid chromatography; LCR, ligase chain reaction; LFT, lateral-flow test; MALDI, matrix-assisted laser desorption/ionization; MS, mass spectrometry; PAGE, polyacrylamide gel electrophoresis; PCR, polymerase chain reaction; QTOF, quadruple time of flight mass spectrometry; RP, reversed-phase; SDS, sodium dodecyl sulfate; SERS, surface-enhanced raman spectroscopy; TLC, thin-layer chromatography; TOF, time of flight; UHPLC, ultrahigh-performance liquid chromatography; UV, ultraviolet.
13.3.2.1 Adulteration of protein content

Dairy products can be adulterated with protein from a variety of sources. Chromatographic, immunological, electrophoretic, and spectroscopic methods are among most common approaches used for detecting nondairy proteins in dairy products. Enzyme-linked immunosorbent assay (ELISA), an immunological analysis, emerged as a common way of identifying milk proteins in the early 1990s; through this method the fraction or amount of dairy protein is detected by monoclonal or polyclonal antibodies (Poonia et al., 2017). A number of companies have developed ELISA-based testing kits for routine analyses of dairy products. Liquid chromatography (LC), in particular, reversed-phase high-performance liquid chromatography (RP-HPLC), which separates analytes based on hydrophobic properties, is commonly employed to analyze and separate nondairy proteins in dairy products. Sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS–PAGE) is commonly used to detect proteins of different animal species. Polarimetry, isoelectric precipitation, capillary electrophoresis (CE), immunodiffusion, near-infrared spectroscopy, and biosensors are among other methods used to detect nondairy proteins. Spectroscopic methods, CE, and SDS–PAGE are the most common tests used to detect the presence of whey protein in dairy products. Adulteration with rennet whey is commonly detected through CE and HPLC.

13.3.2.2 Adulteration with milk from different animal species

The detection of milk from another species can be accomplished through the analysis of genetic factors, such as DNA base pair sequences (Recio et al., 1997), and nongenetic factors, including basic chemical components such as crude protein, fat, ash, and dry matter (Borková and Snášelová, 2005). However, these analyses can be complicated by the similarities in these factors across species, and due to processing techniques (Borková and Snášelová, 2005; Recio et al., 1997). Historically, protein analysis has been used to detect adulteration with milk from a different animal species (Borková and Snášelová, 2005; Strange et al., 1992). Due to their ability to detect genetic differences, DNA-based methods are particularly useful for detecting adulteration with different animal species. Some examples of commonly used methods include polymerase chain reaction, CE, and isoelectric focusing. Both PAGE and SDS–PAGE have been useful in identifying species differences in a variety of dairy products, including cheese, milk, yogurt, and kishk. In addition, ELISA is used to detect the presence of different species in a variety of dairy products, including raw, pasteurized, and frozen milks, soft cheeses, and powdered milk. Common chromatographic methods used to detect this form of adulteration include RP-HPLC, gas chromatography (GC), and hydrophobic interactive chromatography.

13.3.2.3 Adulteration with milk from different geographical area

Fraudulent documentation involving the misrepresentation of geographic origin or misuse of geographical indication labeling is a common type of fraudulent activity in the dairy industry. To help one to detect and reduce this form of fraud, it is important to establish ways to detect differences in dairy products based on their place of origin. This is particularly important in the case of PDO dairy products. Traditionally, the industry has
relied on microbiological and physical—chemical (fatty acids, enzymes, pH, and nitrogen fractions) parameters to determine or verify the geographical origin of dairy products (De la Fuente and Juarez, 2005). However, given the economic implications surrounding PDO products, additional, more specific methods have been explored.

In particular, a variety of spectroscopic methods have been successfully employed to detect PDO adulteration. Near and mid Fourier transform infrared (FTIR) spectroscopies have been used to detect geographical differences in cheese samples from Europe. Isotopic fractionation can lend useful information regarding the geographic origin of dairy products that can be further enhanced when coupled with metal concentrations (Brescia et al., 2003; De la Fuente and Juarez, 2005). Isotope ratio mass spectrometry coupled with other spectroscopic approaches have been used to distinguish between milks and cheeses produced in different areas of Italy (Brescia et al., 2003, 2005; De la Fuente and Juarez, 2005; Manca et al., 2006), and butters produced in different regions throughout Europe (De la Fuente and Juarez, 2005). In order to make these distinctions, the concentrations of selected metals (Ba, Mn, Zn, Al, Fe, and Cu), phosphorous, as well as the isotopic ratios of carbon ($^{13}$C/$^{12}$C) and nitrogen ($^{15}$N/$^{14}$N) are evaluated. Among these molecules the isotopic ratios and Ba concentration were most useful in differentiating between the geographic origins of the samples (Brescia et al., 2003).

In their review of the use of metabolomics to authenticate food, Cubero-Leon et al. (2014) highlight cases where nuclear magnetic resonance was used to identify the geographic origin of milk and cheeses. GC tandem mass spectrometry and HPLC are other potentially useful methods for determining differences in the geographic origin of cheeses.

### 13.3.2.4 Adulteration with nitrogen-rich compounds

Due to their high nitrogen content and low costs, some nitrogen (N)-rich compounds, including melamine, urea, and whey, have been used to artificially inflate apparent protein content (Nascimento et al., 2017). Other N-rich compounds, including ammeline, cyanuric acid, cyanamide, guanidine, choline, hydroxyproline, nitrate, and various amino acids, have also been used as dairy product adulterants (Poonia et al., 2017).

As seen in Table 13.1, spectroscopic methods are among the most common approaches used to detect this form of adulteration. Methods based on Raman spectroscopy, a form of vibrational spectroscopy, are widely used to detect urea and melamine in dairy products. For example, a SERS-based portable sensor has been developed to instantly detect melamine (Kim et al., 2012). Medium-infrared, near-infrared, FTIR, and electrospray ionization mass spectrometry have also been used to detect melamine in dairy products.

Several emerging technologies also hold promise for detecting nitrogen-rich adulterants. Biosensors are becoming a popular method of detecting adulteration with urea (Azad and Ahmed, 2016; Das et al., 2016; Poonia et al., 2017). Other N-rich adulterants such as synthetic urine can also be detected through spectroscopic methods such as near-infrared, medium-infrared, Raman, and flame atomic absorption. One novel method that may prove useful in developing countries is a low-cost disposable microfluidic device that uses ultraviolet detection methods and can detect low levels of melamine in milk (0.23 g/mL; Zhai et al., 2010).
13.3.2.5 Adulteration of fat content

In order to identify fat content adulteration of dairy products, it is necessary to determine the fatty acid composition, triacylglycerol (TAG) profile, and fractions of other minor lipid constituents in the unsaponifiable fraction (De la Fuente and Juarez, 2005; Poonia et al., 2017). As summarized in Table 13.1, chromatographic methods, in particular GC, are commonly used to identify adulteration of fat content. In 2010 the International Dairy Federation (IDF) and International Organization for Standardization (ISO) specified a GC-based reference method for detecting foreign fats (IDF, 2010). GC methods have been used to detect fat content adulteration in a variety of dairy products, including milk fats (e.g., anhydrous, raw, ultrapasteurized butter and ghee). The LC–GC method is popular for detecting adulterated fat content in dairy products and has been used to detect the presence of cotton and rapeseed oils (Kamm et al., 2002), and a variety of partially hydrogenated vegetable oils (Destaillats et al., 2006) in milk fat samples. This method is advantageous because it is rapid and does not require laborious sample preparation (Lanuzza et al., 1996). Spectroscopic methods such as Raman, derivative, fluorescence, and matrix-assisted laser desorption/ionization-quadruple time of flight mass spectroscopy have also been used to successfully identify fat content adulteration in dairy products.

13.3.2.6 Adulteration of organic dairy products

In recent years, several methods to identify the fraudulent practice of substituting conventional for organic dairy products have been explored. It has been found that the concentration of several fatty acids, including phytanic acid, pristanic acid, $\alpha$-linoleic acid, conjugated linoleic acid, and omega-3 fatty acids, differ between organic and conventionally produced milk. These fatty acid concentrations are higher in organic milk, which is attributed to the higher proportion of grass in organic cattle feed compared to conventional cattle feed (as reviewed in Capuano et al., 2012). Among these, phytanic acid has received particular attention as a potential marker for organic dairy products (Capuano et al., 2012; Schröder et al., 2010; Vetter and Schröder, 2010).

Differences in dietary intake between organic and conventional animals can also be detected by testing for stable isotope ratios in milk. Specifically, milk produced from organic (and pasture-fed) cows is expected to have higher levels of certain stable isotopes ($\delta^{13}$C, $\delta^{15}$N) compared to milk produced from nonorganic (and maize- or crop-fed) cows (Capuano et al., 2012; Molkentin and Giesemann, 2007, 2010). Molkentin and Giesemann (2010) suggest that the percentages of $\delta^{13}$C in both milk fat and milk protein are suitable for authenticating organic milk samples, as both can be indicators of feed composition. Other authors report some success in using TAG fingerprinting to differentiate between organic and conventional milk samples (Capuano et al., 2012).

13.3.2.7 Adulteration with other compounds

A variety of other compounds, including water, preservatives, detergents, and urine, have also been found in adulterated dairy products. “Watering” is one of the most common forms of adulteration of dairy products (Das et al., 2016). Spectroscopic methods such as medium-infrared, near-infrared, and FTIR as well as a variety of other methods based on freezing
point, ultrasonic transmission, and electrical conductivity have been successfully used to detect this form of adulteration. Adulteration using detergent can be detected and quantified using a simple paper chromatography-based approach, spectrophotometry, and combination methods. A variety of spectroscopic, ultrasonic, and voltammetric approaches have been used to detect and quantify the presence of preservatives in dairy products. In addition, several analyzer instruments have been developed to specifically detect adulterated milk. By way of example, Poonia et al. (2017) and Coitinho et al. (2017) highlight instruments developed by FOSS, the MilkoScreen and MilkoScan, which use FTIR to detect extraneous water, urea, starch, formaldehyde, melamine, and other adulterants in milk samples.

13.3.3 Advantages and disadvantages of commonly used quantitative methods

The analyses highlighted here have been successfully used to detect dairy products affected by fraud. These general types of approaches and the specific methods within them do, of course, vary in their sensitivity, cost, equipment requirements, and other characteristics that may make one test preferable to another in a particular application. While reviewing the benefits and drawbacks of each specific analytical method is beyond the scope of this chapter, some of the key advantages and disadvantages of each of the general types of analysis considered herein are presented in Table 13.2.

<table>
<thead>
<tr>
<th>Type of analysis</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>References</th>
</tr>
</thead>
</table>
| Chromatographic  | • Well standardized  
                   • Widely accepted  
                   • Relatively inexpensive | • Variable and relatively limited ability to detect low concentrations of adulterants  
                   • Preparation and analysis may be time consuming | Borková and Snášelová (2005) and De la Fuente and Juarez (2005) |
| DNA-based        | • Rapid  
                   • Highly sensitive  
                   • Highly specific | • High cost  
                   • Complexity | Borková and Snášelová (2005), De la Fuente and Juarez (2005), and Poonia et al. (2017) |
| Electrophoretic  | • Rapid  
                   • High resolution  
                   • Reliable | • Some are only semiquantitative in nature  
                   • Low precision  
                   • Time consuming  
                   • Labor intensive  
                   • Requires specific equipment | De la Fuente and Juarez (2005) and Poonia et al. (2017) |
| Immunological    | • More practical than DNA-based methods for routine analysis  
                   • Sensitive | • Semiquantitative; not as accurate as other methods | De la Fuente and Juarez (2005) and Poonia et al. (2017) |
| Spectroscopic    | • Minimal sample preparation  
                   • Highly sensitive and specific  
                   • Able to detect multiple compounds at once | • Time consuming  
                   • Expensive  
                   • Requires technical skill and equipment | De la Fuente and Juarez (2005) and Nawrocka and Lamorska (2013) |

16 Information about this company can be found at: https://www.fossanalytics.com/en#.
13.4 Dairy fraud risk mitigation strategies

After gaining an understanding of the nature, causes, and consequences of dairy fraud as well as the analytical methods employed to detect it, we now turn to some of the strategies that can reduce the risk of dairy fraud. Three broad types of actions are needed to reduce food product fraud: (1) improved collaboration among companies with the food industry by sharing intelligence, audit program, and ingredient reference samples; (2) ongoing improvement of product safety and quality programs such as integrating additional fraud prevention strategies; and (3) involvement of all members of the value chain, including employees, suppliers, retailers, consumers, and government (Wilcock and Boys, 2014). The potential roles that the national governments and regulatory authorities, the dairy industry as a whole, and individual firms engaged in this sector can take to help one to mitigate the impact of dairy fraud are introduced in the following discussion.

13.4.1 Role of the dairy industry

13.4.1.1 Dairy industry standards

A number of regulations as well as required and voluntary standards exist at both national and multinational levels of governance to ensure product safety and protect the interests of dairy industry consumers and other stakeholders. Among the most important global dairy standards are those developed by the Codex Alimentarius and the ISO. The Codex Alimentarius has developed standards for milk products, horizontal (general) cheese standards, and individual cheese standards (specific to varieties). In addition, Codex has developed general texts that provide standards on the use of dairy terms, a code of hygienic practices for milk and milk products, and guidance for developing export certificates for products that meet food safety and suitability requirements (Codex Alimentarius, 2011). ISO has developed sampling procedures and microbiological, physical, and chemical testing methods of analyzing milk and milk products (ISO/TC 34/SC5; Burke et al., 2018; ISO, 2009), and standards regarding milking machines and other technical topics. The Terrestrial Animal Health Code, which is offered by the World Organization for Animal Health (OIE), provides standards for the improvement of animal health and welfare in dairy production systems (Chapter 7.11; OIE, 2019). The IDF, a nonprofit organization representing the dairy sector worldwide, works in closely with these organizations in developing these standards.

In addition to these multinational standards, a number of voluntary third-party certifications and standards have emerged. Some are directly relevant to the dairy sector such as SSafeMILK, while others are more generally related to food production, processing, and distribution practices, such as those offered by the Humane Farm Animal Care, Kosher, ISO 22000, the Non-GMO (Genetically Modified Organism) project, and Fairtrade International. While such certifications generally do not explicitly address fraud, the oversight required by their compliance and administrative requirements may reduce fraud. At

17 SSafeMILK is a circular production model that aims to provide a sustainable, safe and environment-friendly MILK supply chain. Details about this standard can be found here: https://www.ssafemilk.com/
the same time, however, particularly in cases where certified firms have the option to include a logo on their consumer-facing packaging, these standards may provide incentive for additional labeling fraud.

It is important to note that it is not mandatory for firms to adhere to the requirements of these standards. In the case of Codex and OIE, World Trade Organization members are encouraged to harmonize their national regulations with Codex texts to facilitate the international trade of agrifood products. With scientific justification, national governments, however, may opt to implement national standards that are more stringent than Codex requirements. In contrast, ISO standards and voluntary third-party certifications may be voluntarily adopted by an industry or, more commonly, by individual businesses. In addition to using them in their own operations, companies may require their suppliers to adhere to these standards.

### 13.4.1.2 Individual firm actions to strengthen the dairy supply chain

Oversight and adoption of quality assurance methods throughout the dairy supply chain are critical to deter dairy fraud (Lotta and Bogue, 2015). Implementation of a Global Food Safety Initiative recognized food safety standard (e.g., BRCGS, SQF 2000, FFSC 22000/ISO22000, IFS), or another food safety standard such as Good Agricultural Practices, and/or on-farm Hazard Analysis and Critical Control Points (HACCP) systems\(^{18}\) can help one to ensure the quality and safety of milk production and processing (Papademas and Bintsis, 2010). In addition, it is recommended that dairy business operators develop a Vulnerability Assessment and Critical Control Point (VACCP) system. Based on HACCP principles, VACCP offers a method to assess vulnerabilities and to help one to protect food and beverage operations from fraud and potential adulteration.\(^ {19}\) Conducting periodic product tests, understanding supplier history and relationships, and monitoring the food fraud incidents in supplier countries of origin are among many practical strategies that dairy companies can implement to alleviate their vulnerability to the risk of fraud (Tola, 2018; Wareing and Hines, 2016). General business strategies that can be used to help one to reduce fraud include aspects of internal and external firm leadership, strategic planning, customer education and information sharing, and employee and partner training and are described by Wilcock and Boys (2014).

Increasingly technology has also been instrumental in helping one to assure the integrity of food supply chains. While still in initial stages, blockchain technology has gained popularity in the dairy industry (DeLoitte, 2017; Kasten, 2019). Blockchain serves as a secure record of exchange and can be used to record information about product handling and testing at each step along the supply chain. Complementing this with the “Internet of Things,” which offers the potential to introduce internet-connected sensors and other equipment throughout handling and storage environments (e.g., storage coolers), greatly improves traceability and reduces the potential for fraud along the entire length of the supply chain.

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\(^{18}\) HACCP is an internationally recognized food safety management system that provides a means of identifying and assessing potential hazards in food production and establishing preventive control procedures for those hazards (Wareing and Hines, 2016).

\(^{19}\) For an example of VACCP guidance, see British Retail Consortium (2015).
supply chain. Importantly, however, the benefits of introducing these technologies will be limited if this information is solely used internally. Rather, the benefits of these technologies related to food fraud will only be fully realized when information is shared and integrated among a firm’s supply chain partners.

13.4.2 Role of government

National governments and regulatory authorities are becoming increasingly cognizant of the economic and health impacts of food fraud. While many countries had existing food safety laws, the Chinese melamine incident reinforced the need to strengthen food laws to more comprehensively address food safety and extend them to include food fraud. By way of example the European Parliament and the Council adopted a General Food Law Regulation (EC No. 178/2002) establishing general principles, requirements, and procedures on food and feed safety. Enhanced regulations addressing food traceability (EU Regulation 931/2011), product labeling (EU Regulation 1169/2011), and geographical indications (EU Regulation 1151/2012) were later added. In the United States the Food Safety Modernization Act (FSMA) was signed into law in 2011; the Act was the first major overhaul of US food safety legislation since the US Federal Food, Drug, and Cosmetic Act was passed in 1938. Included among rules governing implementation of this law are explicit requirements that food manufacturing firms take action to offset the risk of intentional food adulteration.\(^{20}\) In response to the melamine milk incident, the Chinese government adopted a Chinese Food Law in 2009 which is similar to the EU’s General Food Law (Pei et al., 2011).

In addition to regulations, national and subnational governments also hold a crucial role in deterring and enforcing laws concerning food fraud. Implementing harsh penalties commensurate with the type of fraud committed and the subsequent harm to public health is thought to reduce the probability of fraud (DEFRA, 2014). The international trade of dairy products, however, increases both the potential for fraud and the difficulty in identifying the source of the fraud and limits legal remedies to stop it. It has been noted that one of the biggest fraud risks is the number of times food changes hands—not the number of miles food travels (Sampson, 2017). In our globalized international agrifood supply chains, ingredients can be sourced and aggregated through a complex network of brokers and distributors who, themselves, may have little knowledge or accountability for the products they handle (GMA, 2010). While economic incentives are always present, fraud can particularly flourish in products sourced from or shipped through countries that have weak domestic regulations, where there is low probability of detection, and/or where the legal system is poorly structured or insufficiently enforced. Further, in cross-border transactions, laws from several jurisdictions may apply, further challenging the ability to prosecute fraud cases through civil and/or criminal channels. Ehmke et al. (2019) and Spink and Moyer (2011), among others, offer further discussion about the role of government in providing incentives and deterrents to food fraud.

In the case of milk and dairy products, the relatively shorter supply chain for fluid milk should reduce the potential for fraud. Further, in many markets such as the United States,

\(^{20}\) FSMA rule for mitigation strategies to protect food against intentional adulteration.
Canada, and E.U. there are established food safety regulations (which address food fraud) and these countries (regions) import relatively small amounts of fluid milk. Coupled together, the risk of fraud in fluid milk is expected to be lower than for processed dairy products. Some evidence of this is found in our HorizonScan analysis where processed dairy products such as cheese, yogurt, butter, and ghee were identified as having more incidents of fraud than fluid milk.

13.5 Conclusion

Milk fraud is one of the oldest and most pervasive examples of food fraud. Milk and dairy products are among the food products most susceptible to fraud and consistently rank among the top food categories affected by reported fraud cases. The perishable and bulky nature of milk, the production and processing cost structure, and interindustry linkages set it apart from other agrifood products. These distinguishing features also contribute to the high susceptibility of dairy products to fraud. Milk is a key ingredient in many value-added, processed dairy products such as cheese, butter, and yogurt which additionally extends the risk of fraud to these product categories. Economic incentives for dairy fraud are further strengthened by gaps between milk supply and demand in some geographic areas, and by the high profit margins offered by processed dairy products.

Examples of types of fraud in this sector include adulteration by diluting and adding other (sometimes harmful) substances to meet quality parameters, addition of chemical preservatives to increase shelf-life, addition of or replacement with lower value milk (that from a different species or a different geographical region), and faulty documentation or labeling (such as selling nonorganic milk as organic). Due to the nature of dairy fraud and the high global consumption of these products, the economic and human health impacts of fraud can be substantial.

Overall there has been an increase in the number of dairy fraud reports in recent years. Cheese, milk, and cream have been products particularly targeted with by fraudulent activity. Fraudulent documentation is a common form of dairy fraud, which includes inaccuracies regarding the place of origin of the product and undeclared allergens. Product adulteration and production on unapproved premises are other prevalent types of dairy fraud.

Given the prevalence and complexity of dairy fraud, it is important to understand the analytical methods and techniques used to detect it. While some simple, rapid qualitative tests can be used to detect adulteration of milk and dairy products, oftentimes more complex methods are preferred due to the higher degrees of sensitivity and more precise results they offer. A variety of chromatographic, immunological, DNA-based, and spectroscopic methods are commonly used to detect different types of adulteration. However, in some settings, use of these more precise and sensitive methods is limited by the technical expertise, (costly) equipment, and supply requirements.

The continued upward trend in the number of reported incidents of dairy fraud indicates that more work is needed to dampen the growth and impacts of this type of fraud. Dairy industry stakeholders each play an important role in the prevention and detection of dairy product fraud. In addition to undertaking analyses that monitor and detect adulteration, dairy firms must assume responsibility for assuring the integrity of their supply
chains through their quality management and risk mitigation plans, and other strategic planning, training, and outreach initiatives. Through the efforts of nongovernment organizations, the dairy industry must remain engaged in developing and promoting the uptake of industry standards. Dairy industry standards, and less directly, other food industry standards and certifications, affect the potential for fraud through their impacts on dairy production and distribution processes. Such efforts, however, must remain cognizant of firm-level implementation cost and other challenges and take care not to unintentionally incentivize additional fraud. And finally, national governments have a role in developing regulations that address food fraud, in performing border inspections and testing, and in establishing and enforcing penalties sufficient to deter it. As processed dairy products are frequently traded internationally, coordination across national governments is needed to help one to identify, limit, and prosecute cross-border fraud cases. While it is not possible to prevent all incidents, such continued efforts by dairy industry firms, other industry stakeholders, and governments, combined with the ongoing evolution of analytical techniques, will help one to mitigate the public and private economic and human health consequences of dairy fraud.

References


References


13. Dairy product fraud


Food Fraud


Vetter, W., Schröder, M., 2010. Concentrations of phytanic acid and pristanic acid are higher in organic than in conventional dairy products from the German market. Food Chem. 119, 746–752.


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A discussion of grains and cereals as a food source is best initiated with clarification of their nuanced definitions. Grain is a general term, used to describe the harvested, edible seed or fruit of a cereal crop, or that of a crop that bears similar seeds or fruit (Price and Welch, 2013). Botanically known as a caryopsis, this dry seed comprises the bran, endosperm, and embryo and may be enclosed in an inedible hull (Price and Welch, 2013).
Commercial grain crops, or grain-producing plants, can be divided into cereals, pseudocereals, and legumes. Cereals refer to grain crops from the monocotyledonous grass family, Poaceae (formally known as Graminae) \(\text{(Grass Phylogeny Working Group, 2001)}\). The main commercial cereal grain crops include maize, rice, wheat, barley, rye, oats, millet, and sorghum (some notable secondary crops exist such as the wheat/rye hybrid, triticale) \(\text{(Potter and Hotchkiss, 1995)}\). Conversely, pseudocereals are plants harvested for their edible grain, just like cereals, but do not belong to the Poaceae family—amaranth, quinoa, and buckwheat are notable pseudocereals \(\text{(Schoenlechner, 2016)}\). When all three parts of a caryopsis are intact (germ, endosperm, and bran), it is referred to as whole grain, whereas a grain that had gone through a milling process (where the bran and germ are removed) is known as refined grain \(\text{(van der Kamp, 2012)}\). Furthermore, grain crops from the family Fabaceae are known as legumes, which can be further divided into pulses and oilseeds \(\text{(Potter and Hotchkiss, 1995)}\). Legumes are flowering plants characterized by their pods containing beans or seeds, and their root nodules housing symbiotic nitrogen-fixing bacteria \(\text{(Potter and Hotchkiss, 1995; Postgate, 1982)}\). Pulses refer to legumes used as a dry grain, including important crops such as beans, chickpeas, dried peas, lentils, and lupins. Certain crops are notably excluded from identification as pulses, due to their primary use for extractable oil (referred to as oilseeds); included are soybeans and peanuts \(\text{(Potter and Hotchkiss, 1995)}\).

The vast variety of economically significant grain commodities is exceptionally important for their role in human health, feeding livestock, and industrial purposes. Recent studies have identified low intake of whole grains as one of the top dietary risk factors globally for death and disability-adjusted life years \(\text{(GBD, 2017 Diet Collaborators, 2019)}\). The majority of the world population’s food calories, and about half of its protein, are provided by cereal grains \(\text{(Potter and Hotchkiss, 1995)}\). An estimated 70% of land dedicated to cultivated crops is dedicated to cereal grasses \(\text{[Food and Agriculture Organization of the United Nations (FAO), 2019a]}\) with maize, rice, and wheat making up close to 90% of that \(\text{(Wrigley, 2017)}\). Current global production of cereal grains is on a steady increase, with a forecasted utilization of 2.708 million metric tonnes (mmt) for 2019/20 (1.0% increase from 2018/19) \(\text{[Food and Agriculture Organization of the United Nations (FAO), 2019b]}\). Coarse grains (cereal grains such as maize, barley, sorghum, rye, and oats used primarily for animal feed, brewing, or biofuels) are experiencing the largest increase in demand (1.3%) \(\text{[Food and Agriculture Organization of the United Nations (FAO), 2019b]}\). Table 14.1 presents global production quantity data from the most economically significant crops, comparing 2007 and 2017 (most recent data available at the time of writing this book). Of the cereal grains, maize has the highest production, with the Food and Agriculture Organization of the United Nations (FAO) reporting 1135 mmt being produced in 2017. It is globally important as a staple food and for its use as animal fodder and as a biofuel. Following maize, rice and wheat are the next most important crops, which had similar production quantities in 2017 (771 mmt) \(\text{[Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT), 2019]}\). Rice is primarily used as a human food source, making it the most consumed cereal grain, with the majority of the crop being cultivated in Asia (over 90%); China, India, and Indonesia are the top producers \(\text{[Potter and Hotchkiss, 1995; Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT), 2019]}\). Cultivation of the crop is labor intensive and has exceptionally high irrigation requirements \(\text{(Arvanitoyannis and Tserkezou, 2008)}\). Wheat is unique
### TABLE 14.1  Global production quantity [million metric tonnes (mmt)] data of grain crops for 2007 and 2017 [Food and Agriculture Organization of the United Nations Statistics Division (FAOSTAT), 2019].

<table>
<thead>
<tr>
<th>Grain crop</th>
<th>Latin name</th>
<th>Production (mmt) 2007</th>
<th>Production (mmt) 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cereals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td><em>Zea mays</em></td>
<td>792.85</td>
<td>1134.91</td>
</tr>
<tr>
<td>Rice</td>
<td><em>Oryza sativa</em></td>
<td>657.92</td>
<td>771.41</td>
</tr>
<tr>
<td>Wheat</td>
<td><em>Triticum spp.</em></td>
<td>606.68</td>
<td>771.73</td>
</tr>
<tr>
<td>Barley</td>
<td><em>Hordeum vulgare</em></td>
<td>131.15</td>
<td>147.4</td>
</tr>
<tr>
<td>Sorghum</td>
<td><em>Sorghum vulgare</em></td>
<td>62.76</td>
<td>57.6</td>
</tr>
<tr>
<td>Millet</td>
<td><em>Various sp.</em></td>
<td>33.67</td>
<td>28.46</td>
</tr>
<tr>
<td>Oats</td>
<td><em>Avena sativa</em></td>
<td>24.97</td>
<td>25.95</td>
</tr>
<tr>
<td>Rye</td>
<td><em>Secale cereale</em></td>
<td>15.17</td>
<td>13.73</td>
</tr>
<tr>
<td>Triticale</td>
<td><em>× Triticosecale</em></td>
<td>12.12</td>
<td>15.56</td>
</tr>
<tr>
<td><strong>Pseudocereals</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quinoa</td>
<td><em>Chenopodium quinoa</em></td>
<td>0.05912</td>
<td>0.1467</td>
</tr>
<tr>
<td>Buckwheat</td>
<td><em>Fagopyron esculentum</em></td>
<td>2.379</td>
<td>3.828</td>
</tr>
<tr>
<td><strong>Legumes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Oilseeds</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td><em>Glycine max</em></td>
<td>219.79</td>
<td>352.65</td>
</tr>
<tr>
<td>Groundnut with shell (peanut)</td>
<td><em>Arachis hypogaea</em></td>
<td>37.56</td>
<td>47.16</td>
</tr>
<tr>
<td><strong>Pulses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beans, dry</td>
<td><em>Phaseolus spp.</em></td>
<td>21.75</td>
<td>31.42</td>
</tr>
<tr>
<td>Peas, dry</td>
<td><em>Pisum sativum; Pisum arvense</em></td>
<td>9.106</td>
<td>16.21</td>
</tr>
<tr>
<td>Chickpea</td>
<td><em>Cicer arietinum</em></td>
<td>9.69</td>
<td>14.78</td>
</tr>
<tr>
<td>Lentils</td>
<td><em>Lens esculenta; Eruum lens</em></td>
<td>3.225</td>
<td>7.59</td>
</tr>
<tr>
<td>Cowpeas, dry</td>
<td><em>Vigna sinensis; Dolichos sinensis</em></td>
<td>5.33</td>
<td>7.41</td>
</tr>
<tr>
<td>Pigeon peas</td>
<td><em>Cajanusa cajan</em></td>
<td>3.603</td>
<td>6.8</td>
</tr>
<tr>
<td>Broad beans, dry</td>
<td><em>Vicia faba</em> (var. equina), (var. major), (var. minor)</td>
<td>3.89</td>
<td>4.84</td>
</tr>
<tr>
<td>Pulses nes</td>
<td><em>Dolichos spp.; Canavalia spp.; Psophocarpus tetragonolobus; Cyamopsis tetragonoloba; Stizolobium spp.; Pachyrhizus erosus</em></td>
<td>3.215</td>
<td>4.233</td>
</tr>
<tr>
<td>Lupins</td>
<td><em>Lupinus spp.</em></td>
<td>0.778</td>
<td>1.611</td>
</tr>
<tr>
<td>Vetches</td>
<td><em>Vicia sativa</em></td>
<td>0.98</td>
<td>0.9185</td>
</tr>
<tr>
<td>Bambara beans</td>
<td><em>Voandzeia subterranea</em></td>
<td>0.1056</td>
<td>0.1795</td>
</tr>
</tbody>
</table>
in its exceptional genetic variability that allows it to adapt to different climatic conditions; the
crop can grow in temperate, tropical, and subtropical climates, but the majority is grown in
the United States [International Wheat Genome Sequencing Consortium (IWGSC), 2014; Food
and Agriculture Organization of the United Nations Statistics Division (FAOSTAT), 2019]. It is
the largest cereal crop in the United States, being used primarily for human food. Wheat
world trade is greater than all other crops combined (Curtis et al., 2002). Apart from maize,
rice, and wheat, the production of the remaining 10% of economically significant cereals
decides sequentially in the following order: barley (used for fodder, malt for beer brewing,
and alcohol distillation), sorghum (mostly used for animal feed), millet (drought-resistant
groups of small-seeded grasses that are grown mostly in developing countries and are used
for fodder or human food), oats (mostly used for fodder, but also human food), and rye (used
widely in bread making and alcohol distillation for whiskey) [Food and Agriculture
Organization of the United Nations (FAO), 2019c]. Other cereal grasses exist but are of mini-
mal economic importance, such as teff, an annual grass native to Ethiopia [Food and
Agriculture Organization of the United Nations (FAO), 2019c].

Many important pseudocereals are cultivated for their edible grain, with some boast-
ing a high protein content. Quinoa is a dicot of the Amaranthaceae family of plants and
is harvested for its high-protein seed. It is grown in the Andes (Ecuador, Bolivia, and
Peru) and has seen production increase by close to triple in the past decade (2007–17)
[Food and Agriculture Organization of the United Nations (FAO), 2019c]. Other pseudo-
cereals with economic significance that are used as food or fodder include buckwheat,
amaranth, and chia seeds (Das, 2016). Amaranth refers to the Amaranthus genus of
plants, containing at least 60 species, though the major species used are Amaranthus hypo-
chondriacus L., Amaranthus cruentus L. (syn. Paniculatus L.), and Amaranthus caudatus
L. (syn. Edulis Spegazzini) (Schoenlechner, 2016). The FAO does not report production
quantity individually for Amaranth, but rather as part of a “cereal nes” group (nes: not
elsewhere specified) that serves as a designation for crops that are “identified separately
because of their minor relevance at the international level” [Food and Agriculture
Organization of the United Nations (FAO), 2019d].

The final group of grains important in world trade is legumes. Contrasting the typically low-
protein cereal grains, legumes are desired for their high protein content and more balanced
essential amino acid profile (Potter and Hotchkiss, 1995). As mentioned, some legumes are des-
ignated as “pulses.” The FAO recognizes 11 pulses, cultivated for their dry grain. These include
dry beans, broad beans, dry peas, chickpeas, cowpeas, pigeon peas, lentils, Bambara beans,
vetches, lupins, and pulses nes [Food and Agriculture Organization of the United Nations
(FAO), 2019e].

Legumes that are not designated pulses are primarily used for purposes other than
human consumption or may not be cultivated for their dry seed. Various oilseeds are
included, desired for their high oil content. Soybean is a globally important crop with sev-
eral uses. High in protein, it is used for cheap animal fodder as well as protein supple-
mentation for humans. The oil from soybeans is the primary type used in vegetable oil
[Food and Agriculture Organization of the United Nations (FAO), 2019c, 2019f]. In 2017
352.65 mmt of soybeans were produced, with the United States topping the list, followed
by Brazil [Food and Agriculture Organization of the United Nations Statistics Division
(FAOSTAT), 2019]. Peanuts (designated as groundnuts by the FAO) are also a
notable crop, cultivated for oil and food due to their exceptional protein content [Food and Agriculture Organization of the United Nations (FAO), 2019f]. There are also other oil-seed crops not a part of the legume family that are of economic importance, including cottonseed, sunflower seed, safflower seed, rapeseed, flaxseed, hemp seed, and poppy seed. As there is a dedicated oil chapter in this book, we will restrict our focus on crops that are also important for their protein content, namely soybean.

14.2 Vulnerability of grains and cereals to food fraud

14.2.1 Introduction to fraud vulnerability in grains and cereals

Developing strategies to mitigate food fraud can only be achieved with a foundational understanding of the characteristic vulnerabilities of a commodity of interest (Esteki et al., 2019). Existing literature has well outlined strategic approaches for anticipating fraud in certain commodities and developing analytical laboratory tests to address it. Documentation of such matters, including those concerning cereal grains, can even be traced back to the early 1800s (Accum, 1820). Current industry guidelines for avoiding fraud describe sequential steps to develop a food fraud risk management system (see Chapter 3: Food Fraud Mitigation: Strategic Approaches and Tools). Helpful organizations such as the Global Food Safety Initiative (GFSI) (2019) and SSAFE (2019) seek to help promote food safety across the supply chain by bringing together key actors in the food industry to work toward better risk mitigation plans.

Efficient assessment of vulnerability to adulteration involves developing comprehensive profiles of commodities and their supply chains that allow identification of opportunities for fraudsters. Interestingly, some experts claim that because fraud is motivated by illicit monetary gain, the significance of a presence of opportunity to adulterate is paramount over the type of food that is being adulterated (Esteki et al., 2019). There are many factors that can play a role in encouraging fraud, which some literature has helpfully organized into larger groups. These include technical opportunities unique to the commodity and its trade (e.g., involving supply chain access, difficulty of fraud, likelihood of detection, and profit), factors of motivation (i.e., economic considerations such as supply, pricing, and value-adding product attributes), and control measures (i.e., efficacy of analytical method for detecting fraud and appropriate organizational systems for quality control throughout the supply chain) (van Ruth et al., 2017; Silvis et al., 2017; Jack, 2015). Factors that implicate grains exist in all areas of this framework; hence, a complete understanding of the full production and trade of a commodity is a prerequisite for effective fraud mitigation design. Grain crops’ fraud risk is linked to the global status of crop availability (i.e., global supply and its influencing factors such as climate), the physical state of trade material, value-added premiums on crops, the complexity of supply chains, and issues with the fitness of analytical techniques.

Logically, an easy method by which vulnerabilities can be identified involves looking at past instances of fraud. Multiple databases are available that serve as fraud records and function as alert systems (see Chapter 3: Food Fraud Mitigation: Strategic Approaches and Tools). In a study by Bouzembrak et al. (2018), involving a comparison of reported food fraud incidents in different databases, the Rapid Alert System for Food and Feed and Economically Motivated Adulteration (EMA) databases revealed “cereals and baked goods” and “grain products,” respectively, among the main product categories related to food
fraud. The EMA database ranked grain products 9th out of 19 categories based on the number of fraud notifications in the system from 2000 to 2015 (Bouzembrak et al., 2018). Though some groups of commodities see more rampant adulteration than grains, some key vulnerabilities lead to susceptibility. Fortunately, the majority of grain fraud practices are not harmful to humans, involving substitution of different crop varieties or species for economic gain (Delwiche, 2016). However, the practice of adulteration with toxic melamine or its derivatives is a real risk with some grain products, making it all the more important to recognize and address vulnerabilities (Gossner et al., 2009). We will touch on some of these issues and then explore their real-world consequences with examples of fraud and corresponding mitigation efforts.

14.2.2 Climatic influence on supply and demand

Grains, like many widely grown staple crops, are sensitive to events such as drought, flood, and other abnormal climatic events that may negatively impact yield and result in lower supply. A global climate change report prepared by the US Global Change Research Program (USGCRP) collected data on annual corn yield in the United States from 1960 to 2008 and was able to associate atypical reductions in yield with significant climatic events. For example, droughts occurring at different points during the 1980s coincided with crop yields that were reduced up to 29% from the previous year (Karl et al., 2009). A historical upward trend exists in yield, but it may be threatened by volatile climatic events and temperatures increasing past vegetative optimums due to climate change (Karl et al., 2009). Crops do not respond well to extreme excesses or deficits of water, which warrants concern given the projected less frequent but more intense rainfall in the United States (Kunkel et al., 2008). The same USGCRP report cites a 2008 example of extreme rainfall causing overflow of the Mississippi River. The flooding implicated hundreds of thousands of acres of cropland, preventing harvest of wheat, and planting of corn and soybean; agricultural losses were estimated at approximately $8 billion (Karl et al., 2009). Such threats to crop yield and global supply increase risk for fraud, as suppliers may choose to substitute or add bulking agents to material in an attempt to meet demand (Johnson, 2014).

14.2.3 High-volume trade

One of the issues that implicates multiple grain crops is the convention of high-volume trade. Large bulk handling of crops makes even a small amount of adulteration profitable in a large enough final volume. This problem is exacerbated in the case of later supply chain material transported in bulk processed form, where adulteration is easily carried out and likely undetectable by simple vision tests (like in the case of legume-based protein powders) (Everstine et al., 2013). This issue is a prime example of the importance of developing sensitive analytical tests that can detect adulteration in what could be small, but economically problematic, volumes. Rice is a good example where varietal adulteration is a plaguing issue. At any point in the supply chain where material is received and redistributed, an amount of nontarget rice can be used to adulterate the main crop (Vemireddy et al., 2015).
14.2.4 Supply chain complexity

Trade and handling are the key concepts leading to the very important topic of supply chain traceability and complexity. Increasing complexity of the supply chain leads to an increased risk of fraud [United States Pharmacopeia (USP), 2016; Moyer et al., 2017]. Many crops have supply chains that involve several points of sale and purchase, sometimes to take advantage of subsidies or avoid tariffs (Everstine et al., 2013). With every new step in material transport, a potential opportunity for fraud is created. According to a “Food Fraud Vulnerability Assessment” by the Canadian Grain Commission (CGC) (2018), vulnerabilities to fraud exist at each stage of the supply chain, from on-farm harvesting to final product shipping. Effective mitigation strategies do exist for many of these potential issues, but this is dependent on proper moderation and control of quality assurance efforts throughout the entirety of the supply chain. Wheat is a good example of a grain that faces issues due to complexity in quality and trade. There are many grades of wheat with different end uses, and mixtures are customary in the supply chain. Control is dependent on attentive grading systems of suppliers; thus any lack of accountability at a point in material transition opens the door to adulteration (Kennett et al., 1998).

14.2.5 Non-genetically modified organism and organic added value factors

Products marketed with a specific added value quality claim are subject to increased fraud risk, namely, in the case of “organic” or “non-genetically modified organism (GMO)” crops. These added value factors create economic incentive to pass off inauthentic substitutes as the premium product, such as with many organically grown grains such as soybean and maize (Jack, 2015). Informal practices of organic farming in organized movements can be traced back to the 1940s, persisting to the 1960s when the first organic production standards were promulgated (Lockeretz, 2007). Despite minimal economic relevance as recently as the 1980s, organic farming has since grown in popularity to the current day where nearly 70 million hectares of farmland are organic, contributing to a global market valuation at USD 97 billion [International Federation of Organic Agriculture Movements (IFOAM), 2019]. Organic farming is a multifaceted approach to agriculture that emphasizes environmental protection and human health facilitated by integration of farming techniques with natural ecological processes. A prime focus is placed on soil quality, with a reliance on natural alternatives to conventional synthetic fertilizers, pesticides, and herbicides [International Federation of Organic Agriculture Movements (IFOAM), 2019; Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), 2009]. Understandably, factors such as greater labor input and smaller harvest result in organically grown crops being sold at a higher price than their nonorganic counterparts [Food and Agriculture Organization of the United Nations (FAO), 2019g]. For example, the average organic premium of wheat, rice, corn, and barley in the United States has reached 2.5 times the cost, as of 2016 (Reaves et al., 2019). Thus an opportunity is created for fraudsters to economically benefit from falsely claiming organic status. In 2018 a farmer in Missouri, United States was charged for the false marketing of USD 140 million worth of soybeans, corn, and wheat as certified organic grain for over 2 years (Foley, 2018).

All grain crops are able to be grown organically; in fact, multiple crops grown together epitomize the organic effort. A recent report from the US Organic Grain Collaboration...
(in partnership with the Organic Trade Association) argues the importance of not limiting organic grain rotations to corn, soy, and wheat, but rather implementing more complex rotations of other cereals, nitrogen-fixing legumes, and forage crops, which contribute to soil health and control of pests and weeds (Reaves et al., 2019). Earlier, we discussed increased vulnerability to fraud associated with supply struggling to meet demand. Organic grain farming has experienced growth in the United States, with an increase of 626,000–765,000 acres of cropland (2008–16) dedicated to organic corn, soybeans, wheat, oats, and barley (Reaves et al., 2019). However, this growth has been insufficient to meet demand, in large part due to the rapid growth of the organic livestock industry and its need for organic feed, since the United States Department of Agriculture (USDA) regulations require 100% certified organic feed as a prerequisite for “organic” livestock [United States Department of Agriculture (USDA), 2013; Reaves et al., 2019].

Similarly, falsely claiming non-GMO crops offer an economic incentive. Several genetically modified crops exist, engineered to possess traits such as insect resistance or herbicide tolerance (Ervin et al., 2010). Two grain crops with an exceptional global presence of GMO varieties include soybean and maize, with the large majority of grown crops being genetically engineered. In 2018 92% of maize grown in the United States was herbicide tolerant, specifically to glyphosate, which is the active ingredient in certain herbicides that is typically toxic to plants. In addition, 82% was insect resistant, known as “Bt-corn,” which refers to added genes from the Bacillus thuringiensis bacterium. The added genes allow expression of proteins that are toxic to many common insect pests [Ervin et al., 2010; United States Department of Agriculture (USDA), Economic Research Service, 2002]. GMO soybeans represented 94% of the planted crop in 2018 [United States Department of Agriculture (USDA), Economic Research Service, 2002]. Other GMO grain varieties have been created and approved by some countries but are not grown widely or at all; these include wheat, rice, and sorghum [Canadian Food Inspection Agency (CFIA), 2018].

Recently, public fears surrounding some of the potential concerns of GMO farming (ranging in scientific relevance) prompted companies to market non-GMO products. Debate around potential dangers, regulation, and labeling has been ongoing for decades and has been thoroughly reviewed in the literature, though is outside the scope of this report [Yuan et al., 2019; Walters, 2004; World Health Organization (WHO), 2014; Borges et al., 2018]. The advantages of GMO farming include cost-effective weed control and minimal pest-related loss leading to higher yields and reduced production costs; hence, GMO commodities often end up being less expensive than their non-GMO counterparts (McHughen, 2013; Ervin et al., 2010). Ultimately, the added value of the non-GMO designation presents an opportunity to falsely claim the premium despite the inclusion of GMO ingredients. Corresponding quality control must be present to mitigate this type of adulteration.

### 14.3 Risk mitigation (nonlaboratory)

An effective food fraud mitigation plan not only involves having fit for purpose analytical techniques, but also a risk assessment component involving logistical considerations that limit vulnerabilities to adulteration (discussed in Chapter 2: History of Food Fraud and Development of Mitigation Requirements and Standards and Chapter 3: Food Fraud...
Mitigation: Strategic Approaches and Tools). Much work has been put into defining food fraud, classifying its associated risks, and determining its origins so that the initial preventative efforts can be as effective as possible (Spink and Moyer, 2011). Ultimately, the onus is on industry to incorporate appropriate safeguards against preventable fraud events [Global Food Safety Initiative (GFSI), 2019]. These efforts from industry, combined with frontier research on tools for anticipating vulnerability, lead to comprehensive preventative control. For example, Bouzembrak et al. (2018) sought to address a gap in database tools by developing a system that can collect media reports on food fraud, updated every 10 min. This was another study that identified adulteration of grains among the top commodity groups affected by fraud (Bouzembrak et al., 2018).

As discussed, complex and fast-moving supply chains are a prime target for fraudsters, with several grain supply chains being an example (Moyer et al., 2017; Kennett et al., 1998). The Canadian Grain Commission (CGC) (2018) released a “Food Fraud Vulnerability Assessment” with mitigation strategies that reach across the supply chain. A common theme woven throughout strategies hinges on developing trusting relationships with all suppliers and handlers who are part of the supply chain. Opportunities for fraud may arise as early as the farm, and as late as final shipping. The Canadian Grain Commission (CGC) uses the example of organic crop fraud and non-GMO adulteration with GMO crop varieties, suggesting control strategies such as contracting with producers, use of certified seeds, and routine inspections at new material reception points. But most importantly, they describe a program that aids in these efforts and epitomizes the idea of traceability. The Canadian Identity Preserved Recognition System (CIPRS) is a voluntary program created by the CGC to certify “that a company’s identity preserved system for the production, handling and transportation of specialty grains, oilseeds or pulses is effective” [Canadian Grain Commission (CGC), 2019]. As part of the program, companies document the production and transport of grains, such as identity preserved (IP) non-GMO soybeans. The CGC works closely with elevators, shippers, and buyers to facilitate appropriate handling of specialty grains. They achieve this by providing quality management requirements that must be adhered to, third-party audits to evaluate IP systems, and certificates of recognition following audits. The CGC website offers a tool kit outlining their standards [Canadian Grain Commission (CGC), 2019]. This outline is a good example of risk mitigation using preventative techniques, and its success with IP soybeans has led to it being globally renowned as a trailblazing example of which others should follow suit. Since 2000 at least 80% of exported soy from Canada has been IP soy, particularly non-GMO varieties (Whitelaw, 2017). The CIPRS has allowed buyers to be confident that IP soybeans are traceable through every step of production and handling, back to a certified seed grower, and have been properly segregated at each checkpoint [Canadian Grain Commission (CGC), 2019].

14.4 Types of fraud and analytical techniques

14.4.1 Introduction to fraud in grains and cereals

When it comes to addressing instances of fraud with analytical techniques, it is important to understand that each method has advantages and disadvantages. When choosing the correct approach, prime consideration should be given to fitness for purpose.
Many analytical techniques are used to authenticate food, as well as combinations of techniques [e.g., separation techniques are commonly combined with mass spectrometry (MS)]. A list of some of the common groups of techniques (adopted from Esteki et al., 2019) include spectroscopies [mid-infrared (MIR), near-infrared (NIR), Raman, NMR, and UV–vis], separation techniques [GC, high-performance liquid chromatography (HPLC), capillary electrophoresis], MSs (MS, MS/MS), stable isotope measurements [isotope-ratio mass spectrometry (IRMS)], enzyme-linked immunosorbent assays (ELISA), and DNA methods [polymerase chain reaction (PCR)]. A study by Hong et al. (2017) looked at the main technologies used for the detection of food fraud in different commodities (according to amount of keyword use in literature from 1995 to 2015) and found that in grain products the most used methods were MS, LC, HPLC, PCR, GC, IR, ELISA, NMR, Ramen, IRMS, and biosensor (ranked based on almost 900 publications).

There are many types of fraud that occur in grain products, along with several associated methods of analytical testing. Table 14.2 provides several of these examples with

<table>
<thead>
<tr>
<th>Grain product</th>
<th>Adulterant/fraud</th>
<th>Analytical method of detection</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>RP-HPLC</td>
<td>McCarthy et al. (1990)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>ELISA and immunoblotting</td>
<td>Stevenson et al. (1994)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>PCR</td>
<td>Bryan et al. (1998), Arlorio et al. (2003), and Ibrahim et al. (2011)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>qPCR</td>
<td>Alary et al. (2002), Terzi et al. (2003), Pasqualone et al. (2007), Sonnante et al. (2009), and Carloni et al. (2017)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Geographic origin</td>
<td>IRMS</td>
<td>Brescia et al. (2002)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>NIR reflectance</td>
<td>Cocchi et al. (2006)</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>Common wheat</td>
<td>LC–MS/MS</td>
<td>Knödler et al. (2010), Prandi et al. (2012), and Russo et al. (2014)</td>
</tr>
<tr>
<td>Waxy common wheat</td>
<td>Common wheat</td>
<td>NIR reflectance</td>
<td>Delwiche and Graybosch (2014)</td>
</tr>
<tr>
<td>Wheat, maize, and</td>
<td>Melamine</td>
<td>HPLC</td>
<td>Ehling et al. (2007)</td>
</tr>
<tr>
<td>rice flour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat products</td>
<td>Melamine</td>
<td>ELISA</td>
<td>Garber and Brewer (2010)</td>
</tr>
<tr>
<td>Wheat gluten</td>
<td>Melamine</td>
<td>SERS, HPLC</td>
<td>Lin et al. (2008)</td>
</tr>
<tr>
<td>Soy-based infant</td>
<td>Melamine</td>
<td>LC–MS/MS</td>
<td>Tittlemier et al. (2009)</td>
</tr>
<tr>
<td>Soy drink</td>
<td>Melamine</td>
<td>LC–MS</td>
<td>Ibáñez et al. (2009)</td>
</tr>
<tr>
<td>Soya milk powder,</td>
<td>Melamine</td>
<td>GC–MS</td>
<td>Araújo et al. (2012)</td>
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</tbody>
</table>

(Continued)
TABLE 14.2 (Continued)

<table>
<thead>
<tr>
<th>Grain product</th>
<th>Adulterant/fraud</th>
<th>Analytical method of detection</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat gluten, soy protein isolate, rice protein concentrate</td>
<td>Melamine</td>
<td>GC–MS, LC–MS/MS, HPLC–UV</td>
<td>Levinson and Gilbride (2011)</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>Sorghum, oats, maize</td>
<td>HSI</td>
<td>Verdú et al. (2016)</td>
</tr>
<tr>
<td>Basmati rice and others</td>
<td>Cultivar substitution</td>
<td>HPLC</td>
<td>Huebner et al. (1990)</td>
</tr>
<tr>
<td>Basmati rice and others</td>
<td>Cultivar substitution</td>
<td>GC–MS</td>
<td>Suzuki et al. (1999)</td>
</tr>
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<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>NIR reflectance</td>
<td>Osborne et al. (1993)</td>
</tr>
<tr>
<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>PCR (SSLPs)</td>
<td>Bligh (2000)</td>
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<td>Basmati rice</td>
<td>Geographic origin fraud</td>
<td>IRMS, ICP-MS</td>
<td>Kelly et al. (2002)</td>
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<tr>
<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>PCR (DNA microsatellites)</td>
<td>Vemireddy et al. (2007) and Colyer et al. (2008)</td>
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<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>PCR (ASA)</td>
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<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>Calorimetry</td>
<td>Ahmed et al. (2008)</td>
</tr>
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<td>Multiple rice cultivars</td>
<td>Cultivar substitution</td>
<td>FT-NIR</td>
<td>Attaviroj et al. (2011)</td>
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<tr>
<td>Multiple rice cultivars</td>
<td>Cultivar substitution</td>
<td>FT-MIR</td>
<td>Largo-Gosens et al. (2014)</td>
</tr>
<tr>
<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>1H NMR</td>
<td>Monakhova et al. (2014)</td>
</tr>
<tr>
<td>Basmati rice</td>
<td>Non-Basmati rice</td>
<td>ddPCR</td>
<td>Bucher and Köppel, 2015</td>
</tr>
<tr>
<td>Rice, soybean, millet, wheat, and corn</td>
<td>Geographic origin fraud</td>
<td>EA-SIRMS</td>
<td>Wu et al. (2015)</td>
</tr>
<tr>
<td>Gluten-free foods</td>
<td>Gluten (wheat, rye, barley, oats)</td>
<td>qPCR</td>
<td>Sandberg et al. (2003)</td>
</tr>
<tr>
<td>Gluten-free foods</td>
<td>Gluten (wheat, rye, barley)</td>
<td>QC-PCR, ELISA</td>
<td>Dahinden et al. (2001)</td>
</tr>
<tr>
<td>Oats</td>
<td>Gluten (wheat)</td>
<td>PCR, ELISA</td>
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<tr>
<td>Oats</td>
<td>Gluten (wheat, rye, barley)</td>
<td>ELISA</td>
<td>Lacorn et al. (2019)</td>
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<tr>
<td>Oats</td>
<td>Gluten (wheat, rye, barley)</td>
<td>NIR</td>
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<td>Sorghum syrup</td>
<td>High-fructose corn syrup</td>
<td>IC-IPAD</td>
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<td>Cooked millet flour</td>
<td>Cooked soybean flour</td>
<td>HIS</td>
<td>Shao et al. (2018)</td>
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<td>Quinoa flour</td>
<td>Soybean, maize, wheat flour</td>
<td>FT-MIR</td>
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<td>Chickpea flour</td>
<td>Pea flour</td>
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<td>Organic wheat, barley, faba bean</td>
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<td>Organic maize</td>
<td>Organic fraud</td>
<td>GC–MS</td>
<td>Röhlig and Engel (2010)</td>
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(Continued)
reference relevant studies, but the following section will elaborate on select key examples in depth.

### 14.4.2 Adulteration of durum wheat with common wheat

The complexity of wheat quality opens the door for adulteration in any scenario where grading systems or techniques cannot adequately discern identity (Kennett et al., 1998). Several species comprise the wheat genus, *Triticum*, with most global production (~95%) dedicated to the allohexaploid “common wheat” or “bread wheat”—*Triticum aestivum* L. ([International Wheat Genome Sequencing Consortium (IWGSC), 2014](http://www.iwgsc.org/)). This wheat is commonly used in bread making and itself can be graded into different classes that have different physical properties and end uses—classes in North America consist of hard red spring, hard red winter, soft red winter, hard white, and soft white (Kennett et al., 1998). Another allotetraploid species, *Triticum durum* (synonym: *Triticum turgidum* L. var. *durum*), is commonly known as durum wheat (also classed as “durum” in the grading system) and is used to make pasta (from the wheat middlings, called semolina) ([International Wheat Genome Sequencing Consortium (IWGSC), 2014](http://www.iwgsc.org/); Maccaferri et al., 2019). It differs from common wheat in its superior rheological properties for pastas (Sissons, 2008). Durum wheat typically holds a higher market value than common bread wheat (~20% higher), and thus instances of adulteration involve actions such as addition of common wheat flour to durum wheat flour ([Cocchi et al., 2006](http://www.iwgsc.org/); [United States Department of Agriculture (USDA), Economic Research Service, 2019](http://www.iwgsc.org/); [Hong et al., 2017](http://www.iwgsc.org/)). Some countries allow a mixture of the two flours for some products like pasta, but this differs in countries such as

<table>
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<tr>
<td>Organic wheat</td>
<td>Organic fraud</td>
<td>EST-based microarray (transcriptomics)</td>
<td>Lu et al. (2005)</td>
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<tr>
<td>GMO soy, GMO maize</td>
<td>“Non-GMO” fraud</td>
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<td>Vaitilingom et al. (1999) and Mano et al. (2018)</td>
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<td>GMO soy, GMO maize</td>
<td>“Non-GMO” fraud</td>
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<td>“Non-GMO” fraud</td>
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<td>GMO maize</td>
<td>“Non-GMO” fraud</td>
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<td>Zolla et al. (2008)</td>
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<tr>
<td>GMO soy, GMO maize</td>
<td>“Non-GMO” fraud</td>
<td>Microarray</td>
<td>Turkec et al. (2016)</td>
</tr>
</tbody>
</table>

ASA, Allele-specific amplification; ddPCR, digital droplet polymerase chain reaction; EA–SIRMS, element analyzer stable isotope-ratio mass spectrometry; ELISA, enzyme-linked immunosorbent assay; EST, expressed sequence tag; FT–MIR, Fourier-transform mid-infrared; HPLC, high-performance liquid chromatography; HRM, high-resolution melting; HSI, hyperspectral imaging; IC–IPAD, ion chromatography integrated pulsed amperometric detection; ICP–MS, inductively coupled plasma mass spectrometry; IRMS, isotope-ratio mass spectrometry; LC–MS, liquid chromatography–mass spectrometry; LC–MS/MS, high-performance liquid chromatography tandem mass spectrometry; NGS, next-generation sequencing; NIR, near-Infrared; PAGE, polyacrylamide gel electrophoresis; PCR, polymerase chain reaction; QC–PCR, quantitative competitive polymerase chain reaction; qPCR, quantitative polymerase chain reaction (syn. real-time PCR); RP–HPLC, reversed-phase high-performance liquid chromatography; SERS, surface-enhanced Raman spectroscopy; SSLPs, simple sequence length polymorphisms.
Italy, France, and Spain. Italian law goes so far as to stipulate that pasta may only be made using semolina and water, and thus low thresholds are set for common wheat in durum as contamination during transport along the supply chain (<3%) (Cocchi et al., 2006). This standard also applies to exported pasta from this region as outlined by European Commission Regulation (1222/94, EC, 1994) [Commission Regulation (EU), 1994].

The risk of durum adulteration with common wheat is well understood, with a rich body of literature exploring adulteration and evaluating techniques to distinguish durum from other sources. Ibrahim et al. (2011) used PCR-based methods to study the identity of pasta products in the Jordanian market that claim to only include semolina as an ingredient. This technique was not quantitative, but the study recorded any presence as adulteration since potential minor common wheat contaminants were not noted on the products. In testing 26 samples (22 of known provenance from 9 different countries), they found that 65.4% contained common bread wheat as an adulterant, including two of the seven products from Italy (Ibrahim et al., 2011). The use of DNA-based diagnostic techniques, such as the PCR protocol by Ibrahim et al., is an effective approach due to the genetic differences between common wheat and durum wheat. The allohexaploid genome of T. aestivum contains three genomes in duplicate (AABBDD), while the allotetraploid T. durum lacks the D genome (AABB) [International Wheat Genome Sequencing Consortium (IWGSC), 2014; Maccaferri et al., 2019]. By targeting a unique sequence in the D genome, such as the 287 bp Dgas44 sequence used by Ibrahim et al., common wheat can be detected if present. Importantly, Ibrahim et al. used a short sequence length of a high copy number, increasing the likelihood of successful amplification amid DNA degradation during wheat processing (Tilley, 2004).

Multiple researchers have found success in using DNA-based techniques, making use of unique DNA microsatellites or polymorphisms (Bryan et al., 1998; Alary et al., 2002; Tilley, 2004; Terzi et al., 2003; Arlorio et al., 2003). Using quantitative PCR methods, the quantity of common wheat in durum wheat could be estimated, demonstrated by Alary et al. (2002) who used the puroindoline-b gene unique to T. aestivum to identify common wheat and quantify against a standard curve (then compare to total DNA to determine percent composition). They also investigated the influence of pasta drying temperature (30°C, 70°C, and 85°C). Quantitative assay data was compared against total DNA from samples with 3% adulteration of T. aestivum in T. durum, and experimentally determined mean values from the assay were 2.6%–3.4% depending on drying technique. These findings, along with those in other similar studies, underscore the utility of PCR-based techniques due to exceptional sensitivity and specificity, and requirement of only minimal quantities of template DNA (Alary et al., 2002; Pasqualone et al., 2007). Pasqualone et al. demonstrated a 2.5% detectable threshold of common wheat adulteration in durum using qPCR, which was improved upon by Sonnante et al. (2009) who achieved a 1.25% threshold by use of dual-labeled probes (instead of SYBR Green).

Alternative analytical methods have been investigated for the purpose of wheat differentiation, beginning with crude electrophoretic protein separation, immunoenzymatic assays, and reversed-phase HPLC. These early methods were not suitable in the case of denatured proteins (a problem, as conventional drying temperatures for pasta making went up over the years), or lacked specificity or sensitivity (Resmini, 1968; Stevenson et al., 1994; McCarthy et al., 1990; Alary et al., 2002; Pasqualone et al., 2007). Over the
years, other methods were explored with the goal of improving experimental time in detection (Delwiche, 2016). With the motivation of minimizing turnaround time, specialized personnel, and cost, while still maintaining the specificity required to detect 3% adulteration, Cocchi et al. (2006) sought to use multivariate analysis (partial least squares and a wavelet-based calibration algorithm) of NIR spectral data to distinguish common wheat from durum. They demonstrated a detectable effect of adulteration on NIR spectra, achieving a low uncertainty of about one half that of the official Italian method at the time (~0.3%) (Cocchi et al., 2006). However, this study was critiqued for its limited set of experimental mixtures and uncertain applicability to real market testing (Delwiche, 2016).

LC–MS/MS methods may serve as a quantitative method to study wheat mixtures via amino acid sequencing of tryptic digestion of target peptides. Knödler et al. (2010) found success in using HPLC–MS/MS to measure C17:0 to C21:0 alkylresorcinol homolog ratios, but they tested quantification limit down to 5% adulteration with common wheat (thus precluding a conclusion of use in industry to quantify down to the 3% threshold). Prandi et al. (2012) achieved similar assay capabilities using ultra performance liquid chromatography/electrospray ionization–MS and HPLC/ESI–MS/MS analyses to identify gliadin peptide markers. Interestingly, they used their assay to screen eight durum wheat pasta samples from the Italian market and found that all samples had common wheat contamination to some degree, with two samples over the 3% threshold. Lastly, Russo et al. (2014) achieved good linearity of (UPLC–ESI)–MS/MS assays (r > 90%) quantifying puroindoline-a (Pin-a)—unique to common wheat—by comparing it to a universal reference protein, purothionin A-1 (Russo et al., 2014). The assay also had great sensitivity in measurement of Pin-a (limit of detection: 0.01% and limit of quantification (LOQ): 0.03% based on weight ratios of common and durum wheat).

Ultimately, multiple techniques show promise in serving to detect common wheat adulteration in durum wheat to a threshold of 3%, with PCR-based assays emerging as exceptionally fit for purpose. The sensitivity, specificity, and accuracy of the assays coupled with the greater heat stability of DNA compared to proteins fit well with the need for common wheat detection in durum at lower thresholds (Delwiche, 2016). New assays are still being designed and validated to improve analytical specifications (Carloni et al., 2017).

14.4.3 Varietal substitution in rice

Rice (Oryza sativa L.) is arguably the most important cereal grain with regards to human nutrition and is a staple crop for much of the world (Vemireddy et al., 2015). The global rice market is particularly susceptible to adulteration based on substitution of more expensive varieties with cheaper ones. Difficulty in morphologically differentiating cultivars coupled with significant variation in price among similar looking kernels makes this type of adulteration a pervasive problem (Vemireddy et al., 2015; Anami et al., 2019). Thousands of varieties exist, placing limitations on the effectiveness of quality control efforts that cannot unambiguously determine provenance (Vemireddy et al., 2015). The simplicity by which product can be adulterated also allows for it to occur at any point from harvest until final delivery to consumers (Vemireddy et al., 2015). Bulk transport contributes to the ease of partial adulteration going undetected. A prominent example of varietal substitution for economic gain is the
adulteration of Basmati rice with cheaper alternatives. Basmati rice maintains an exceptional premium based on its unique aromatic properties, with prices reaching around four times that of a typical common variety (Hong et al., 2017). Traditionally grown in the foothills of the Himalayan mountains and across India and Pakistan (largely in the Punjab province and in the Haryana and Uttar Pradesh regions), the valuable product is coveted for its quality in sweetness, texture, and aroma (Delwiche, 2016; Bhattacharjee et al., 2002). Only 15 varieties exist that are approved by India and Pakistan (and British Retail Consortium) to be sold under the name “Basmati” (Bucher and Köppel, 2015). In a comprehensive review of methods to detect and quantify rice adulteration, Vemireddy et al. (2015) describe the time line of methodological improvement, starting from crude morphological techniques prone to error (Vemireddy et al., 2015; Vaingankar and Kulkarni, 1989). Even advanced approaches such as electron microscopy, histological analysis, NIR, sodium dodecyl sulfate—polyacrylamide gel electrophoresis, and immunoassays lacked precision or had unclear applicability to real market mixtures (Vemireddy et al., 2015; Osborne et al., 1993). Some techniques that researchers found success in combining with chemometric and multivariate analysis for the purpose of varietal identification were GC–MS (Suzuki et al., 1999), HPLC (Huebner et al., 1990), calorimetry (Ahmed et al., 2008), MIR spectroscopy (Largo-Gosens et al., 2014), and FT-NIR (Attaviroj et al., 2011). A significant turning point came in 2000 when DNA techniques were first employed by Bligh (2000), who used fluorescent detection of microsatellite marker polymorphisms to detect non-Basmati rice in Basmati samples and estimate adulteration level, albeit crudely. O. sativa L., a self-pollinator, was a prime candidate for DNA fingerprinting work due to its homozygous pure lines for most varieties that involve a single allele per marker (Nader et al., 2016). Other works improved upon Bligh’s techniques, including Vemireddy et al. (2007), who determined that capillary electrophoresis was the most accurate and repeatable method for microsatellite-based rice purity assays. Assays need to be able to achieve quantification to 5%—the maximum allowed accidental non-Basmati contamination level as outlined by EU Commission Regulation No 272/2010 (Commission Regulation (EU), 2010). Genetic differentiation techniques emerged as the most cost-effective, repeatable, standardizable, and fast methods for detection; many advancements sought to further improve accuracy (Vemireddy et al., 2015). In 2005 Bradbury et al. (2005a, 2005b) identified an 8 bp deletion in the betaine-aldehyde dehydrogenase-2 gene (bad-2) unique to aromatic rices and demonstrated its utility as a suitable marker for fragrant rice. It was the focus of multiple qPCR assays (Lopez, 2008; Inam et al., 2017; Ganopoulos et al., 2011). Ganopoulos et al. (2011) went so far as to combine the assay with high-resolution melting, effectively reducing operation time and sensitivity down to reliable adulteration detection at 1%. Assays continue to be developed on different platforms, such as the exceptionally sensitive ddPCR (Bucher and Köppel, 2015). Many of these key studies contributed to the adoption of DNA techniques as standard. In 2004 the Food Standards Agency (FSA) in the United Kingdom conducted a survey of 363 samples of Basmati rice from the UK market using microsatellite analysis. They discovered that 17% of samples contained non-Basmati varieties in excess of 20% composition, and 9% of samples were adulterated over with over 60% non-Basmati [Food Standards Agency (FSA), 2004]. This prompted creation of a new Code of Practice for Basmati rice in 2005 (from the British Retail Consortium, Rice Association and the British Rice Millers Association) to provide information on varietal standards of Basmati rice (Rice Association, 2017). To note, the FSA also investigated the issue in 2008 and 2009 to find that Basmati adulteration was a persisting problem (Nader et al., 2013).
Also in 2005 India created the Agricultural and Processed Food Products Export Development Authority and Centre for DNA Fingerprinting and Diagnostics for the purpose of certifying Basmati rice samples from companies or inspection agencies (Vemireddy et al., 2015; Delwiche, 2016). They use a standard PCR protocol and a DNA microsatellite-based capillary electrophoresis method to measure relative fluorescence of the adulterant and main variety to quantify adulteration (Vemireddy et al., 2015). Two final notable mentions of methods to determine geographic origin of rice cultivar include using $^1$H NMR spectra of rice type or using IRMS or inductively coupled plasma (ICP)-MS to measure $\delta^{13}$C, $\delta^{15}$N, and $\delta^{18}$O signatures (Monakhova et al., 2014; Kelly et al., 2002). Indian and Pakistani varieties can be distinguished by low $\delta^{18}$O (Hong et al., 2017).

### 14.4.4 Protein content testing and melamine adulteration

Cases of fraud in protein-rich grain products are an important example of how shortcomings of analytical techniques can be exploited. The protein components of multiple different grains can be concentrated to create high-protein products such as animal feeds or protein supplements for human consumption; examples include wheat gluten, corn gluten, rice protein, pea protein, and soy protein. Since the market value for these types of products is dependent upon protein content, typical quality control efforts focus on measuring levels of peptide bound amino acids as an analyte (Moore et al., 2010). Current techniques include the Kjeldahl and combustion (Dumas) methods, which measure total nitrogen content as an indication of protein content (Dumas, 1831; Kjeldahl, 1883; Moore et al., 2010). These indirect protein measurement techniques rely on a conversion factor to associate total measured nitrogen levels with estimated protein content. Historically, this factor was set at 6.25, based on an assumed 16% nitrogen content of proteins, though due to variation based on specific amino acid content, different protein sources use different conversion factors (Mariotti et al., 2008; Müller, 2017). Notwithstanding the conventional use of different factors, the technique lacks precision for many reasons, including, but not limited to, the fact that nitrogenous compounds other than amino acids and proteins exist in different levels within foods (Mariotti et al., 2008). These dated techniques are still the standard in industry and are open to exploitation via adulteration of nitrogen levels to consequently boost estimated protein content measurements.

Unfortunately, these practices can have grave implications. Adulteration of milk formula with melamine in 2008 affected 300,000 children in China, including 6 deaths (Gossner et al., 2009). Relating to grains, pet food that had been formulated with wheat gluten sourced from China led to acute renal failure in hundreds of pets in 2007 (Dobson et al., 2008). Melamine (a compound used in production of plastics) and its analogs are used as adulterants due to their high nitrogen content, intended to exploit the indirect protein measurement method of the Kjeldahl or Dumas techniques (Delwiche, 2016). Unfortunately, the highly insoluble complex that melamine and its analog cyanuric acid create is toxic to humans and animals via creation of intrarenal uric acid crystals that can lead to renal failure (Delwiche, 2016). This threat to human health is relevant in food and feed, with evidence of food production animals consuming tainted feed that enters the food supply (Everstine et al., 2013). Harm is not a goal of EMA, but these events illustrate...
the unscrupulous nature of fraudsters and the importance of developing comprehensive quality control programs. Any product that is valued based on its protein content is at risk of undetected adulteration via failure of nonspecific nitrogen tests. The many plant-based proteins that are rapidly growing in popularity are no exception and must be efficiently monitored to protect consumers (Levinson and Gilbride, 2011; Everstine et al., 2013).

Several works exist that provide a comprehensive review of the history of protein determination in food and the validated use of commonly used techniques in quality control (Moore et al., 2010; Lynch and Barbano, 1999; Thompson; Miller et al., 2007; Müller, 2017; Sáez-Plaza et al., 2013; Marinangeli et al., 2017). Here, we will briefly touch on some notable methods that represent a migration away from total nitrogen content approaches. An array of techniques introduce alternative routes to the detection of protein analytes, but many reveal similar downfalls, namely, issues with consistency as a result of food matrix effects, susceptibility to other forms of adulteration, and specificity (Moore et al., 2010). UV absorbance at 280 nm allows for the detection of proteins (due to the presence of aromatic amino acids that absorb that wavelength) and has been found to have exceptionally high correlation with Kjeldahl protein estimates for products such as wheat flour and bean proteins (Toma and Nakai, 1971). However, other chemical constituents such as free amino acids, phenol, or nucleic acids also absorb at that wavelength, compromising specificity (Moore et al., 2010). This can be improved by combination with HPLC separation techniques that precede absorbance analysis, but the risk of adulteration with inauthentic proteins (that would also absorb at 280 nm) is unavoidable (Moore et al., 2010). Alternative absorbance techniques, MIR and NIR, have also shown promise in protein detection. MIR has been more commonly used for milk protein analysis (AOAC 972.16), and NIR reflectance has been employed by the American Association of Cereal Chemists (2000) for small grains, wheat flour, soybeans, and whole grain wheat. AOAC methods also exist for NIR reflectance (AOAC 997.16). However, these methods require extensive calibration and complex multivariate analysis to interpret data and are no exception to the host of methods lacking protein specificity (Moore et al., 2010). Methods that have been the subject of more recent investigation seek to improve the selectivity for individual proteins (Moore et al., 2010). ELISA is a highly selective biochemical approach that can be used quantitatively but is sensitive to protein degradation (Sharma, 2012). Electrophoretic methods can be less sensitive to protein degradation but can be hampered by cost and restriction to solubilized proteins (Moore et al., 2010). Various mass spectrometric methods (e.g., ESI–MS or matrix-assisted laser desorption/ionization–time-of-flight–MS) can be very efficient in full protein analysis and structural characterization, quantification, and compatibility with more complex food matrices, but also can have prohibitively expensive equipment costs (Moore et al., 2010). A similarity among methods that proves to be the root of a greater challenge is their need for reference materials against which to compare measured samples. As has been touched upon, different products can have vastly different food matrices that change with different types or degrees of processing (De Noni, 2004). Though difficult, the only way to achieve consistency in results and address compositional variability is to use matrix-specific validation with matrix-specific reference standards when designing assays. Without normalized data, we cannot achieve the specificity required in analytical techniques to quantify target protein and mitigate adulteration with unwanted materials such as melamine.
The other consideration in protein quality control is the direct screening for adulterants. Continuing with the prominent example of melamine, several methods have been used to detect the toxic synthetic chemical and its derivatives, cyanuric acid, ammeline, and ammelide (Tittlemier et al., 2009). Lu et al. (2017) reviewed the available techniques used to detect and quantify melamine, including ELISA, GC–MS, GC–MS/MS, HPLC–UV, LC–MS, LC–MS/MS, and SERS. Tittlemier et al. (2009) validated a method using simple liquid extraction followed by mixed-mode cation exchange/reversed-phase solid-phase extraction and LC–MS/MS for milk and soy infant formula. Their method was sensitive (4 ng/g LOQ) and fit for quantifying presence well below the standard safety threshold for food of 2500 ng/g [World Health Organization (WHO), 2009]. They further used their assay to survey milk- and soy-based infant formulas from Ottawa, Canada and detected melamine in 71 of 94 products, though to a maximum of 346 ng/g (below the WHO standard). Ehling et al. (2007) were able to develop an HPLC-based method that detected melamine and all of its derivatives to a reasonable limit, just over the WHO regulation. Another study described a fast LC–ESI-MS/MS method for detection and, as part of their study, surveyed 20 soy-based products in Spain (e.g., drinks and curd), finding one soy drink that contained melamine at a low level (Ibáñez et al., 2009). The United States Food and Drug Administration (U.S. FDA) (2019a) links to GC–MS and LC–MS/MS methodologies on their website. Cautionary screening of food and feed must occur to guard against this unique problem involving not just economic, but human health implications.

14.4.5 Genetically modified organism and organic fraud

In a rapidly growing market driven by an expensive “value-added” premium such as organic certification, fraud risk will be high due to the significant potential economic gain (Capuano et al., 2012). Organic farming involves several factors as described earlier in this chapter, but a notable area where fraudsters cheat involves using synthetic fertilizers and pesticides. Thus analytical techniques that can reliably test for synthetic residues and distinguish conventional from organic crops are required. Stable isotope analysis, specifically \( \delta^{15}N \) signatures (\(^{15}N:\text{^{14}N} \) ratio), has been heavily investigated for potential differentiation between crops that have been organically fertilized and those that have been fertilized with synthetic fertilizers. The idea is that synthetic nitrogen fertilizers have a \( \delta^{15}N \) of close to zero, whereas organic crops grown with compost and manure are enriched in \(^{15}N\) (Capuano et al., 2012). Past work has demonstrated lower \( \delta^{15}N \) signatures in grain crops grown with synthetic fertilizers as opposed to manure (Kohl et al., 1973). However, while exploration into the utility of this approach found some clear differences in mean \( \delta^{15}N \) values for different vegetable and grain products, overlap of organic and synthetic crop measurements inhibited reliable discrimination (Šturm and Lojen, 2011; Schmidt et al., 2005). It seems as though variability in \( \delta^{15}N \) due to soil treatment and conditions hampers the consistency and accuracy of the tool. Alternately, GC–MS-based metabolite profiling with principal component analysis was investigated for maize, and despite minor differences between organic and conventional farming, genetic cultivar and environmental differences proved to be a greater influence on metabolite composition (Röhlig and Engel, 2010). Greater promise in reliable organic grain discrimination was found by Laursen et al. (2011) who analyzed the multielemental composition of organic and conventional winter
wheat, spring barley, and faba bean with ICP–OES and ICP-MS. Semiquantitative ICP-MS and chemometrics allowed discrimination between organically and nonorganically grown grains via multielemental fingerprinting with up to 25 elements (Laursen et al., 2011). The only downfall to this approach is the high complexity and labor requirements. More work to generalize the use of the approach, or combination with other techniques such as isotope analysis, will help integrate it into routine authenticity testing (Laursen et al., 2011). Other interesting techniques being investigated are $^1$H NMR profiling and even transcriptomics, based on some evidence that differential gene expression exists in the grain endosperm of wheat grown with organic fertilizer compared to synthetic (Hohmann et al., 2014; Lu et al., 2005). Though not involving grains, an important 2010 pilot study conducted by the USDA National Organic Program and Technology Program screened for 195 pesticide residues on 571 domestic and foreign fruit and vegetable samples considered USDA organic produce. They used a multiresidue screening approach slightly modified from AOAC 2007.01 (acetonitrile extraction and partitioning with magnesium sulfate followed by LC–MS and GC–MS) to analyze samples in an accredited government laboratory [United States Department of Agriculture (USDA), National Organic Program, 2012]. Sampling was not random, as this report was not meant to be an accurate representation of the whole organic industry. Rather, this study was important in its demonstration of a successful time and cost-effective execution of an industry-grade, organic foods quality control program [United States Department of Agriculture (USDA), National Organic Program, 2012].

The other prominent example of a value-added factor that created an opportunity for EMA and subsequent need for analytical screening techniques is genetically modified crops. We previously discussed the premium on non-GMO cultivars in soybean and maize and the need for authentication techniques that can identify GMO botanical material in raw and finished products. Fortunately, the differentiation between natural and genetically engineered organisms is straightforward, based on the clear presence of additional genetic material and subsequently translated proteins in GMO varieties. Thus approaches to screening are divided into DNA and protein approaches (Salisu et al., 2017). Conventionally, simple PCR has been used for the detection of raw and processed GMOs (Zimmermann et al., 1998), but advancements in DNA-based techniques have allowed greater sensitivity and reliability given suitable markers (Salisu et al., 2017). There are several key considerations in devising an effective DNA-based GMO detection strategy. Success depends on obtaining sufficient template DNA quality and quantity, which is influenced by extraction method, associated food matrix effects on that process, and DNA degradation (Salisu et al., 2017). Pending successful amplification amid possible chemical inhibition, an assay must involve sufficient markers for identification. For some time the most common and reliable method for GMO quantification has been qPCR, with many assays designed for transgenic grains (Vaitilingom et al., 1999; Mano et al., 2018). A drawback of these assays has usually been a limitation to single marker amplifications in a reaction, but advancements in the multiplex capabilities of many platforms have mitigated this concern (Pla et al., 2012). Capillary gel electrophoresis and microarrays are other methods that have easy multiplex ability but can be laborious. qPCR is cost-effective and time efficient, but the development is moving toward more sensitive or high-throughput techniques, such as ddPCR and next-generation sequencing (Salisu et al., 2017; Demeke and Dobnik, 2018; Fraiture et al., 2017). Regarding proteins, early methods made use of ELISA to bind to transgene products
(Fraiture et al., 2015). Alternately, MS techniques can be effective in their simplicity and speed but can encounter difficulty in the case of variable expression in different plant tissues, or protein degradation (Fraiture et al., 2015; Garcia-Cañas et al., 2011). The development of DNA-based approaches to GMO detection remains the focus of most research.

### 14.4.6 Cereals as adulterants

A final notable example of adulteration as it relates to grains is the unique instance of cereals as adulterants. This topic is worth discussion since, like melamine, it is a situation where EMA may lead to unintentional risk to human health. Celiac disease is a digestive disorder marked by irritation of the small intestine and degeneration of the villi [National Institutes of Health (NIH): The National Institute of Diabetes and Digestive and Kidney Diseases, 2016; Delwiche, 2016]. This unfortunate illness is triggered by consumption of gluten in affected people. Gluten refers to the prolamin and glutelin proteins in the endosperm of cereal grains such as wheat, barley, rye, oats, and triticale (Delwiche, 2016). In 2013 the FDA officially defined the “gluten-free” designation on products involving stipulations such as the product not containing any gluten-containing grain ingredients and that unavoidable gluten presence must be below 20 ppm gluten [United States Food and Drug Administration (U.S. FDA), 2019b]. A 2015 survey by the FDA of 275 food products claiming gluten-free status revealed only three above the 20 ppm gluten standard (Sharma et al., 2015).

Analytical techniques used to quantify gluten in food products include immunological, protein, and DNA approaches. The Codex Alimentarius recommends immunological methods that can detect to 10 ppm of gluten [Canadian Celiac Association (CCA), 2018]. ELISA is the most common approach with advantages of low cost and fast turnaround time, but some difficulty can be encountered with cross-reactivity in complex food matrices [Canadian Celiac Association (CCA), 2018; Koerner et al., 2011; Monaci and Visconti, 2010]. The best approach to reliable quantification is optimization and validation of the method for each food matrix. DNA approaches such as quantitative competitive PCR and qPCR assays focus on the detection of genes responsible for allergenic proteins and have been demonstrated to show good correlation with ELISA assays (Sandberg et al., 2003; Dahinden et al., 2001). These methods are quick and very sensitive; some commercial kits report LOQs down to 0.4 ppm (R-Biopharm, 2019). In addition, they are superior in determination of the gluten species origin [Canadian Celiac Association (CCA), 2018]. The critique is that DNA is being used as a proxy measurement for gluten presence, and the detection of gluten genes does not necessarily indicate protein presence. Quantitative measurements also do not necessarily correlate due to differential gene expression [Canadian Celiac Association (CCA), 2018]. Issues may arise in processed materials where DNA is degraded, threatening quantification abilities and even detection ability in general (Monaci and Visconti, 2010). However, ELISA methods can also be negatively impacted by heat denaturation of proteins (Delwiche, 2016). A combination of testing methods may achieve the maximum sensitivity to trace ingredients, specificity in origin, and quantification of the actual allergen (Monaci and Visconti, 2010). HPLC–MS has also been investigated as a tool that can achieve sensitive peptide identification, but the requirement of comprehensive protein sequence databases proves to be an impediment due to a lack of curated...
sequences for some key cereals (Fiedler et al., 2014; Mena and Sousa, 2015). Currently, frontier research into development seeks quick assays that can simultaneously detect multiple allergens. Biosensors, receptor–transducer devices that provide real-time quantification of compounds, make use of antibody–antigen interactions or DNA hybridization to detect gluten proteins or genetic material (Monaci and Visconti, 2010). Some boast gluten detection in under 5 minutes. The development is ongoing, and for now, ELISA remains the most efficient tool.

### 14.5 Conclusion

Grains and cereals provide a great deal of the global population’s calories and are immensely important to many countries’ economies. Much of the intentional adulteration that takes place in different grain crops is primarily of economic concern, such as varietal or species substitution, organic fraud, and GMO adulteration. However, some issues exist that also have human health implications, namely, the adulteration of protein products with toxic melamine, or the mixing of gluten-containing cereals with nongluten products (a threat to celiac individuals). These events behove quality control scientists to develop accurate analytical measurement techniques that are fit for purpose. But before analytical methods of detection can be applied most efficiently, comprehensive risk management plans must be in place that seek to mitigate fraud vulnerabilities in commodity chains of supply and production. There are multiple clear factors that expose opportunity for fraudulent activity, including trade in bulk through complex supply chains, price disparities due to premium products, and shortcomings of analytical techniques. Companies must apply due diligence in creating fraud mitigation plans that are rooted in good communication with all involved parties of the supply chain. With a unified network and routine testing with fit for purpose methods, the global grain industry can ensure that authentic, quality products make it from farms to the hands of consumers.

**References**


Food Fraud


Food Fraud
Honey fraud

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15.1 What is honey?

15.1.1 Historical perspective

Honey is a sweet, nutritious, and stable food produced by honey bees from the nectar of plants or excretions of plant-sucking insects found on living parts of plants. It has a unique taste—sweet—which has been accessible to ancient human beings for ages in most parts of the world. In comparison the history of sugarcane dates back to around 4000 BCE in New Guinea, from where it spread to the south Asian region (including India and China) around 1000 BCE. Through trade, it was then introduced into the Mediterranean Basin around the 1st century and to the Americas by Columbus at the end of the 15th century (Warner, 1962).
Sugarcane remained the most important source of sugar until human breeding produced the sugar beet at the beginning of the 18th century (Biancardi, 2005). Bees and honey production were scientifically studied by the ancient Greeks (Crane, 1999). Honey hunting and beekeeping were indeed so important that they found early mention in law-making: issues such as ownership of bees, liability for damages through bees, and charges for theft of colonies or honey were cast into laws in the 6th century BCE (Crane and Walker, 1998).

Scientific research on the composition of honey has led to an ever-increasing understanding of the quality factors associated with beekeeping and has had a profound influence on current guidelines for honey (Codex Standard for Honey, 2019; European Council Directive, 2001). However, since these guidelines/directives were put into force, the quality requirements in the honey market and the modes of adulteration of the product have changed drastically. With advances in food technology and food processing, new procedures and technologies have also been introduced in the honey industry. While many advances are beneficial and help present the consumer a high quality and compliant product in line with regulations, others represent clear violations of laws and constitute fraud, especially considering that beekeeping practices exist that allow avoidance of such procedures. Consumers should be clearly informed about the contents of all honey products and whether they are distinctively and unambiguously honey, the natural food produced by bees.

15.1.2 Biology of honey production

Bees transform nectar into honey in order to achieve a long-term provision of food for their own use when there is no nectar available in the foraging area. Some special characteristics of honey, such as its low water content, elevated concentration of sugars, low pH, and content of various antimicrobial substances, make it a nonfermentable and long-lasting food for bees. Fermentation in honey would be an undesirable process for bees since ethanol negatively affects their behavior in a similar way to other vertebrates (Abramson et al., 2000). During the ripening process, bees also add enzymes such as invertase and glucose oxidase; the latter being essential for the prevention of fermentation through the production of gluconic acid and hydrogen peroxide (Traynor, 2015).

Honey production starts when foraging bees, the eldest bees of a colony, gather nectar not only from floral or extrafloral nectaries but also from the excretions of plant-sucking insects found on the living parts of plants, which is called honeydew. The transformation of nectar and/or honeydew into a mature and stable product starts in the honey stomach while the bee completes foraging and during the return flight (Nicolson and Human, 2008). The nectar is then passed from foraging bees to food-storing bees, which ripen the nectar by manipulating and passing it many times from bee to bee and by reallocation of the immature product contained in the cells of the honeycomb. As nectar is passed from bee to bee, enzymes are added and water is evaporated (Traynor, 2015). The allocation and relocation of the immature content of cells is essential for the ripening process and needs sufficient space in the beehive for its occurrence (Gary, 2015). Bees finally cap the cell when it is full of mature honey.
The transformation of nectar into honey requires the following steps: (1) addition of enzymes by foraging and storing bees (invertase, diastase, glucose oxidase, and phosphatases); (2) addition of other substances that originate in the bee’s salivary glands; (3) lowering the pH through the production of acids in the honey stomach of the bee; (4) changes to the chemical composition, especially the sugar ratios; and (5) evaporation of water (the water content of nectar may be as high as 80%, while that of honey should be 16%–20%) (Crane, 1980). Eyer et al. (2016) provide evidence for the occurrence of both passive and active mechanisms of nectar dehydration inside the hive. Active dehydration occurs when worker bees concentrate droplets of regurgitated nectar with movements of their mouthparts. This behavior is called “tongue lashing.” Passive dehydration of nectar occurs through direct evaporation of water from nectar inside the beehive; this process occurs faster when bees are provided with ample space to distribute small droplets over a large surface area in relation to their volumes (Park, 1928). As the nectar is dehydrated, the product becomes increasingly hygroscopic. The bees protect the mature product and prevent the uptake of water from the air by sealing off cells with a lid of wax (Eyer et al., 2016).

After harvesting honeycombs from the beehive, it is the beekeeper’s duty to ensure that honey quality is preserved. Hence, it is good beekeeping practice to ensure a suitable dry environment for subsequent storage of honey frames (the movable combs of the modern beehive) and honey extraction. During honey extraction, honey is exposed to air, which facilitates the uptake of moisture. Appropriate planning of a suitable harvesting and processing schedule is recommended to minimize idle times. Martin (1958) showed that a relative air humidity of 60% results in an equilibrium water content of honey of 18.3%. Maintaining such a low water content in honey is pivotal for preventing fermentation, which, according to Lochhead (1933), is also dependent on the number of yeast cells present in the honey. It is important to note that honey that has begun to ferment cannot be put into the market as honey for direct consumption (Codex Alimentarius, 1981). According to the European Directive (2001), at best, that honey can be put into the market as “baker’s honey,” meaning it can be used in food processing.

It is known that under certain climatic conditions, for example, tropical climates, even honey in capped combs may have a moisture content over 18%. Frames with fresh nectar that can be shaken out of the cells like water should not be harvested by the beekeeper (Matheson, 1993; Horn and Lüllmann, 2019). Of course the beekeeper cannot always harvest only 100% capped frames, and the possibility of harvesting some partially capped honeycombs will depend on the ambient humidity conditions of the year and/or the region.

In terms of consumer expectations, humans have been exposed mainly to ripe honey since ancient times, which has given rise to certain expectations regarding the properties of honey. Unripe honey is more fluid, less tasty, more difficult to handle, and has no microbial stability for long-term storage. Consumer expectations have been transmitted from generation to generation up to the modern honey consumer, who appreciates the properties and nature of honey as never before in history. In contrast with other foods that have experienced an evolution in both manufacturing practices and consumer tastes, honey is nowadays consumed in practically the same way as it was in ancient times. The fact that honey is a unique and highly estimated product is also evident from its important role in many religions (Crane, 1999).
15.2 The importance of bees

In order to better understand the magnitude of the problem of honey adulteration, we must remember that honey is the best known product of bees but surely not the most important one. The greatest contribution of bees and other insects is pollination. In the community of pollinators the honey bee stands out as the most economically valuable pollinator of crop monocultures worldwide and yields of some fruit, seed, and nut crops would decrease by more than 90% without these pollinators (for review see Klein et al., 2007). The cultivated area of pollinator-dependent crops is expanding more rapidly than the area of pollinator-independent crops (Garibaldi et al., 2011).

Over the past 50 years the amount of crops that depend on pollinators (i.e., fruit, vegetables, seeds, nuts, and oilseeds) has tripled. According to the estimates of an international study conducted in 2016 by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the annual global production of food that depends directly on pollination was worth between USD 235 and 577 billion (IPBES, 2016). The cultivated area of pollinator-dependent crops is expanding more rapidly than the stock of managed honey bee colonies (Aizen and Harder, 2009). In terms of ecosystem health, approximately 90% of wild plants rely on pollinators that support biodiversity (Garibaldi et al., 2016). Therefore the protection of honey purity is not only a problem of food safety and food defense but also of food security, thereby affecting the capacity of countries to provide their own food.

15.3 Why is honey vulnerable to fraud?

It is historically well documented that honey has long been subject to fraud (Crane, 1999). However, the conditions for honey fraud have never before been so well aligned. At least four conditions are promoting honey fraud in current times: (1) honey is becoming a scarce and expensive-to-produce product, (2) the modes of honey adulteration rapidly evolve, (3) official methods of detection have not been updated frequently enough to keep pace with this evolution, and (4) there is an opportunity for strong profits through fraud. Each of these will be discussed in more detail next.

15.3.1 Honey: An increasingly scarce and expensive-to-produce product

As previously stated, global honey consumption has steadily increased over the past decades for two main reasons: the increase of world population and the preference toward natural foods by a growing portion of consumers (primarily young people). As the world population and the demand for natural and healthy products increase, many countries cannot meet the demand for honey with domestic production and need to import increasing volumes from exporting countries. The United States, Germany, Japan, the United Kingdom, and other European countries currently lead the ranking of honey import countries (García, 2018). Since 2010, net global honey demand has grown at a rate of 19,504 MT/year (García, 2016). However, the
advance of agriculture, the destruction of natural environments, the contamination of bee forage lands with pesticides, and the appearance of new bee diseases make honey an increasingly scarce, difficult, and expensive-to-produce natural food. Another factor is the increasing average age of beekeepers around the world, with new generations preferring less difficult and more profitable activities. All of these factors have challenged the honey production market.

According to FAOSTAT data (FAO, 2019), the global number of beehives increased from 70,393,523 in 2001 to 90,999,730 in 2017. This represents a moderate 29% increase compared to world honey exports that increased 91% during a comparable timeframe (from 357,535 MT in 2001 to 682,792 MT in 2018) (COMTRADE, 2019). This statistical information gives the first evidence that the increase in honey trade appears to be at odds with the increasing difficulties to produce honey. The aforementioned increase in world honey exports has not been homogeneous between regions. The main four honey-exporting countries in the Americas (Argentina, Brazil, Canada, and Mexico) showed an average increase of total exports of 1842 MT/year between 2001 and 2009 (statistically n.s.) and of 2670 MT/year between 2009 and 2018 ($P \leq .05$) (Fig. 15.1). On the other hand the four main honey-exporting countries from the East (China, Ukraine, India, and Vietnam), showed stable exports between 2001 and 2009 and then steeply and significantly increased their honey exports after 2009 at an average rate of 19,787 MT every year ($P \leq .01$) (Fig. 15.1). It is very difficult to justify the current export volumes of these countries with

![Graph showing honey exports for two groups of countries, 2001-2018. Source: ITC-UNCOMTRADE.](image-url)
their levels of beekeeping activity, their floral sources, and their historical production (García, 2016).

15.3.2 Evolution in the modes of honey adulteration

The European Commission (2018) states that four key criteria must be present in a case of food fraud: (1) violation of law; (2) intention; (3) economic gain; and (4) deception of consumers.

Honey fraud can be achieved through

- dilution with different sugar syrups (such as those produced from corn, cane sugar, beet sugar, rice, wheat, and tapioca)
- the intentional harvesting of immature honey, which is subsequently actively dehydrated by the use of devices such as vacuum dryers
- the use of ion-exchange resins to remove residues and lighten the color of honey
- masking and/or mislabeling the geographical and/or botanical origin of honey
- supplemental feeding of bees during a nectar flow

The product which results from any of the methods described earlier should not be called “honey,” the same is true of the blends containing it, as the internationally accepted standard only allows blends of pure honeys (Codex Alimentarius, 1981). Information coming from global honey trade statistics, official surveys, and private laboratories on the prevalence of honey fraud allows us to conclude that there is a substantial volume of diluted and/or nonconforming honeys in the marketplace (García, 2016). The current honey fraud problem has an extensive global magnitude and impacts both the price of honey and the viability of many beekeeping operations.

In 2016 the European Union (EU) published the results of a plan to determine the prevalence of fraud in honey, although the most advanced methods for the detection of honey adulteration were not used (European Commission, 2016). Nevertheless, of the 2264 honey samples collected by EU member states, it was determined that 14% likely had foreign sugars added to them. According to the US Pharmacopeia’s Food Fraud Database, honey ranked as the third “favorite” food target for adulteration, only behind milk and olive oil (Moore et al., 2010). Similarly, the EU has identified honey to be at high risk of fraud (European Parliament, 2013), and the European Parliament resolution of March 1, 2018 called on the Commission to implement various actions to combat honey fraud (European Parliament, 2018).

15.3.2.1 Honey dilution with syrups

Syrups used to adulterate honey, which are significantly less expensive than honey, may be sourced either from C3 or C4 plants (a classification of plants based on their carbon metabolism). C3 plants fix atmospheric CO₂ using the Calvin (C3) cycle and have a lower \(^{13}\text{C}/^{12}\text{C}\) ratio (\(\delta^{13}\text{C}\)) than C4 plants, which fix CO₂ using the Hatch–Slack (C4) cycle. Most of the honey-contributing plants are C3 plants, while corn and sugarcane are C4 plants.
During the last decades of the 20th century, honey was adulterated mostly with C4-type sugars originating from corn or sugarcane. This changed during more recent years when C3-type syrups, made from crops such as rice, wheat, sugar beet, and tapioca, became available for honey adulteration. While C4 adulteration is effectively detected by the use of the AOAC 998.12 elemental analyzer/isotope ratio mass spectrometry (EA-IRMS) method, the addition of syrups derived from C3 plants remains a considerable analytical challenge (Raezke et al., 2019). The evolution of the use of C3 syrups was a logical means of avoiding adulteration detection.

15.3.2.2 Harvesting and postharvest processing of immature honey

In many Asian countries, honey is often harvested too early and unripe. This unripe honey usually lacks the typical taste and odor associated with honey and has far too high a water content (Du¨ becke et al., 2018). Water content of the immature product must be reduced before export in the so-called honey factories that also filter, eliminate veterinary drug and pesticide residues, and pack the product (Phipps, 2016). Harvesting of immature honey, with its concomitant artificial extraction of water, also results in a significant loss of honey aromatics and flavonoids which are stable at normal atmospheric pressure (Cui et al., 2008).

In a recent study, Lang and Schwarzinger (2020) investigated whether the current version of the European Honey Council Directive 2001/110/EC provides any ground for water removal from a legal perspective. Regarding the Directive prohibition that “...no pollen or constituent particular to honey may be removed...” (Annex II, 2001/110/EC), a frequently used argument in favor of honey drying is that “water is not particular to honey because it is found in many other foods.” A constituent particular to honey is any substance naturally occurring in honey within its typical range of concentration. In the view of the authors, this interpretation of the term “particular” in the sense of “unique to honey” is not accurate. There are many specific constituents that are inherent in and universal to all authentic honey. These constituents include, but are not limited to, sugars, pollen, proteins, organic acids, glucose, fructose, proline, enzymes, water, chemical compounds, which add flavor and color, and other minor substances. Most of these are not unique to honey. Therefore the only logical consequence for using the term “particular” in the context of defining the very special composition of honey should always be used as a combination of the constituent and its naturally occurring typical concentration range as found in ripe and matured honey.

Moreover, Lang and Schwarzinger (2020) provide evidence that the European Council Directive 2001/110/EC also aims to protect honey as a natural product of bees, which is outlined in several other parts of the Directive and almost identically in the Codex Standard for Honey. The postharvest removal of water from immature honey which is used to increase productivity alters the natural quality of the product and, in the view of the authors, is clearly not in line with these guidelines. The resultant processed product should not be labeled as “honey.” APIMONDIA, the International Federation of Beekeepers’ Associations, recently released the “Apimondia Statement on Honey Fraud,” which supports only production methods that allow bees to fully do their job in order to maintain the integrity and quality of honey. In parallel, APIMONDIA rejected the development of methods intended to artificially speed up the natural process of honey
production through the undue intervention of people and technologies that may lead to a violation of Codex Standard for Honey (Apimondia, 2020).

In conclusion, honey is the result of a complex process of transformation of nectar/honeydew that occurs exclusively inside the beehive. Honey is unique because of its production process and its composition. Water, as well as glucose, fructose, other sugars, proteins, organic substances, and other natural components should be considered constituents particular to honey that cannot be removed.

### 15.3.2.3 The use of ion-exchange resins

In recent years, ion-exchange resins have been used in some countries to remove residues (e.g., of veterinary drugs) and/or offensive aromas and also to lighten the color of honey, as lighter honey often earns a premium price in the market. The ion-exchange resin process requires the dilution of honey with water in order to make the process possible. This is a processing step that should not be permissible, as it changes the water concentration particular to natural honey.

Ion-exchange resins not only remove residues from honey but also many natural components that contribute to the particular aroma, taste, and beneficial properties of honey. According to Codex Alimentarius (1981), honey shall not be processed to such an extent that its essential composition is changed and/or its quality is impaired. As noted earlier, no constituents particular to honey may be removed. The European Parliament recently called to ban the distribution of resin-filtered honey as soon as possible, since such honey “contains nothing whatsoever of biological value” (European Parliament, 2018). New methods are now becoming available to differentiate the natural water of honey from externally added water, which would aid in the detection of honey that has gone through an ion-exchange resin process (Luellmann et al., 2019).

### 15.3.2.4 Masking and/or mislabeling the geographical and/or botanical origin of honey

Honey from a particular geographical origin may receive a premium price if consumers recognize and appreciate the unique characteristics of that product, for example, Greek Hymettus honey, Mexican Mountain honey, and “Mel de Galicia” from Spain. As such, masking and/or mislabeling the geographic origin of honey is a clear case of fraud. This phenomenon in honey prices may have incentivized some European countries to import less expensive honey and then reexport it as a locally produced product in order to make a profit. The data on honey imports and exports for various European countries over 10 years show interesting trends supporting this hypothesis.

Fig. 15.2 shows the relationship between the change in imports versus the change in exports over time for two groups of European countries between 2009 and 2018. Between 2008 and 2018 a group of European countries (Spain, Belgium, Poland, and Portugal) significantly increased their honey imports; meanwhile, honey exports from these countries also increased significantly. This is an interesting finding, since these countries are traditionally net honey importers and it may be difficult to properly trace the country of origin of the product. Meanwhile, Germany, France, Denmark, and Switzerland, which are also traditionally honey importers, did not show the same pattern over the same time period and are included in our analysis for comparison. While there could be other variables...
explaining the rise in honey exports in Spain, Belgium, Poland, and Portugal, we found that variations of honey imports can explain 83.5% of variations of honey exports from these four countries ($r^2 = 0.835$).

Transshipment of Chinese honey to evade US antidumping duties has been denounced in recent years (True Source Honey, 2015). In 2008 the US authorities investigated circumvention and transshipping schemes of Chinese honey through intermediate countries with the purpose of evading antidumping duties. These investigations resulted in what was called “the largest fraud of the food industry in the United States” and involved the prosecution of several operators in the US honey market (Strayer et al., 2014; Phipps et al., 2015).

Mislabling the botanical origin of honey is another way to mislead consumers. Bees sometimes forage from a single species of plant, but, in most cases, they produce honey by foraging multiple sources. Some sources such as orange blossom and acacia (Robinia pseudoacacia) receive a higher price in the market. Another outstanding example is the case of Manuka (Leptospermum scoparium) honey from New Zealand. Manuka honey is recognized as particularly beneficial to human health due to its exceptional antiseptic properties. The increased risk of fraud due to the high price of this honey has driven the New Zealand Ministry for Primary Industries to publish a definition of Manuka honey (Ministry of Primary Industries, 2018). In order to judge the designation of the honey according to its floral origin, its physical, chemical, and microscopical characteristics have to be evaluated (Raezke et al., 2019; Horn, and Lüllmann, 2019).
15.3.2.5 Supplemental feeding of bees during a nectar flow

Supplemental (sometimes called artificial) feeding of honeybees with sugar syrups is a normal and necessary management practice to maintain colonies during times of the year when there is no natural nectar income to the beehive. Beekeepers must be especially careful with this practice to avoid contamination of honey with these syrups when bees are fed quite close to or during a nectar flow. Although this is not the most frequent mode of honey adulteration, artificial feeding of bees may contaminate honey with sugar syrups if not performed adequately. It would be advisable that any method used to detect honey adulteration should allow a threshold of around 5% tolerance in order to differentiate intentional honey adulteration from minor unintentional contamination of honey with products used for supplemental feeding.

15.3.3 The need to continuously update official methods to detect honey adulteration

The dilution of honey with corn or sugarcane syrups (both C4-type) was the most common method of honey adulteration during the last decades of the 20th century. White and Doner (1978) and afterward White and Winters (1989) developed the EA-IRMS method (AOAC 998.12, as noted earlier) to detect honey dilution with C4-type syrups. This method is based on the values of the stable isotope ratio ($\delta^{13}$C) of the honey fraction and the protein fraction, which must not differ more than 1%—the practical limit to consider a honey free of C4 sugars (Padovan et al., 2003). This method still remains as the official method of many authorities to detect honey fraud (AOAC 998.12).

However, during the last decade, new syrups have become available to adulterate honey; these syrups are produced from C3-type plants (rice, wheat, and tapioca) and are not detected by the AOAC 998.12 method (EA-IRMS). This leaves a vulnerability to fraud detection and demonstrates why methods need to be continuously updated; perpetrators continue to update the adulterants used in honey fraud. In addition, the sole use of the AOAC method for honey authentication because it is the “only official method” may be deliberate to whitewash adulterated honey (Apimondia, 2020). From a food fraud mitigation point of view, as the method is required by many quality norms, this weakness of the AOAC method 998.12 has to be classified as an additional vulnerability regarding honey authenticity.

15.3.4 The opportunity for strong profits through fraud

The explosion in exports of what is labeled “honey” from certain Eastern countries after 2009 (Fig. 15.1) has led to at least three visible consequences in the international market: (1) a downward pressure on honey prices as a result of oversupply, (2) a disincentive to produce and export honey by several traditional countries, which have shown significant decreases in their export volumes during the past 10 years, and (3) the appearance of new important exporters that may be reexporting cheap imports, straight or in blends, as “locally produced” (García, 2018).
Honey adulteration has negatively impacted global honey trade prices during recent years. During the period 2005–2014, unit prices of exported honey steadily increased at an average rate of USD 229.6/t/year as a consequence of difficulties of production to meet the growing demand (Fig. 15.3). However, the flooding of the international market with this product of dubious quality, which started at the beginning of this decade, pressed down prices visibly after 2015. If honey adulteration would not have distorted prices, and if prices would have followed the tendency shown between 2005 and 2010, the average price for 2018 should have been around USD 4886/t compared to the observed USD 3239/t (see Fig. 15.3). That means a loss of USD 1647/t, which multiplied by the total exported volume in the world gives a total estimated loss of 1.13 billion dollars for the beekeeping industry during 2018. Of course, this is just an estimation based on the assumption that the conditions observed in the international honey market during 2005/14 would have been sustained during the following years.

15.4 Risk mitigation

Due to the complexity and magnitude of the problem, a multipronged approach to combat honey fraud is recommended. Every honey manufacturer or trader should have a documented fraud management system, which should include a vulnerability assessment,
a mitigation strategy, and its implementation. Vulnerability should be lowered to an acceptable level, and the entire process should be revised and updated periodically. As a general principle, honey should be preferentially sourced from suppliers without a documented history of food fraud activity. The closer the relationship between buyer and supplier, the lower the risk of having fraud problems.

The use of statistical information is a valuable tool for authorities to detect anomalies in order to investigate and to combat more efficiently the scourge of honey adulteration, which can vary depending on the source countries and the import markets. Less-than-market pricing, honeys are offered at different prices according to the test/s they pass, the ability to maintain surprisingly more stable pricing than competitors, the sharp increases of export volumes of countries without parallel increments of productive capacities, and the increase of import and reexport activities are good indicators of potential fraud problems (García, 2016, 2018). Honey trade data, including quantities and unit prices, are available from sources such as COMTRADE (http://comtrade.un.org/). For many commodities the production by country is available from FAO (http://fao.org); these data can be used to identify inconsistencies with trade flows (García, 2016). Risk maps should be developed by companies with many suppliers from around the world.

Sound traceability systems coupled with efficient audits are also important tools to assure honey purity and authenticity and should be used to complement laboratory testing. Honey should be able to be traced back to the beekeeper, to the botanic floral source from where the bees gathered the nectar, and to the geographic location of the apiary. Computer applications, with the use of barcodes in honey containers, should ensure the full traceability of honey, and all events occurring through the production chain until the final consumption of the product should be reported to an online program (Vázquez and Borgna, 2019). Finally, third-party audits of the fraud management systems are an important verification method. Audits should be carried out onsite at supplier facilities by well-qualified auditors who should have an adequate knowledge of good beekeeping practices, good manufacturing practices, and honey quality parameters, in order to detect deviations in the modes of honey production and/or processing that may result in a nongenuine product.

15.4.1 Testing

An important aspect of mitigating honey fraud is analytical testing, which should include up-to-date methods and be tailored to the specific risks associated with a particular sample (i.e., the methods of choice are the outcome of a sample-specific risk assessment by the owner of the sample). Methods for honey quality testing have historically evolved based primarily on research carried out in Europe. Analytical methods suitable for analyzing the authenticity of honey have been reviewed by several authors (Zábrodská and Vorlová, 2014; Soares et al., 2017; Raezke et al., 2019; Bogdanov et al., 2004).

Traditionally, these methods target an analytical marker, which is typically a compound or property that indicates the likely presence of syrups. A well-known example is AOAC method 998.12 (EA-IRMS, discussed earlier) for detection of the addition of C4 sugar syrups such as those from corn or sugarcane. However, in order to determine the exact
amount of syrup added, the $\delta^{13}C$ isotope ratios of both the original honey and the syrup have to be known. This is due to the fact that honeys and syrups show a natural variation in the range of their respective $\delta^{13}C$ values. Caution has to be taken when applying this method as the sole method for syrup addition testing. While failing this test is a clear indication for the presence of exogenous C4-sugars, passing the test cannot rule out the presence of a C3 plant-based sugar syrup (such as those originating from rice, wheat, and sugar beet), since those show $\delta^{13}C$ values practically identical to those of honey and are available at very low costs and in high quantities in the global market today.

The increasing availability of syrups not detectable by the AOAC 998.12 EA-IRMS method called for additional developments in analytical testing. While the original method was based on the $\delta^{13}C$ of the total carbohydrate fraction of honey only (and therefore limited to the detection of C4-based syrups), improved adulteration detection can be achieved by considering the $\delta^{13}C$ values of individual constituents of honey, namely, the $\delta^{13}C$ of mono-, di-, and oligosaccharides, as well as the $\delta^{13}C$ of the protein portion of honey (Elflein and Raezke, 2008). This advanced detection, which can detect some C3 plant-based syrups such as rice and sugar beet, was made possible by coupling the IRMS with liquid chromatography (LC) which enables separation of the abovementioned constituents of honey. In addition, the sensitivity of the LC-IRMS method is higher when compared to the EA-IRMS method. The LC-IRMS method relies on many more decision criteria allowing an improved limit of detection of syrup addition. It may be considered the first multivariate method applied in honey authenticity testing. However, due to continuing developments in the syrup producing industry, there are still syrups that cannot be detected using the methods introduced so far. Additional methods relying on single markers or even combinations of markers are needed, which will be reviewed next.

**15.4.1.1 The detection of other markers for adulteration**

The chromatographic analysis of the sugar spectrum is another method that has been successfully applied to detect adulteration in honey. From the analysis of the chromatographic sugar spectrum of numerous samples of honey, it has become clear that honey essentially consists of mono- and disaccharides, and of only a few (but very specific) higher oligosaccharides. On the contrary, sugar syrups, which are obtained by enzymatically breaking down starch into glucose, may contain higher glucose-oligosaccharides as remnants from incomplete starch degradation. Consequently, the presence of a higher level of glucose-oligosaccharides is a clear indication of honey dilution with a syrup. These honey-foreign oligosaccharides may be detected by LC, often in combination with very sensitive elastic light-scattering detectors (Zhou et al., 2014).

The aforementioned process of syrup biotechnology, namely, enzyme-catalyzed breakdown of plant material, offers two additional classes of adulteration markers: foreign enzymes and process by-products. The enzymes used to break down starch are different from those produced by bees (Voldřich et al., 2009; Raezke et al., 2019). Therefore honey-foreign enzymes such as $\beta$-fructofuranosidase, $\alpha$, $\beta$, $\gamma$, as well as heat-stable and honey-foreign amylases are also sensitive indicators for the addition of syrups.

The second class of indicators is the by-products that result from starch breakdown and from the enzymatic conversion of glucose to fructose. A recently identified marker that belongs to this category is psicose (Kämpf, 2018). Another marker of this kind is the sugar
molecule mannose, which is a marker for both syrup admixture and resin treatment of blossom honey (Missler et al., 2016). Other markers foreign to honey include small molecules that originate from the botanical source of the syrup. Known examples are the markers for rice syrup (2-acetyl furan-3-glucopyranoside, also known as glycosylisomaltol; Xue et al., 2013) and beet syrups (3-methoxytyramine; FoodQS, 2019). A further marker found in syrups but not in honey samples is difructose-anhydride (Ruiz-Matute et al., 2007).

Food additives such as colorants (e.g., E150d) are also sensitive indicators for illegal manipulations of honey, since these may be used to improve the color of honey whose color has become too light after syrup addition. Another marker that can be exploited to detect dilution of honey is an increased concentration of arsenic, which may be found in elevated concentrations in certain syrups, but not in honey (Gui et al., 2014). Finally, DNA methods frequently used to reveal the presence of nonpermitted GMOs can also provide hints on the source of an added sugar syrup; for example, the presence of rice DNA in honey may be a clear hint for added rice syrup (Länder et al., 2011).

It has to be noted that the presence of certain markers is an indisputable proof of the occurrence of exogenous sugars in honey, while their absence cannot rule out syrup admixture. Syrups can efficiently be passed through various purification processes during production, which results in the availability of a very diverse range of plant-based syrups that may contain one or another marker. In the past, even newly discovered markers showed a quite short useful life because newly processed syrups lacking these new markers very quickly appeared in the market. As a matter of fact, it is practically impossible to ensure the “absence” (i.e., concentrations of syrups below the limit of detection of the respective method cannot be detected and therefore not been ruled out) of syrup admixture to honey with a single test. Rather, suitable combinations of tests are indicated. As previously discussed, an identification of the best combination of methods should be incorporated into an effective fraud management system, which is a responsibility of every participant in the supply chain.

### 15.4.1.2 Screening, profiling, and nontargeted testing

In contrast to the methods discussed so far, which are characterized by one parameter per test, multiparameter screening methods are analytical methods that provide information on multiple parameters in one test. One such method is $^1$H NMR (nuclear magnetic resonance; discussed in Section 15.4.1.3) spectroscopy, including (but not limited to) the Honey-Profiling method. Other methods suitable for multiparameter screening include separation techniques (liquid, gas, ion-mobility, etc.), either as stand-alone methods or in combination with mass spectrometry; various optical technologies such as infrared (IR)- and Raman spectroscopy; and electrophoretic methods. When reading about these technologies, one often comes across terms such as “profiling,” “fingerprinting,” and “targeted and nontargeted testing.” In a recent article, Ballin and Laurin (2019) noted that, quite commonly, the use of these terms does not follow a strict definition. In fact, many authors try to define terms such as “profiling” or “fingerprinting” and associate them with the terms “targeted” and “nontargeted,” thereby contributing to terminology confusion. Therefore as these terms are important in the following context, we will give a brief introduction to the associated terminology.

$^1$ Honey-Profiling is a trade mark of Bruker BioSpin.
Multiparameter screening methods, as noted earlier, typically provide information about several analytical markers. An analytical marker must be biologically, chemically, and/or physically well defined. An analytical marker therefore can be any compound (organic and inorganic molecules as well as macromolecules including enzymes and defined DNA-sequences) or signal, such as a given mass-to-charge-(m/z)-ratio in mass spectrometry-signal or a defined intensity of an NMR-signal at a certain chemical shift, associated with the analytical question. It should also be noted that an analytical marker includes the ratio of selected compounds or signals, respectively, or the copresence (or absence) of compounds or analytical signals. In any case the applicability of an analytical marker will critically depend on the analytical question and the quality of its validation. Several markers can now be combined into a profile; methods delivering several markers can therefore be called profiling methods.

The oldest use of the term “profile” was likely in conjunction with the term “portrait”: “profile portrait is a silhouette of a person, animal, object or scene . . . matching the outline of the subject.” Since then the term has been used in many different contexts, such as “user profile” and “forensic profile” but always with the purpose of summarizing features particular to a specific context that ultimately target identification of some sort (a person, group, property, etc.). In the context of analytical methods, profiling is hence associated with methods/applications that allow the derivation of several analytical markers relevant to the investigated question. The analytical markers underlying a profile can be qualitative or quantitative. The terms “profiling” and “fingerprinting” may be used synonymously but always in conjunction with the applied technology/method. In particular cases, when quantitative analytical information can be extracted, it is strongly suggested to add the word “quantitative.” An example for a precise application of the suggested nomenclature would be “High-resolution-LC(C18)-mass spectrometry profiling (or fingerprinting) of honey” or “Quantitative 1H NMR-profiling (or fingerprinting) of Honey.”

The term “targeted analysis” is quite simple to define: any test where the analytical target is known, that is, biologically, chemically, and/or physically well defined. This definition is not only limited to, for example, known compounds or DNA-sequences, but also includes combinations and ratios of compounds and analytical markers such as chromatographic retention times of (yet) unknown compounds (as the retention time is well defined in the context of the analytical question). Again, it shall be emphasized that the applicability of the marker critically depends on the quality of validation during the development and the implementation of the method. By contrast, there is much more confusion regarding the use of the term “nontargeted.” The confusion is even increased when the term “untargeted” is used. Again, for simplicity, these authors suggest that “nontargeted” and “untargeted” should be used synonymously. In this chapter, we will use the term “nontargeted.” “Nontargeted” is often used when multiparameter technologies/methods (such as mass spectrometry and NMR) are utilized for the differentiation of groups of samples and when the outcome of such a study is open; in other words, at the beginning of the study, it is not known what the nature of the discriminating analytical markers will be or if there are any discriminating factors at all. However, at the end of such a study, typically one or several analytical markers are identified that can be used to discriminate among the groups investigated. It is therefore correct to speak

of nontargeted developments that result in targeted testing when applied to classify new samples. Of note, the quality of the groups (which may be called the reference database or reference sample/data collection underlying the development) used for such studies, that is, the number of samples per question and the related quality of the sample-metainformation, is of utmost importance for the quality and robustness of the resulting method.

A common mistake is also the attempt to fuse the term “nontargeted” with an analytical technology, such as NMR, or—even more specific—with a method, that is a specific protocol (SOP, standard operating procedure) for an analytical technology. Per se, technologies and methods are neither targeted nor nontargeted. Rather, it is the application of these technologies/methods that determines the targeted or nontargeted nature. For example, quantitative $^1$H NMR profiling of honey can be used in the classical targeted approach to determine quality factors for honey or even known syrup-related marker compounds. For instance, the Honey-Profiling method delivers more than 35 concentrations of substances, many of which are directly associated with honey quality, deterioration, variety, or syrup addition. It also allows for the targeted verification of selected botanical and geographical origins utilizing known markers. However, identification of these markers resulted from a development conducted in a nontargeted manner as described in more detail later in Section 15.4.1.3. Finally, the Honey-Profiling method can be applied in truly nontargeted manner to identify unexpected and/or unknown deviations as outlined next.

In the particular case of Honey-Profiling, thousands of verified natural honeys, syrup samples, and proven adulterated samples have been characterized by their quantitative NMR-profiles. To ensure the authenticity of honey, samples have been analyzed by several independent state-of-the-art methods. Samples were collected from sources from all over the world with an emphasis on regions contributing large volumes to the international market and on varieties/regions of special interest or of known risk with regard to adulteration. In this manner a large reference collection was established providing a positive definition$^3$ of natural honey from the sampled locations/varieties. The method can now be applied for true nontargeted testing, in which a sample is compared with the analytical data of this reference collection. This process offers the possibility of (1) conformation of compliance with the reference collection and (2) detecting deviations from the distribution defined by the reference data. This strategy also has the particular advantage of detecting unknown or unexpected deviations, that is, the presence of compounds or other markers not specifically investigated. Interpretation of the results, however, is not straightforward: not every deviation is necessarily an indication of fraud but might also be an exemption caused by nature. The composition of the reference collection may also impact data interpretation. Therefore expert interpretation is strongly advised for nontargeted testing. Nevertheless, despite challenges in the interpretation of results, experience has shown that many deviations found are atypical for a region/variety and provide evidence of misrepresentation or undue manipulations.

In the context of food authenticity testing a nontargeted approach allows detection of new modes of adulteration. However, as nonexpected deviations may also have a natural origin and are not necessarily associated with unlawful adulteration; interpretation of such

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$^3$ A positive definition refers to the sum of the constituents of natural honey, detected by the respective method, and the natural variation in their concentrations.
results requires expert knowledge. At the time of writing this article, there are very limited possibilities for nontargeted testing of honey; surprisingly, this includes pollen profiling by microscopy and even sensory analysis, where unexpected finds in the microscope (e.g., synthetic debris) or an atypical taste/smell may appear. In terms of instrumental chemical analysis, at this point only NMR spectroscopy can be applied for nontargeted testing of honey. Therefore, despite other technologies appearing on the horizon, we will focus on NMR-spectroscopy to highlight the merits of screening and profiling methods for targeted and nontargeted testing of honey samples.

**15.4.1.3 Profiling by \(^1\)H NMR spectroscopy**

\(^1\)H NMR spectroscopy is a reference method for quantification of the contents of drugs and impurities in pharmaceutical analysis, but it has also been applied in food quality and authenticity analysis in the field of wine and juice for more than a decade (Spraul et al., 2009; Godelmann et al., 2013). The \(^1\)H-nuclei (protons) in a compound respond with a characteristic resonance frequency when perturbed by a radio-frequency pulse in a strong magnetic field. This principle is also utilized in the medical field to produce images of the body (magnetic resonance imaging or MRI). The advantages of the method are (1) that the proton is very sensitive and abundant compared to other nuclei (such as \(^{13}\)C) allowing a very fast analysis, (2) the resonance frequencies, expressed as chemical shifts, detected are very specific for the detected compounds, and that (3) the number signal is proportional to the concentration of the respective compound. In the field of honey analysis, successful application of quantitative NMR was first described by Donarski et al. (2010), and then the development of multiparameter methods followed (Spiteri et al., 2015; Schwarzinger et al., 2016). In recent years, governmental laboratories in Germany have been using NMR as a screening tool for products, including honey (Kuballa et al., 2018). The advantage of the NMR technology is that it can distinguish and quantify dozens of major constituents in a food—over 50 in the case of wine and more than 35 for honey (Bruker, 2019a,b). Knowledge of these parameters often allows a quick judgment of the overall quality of the honey. Also, certain markers for adulteration can be directly determined, such as the monosaccharide mannose, which is not typical for blossom honey.

\(^1\)H NMR allows a rather different approach to the problem of adulteration testing. The multiparameter method delivers a large number of analytical signals in a short analysis time. These signals are quantitative and can be assigned to specific substances that are constituents of honey or to adulterants of honey. A major advantage of \(^1\)H NMR is that signals are recorded regardless of whether they are deliberately looked for or not. In other words, \(^1\)H NMR provides access to analytical parameters that have not been investigated in honey before—at least not systematically. This means that, in addition to traditional honey quality parameters, such as sugar profile, 5-HMF, or proline, other amino acids are now routinely accessible. In previous (non-NMR) studies, specific amino acids have been shown to indicate information about varietal and even geographic origin of the sample (Cometto et al., 2003). Similarly, \(^1\)H NMR provides access to floral markers, for example, kynurenic acid for chestnut honey (Truchado et al., 2009), as well as methylglyoxal, dihydroxyacetone, and 3-phenylactic acid as markers for Manuka honey (Schwarzinger et al., 2016; Spiteri et al., 2017). In addition, \(^1\)H NMR can directly detect marker molecules such as mannose, which has already been described earlier.
If the number of parameters is large enough, then the results of the test provide a profile (or fingerprint). For honey, NMR spectroscopy involves a very simple sample preparation—namely, dissolution of honey followed by pH-adjustment—which allows access to essentially all soluble constituents of the product (within the limits of detection). Of course, sample preparations involving extraction and concentration steps are also possible for NMR, but they unequivocally lead to fractionation of constituents. NMR is not the most sensitive method—typically the lower limit of quantification is in the range of mg/kg (depending on the spectral details of the signals of the targeted compound and the spectral background). However, a unique advantage of NMR is its huge dynamic bandwidth, which in the case of honey allows detecting even the main sugars (up to 500 g/kg) in the very same measurement (lasting only ~20 minutes). As previously explained, the method provides simultaneous access to many traditional quality parameters of honey. $^1$H NMR is a so-called primary quantitative method, which means that any newly detected compound can be immediately quantified once the instrument has been calibrated with a universal standard. By contrast, quantification in most other routinely applied technologies in food chemistry (including chromatography, mass spectrometry, or optical spectroscopy) requires calibration with the compound that an analyst wants to quantify.

Identification of markers in adulterated honey samples can be seen as a nontargeted classification task between one class, constituted by natural honeys, and another class, composed of adulterated honeys and syrups. The first group ideally contains only samples from trusted sources (beekeepers whose beekeeping sites and beekeeping practices are known and documented) that have proven to be pure by existing methods in order to increase the level of confidence. The second group may include samples that have already been proven adulterated by other methods, samples that have been purposefully adulterated in the laboratory in a defined manner, as well as samples of the raw materials used to adulterate honey. When these two groups are measured by multiparameter methods (in this case $^1$H NMR), spectral data describing both groups are obtained. The signal patterns that describe constituents and ingredients of the samples can now be compared by chemometric (statistical) methods to identify spectral differences between the two groups. In certain cases, such a nontargeted development allows identification of single marker compounds for adulteration. In many other cases a combination of markers (signal-patterns or compounds) is used for discriminating individual classes in chemometrics, which are expressed by mathematical functions (so-called discrimination functions). The fact that identification of fraud is performed through identification of several substances raises the bar for the adulterators; it makes it increasingly difficult to optimize adulteration strategies by adjusting the compound concentrations.

What has been described so far for NMR spectroscopy is, in principle, also possible with other multiparameter methods, such as IR spectroscopy and high-resolution mass spectrometry (HRMS). A particular advantage of $^1$H NMR is its capability for quantitative measurements, which also allows characteristic concentration differences of selected compounds to be distinguishing features. By contrast, mass spectrometry typically allows identification of a larger number of compounds due to its improved performance for substances present at very small concentrations. Also, DNA metabarcoding offers interesting possibilities for the future (Utzeri et al., 2018).
15.4.1.4 Profiling by high-resolution mass spectrometry

Recently, the authenticity testing regime has been extended by HRMS as a screening method for adulteration markers, which is now offered routinely by several independent laboratories. Mass spectrometry is complementary to $^1$H NMR spectroscopy, and, due to differences in sample preparation and physical detection, it detects a different set of molecules.

In comparison to NMR spectroscopy, HRMS is highly sensitive and can detect very small amounts of compounds, but the sample typically requires a complex preparation, often involving extraction and enrichment of the desired compounds. While NMR screens can cover in the order of 150–250 compounds (depending on food matrix investigated), HRMS routinely delivers thousands of analytical markers. This is an enormous amount of analytical information that creates challenges by itself, for instance, regarding data handling and chemometric evaluation of the resulting data. High resolution and sensitivity are not always “good friends.” With such an information density, reproducibility of data is a major challenge for chemometric data evaluation and requires massive computing to compensate. Factors including shifting retention times by wear of chromatographic columns as well as diversity in mass detector design (quadrupole, ion trap, time-of-flight, etc.) increase interlaboratory and even interinstrument variance. By contrast, NMR does not offer this multitude in detector design and can—for conceptual reasons—be better standardized in terms of quantitative and qualitative reproducibility of the NMR signal.

Unfortunately, the developments of novel HRMS-based methods taking place in different laboratories have not been harmonized (to the knowledge of these authors). Various routes for sample preparation have been taken by different laboratories, which prevents a direct comparison of the developments. Hopefully, the methods will become more comparable in the future, which will also facilitate standardization and regulation of the new test. Nevertheless, it has already become clear that LC-HRMS provides access to new additional markers for adulteration, such as lyso-C14:0-phosphatidylcholine, lyso-C16:0-phosphatidylcholine, lyso-C18:0-phosphatidylcholine, and lyso-C18:1-phosphatidylcholine, which are complementary to all other technologies (FoodQS, 2019).

In principle, HRMS should also allow nontargeted testing of honey, but this will depend on the availability of sufficiently large reference databases of syrups and honeys for method development and validation. It is also foreseeable that HRMS can be used for verification of botanical and geographical origins in the very same way that NMR is already applied, namely, as targeted test for markers resulting from nontargeted development approaches. However, and for the near future, it must be expected that this will only be possible for single laboratories, since comparability between laboratories will remain difficult due to technical issues and lack of standardization. Exemptions will be developments that result in chemically well-described marker substances, which facilitates standardization and harmonization of tests between laboratories.

The future of authenticity analysis in honey will likely involve a combination of screening methods, such as $^1$H NMR and HRMS-based methods, in combination with pollen profiling (melissopalynology). In the case of honey from which the pollen has been removed, it is still possible to verify the variety and the country of origin using the $^1$H NMR technology, which relies on the honey compounds described by the $^1$H NMR...
spectral profile. In this combination of methods, $^1$H NMR will also provide good insight about the overall quality of the honey as it provides results of parameters such as glucose, fructose, sucrose, and HMF, which are regulated in Codex Alimentarius. Additional simple analysis, such as moisture, conductivity, and (honey-own) enzyme activity, will provide a more complete picture. Depending on the outcome and the accompanying risk assessment for the sample, additional tests may (or must) be added. For instance, in case of suspicion that a sample has been harvested prematurely and then mechanically dried, it is advisable to screen for indications of fermentation, such as ethanol and other fermentation products (Huidobro et al., 1994) including glycerol (Huidobro et al., 1993), and/or increased number of yeast cells in the microscopic picture.

15.4.1.5 Databases

While discussing these modern screening methods, in particular in the context of profiling, nontargeted development approaches, and nontargeted testing of samples, it is also necessary to address the importance of databases (reference collections of samples—including positive and negative control samples—and the associated data). As a matter of fact, essentially no analytical method has ever been developed without a database. In a typical method development the method is tested with numerous samples, and this collection of samples may be considered a database. The required size of a database is determined by the analytical problem, and more specifically by a combination of the natural variation encountered in the data set and the number of parameters required for chemometric evaluation (see Schwarzinger, 2018, for a review).

It is consequently very difficult to provide even a rough guidance about the required size of a database suitable for addressing a specific honey authenticity. For instance, certain honey varieties contain very specific compounds which set them apart from other honeys. In such case, even a moderate number of samples can be used to define a profile for this variety of honey. However, for a honey variety with a very unique composition and production areas around the globe (in very different natural habitats), a fairly large number of samples must be used for validation of the distinguishing pattern/marker substances and to account for local and/or seasonal effects. The situation is even more complex for authentication of geographic origin. Typically, the minimum numbers required for devising patterns characteristic of a particular geographical region are greater than what is required for distinguishing among floral sources. The number of samples should account for the size of the region and encompass seasonal variations. Examples from NMR-technology have shown that a database of several thousand carefully selected samples (with reference analysis) is suitable to identify countries of origin (Schwarzinger et al., 2016).

Very often, the reliability of a statistic-based approach in analytics is questioned, as 100% certainty cannot be obtained. It is important to keep in mind that every measurement is associated with an uncertainty of measurement. Even a quantitative measurement as simple as the pH constitutes an estimation of the true value with a certain confidence interval. In particular, for the NMR-based adulteration tests, one is often confronted with the fact that certain geographical regions are not well covered. However, it is still possible

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4 A minimal database for method development will consist of reference samples, positive and negative control samples, and the associated metainformation for these samples.
to perform a test for adulteration with syrups by validating against a suitably large reference collection of verified nonadulterated samples, as the resulting analytical markers are then independent of the geographic origin of the sample. This kind of argument is independent from the technology applied and will, for instance, also apply to HRMS.

A recently emerging challenge in honey analysis is the desire to build reference data sets specific to varieties of honey of selected regions (e.g., country, state, and region) using profiling methods. Two main applications may be conceived: (1) mapping of ecological heritage of a region and (2) defining the profiles of local honey varieties for the purpose of distinguishing them from other geographic locations. In particular the latter is problematic; unless certain varieties or patterns for polyfloral honeys can be ruled out in all other geographic locations, such a test would be only a confirmation of similarity of a sample with the reference collection but never a proof of geographic origin. In other words, any isolated (regional) collection cannot be used to rule out the similarity with other regions, simply due to the lack of reference data. On the other hand a sample that has a different profile from the reference collection for a given geographic region may be regarded as conspicuous and warrants further investigation. Hence, establishing regional (or otherwise limited) reference collections is only advisable if several independently generated collections can be combined for comparison. For a given analytical sample, this will allow confirmation of membership with one group of reference samples while ruling out membership with the remaining groups. Therefore independent of the technology of choice, standardization of protocols for sample preparation and measurements on an international level is of utmost importance.

When submitting a sample for authenticity testing the precision of the analysis may be drastically increased when additional metainformation is provided with the sample. For example, if a sample is submitted for analysis just as “honey,” the sample will be tested against a general pattern valid for all honeys. If, however, additional information is provided about the geographic origin and/or the variety, a much more specific reference data set can be used for testing, which will result in a much more stringent authenticity test.

### 15.5 International standards

There are differences in legislation and standards that regulate honey in various countries, which may lead to unfair competition, misleading of consumers, and obstacles to honey trading (Thrasyvoulou et al., 2018). The two main international regulations for honey are Codex Alimentarius (1981, amended 2019), the internationally accepted standard for foods issued by FAO, and the European Directive 2001/110/EC (European Directive, 2001). While the Codex Standard for Honey has voluntary application and serves in many cases as a basis for national legislation, the European Directive 2001/110/EC, which essentially follows the recommendations of Codex, is mandatory in the EU.

**Codex Alimentarius (1981)** strictly defines the biological aspects of honey production: "Honey is the natural sweet substance produced by honey bees from the nectar of plants or from secretions of living parts of plants or excretions of plant-sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honeycomb to ripen and..."
mature.” APIMONDIA (2020) has adhered to that definition of honey and to the essential composition and quality factors established by Codex Alimentarius. The Codex definition further rules out any additions to honey (including those substances that are naturally contained in honey such as water, pollen, and enzymes), if not introduced by bees from natural sources, as well as any treatment intended to change honey’s essential composition or impair its quality. APIMONDIA also considers that such nonpermitted treatments include (but are not limited to) the use of ion-exchange resins to remove residues and lighten the color of honey, and the active removal of water from honey with vacuum chambers or any other devices.

Geographic differences in standards are another factor that can provide an opportunity for honey fraud. Among those differences the most striking one may be found in the English translation of the Chinese Standard (National Standards of People’s Republic of China GB 16740-2014, 2015), which defines honey as “a natural sweet substance produced through fully brewing when the nectar, secretion and sweet deposits from plants are gathered, mixed with the secretion of their own, modified and stored in the honeycomb by honey bees.” In addition, the word “brewing” in the translation of the Chinese honey standard implies a human-driven process. On the other hand, nothing is said about the ripening process in the combs or about the impossibility of adding or extracting substances from honey. The difference between the Chinese and Codex standards should not be underestimated. China is by far the biggest international honey exporter, and this gap between standards opens the possibility of naming many thousands of metric tons of sweet product with the same name but with very different biological and biochemical properties.

In 2018 the US Pharmacopeia formed an international panel of experts for preparing an Identity Standard for honey with an international scope. It is hoped that an updated and dynamic standard will greatly contribute to a cleaner and fairer honey market in the near future. This type of initiative can surely help support authentic production and supply chain management in circumstances where a strong national standard does not exist.

15.6 Conclusion

The consistent increase in production costs, diminishing honey yields per hive due to the growth of industrial agriculture, and decreasing prices have combined to make honey production economically unattractive in many cases. There is evidence that countries that have traditionally been focused on the production of pure honey for export are succumbing to the model developed by some Eastern countries, which may include one or multiple modes of adulteration. As long as honey fraud, customs fraud, and the violation of national and international trade laws persist, the well-being and stability of world’s beekeepers remain in jeopardy. The role of national authorities is absolutely essential to stop honey fraud. There is an urgent need to update official methods and old standards, which offer a protective umbrella of impunity to fraudsters. If the current situation of low prices persists, many beekeepers will abandon their activities, and those who decide to continue will not be incentivized to keep their current colony counts. Honey fraud defies honey’s image as a natural product and efforts to protect honest beekeeping. Fraud also happens
at the expense of consumers who often do not receive the product they expect and pay for. The overall result is a threat to food safety, to global food security, and to ecological sustainability.

References


15. Honey fraud

CHAPTER 16

Fraud in organic foods*

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Food Fraud
DOI: https://doi.org/10.1016/B978-0-12-817242-1.00001-4
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16.1 Introduction

The US Department of Agriculture (USDA) organic seal tells consumers that products have been produced and processed according to a consistent standard, overseen by USDA and its private partners. The USDA organic regulations define organic production as the use of cultural, biological, and mechanical practices that support cycling of on-farm resources, promote ecological balance, and conserve biodiversity (U.S. Department of Agriculture, Agricultural Marketing Service, 2019a,b). The US agriculture and food industries have undergone many changes over the past several decades, as consumers continue to demand increased transparency and sustainability. A noticeable change has been the rise in demand for organic food products, which has continued to grow since the introduction of a national standard for organic food labeling.

For the past two decades, organic sector growth has outpaced any other segment of the US food industry. As a result, the United States is now the world’s largest market for organic foods, with US$49 billion in retail sales in 2017—a significant increase from US$4.2 billion and US$11 billion in organic foods retail sales registered in 1997 and 2011, respectively (Scott, 1988; Organic Trade Association, 2018; U.S. Department of Agriculture, 2016). Organic food sales now account for over 5% of total at-home US food sales, with fruits and vegetables representing the highest share of organic food sales by volume. Other products such as organic dairy, beverages, packaged food, as well as meats, breads, and grains are also experiencing significant growth in sales (Greene, 2014; Organic Trade Association, 2018).

The United States is also a top global organic producer—ranking third in terms of organic agricultural after Australia and Argentina—among the 179 countries with organic production in 2016 (Willer et al., 2018). The number of US-certified organic operations continues to expand. The latest USDA Organic Survey identified 14,217 certified organic farms and US$7.6 billion in farm sales of certified commodities in 2016 (USDA-NASS, 2017). Despite years of robust expansion, overall domestic organic production has not kept pace with organic demand and organic agricultural land in 2016 (5 million acres) accounted for less than 1% of total US agricultural land (Lernoud et al., 2016). As a direct result of these supply gaps, the US organic sector has been increasingly integrated with the global marketplace. Specifically, US organic imports have increased in size and scope from US$667 million (originating from 72 countries) in 2011 to US$2.2 billion (from 97 countries) in 2018 (U.S. Department of Agriculture Foreign Agricultural Service’s Global Agricultural Trade System, 2019).

As with any large and complex supply chain, the risk of fraud in organic food may elevate as the market grows. Some mislabeling activities are simply the result of a misunderstanding of organic regulations. Many small growers and businesses make organic claims without realizing that their claims require certification by USDA. Others struggle to keep...
the necessary documents and records to show how their practices comply with USDA requirements. The overall market shows healthy compliance. For example, there were approximately 43,000 total farms and businesses certified around in the world at the end of 2018, and only approximately 650 farms and business were listed as suspended or revoked (U.S. Department of Agriculture, Agricultural Marketing Service, 2019a,b).

In other cases, however, market conditions such as high organic premiums or supply shortages create economic incentives for deliberate fraud. Though it is difficult to measure the extent of fraud in the organic market, robust enforcement and policing efforts by the food industry are necessary to maintain consumer confidence and to prevent fraudulent operations from realizing unfair economic advantages over marketers of legitimate organic products. The USDA’s role in enforcing organic standards sets it apart from other marketing claims, as enforcement actions can both stop fraud and deter other market actors from violating the federal rules. Through public–private partnerships, both the US government and organic businesses can decrease incentives for dishonest transactions and uphold the value of the organic market.

The future of organic agriculture and demand for organic foods depends on consumer trust in the integrity of the organic food supply chain. This chapter provides a comprehensive overview of this issue, starting with a discussion of the role of USDA and a definition of organic fraud. Following a review of the body of literature, the chapter presents a theoretical framework depicting the cost of fraud for consumers in organic markets. The chapter also discusses different methods and strategies adopted by USDA to assess and mitigate risk and to detect fraud. This chapter concludes with a look into future challenges and opportunities for those involved in this very dynamic economic sector.

16.2 Understanding the oversight role of US Department of Agriculture National Organic Program

Organic is a voluntary opt-in certification program, where organic producers and handlers comply with the set of organic standards established by the National Organic Program (NOP), housed within the USDA Agricultural Marketing Service. These standards define the processes by which organic food must be grown, processed, and labeled, from the seed to the retail shelf to be certified organic. Industry participants, consumers, and other stakeholders contribute to the development of organic standards through an open public comment process.

Prior to the USDA organic regulations, organic agricultural goods were primarily marketed in farmers’ markets or natural food stores without consistent labeling or certification (Greene, 2009). During these earlier stages the organic food industry faced skepticism about organic claims and labels (Giannakas, 2002). Third-party monitoring is normally necessary for markets with high-quality credence goods, such as organic, to emerge and function (McCluskey, 2000).

A credence good is one for which a buyer’s decision choice is dominated by perceptions about certain product’s characteristics (Andersen and Philipsen, 1998). Credence goods include those with qualities that cannot be readily observed by consumers after purchase, making it difficult to assess its utility.
As a response to market demands for more integrity and consistency, government-supported organic certification programs have emerged in many countries. In the United States the NOP has its origins in the Organic Foods Production Act (OFPA), under the 1990 Farm Bill. The NOP’s responsibilities include the development, implementation, and enforcement of production, handling, and labeling standards for organic agricultural goods.

US federal organic rules first took effect in 2002. Today, anyone who wants to sell, label, or represent products as organic in the United States must follow the NOP’s rules. Through publicly posted federal regulations, the NOP prohibits the use of all synthetic fertilizers and most synthetic pesticides on organic farms, as well as limiting livestock healthcare products and food processing aids that can be used on organic animals or foods. As part of the certification process, conventional producers must avoid using prohibited materials for a 3-year period prior to selling crops labeled as organic.

Duffield and Grabosky (2001) stated that fraud can be explained by three factors: a supply of motivated offenders, the availability of suitable targets, and the absence of skilled guardians and control systems. To address the third factor, the NOP oversees a system of accreditation and certification. Approximately 80 certifying agents worldwide hold USDA accreditation to review, inspect, and certify organic producers and handlers. These certifiers work in tandem with the NOP to detect and prevent fraud in the organic market. The NOP audits all certifiers to make sure that they are applying the organic rules correctly which, in turn, inspect all certified operations and approve all organic labels.

The NOP and accredited certifiers conduct enforcement activities to protect the integrity of the organic seal and of consumers who opt to buy certified organic food products. These include certifiers leading annual and unannounced compliance inspections, the collection of samples to detect the presence of pesticides or other prohibited substance, collaboration between the USDA and other government agencies, development of analytical tools to monitor and assess risk in organic markets, and the oversight and auditing of certifiers by NOP.

Several other countries have also established national organic standards and certification regimes. The United States currently has organic equivalency arrangements with Canada, the European Union (EU), Korea, Japan, and Switzerland. The USDA also recognizes the governments of India, Israel, and New Zealand to conduct USDA accreditation and certification within those countries. In countries where the USDA does not have a formal relationship with the local country government, accredited certifiers conduct organic inspections and grant certificates to allow foreign businesses to export products to the US organic market, so long as foreign producers and food handlers meet all the requirements of the USDA organic regulations.

The USDA provides an open and accessible complaints process that allows stakeholders to file complaints on operations suspected of violating regulations. These complaints are reviewed by the NOP and investigations are conducted by either certifiers or by the NOP itself. Certifiers or the NOP may enter into settlement agreements with violating operations and dictate the terms needed to correct noncompliance issues. Operations with outstanding violations may also have their certification suspended or revoked, preventing them from selling, labeling, or marketing their products as being organically produced or certified. Furthermore, in certain cases, willful violations of the OFPA or the USDA organic regulations may result in civil penalties.

The volume of complaints reflects the high level of consumer interest in organic foods: the USDA receives around 400–600 complaints and inquiries per year, most of which come from...
members of the public (Fig. 16.1). Approximately 200 of these are considered inquiries, which can be resolved quickly through educational information or the verification of organic certificates. The USDA began resolving inquiries this way in fiscal year 2017, which has allowed federal investigators to reduce the backlog of complaints filed in prior years. Nearly half of all complaints filed are closed either because the business complies with the organic regulations, or because the filer could not provide enough information to allow USDA to investigate. As the organic industry grows, the number of complaints and inquiries increases as well.

In 2018 approximately 400 complaints about people and businesses were considered candidates for further review or investigation, where the NOP opened a complaint case. As Fig. 16.2 shows, nearly two-thirds of those complaints alleged that someone was selling a nonorganic product as organic. This type of complaint often relates to very small businesses, many of whom are unaware that they are breaking organic rules. Farmers’ market vendors and coffee roasters are common subjects of these complaints. In the first instance, USDA assists farmers with information on organic certification and cost sharing programs. In the second instance, USDA has a similar response, helping coffee roasters—who may be buying certified organic coffee—get certified for any handling and processing activities.

This complaint classification shows that in 2018, the USDA received about 300 complaints alleging organic labels on nonorganic products and about 100 complaints alleging violations about certified organic producers and handlers. These include complaints about minor labeling errors, pesticides residues, and prohibited practices, such as the use of synthetic

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*Fig. 16.1* Number of complaints received by the NOP, 2009–19 summary. NOP, National Organic Program. Source: Data from National Organic Program, Compliance & Enforcement Division.

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4 Labeling errors are typically straightforward to resolve and usually involve a printing error, so they are not addressed in this chapter.
hormones on organic cows or the intentional sale of nonorganic corn as organic. The rest of this chapter discusses examples of three cases: (1) a case of pesticide residues on organic products; (2) prohibited practices on organic farms; and (3) fraud, defined as the intentional sale of nonorganic products as organic.

16.2.1 Pesticide residues on organic products

The USDA requires certifiers to collect product samples for pesticide residue testing on at least 5% of all certified organic operations annually. The organic regulations prohibit the use of most synthetic pesticides, and they exclude products from organic sale if testing shows that residue results exceed defined levels. While these tests present an important outcome-based option for determining organic compliance, they also pose challenges. First, pesticide metabolites may break down quickly when exposed to sun or water. Even if a pesticide was used, it cannot always be detected with testing. Second, USDA regulations set tolerances based on pesticide residues in plants. Residues found in soil require additional investigation but do not immediately exclude a product or farm from organic certification. Third, many agencies and buyers sample products at the point of distribution or retail. Tracing back the chain of custody may require coordination by several brokers and organic certification agencies, before finally reaching the point of origin—where any residues in the field are likely long gone. Finally, pesticide residues may result from airborne or waterborne drift. Proving the intentional use of pesticides in legal proceedings poses a challenge.

In addition to the technical challenges mentioned earlier, the underlying limitation of testing is this: it is not possible to test a product to determine whether it is grown organically. Laboratory testing can only detect certain “markers” of noncompliance with organic standards, such as whether it was genetically modified or subjected to prohibited substances. Since organic agriculture is a process-based certification, validation occurs...
through measures such as attesting to the methods that were used to produce and handle a product and scientific tests for the absence of certain attributes. Testing alone cannot verify organic methods.

16.2.2 Prohibited practices on organic farms

Complaints about prohibited practices often come from neighbors, competitors, and certifiers. Certifiers play an important role in documenting, submitting, and investigating complaints of prohibited practices, both on their own certified operations and on other farms. Typical complaints allege the knowing use of prohibited pesticides, or the use of prohibited practices such as confining cows during the grazing season. The NOP has focused on the latter issue through a dairy surveillance program. The organic rules require all organic dairy cows to consume approximately one-third of their nutrition from grazing on pasture, for at least one-third of the year. It is important to note that dairy is the second largest organic sector in the United States (Organic Trade Association, 2018) and thus critical to consumer confidence. Both the USDA and certifiers have increased unannounced visits to organic dairies to observe their behaviors during the grazing season, looking for visual evidence that cows are allowed on pasture as the rules require. When surveillance reveals areas of concern, the USDA requests further investigation by certifiers. The surveillance program therefore serves as both a deterrent to potential violators and an enforcement mechanism for existing bad actors.

16.2.3 Intentional sale of nonorganic products as organic

Finally, each year, the NOP receives a small number of complaints alleging fraud. Most of these relate to the falsification of organic certificates, in order to represent nonorganic products as organic. The NOP publishes all such certificates on its website to protect the industry from buying falsely advertised product. The most serious cases allege the knowing and willful sale of nonorganic products as organic, often at the wholesale level. Bulk commodities appear most vulnerable to this type of fraud. Shelf-stable and traded in large volumes, often using rail and ocean freight, these supply chains are designed for consolidation and efficiency—posing a challenge for transparency and traceability. Records are key to proving fraud on this scale. The NOP and certifiers use auditing techniques to trace back product purchases, compare volumes to determine mass balance inventories, examine financial and pricing data for suspicious pricing, and evaluate acreage and yield data against historical trends. Commodity sales often cross state and country borders; as such, the NOP can call on criminal enforcement partners for high-impact, large-dollar cases. Two examples from recent years resulted on one individual serving prison time, and another surrendering US$110 million in assets. In June of 2016, Bernard Saul of Idaho was sentenced to 36 months in prison for the crimes of wire fraud and money laundering. According to the Department of Justice (DOJ) “Saul’s conviction and sentence arose out of his misbranding conventional, nonorganic alfalfa seed as “organic” alfalfa seed, which he then sold for $1,903,727 more than the seed was worth. He did not tell his customers that...”
they were actually purchasing conventional, nonorganic alfalfa seed.” In December of 2018, Randy Constant of Missouri was convicted of one count of wire fraud. The DOJ stated that “Constant admitted the fraudulent scheme involved at least $142,433,475 in grain sales, and the vast majority of those sales were fraudulent. At the hearing, he admitted that, from 2010 to 2017, he misled customers into thinking they were buying certified organic grain when the grain he was selling was not organic.”

### 16.3 Organic fraud: A literature review and welfare analysis

Often, economic fraud has trickle-down effects that impact businesses and individuals that are not directly involved. A 2014 report from the Association of Certified Fraud Examiners (2014) estimated that a typical organization loses 5% of their annual revenue to all types of fraud, which results in a global fraud loss of nearly US$3.7 trillion. Organic fraud is a relatively recent but complex phenomenon, with widening market impacts. This section discusses fraud in the organic market and its implications from both producers’ and consumers’ perspectives. From the producer’s viewpoint, certification is an insurance that their organic product will be properly differentiated from nonorganic products, and that only agricultural goods possessing the right qualifications will be endowed with the label. On the consumer side, the label serves as a credibility signal that the product is indeed organic.

#### 16.3.1 Organic fraud from a producer’s perspective

A farm or business’ decision to enter the organic market accounts for expected prices and costs. Several studies have found that organic farming produces positive returns when compared to conventional (Chavas et al., 2009; Clark, 2009; Delate et al., 2003, 2013; McBride et al., 2015; Pimentel et al., 2005). Converting a field from conventional to organic production is a 3-year process, regulated by the USDA. Over that period, no prohibited substances may be applied. After reviewing the land’s history, production plans, and inspection by certifiers, compliant farms are certified for organic production. Certification provides a license to sell, allowing organic products to be officially marketed as organic. Organic products can be sold as conventional if there is an insufficient demand for organic; however, without organic certification, conventional products cannot be marketed under an organic label.

Several studies identified a positive relationship between increased profitability in a credence good market and the incentives to cheat (Baksi and Bose, 2007; Bonroy et al., 2015).

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7 The National List of Allowed and Prohibited Substances establishes the substances that may and may not be used in organic agriculture. As a general rule, synthetic substances are prohibited, while natural substances are permitted.
Another body of literature analyzed the risk of noncompliance with European regulations on organic farming. Several factors and farm characteristics were found to be good predictors of noncompliance. These include short organic farming experience, farm size, the existence of conversion area, livestock production, and previous noncompliant behavior (Zorn et al., 2013; Zanoli et al., 2014; Gambelli et al., 2014). In addition, fraud in the organic market can become a market barrier to compliant producers, because they are forced to compete with conventional products produced at lower costs but marketed at the organic premium. Farmers selling authentic organic goods and purchasing allowed inputs realize the burden of the counterparty risk and thus are incentivized to want organic market monitoring. If left unchecked, prevalence of fraudulent organic products in the market will negatively impact organic producers by artificially inflating supply, lowering consumer trust, and decreasing organic premiums.

Under the USDA organic regulations, when certifier producers sell fraudulent organic goods, they face revocation or suspension of their organic certification. Beside financial penalties the operation could be forced to reenter the lengthy transition process and could lose their customer base. Cases of organic violations in countries outside the United States may involve additional complexities and a more challenging enforcement.

### 16.3.2 Organic fraud from a consumer’s perspective

While many US consumers may have a general understanding of organic food production, fewer are familiar with the regulations and complexities of the organic production process. A large body of literature has concluded that most consumers purchase organic products based on their perceptions that these products have unique and superior sensory attributes (e.g., nutritive value, taste, freshness, and appearance) when compared to their conventional counterparts, and because of food safety, human health, and environmental considerations (Vindigni et al., 2002; Yiridoe et al., 2006; Shafiea and Rennieb, 2012).

Another area of research focuses on organic products as credence goods (Andersen and Philipsen, 1998; Nelson, 1970; Darby and Karni, 1973; Hansen, 2001; Giannakas, 2002). In the absence of an accreditation process or identifying labeling, information about an organic food product will be asymmetric (Nelson, 1970; Darby and Karni, 1973, Hansen, 2001; Giannakas, 2002). While producers would know the product is organic, consumers are not able to independently make that distinction. In fact, Demeritt (2002) concluded that the primary reason early US consumers hesitated to purchase organic food products was a lack of knowledge or awareness. Organic certification and labeling play a critical role in assuring consumers that the products are indeed organic.

Empirical research presents evidence of consumers identifying organic products and making purchases based on organic labels and logos attached to the product (Von Alvesleben, 1997; Øystein et al., 2001; Shafiea and Rennieb, 2012). Levels of organic knowledge and organic product labeling have been shown to have a positive impact on consumer purchase decisions (Chang and Kinnucan, 1991; Mathios, 1998; Kim et al., 1999; Wessels et al., 1999; Hughner et al., 2007). This is likely because labeling facilitates the transformation of credence characteristics of organic foods into a search attribute, which, in turn, helps consumers to assess quality before purchasing (Caswell, 2000).

Nevertheless, there is evidence that consumers may be suspicious of organic labels in countries where the organic agricultural sector is still developing and without established

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and uniform certification programs (Tregear et al., 1994; Wang et al., 1997; Giannakas 2002). Some of this skepticism originated from cases of mislabeling or the sale of conventionally produced food as organic (Landay, 1996; Groves, 1998). Incidents of fraud in the organic marketplace create uncertainty among consumers about the true attributes of the organic labeled product and may lead to demand-side market failures (Giannakas, 2002). The current USDA system involving third-party certification and labeling of organic products seeks to mitigate this information asymmetry and reduces the likelihood of a demand-side market failure in the organic marketplace.

16.3.3 Modeling fraud in the organic market and measuring its welfare impact

From an economic theory perspective, organic fraud represents a market inefficiency and reduces consumer welfare. Following the work of Sexton (1981), this section presents a theoretical framework that depicts the welfare cost to consumers of fraud in the organic marketplace. The first premise is that organic fraud represents a market with imperfect information as consumers overevaluate the organic attribute of a product—henceforth, product A. In the proposed framework (see Fig. 16.3), $D_{T(1)}$ is the demand curve that would occur if the consumer had perfect information about the fraudulent organic product. That is, this curve

![FIGURE 16.3 Welfare analysis of fraud in an organic marketplace.](image)
represents consumer’s true demand curve for product A based on perfect information—in this case, the accurate organic status of product A. The variable $D_1$ is the consumer’s initial demand curve for organic product A based on a person’s subjective evaluation of the attributes of product A in period $t$. It is assumed that product A has a constant market price, $P^*$. In this context, when $D_1$ and $D_T$ are not identical, this indicates a misallocation of consumer’s expenditures and the corresponding losses in welfare and changes in the consumer surplus.

In the presence of organic fraud, the consumer will incur a loss in welfare for the additional $A_1 - A_2$ units purchased. While the corresponding purchase amount is represented by $A_2ZXA_1$, the actual value of these units, revealed by $D_{T(1)}$, is only $A_2ZYA_1$. Therefore in period $t$, the consumer incurs a welfare loss represented by $ZX$ (Fig. 16.3).

The expected economic loss (ECL) to a consumer from imperfect information on an organic product in any given time period is defined by the loss incurred from overevaluating the product organic attribute weighted by the probability of that same overevaluation.

$$ECL = \left[ \text{probability of fraud} \right] \frac{1}{2} (ZX)(XY)$$

(16.1)

Aggregation of welfare losses from all consumers results in US total welfare losses from organic fraud.

$$ECL = \sum_{j=0}^{m} \sum_{i=0}^{n} ECL_i$$

(16.2)

where $n$ is of the universe of US consumers of organic goods and $m$ represents all the different organic products they purchase. The mathematical derivation of Eq. (16.1) can be expressed as

$$ECL = \left[ \text{probability of fraud} \right] \left[ P^*(A_1 - A_2) - \int_{A_2}^{A_1} f^1(p)dp \right]$$

(16.3)

where demand curves in Fig. 16.1 are expressed by $D_1 = f^0(p)$ and $D_{T(1)} = f^1(p)$.

To solve Eq. (16.3) and calculate the ECL incurred from purchases of fraudulent organic products, $ZX$, the estimated aggregate organic premiums paid by the United States and consumers are weighted by the probability of fraud. Regarding the latter, researchers and regulators acknowledge the difficulty of accurately measuring the prevalence of food fraud. This is because the number of documented incidents may represent a fraction of the true scale of the problems, given that the goal of those deliberately involved in fraud is to avoid detection (Johnson, 2014; Spink and Fejes, 2012). Furthermore, businesses that detect fraud may choose to handle it privately, avoiding negative publicity or legal exposure. From a broader perspective, a 2016 study from the Organization for Economic Cooperation and Development estimated that overall counterfeit and pirated goods represented up to 2.5% of world trade. Estimated fraud rates varied across countries and product categories—including agricultural and food product categories for which there is organic production.

When considering the prevalence of fraud in the organic market, an early study by The Ependitis (1998) posited that it ranged between 15% and 40% in southern countries of the EU. A 2013 EU report ranked organic goods as third out of the top 10 products that
were most at risk of food fraud (European Parliament, 2013). Interestingly, because consumers of organic foods are not likely to know what happens at different points of the supply chain, there may be a lag between the occurrence of fraud and its detection and reporting.

US consumer perceptions may have been influenced in recent years by newspaper headlines highlighting cases of organic fraud; however, a broader look at this issue reveals a different story. Most farms, ranches, and businesses certified to the USDA organic standards are following the organic rules. While organic fraud happens, it is reasonable to say that fraud is the exception, not the rule. In contrast to overall fraud in the organic market, the complaints submitted to the NOP primarily result in voluntary compliance. The NOP investigates and closes hundreds of cases each year (Fig. 16.1) and 88% of those result in voluntary compliance. This shows a healthy level of compliance and enforcement activity while demonstrating that most of the industry—even that which is the subject of complaints—voluntarily complies with USDA’s organic rules. Nevertheless, interpretation of data on organic fraud should involve a degree of caution and consider the issue of partial observability. That is, not all cases of organic fraud are detected, investigated, and recorded by the NOP. Rather, fraud detection will likely be influenced by supply and demand conditions (e.g., traded volume) of certain commodities, by the ease of detection and data availability, and by stakeholders detecting specific issues and initiating the complaint through the NOP.

16.4 Strategies to mitigate organic fraud

Ensuring compliance is critical to successful implementation of the USDA regulatory framework; however, as the global organic marketplace expands and becomes ever more complex, regulators and industry are exposed to a growing degree of compliance risk. In an environment of growing needs and limited resources, the NOP has developed risk-based compliance and enforcement strategies that involve rigorous and systematic data analysis to identify and respond to regulatory risks. NOP’s staff review, interpret, and summarize many data sources. These findings from analytical projects are regularly presented across the program and, when needed, to other pertinent stakeholders, such as other government agencies, certifiers, trade groups, and organic businesses. The goal is to develop innovative approaches and methods for assessing organic fraud risk and to generate risk-based guidance for policy development, organic producers, and certifying bodies.

Through this comprehensive approach, the program also identifies fraud risks with the greatest potential for legal, financial, operational, or reputational damage. A major premise of this approach is that risk is a function of the probability and the impact of noncompliance (Eq. 16.4).

\[
\text{Fraud risk} = f(\text{Likelihood of whether one regulated entity will not comply with NOP regulations, impact of noncompliance})
\]

(16.4)

Estimates of the likelihood of fraud are based on data analysis and on selected parameters such as past noncompliance records, supply chain complexity, and ongoing
market conditions (e.g., supply shortages, high organic premiums, and industry concentration). Measuring the impact of an organic noncompliance event accounts for the transaction value, the size and scope of the businesses involved in fraudulent activities, or some other intricacies of the involved products (e.g., a major input to many other organic products). Using these two dimensions (i.e., likelihood and impact), the NOP categorizes different sources of fraud. Fig. 16.4 presents a risk matrix that segments examples of organic fraud into four different categories: (1) low probability and low impact; (2) high probability and low impact; (3) low probability and high impact; and (4) high probability and high impact. As the NOP continues to monitor the organic marketplace, entries in this matrix will evolve to reflect emerging risk sources.

Technology has become an increasingly important tool in the surveillance of the organic industry. In 2016 the NOP launched its public registry of certified, surrendered, suspended, and revoked organic businesses, called the Organic Integrity Database. This database has increased market visibility for certified organic businesses and also includes listings of businesses that were previously certified but are no longer allowed to sell products as organic. As such, the database is both a marketing tool, and a deterrent that discourages noneligible businesses from selling as organic.

The next stage of NOP’s technology investments will expand into international trade systems, to increase the visibility and surveillance of organic imports. In 2018 NOP launched a new organic export certificate system to provide electronic certificates about organic shipments. This system can also be accessed by other governments to reaffirm the organic status of exported products.

FIGURE 16.4 Organic fraud risk matrix.
There has been significant discussion in the United States about the need for an international system to improve the ability to conduct global mass balance calculations of organic products, and to ensure the traceability and oversight of organic supply chains. The USDA is currently considering foundational needs for a global organic oversight system. The ultimate goal is to develop technologies that would allow organic certifiers to approve transactions along an organic supply chain in real time, enabling them to conduct mass balance checks and to detect fraudulent activity across the supply chain.

A comprehensive system would allow government oversight bodies to audit across supply chains, fulfilling the goal of tracing product from farm to market and back. The goal of this work would be to establish an interconnected surveillance network, where data can be exchanged between different government oversight systems and existing corporate supply chain systems.

Technology, of course, cannot replace the importance of individual organic inspectors, who serve as the primary point of contact in the oversight control system for many farms and businesses. Organic inspectors have traditionally been trained primarily in organic production practices, not investigative techniques, evidence collection, and fraud detection approaches. As such, the NOP is investing in an online training system to increase inspector knowledge and skills in investigative techniques, quantitative methods (e.g., mass balance calculations, crop yield assessments, and forensic accounting), and effective interviewing. Qualified inspectors and record reviewers are critical in ground-level surveillance in a risk-based oversight system.

16.5 Future challenges and opportunities

As the organic sector continues to grow so will consumer demands for a transparent and reliable organic supply chain. Recent publicized cases of organic fraud may have led to growing skepticism among US consumers. This represents a challenge to the organic sector because, when uncertain about the integrity of the supply chain, consumers will refrain from purchasing organic foods. Market dynamics will inevitably continue to shape the organic sector. For example, high premiums and domestic shortages in certain organic commodities will likely create conditions for future fraudulent activities, which, in turn, will require robust oversight and enforcement from regulators and all other responsible stakeholders.

The ongoing training of organic certifiers, inspectors, and reviewers is a critical component of the global organic control system; these agents will need to be continuously trained as bad actors engage in new approaches. New technologies, such as block chain, big data management, and sophisticated computer logarithms, will provide industry and regulators with new tools to monitor the integrity of organic supply chains—from the field all the way to final retail destination. Furthermore, in addition to the government actions, as the organic market continues to mature, trade interests, certifiers, and food producers and processors are developing their own monitoring and oversight best practices and specialized programs. This is a critical step for those businesses that want to capitalize on organic premiums while maintaining their reputation and safeguarding the integrity of their products.
References


CHAPTER 17

Fraud in dietary supplements

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17.1 Introduction

Dietary supplements are products taken by mouth that are intended to supplement the diet and that contain one or more dietary ingredients (FDA, 2015). Dietary ingredients include vitamins, minerals, amino acids, herbs or botanicals, and many other compounds (Table 17.1). The Codex Alimentarius Commission (2005, 2007) offers a definition of dietary supplements in its “Guidelines for Vitamin and Mineral Supplements.” The Guidelines, which are voluntary for all member states, indicate, “Vitamin and mineral food supplements for the purpose of these guidelines derive their nutritional relevance primarily from the minerals and/or vitamins they contain. Vitamin and mineral food supplements are sources in concentrated forms of those nutrients alone or in combinations, marketed in forms such as capsules, tablets, powders, solutions, etc., that are designed to be taken in measured small-unit quantities but are not in a conventional food form and...
whose purpose is to supplement the intake of vitamins and/or minerals from the normal diet.” (Codex Alimentarius Commission, 2005, 2007).

The Guidelines recommend further that all supplements contain ingredients that have been scientifically tested for purity and should take into account standards set by the World Health Organization and international pharmacopeias. Codex Alimentarius labeling guidelines specify that a supplement package should contain (1) a list of ingredients expressed as percent values, (2) an indication of the product’s intended use, (3) a warning to the consumer not to exceed the recommended value, (4) a statement that the supplement should not replace regular food and meals, and (5) a statement that the product should be kept out of the reach of children.

Dietary supplements are an ideal target for fraud due to their high sales value and increasing popularity in the marketplace. The dietary supplement market in the United States is estimated to have at least $43 billion per year in sales while the global supplement market is estimated to have $128 billion per year in sales (Nutrition Business Journal, 2018). The Counsel for Responsible Nutrition (CRN) (2018) estimates that 75% of the US population has used a dietary supplement in the last 12 months. The 2018 CRN survey found that supplement use is diversifying across categories. While vitamin/mineral supplements remain the most popular category among supplement users (98%), the overall use of herbals/botanicals has significantly increased in the past 5 years. In 2018 41% of supplement users reported that they had taken herbals/botanicals in the past 12 months—up 13 percentage points from 2013. Multivitamins continue to be the top choice of supplement users with the main reason being overall health and wellness (CRN, 2018).

The high economic value and enormous surge in dietary supplement sales led the US Food and Drug Administration (FDA) Commissioner Scott Gottlieb to acknowledge that “bad actors” routinely put potentially harmful products or products with unproven health claims on the market. “I’m concerned that changes in the supplement market may have outpaced the evolution of our own policies and our capacity to manage emerging risks,” he was quoted as saying in a 2019 Washington Post news article (McGinley, 2019). This statement aptly applies to some imported dietary supplements that are readily available to consumers around the world (Genuis et al., 2012). FDA’s website warns that consumers who choose to purchase dietary supplements from nonconventional sources such as ethnic or international stores, flea markets, or from websites unknowingly may put themselves in harm’s way (FDA, 2017). False advertising often targets nonnative English speakers with limited health-care funding. These individuals may also originate from cultures that have an established tradition of dietary supplement use. Often, target populations include individuals

### Table 17.1 Examples of dietary ingredients used in supplements.

<table>
<thead>
<tr>
<th>Category of ingredient</th>
<th>Specific examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamins</td>
<td>Vitamins A, D, B3, B5</td>
</tr>
<tr>
<td>Minerals</td>
<td>Calcium, iron, zinc, copper, iodine</td>
</tr>
<tr>
<td>Botanicals</td>
<td>Ginko, guarana, capsicum</td>
</tr>
<tr>
<td>Amino acids</td>
<td>Lysine, leucine, cysteine</td>
</tr>
</tbody>
</table>

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with complex medical issues who are seeking an easy, natural cure. *FDA’s (2017)* website states that such supplements may be adulterated or contain contaminants or drugs that do not appear on the label. *FDA’s (2019)* “Tainted Products Marketed as Dietary Supplements” webpage lists 962 products and acknowledges that this list includes “a small fraction of the potentially hazardous products with hidden ingredients marketed to consumers on the internet and in retail establishments.” The use of unapproved drug ingredients added to dietary supplements sold in the United States was described as a “significant health problem” by Daniel Fabricant, Former Director, Division of Dietary Supplement Programs, FDA and now President and CEO, Natural Products Association. He stated that some undeclared drug ingredients have been detected in dietary supplements up to 10 times the initial dose recommended in the legitimate drug’s labeling (*Thompson, 2012*). Such products have sometimes led to public health harm.

This chapter will discuss US regulations concerning dietary supplements, types of fraud that have been reported with dietary supplements, and strategies for mitigation.

### 17.2 US regulation of dietary supplements

Fraud within the dietary supplement industry has been attributed, in part, to the fact that supplements are regulated differently from both pharmaceuticals and foods (*Wheatley and Spink, 2013*). In the United States, dietary supplements are regulated through the Dietary Supplement Health and Education Act of 1994. This Act requires dietary supplements to be manufactured under good manufacturing practices (GMPs), similar to food products. All ingredients used in a dietary supplement must be safe for consumption, and there must be lot control for traceability. Dietary supplements are also required to only be for oral ingestion, and labels must state the fact that the product is a dietary supplement. In addition, labels must have a “Supplement Facts” panel that includes the name and quantity of each dietary ingredient. False and misleading claims for the product are prohibited, and any health claims must be preapproved by the FDA. Finally, products may have a statement of nutritional support, such as a structure/function claim. However, any such statements must be adequately substantiated and cannot claim to treat, cure, or prevent any disease (*FDA, 1994*).

Fraudulent dietary supplements may be categorized as misbranded or adulterated, or both. Misbranding, per the Code of Federal Regulations Title 21 Food and Drugs, Part 101 Food Labeling, is misrepresentation in labeling that is false or misleading. Misbranded products may lack a complete list of ingredients, a truthful geographical origin, or use a brand name associated with another firm (*https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcr/CFRSearch.cfm?fr = 101.18*). In the case of dietary supplements, misbranding may also include misrepresented health claims. Adulteration, per the Code of Federal Regulations Title 21 Food and Drugs, Chapter 9, Subchapter 4, refers to poisonous or insanitary ingredients or any substance in a product that can cause health illness or injury. These may include pesticide residues, unsafe food additives, filthy or decomposing substances, or ingredients added solely to increase the overall weight of a product. A product may also be considered adulterated if adequate safety information associated with a
17. Fraud in dietary supplements

17.3 Types of dietary supplement fraud

Fraud in dietary supplements can take many forms (Wheatley and Spink, 2013). For example, a vitamin or mineral may not have the correct potency declared on the label. A vitamin may be substituted for a similar, yet less expensive material. Fillers may be added to the material to lower the cost of the material, or the material may contain contaminants that are not normally present. A manufacturer may make a prohibited disease claim or unsubstantiated structure/function claim about a particular ingredient. Another type of fraud is when an active pharmaceutical ingredient (API) is contained in a product marketed as a dietary supplement but does not appear on the label. Any of these types of fraud can be harmful to the manufacturer purchasing the material and to the consumer using the dietary supplement.

17.3.1 Herbal and botanical supplements

When it comes to fraud in dietary supplements, herbal and botanical materials rise to the top of raw materials that are impacted. A 2013 study conducted by researchers in Canada and the United States showed that one-third of 44 products tested had contaminants or fillers not listed on the label (Newmaster et al., 2013). Many of these contaminants could pose serious health risks to consumers. For example, the study found in one case that St. John’s wort had been substituted with Senna Alexandrina, which is an FDA-approved nonprescription herbal laxative. The use of this material could potentially cause gastrointestinal issues for an unknowing consumer.

In 2015 the New York State’s attorney general accused four retailers (GNC, Target, Walgreens, and Walmart) of selling fake and potentially harmful herbal supplements and...
required the retailers to remove the products from their store shelves (O’Connor, 2015). According to the report, *Ginkgo biloba* sold at Walmart and marketed as a memory booster contained little more than powdered radish, houseplants, and wheat, even though it claimed to be wheat- and gluten free. Walgreen’s popular store brand of ginseng pills was found to contain only powdered garlic and rice. Three of six herbal products at Target—St. John’s wort, *G. biloba*, and valerian root—had no herbs and were made of powdered rice, beans, peas, and wild carrots. At GNC, herbal pills contained unlisted fillers such as powdered legumes, a class of plants that includes peanuts and soybeans, two major allergens that have the potential to trigger anaphylactic reactions. As a result of the investigation, GNC agreed to perform regular DNA testing on herbal products and take other measures to ensure the purity of the materials being sold.

Misrepresenting the country of origin for a botanical is another common type of fraud. For example, a 2012 study showed that 50% of ginseng labeled as Korean was actually identified using DNA barcoding as American ginseng (Wallace et al., 2012).

### 17.3.2 Vitamins

A common issue with regard to dietary supplement fraud is the use of synthetic vitamins in place of natural vitamins. Natural vitamins are manufactured using animal or plant sources to extract the nutritional compound (such as omega-3 fatty acids from fish). Synthetic vitamins are manufactured using petroleum by-products such as coal tar. Although many are Generally Recognized as Safe for human consumption (FDA, 2019), an organic or natural product would not be allowed to contain the synthetic form of the vitamin, such as Vitamin A palmitate. Another type of fraud that can occur in the production of dietary supplements is the substitution of an animal feed-grade vitamin or mineral for the food-grade version. Using a feed-grade version of a compound would render the product adulterated and unfit for human consumption. This would also be true for any botanical or vitamin used as an ingredient in food products.

### 17.3.3 Prohibited disease claims

The FDA has warned consumers of dietary supplement products that assert unproven claims to treat disease, also known as prohibited disease claims. Consumers who use such products and choose to delay or forego proper medical treatment can suffer serious, sometimes fatal, injuries (https://www.fda.gov/consumers/protecting-yourself/health-fraud-scams). In 2010 a company called Techmedica was found to have illegally marketed dietary supplements claiming health benefits that were false in nature. The owners of the company claimed that their products had proven reliable through clinical testing for the treatment and prevention of diabetes, irritable bowel syndrome, gout, high cholesterol, high blood pressure, heartburn, and diarrhea. However, no clinical testing had ever been performed. For a company to make such claims, clinical testing on humans would be required with strict requirements for allowing the claims, which in many cases would cause the product to become a drug or pharmaceutical product. The owners additionally placed false testimonials and fake product information on their website. The owners were
eventually convicted of fraud and sentenced to 3–8 years in prison and fined $11.9 MM by the US government (FDA, 2010).

FDA has also identified products dangerously claiming to cure cancer (https://www.fda.gov/consumers/protecting-yourself/health-fraud-scams). Supplements claiming to treat cancer without any evidence of clinical trials and FDA approval are also marketed via websites and social media. Purposed treatments include pills, capsules, powders, creams, teas, oils, and kits. For example, two companies in the United States were charged in the year 2000 with deceptively marketing a shark cartilage product and a skin cream product as cancer treatments (FTC, 2000). In a study conducted almost 20 years later, one company was found to still be promoting the unsubstantiated association between shark cartilage and cancer prevention/treatment (Isaacs and Hellberg, 2019). Such products are often labeled as “natural” dietary supplements that seem to present little to no adverse health risk. However, delaying established cancer treatment regimens in favor of dietary supplements with unproven claims is an extremely dangerous risk (https://www.fda.gov/consumers/consumer-updates/products-claiming-cure-cancer-are-cruel-deception).

17.3.4 Weight loss, sexual enhancement, and body-building supplements

Common categories of fraudulent products identified by FDA include those intended for weight loss, sexual enhancement, and body building. For example, dietary supplements containing ephedrine alkaloid ingredients have been problematic. One such product was the weight loss product marketed as Ephedra, which contained the active ingredient ephedrine. Ephedrine was associated with “an unreasonable risk of illness or injury” such as heart attacks and strokes and caused adverse health effects in over 150 individuals (Nelson, 2004). In 2018 a dietary supplement manufacturer was shut down by the FDA due to the presence of illicit API in its products (Nutraingredients-USA, 2018). MyNicNaxs distributed weight loss and sexual enhancement products via its website. The FDA found undeclared drug ingredients, including sibutramine and sildenafil, in multiple samples, and the products were recalled from the market. Sibutramine in all drug products was banned in October 2016 (Federal Register, 2016). Sildenafil has the potential to interact with a long list of prescription medications, especially those used to treat angina or high blood pressure.

Fraudulent dietary supplements can also have unintended consequences for high school, college, and professional athletes who unknowingly consume banned substances that are included in the dietary supplement product. In November 2017, researchers at Harvard Medical School found that six supplements marketed for weight loss and fitness contained four unapproved, unlisted stimulants in the products. Intake of these stimulants could cause an athlete to fail a test for performance-enhancing drugs (Cohen, 2017). Similarly, a 2005 study showed that undeclared hormones prohibited by the International Olympic Committee and the World Anti-Doping Agency (WADA) found in dietary supplements could cause a failed doping test in athletes. In the study, five healthy male athletes were given a contaminated nutritional supplement and after 2 hours provided a urine sample for testing. In all the cases the urine of the athletes had 19-norandrosterone above the WADA threshold of 2 ng/mL, and in two individuals the level of 19-norandrosterone was
17.3.5 Other adulteration concerns

FDA has issued warnings with regard to commonly adulterated products such as kratom. Kratom products are sold for recreational use or to ease pain from opioid withdrawal. FDA warns of kratom products containing high doses of Salmonella. Salmonella-tainted kratom caused numerous illnesses and led to a thorough investigation and a mandatory recall, the first mandatory recall of dietary supplements in history. Testing also revealed extremely high levels of heavy metals that FDA deemed “not safe for human consumption.” Heavy metals in the form of lead and nickel were identified in laboratory testing of 30 kratom products on the market. Long-term heavy metal exposure has the potential to damage the nervous system or kidneys, cause anemia, elevate blood pressure, and lead to some types of cancers (https://www.fda.gov/news-events/public-health-focus/laboratory-analysis-kratom-products-heavy-metals).

17.4 Mitigation of dietary supplement fraud

As with any food commodity, dietary supplement fraud management requires a systematic approach to ensure the safety and authenticity of the raw material supply. Food fraud mitigation strategies and tools are covered in depth in Chapter 2, History of Food Fraud and Development of Mitigation Requirements and Standards, and Chapter 3, Food Fraud Mitigation: Strategic Approaches and Tools. Briefly, with regard to dietary supplement fraud, the first step is to complete a vulnerability assessment of all of the materials that are being purchased for use in dietary supplement products. This risk assessment should include material type, process complexity to manufacture the material, country of origin, price of material, intended use of the material, frequency/quantity of use for the material, historical evidence of fraud, and previous incoming material test results. An excellent free tool to use is provided by SSAFE on their website. Once a vulnerability assessment of each of the material types for dietary supplements is complete, the next step is to incorporate food fraud questions and observations into audits of raw material suppliers. Whether these audits are carried out by an organization or a third party, fraud needs to be an integral part of these audits. If a Global Food Safety Initiative third-party audit is utilized, a food fraud assessment is now required as of 2018 to be part of the audit protocol.

In addition to audits of suppliers a company may also consider NSF or USP certification of the materials being purchased. Although these seals are not equivalent to FDA approval for the dietary supplement, which is currently not required by the FDA, it demonstrates that they have been tested for safety and efficacy. These organizations do not guarantee that a product has therapeutic value or test every batch of supplements shipped out, their seal is a good indication that the product contains the amount of the ingredient advertised.
on the label and that it is not contaminated with dangerous substances, such as arsenic, bacteria, or lead (Tarkan, 2016).

Another aspect of a strong dietary supplement fraud program is to incorporate analytical testing into incoming raw material controls. This includes testing all vitamins and minerals for assay/purity when they are received at the manufacturing facilities. In addition, a number of raw materials can be tested for additional items of concern based on the vulnerability assessment initially completed. These tests look for items such as heavy metals, pesticides, illegal compounds any previously known adulterants found in that particular material. The testing should be carried out by an accredited third-party lab that has the proper testing equipment to analyze the various vitamins, minerals, and botanicals. This testing should be part of the supplier quality expectations for all raw material suppliers.

Also of importance is the ongoing monitoring and horizon scanning for information related to fraud in the materials that a company purchases. This includes benchmarking with other companies and industry organizations and receiving alerts when instances of food fraud are found in the food supply. In addition, there are many software tools in the industry that now enable an individual to receive alerts when food fraud or adulteration has been detected in a material. Horizon scanning is about foresight and ensuring that new information on a material is discovered before it becomes old news or a company cannot react to that information. Another area to monitor is price spikes in certain materials due to a shortage or natural disaster. As food fraud is about economic gain, criminals will identify materials where the sales price is quite high and the barrier to substituting lower cost and lower quality ingredients is low.

17.5 Conclusion

As dietary supplements continue to grow in popularity, the potential for fraud during the manufacture and sale of these supplements increases. Manufacturers, retailers, and consumers must become more vigilant in their efforts to identify and root out potential fraud. Having a strong dietary supplement fraud program with the elements discussed before will assist a manufacturer or retailer in this work. However, companies must stay up to date and alert to the different fraud types that occur as the criminals will always attempt to stay one step ahead of the industry and the regulators. Dietary supplement fraud has significant economic impacts on the industry as well as the consumer. Even more importantly, it can impact consumer health. For consumers the old adage of buyer beware applies to dietary supplements that promise quick, cure all, natural treatments at a lower cost than traditional medical treatments. The US FDA offers publicly accessible information such as warnings regarding certain types of dietary supplements. This information warns consumers that certain dietary supplements readily available from unconventional sources may not meet established quality standards and may, in some cases, present a health risk, especially when false disease claims are promoted and/or hidden prescription drug ingredients are unknown to the user. Additional regulations required under the FSMA will also enhance the safety of dietary supplements as new rules are enacted. The most effective consumer protection for dietary supplement fraud is a
combination of strong industry food safety and food fraud programs across entire organizations combined with strong consumer education initiatives.

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18

Fraud in probiotic products

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\section*{18.1 Introduction to probiotics and their health benefits}

The applications of probiotics for human health have received much attention among microbiologists and clinicians (Huys et al., 2006). Although some probiotics are considered pharmaceuticals or drugs, most probiotics are marketed as functional foods or dietary supplements (Hoffmann et al., 2013a,b). Probiotics are defined as “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” (Hill et al., 2014). Potential health benefits of probiotics are diverse, spanning their effects on digestive health; role in treatment of infectious diarrhea, antibiotic-associated diarrhea, inflammatory bowel disease, and irritable bowel syndrome (Floch, 2018; Borja et al., 2017; Moayyedi et al., 2010; Ng et al., 2008); immunomodulatory and antiallergic effects (Bubnov et al., 2015; Borchers et al., 2009); cholesterol lowering effect (Nguyen et al., 2007); and cancer prevention (Rajoka et al., 2017; Sharma et al., 2018). This diversity of potential health benefits contributed to rapid growth in the global probiotic market over the years. The value of the global probiotic market increased from USD
35.9 billion in 2016 to USD 48.38 billion in 2018, and it is expected to grow to ~USD 66 billion by end of 2024 (Zion-Market-Research, 2018; Grand View Research, Inc., 2018, 2019).

Health benefits are strain specific and cannot be extended to other strains, even those belonging to the same species (Borja et al., 2017). In addition, the safety of probiotic strains to humans will vary from one strain to another. Thus precautions must be taken when manufacturing, packaging, and labeling probiotic products to accurately identify probiotic strains and to ensure the presence of the correct strains in each product, especially, when claiming health benefits on product labels. Moreover, probiotic health benefits are dose dependent, and thus probiotic cells should be viable and should be delivered in adequate dose to be effective. Viable cell count should be verified throughout the shelf life of probiotic products (Tripathi and Giri, 2014; Borja et al., 2017; Kolacek et al., 2017).

In alignment with the definition of probiotics and the requirements of probiotics to be effective, The Joint Food and Agriculture Organization of the United Nations and World Health Organization Working Group (FAO/WHO) (2002) and The Council for Responsible Nutrition (CRN) and the International Probiotics Association (IPA) (2017) recommend the inclusion of genus, species, and strain name as well as minimum viable cell count in colony-forming units (CFUs) at expiration date, use by date, and proper storage condition on labels. These recommendations are adopted and required by only some national regulations such as Health Canada, where the inclusion of probiotic genus, species, and strain names as well as cell count in a serving size at the end of shelf life on product labels is required when health claims are made (Health Canada, 2009a,b, 2015).

The rapid growth and increasing value of probiotics combined with the specific nature of the product have given rise to numerous vulnerabilities for fraud. For example, products may claim to contain certain strains or viable cell counts that cannot be readily verified by the consumer. Because of the relatively new development of probiotics in relation to other food commodities, there is a limited history of document fraud events in this sector. Therefore this chapter will focus on the potential for fraud within probiotic products, including a discussion of analytical methods for authentication, documented noncompliance with labels, and risk mitigation strategies.

18.2 Most commonly used methods for authentication of probiotic products

In order to ensure strain identity and viable counts in probiotic products, several methods have been developed. DNA-based methods are the most commonly used tools for probiotic species/strain identification. DNA-based methods for probiotic species/strain identification include PCR-denaturing gradient gel electrophoresis (DGGE), terminal restriction fragment length polymorphism, species-specific PCR, strain-specific PCR, and high-throughput sequencing (Fasoli et al., 2003; Theunissen et al., 2005; Marcobal et al., 2008; Drago et al., 2010; Chen et al., 2017; Morovic et al., 2016, Patro et al., 2016).

DNA-based methods can be generally classified as targeted and nontargeted methods. Targeted methods such as species-specific PCR or strain-specific PCR are becoming more commonly used, as they are simple, fast, sensitive, and accurate. Examples of probiotic species/strains for which targeted conventional or real-time PCR assays were developed include Bifidobacterium animalis subsp. lactis Bb12 (Solano-Aguilar et al., 2008); Lactobacillus
In contrast, nontargeted methods such as amplicon based high-throughput sequencing can identify all probiotic strains/species present in a product. Although high-throughput sequencing is especially valuable in detecting undeclared or contaminant species/strains (Morovic et al., 2016; Patro et al., 2016), this technique is more costly and time-consuming compared to targeted PCR assays. It also requires expertise in bioinformatics and may have poor resolution at species and strain levels. For these reasons, targeted PCR methods are more commonly used and can readily be adopted by industry for quality control of probiotic production (Morovic et al., 2016) following industry guidelines recently published in the Journal of AOAC International (Shehata et al., 2019).

In addition to verification of the species/strain identity, it is equally important to verify the viable cell count. The most commonly used method for bacterial enumeration is the plate count method (Davis, 2014). In this method, probiotic products are serially diluted then plated on selective growth media to give CFUs per gram or per dose. Plate count methods are time-consuming, labor intensive and produce highly variable results (Hansen et al., 2018).

Flow cytometry is another method that enables quick enumeration of viable cells; however, this method is nonspecific and may lead to overestimation of cell counts (ISO, 2015). In addition, the performance of flow cytometry may be affected by storage time. Fresh cultures with high viability tend to show higher correlation between viable counts determined using flow cytometry and plate count, while cultures tested following storage tend to show weaker correlation between viable counts determined using flow cytometry and plate count (Wilkinson, 2018).

More recently, targeted PCR-based methods coupled with viability staining were developed for the enumeration of viable probiotic cells. For example, viability real-time PCR methods were developed for the enumeration of L. acidophilus LA-5 and B. animalis ssp. lactis BB-12, and the results were similar to those obtained from flow cytometry (Kramer et al., 2009). In addition, digital PCR methods were designed for specific enumeration of strains L. acidophilus NCFM and B. animalis subsp. lactis Bi-04. Both assays performed well with a 4%—5% relative standard deviation (Hansen et al., 2018). Similarly, digital PCR methods were developed for strains B. animalis subsp. lactis Bi-07 and HN019, L. acidophilus La-14, and L. plantarum Lp-115. The assays showed agreement with culture plate methods and flow cytometry (Hansen et al., 2020).

**18.3 Studies and market surveys that investigated the accuracy of probiotic labels**

Several studies and market surveys have been conducted to investigate the label accuracy of probiotic products. These studies used a wide range of methods for product testing.
and identified various issues of concern. Some of these studies investigated only the presence of the declared species while others investigated the presence of undeclared species and determined the viable cell count (Kolacek et al., 2017). The findings of some of these studies are summarized here and in Table 18.1.

### Table 18.1
Summary of the findings of selected market survey studies that investigated compliance in probiotic products.

<table>
<thead>
<tr>
<th>Study</th>
<th>Test samples</th>
<th>Summary of findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasoli et al. (2003)</td>
<td>Seven lyophilized probiotic preparations from the Italian market</td>
<td>Viable cell counts were lower than declared for all seven products in addition to missing species and presence of undeclared Staphylococcus.</td>
</tr>
<tr>
<td>Theunissen et al. (2005)</td>
<td>Nine lyophilized probiotic products from South Africa</td>
<td>Only three products (33.3%) contained the declared species.</td>
</tr>
<tr>
<td>Huys et al. (2006)</td>
<td>121 probiotic cultures</td>
<td>Overall misidentification rate of 28%.</td>
</tr>
<tr>
<td>Aureli et al. (2010)</td>
<td>41 probiotic products from Italy</td>
<td>Missing species in 19 samples and presence of undeclared Bacillus cereus and Bacillus subtilis in 3 products. Viable count did not meet label claims in some products. Overall noncompliance is 87%.</td>
</tr>
<tr>
<td>Drago et al. (2010)</td>
<td>13 probiotic products from the United States</td>
<td>Only four products (31%) met the label claims.</td>
</tr>
<tr>
<td>Toscano et al. (2013)</td>
<td>24 products from the Italian and European market</td>
<td>Only 14 products (58%) were properly labeled.</td>
</tr>
<tr>
<td>Goldstein et al. (2014)</td>
<td>Five probiotic products</td>
<td>Viable counts were similar to the declared viable cell counts in all products.</td>
</tr>
<tr>
<td>Lewis et al. (2016)</td>
<td>16 probiotic products with Bifidobacteria</td>
<td>Only 1 product matched the label claims.</td>
</tr>
<tr>
<td>Chen et al. (2017)</td>
<td>Eight probiotic supplement products collected in China</td>
<td>No viable cells were detected in two products (25%). All eight samples had missing declared species and/or contained undeclared species.</td>
</tr>
<tr>
<td>Morovic et al. (2016)</td>
<td>52 probiotic products</td>
<td>22 samples (42%) had labeling inaccuracies, such as missing declared species and presence of undeclared species. 17 samples (33%) contained viable cell counts lower than declared.</td>
</tr>
<tr>
<td>Patro et al. (2016)</td>
<td>10 probiotic products from the US market</td>
<td>One product contained undeclared Enterococcus and one product did not meet the claimed cell count.</td>
</tr>
<tr>
<td>Shehata and Newmaster (2020)</td>
<td>182 probiotic products collected from the United States and Canada</td>
<td>11 species could not be detected in ten products and undeclared Bifidobacterium animalis subsp. lactis was detected in one product.</td>
</tr>
</tbody>
</table>
In 2003 Fasoli et al. tested seven lyophilized probiotic preparations from retail pharmacies in the Italian market using species-specific PCR, PCR-DGGE, and plate count methods. The authors reported that the viable cell count was lower than the declared cell numbers for all seven products. In addition, some of the declared species were not detected and undeclared species were detected, including *Staphylococcus* in one product, which may represent a health hazard, as some *Staphylococcus* species are known to be pathogenic (Fasoli et al., 2003). Theunissen et al. (2005) tested nine lyophilized probiotic products from South Africa using DGGE and species-specific PCR and found that only three products (33.3%) contained the declared species. Another study by Huys et al. (2006) evaluated the accuracy of taxonomic identity of 121 probiotic cultures collected directly from producers and distributors using a variety of DNA and protein profiling methods. The study found that 16 cultures were misidentified at the genus level and 18 cultures were misidentified at the species level, resulting in an overall misidentification rate of 28% (Huys et al., 2006). The study suggested that the reason for the high misidentification rate is the use of inappropriate identification methods such as Analytical Profile Index (API) strips by probiotic manufacturers (Huys et al., 2006).

In 2008 Marcobal et al. tested 14 commercial probiotic products from the US market. Species-specific PCR confirmed the presence of all declared species; however, terminal restriction fragment length polymorphism revealed the presence of undeclared species in 12 of the products (Marcobal et al., 2008). Another study by Aureli et al. (2010) assessed 41 probiotic products collected from processing plants and retailers in Italy. The study used PCR-based methods to confirm the presence of the genera/species declared on product labels and used plate count methods to assess viable count of probiotic strains. The study found that at least one of the species declared on the label was missing in 19 of the 41 samples. Spores of the pathogenic *Bacillus cereus* were found in one product and spores of *Bacillus subtilis* were found in three products (Aureli et al., 2010). Viable count did not meet label claims in some of the tested products. Overall, the study reported that 87% of the tested products did not comply with label claims (Aureli et al., 2010).

A study by Drago et al. evaluated 13 commercial probiotic products collected from the US market. Viable count was determined using plate count methods while identity was determined using colony morphology, Gram staining, and API system. The study reported that only four products (31%) met the label claims (Drago et al., 2010). The rest of the samples either showed lower viable count (46%), missing species (38%), or the presence of undeclared species (54%) (Drago et al., 2010). Toscano et al. (2013) examined 24 products from the Italian and European market and found that only 14 out of 24 products (58%) were properly labeled in terms of declared species and bacterial count, while 10 products either contained less cell count than declared or were missing species or contained undeclared species.

Goldstein et al. (2014) determined the bacterial count in five probiotic products and found that the actual viable counts were similar to the declared viable cell count in all tested products. In a subsequent study, Lewis et al. collected 16 probiotic products with *Bifidobacteria* declared as an ingredient and evaluated the accuracy of label claims using a combination of methods. They reported that only 1 of the 16 tested probiotic products matched the label claims (Lewis et al., 2016). A study by Chen et al. (2017) tested eight probiotic supplement products collected in China for labeling accuracy. Samples were
evaluated for viable cell count using plate count methods and for species identity using
Gram staining, biochemical testing, colony morphology, and PCR-based methods. No viable
cells were detected in two products (25%) while the estimated viable count exceeded
label claims in five products and was very close to label claim in one product
(Chen et al., 2017). All eight samples had inaccurate species labeling in that they were
missing declared species and/or contained undeclared species.

More recently, Morovic et al. (2016) evaluated labeling accuracy in 52 probiotic products
using plate count methods, targeted PCR-based methods, and high-throughput sequenc-
ing. The study found that 22 samples (42%) had labeling inaccuracies, with some missing
one or more declared species and others containing undeclared species (Morovic et al.,
2016). In addition, the study reported that 17 samples (33%) contained viable cell counts
lower than the declared cell counts (Morovic et al., 2016). Another study by Patro et al.
(2016) examined 10 probiotic products from the US market for strain content using whole-
genome sequencing and found that all of the products matched label claims, except for
one product, which contained undeclared Enterococcus. In addition, the study identified
some cases where errors in nomenclature were observed. The study also evaluated cell
count using colony counting methods and found that only one product did not meet the
claimed cell count (Patro et al., 2016). Shehata and Newmaster (2020) tested 182 probiotic
products, containing a total of 520 strains, collected from the United States and Canada.
Using species-specific assays, 11 species could not be detected in ten products and unde-
clared Bifidobacterium animalis subsp. lactis was detected in one product. Viable counts did
not meet label claims in 5 out of 72 samples (Shehata and Newmaster, 2020).

The findings from these studies demonstrate the high percentage of probiotic products
that are noncompliant to label claims and further highlight the importance of applying
systematic quality control measures to ensure the products meet label claims in terms of
species/strain content and viable cell count (Kolacek et al., 2017).

### 18.4 Sources of noncompliance and strategies for mitigation

Noncompliance among probiotic product labels may be intentional with the purpose of
economic gain (i.e., fraud) or unintentional due to a lack of proper quality control measures in
the supply chain. One form of intentional fraud is substitution of a less stable declared probi-
otic strain with a more stable undeclared strain since probiotic stability is species/strain spe-
cific (Tripathi and Giri, 2014). Lactobacillus, for example, is generally regarded as more
stable compared to Bifidobacterium (Tripathi and Giri, 2014). Another form of intentional fraud
in multistrain products is producing formulations that meet the declared total viable count,
but not the declared individual strain viable counts. Plate count methods, the most commonly
used methods for viable count determination, are not strain specific and hence cannot deter-
mine the viable counts of the individual strains in multistrain products (Jackson et al., 2019).
This highlights the need to develop enumeration methods that are strain specific to facilitate
the enumeration of individual strains in multistrain products.

Unintentional noncompliance may arise from strain misidentification as a result of the use
of inappropriate identification methods such as API strips (Huys et al., 2006), or as a result of
the lack of appropriate and reliable probiotic identification methods for all probiotic species.
and strains (Morovic et al., 2016). This highlights the need to continue to develop accurate and reliable assays for probiotic identification, especially for strain-level identification (Morovic et al., 2016). More recently, whole-genome sequencing enabled the development of several reliable and accurate identification methods that are expected to mitigate the issue of misidentification by strain manufacturers. Another source for noncompliance is the possibility of strain contamination or strain mix-ups during production, leading to the presence of undeclared strains in probiotic products. This is especially problematic if the contaminant strains are human pathogens that represent a safety concern. An example was the detection of Staphylococcus species in a probiotic product from the Italian market (Fasoli et al., 2003).

Noncompliance can also be seen in products not meeting the declared viable count. This could be attributed to strain instability in the final probiotic formulation leading to cell lysis/death during shelf life. In fact, maintaining viability throughout shelf life is an important challenge for industry (Morovic et al., 2016). Probiotic stability is known to be affected by several factors, including storage temperature, pH, moisture, exposure to light, and type of packaging (Tripathi and Giri, 2014). Among the strategies used to prolong probiotic shelf life are the use of microencapsulation, addition of cell protectants, and freeze drying (Tripathi and Giri, 2014). Lower viable count in probiotic products may also be attributed to the use of inappropriate storage conditions. Probiotics have better survival when frozen; however, freezing and thawing can lead to cell membrane damage and mortality. When the recommended storage condition is refrigeration or freezing but the cold chain is broken, for instance, to reduce or eliminate the cost associated with refrigerating/freezing probiotics during storage, handling, and transport, probiotic viability will be impacted. For these reasons, products should be evaluated for stability and maintaining the declared viable cell count, not only at time of manufacturing but also at expiration date under the specified storage conditions.

To support consumers’ right to distinguish between compliant and noncompliant products in a fast-growing probiotic market, independent third-party certification is recommended. A certification seal on product labels will make it easy for consumers to identify high-quality products (Jackson et al., 2019).

18.5 Conclusion

In a fast-growing probiotic market, noncompliance, whether intentional or unintentional, compromises consumers’ right to obtain high-quality, effective, and safe products. Several studies have investigated compliance in probiotic products and reported variable levels of noncompliance. Thus probiotic products should be routinely authenticated, applying strict quality control measures, throughout the supply chain; in raw materials, as well as in finished products. Authentication will confirm that a product contains the declared species/strains as well as meets the declared minimum viable cell count throughout shelf life to ensure product efficacy (Huys et al., 2006; Hill et al., 2014). As described in this chapter, strain-specific assays have been developed for the identification and enumeration of some probiotic strains; however, many strains are still lacking specific assays for identification and enumeration, and significant efforts are needed to continue developing and validating strain-specific assays to enable accurate probiotic authentication.
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19.1 Overview of the food service and retail sectors

The food service and retail sectors are the segments of the food industry where the consumer has direct access to the food product. By definition, “retail food store/grocery” shall mean any establishment or section of an establishment where food and food products are offered to the consumer and intended for off-premises consumption. “Food service” facility means a facility that prepares and sells food directly to consumers for immediate consumption and does not include facilities that provide food to conveyances, central kitchens, and other similar facilities that do not prepare and serve food directly to consumers (Code of Federal Regulations, 2019). The importance of these nodes of the food supply chain is easily understood when one visualizes the global food system (including primary production,
processing, manufacturing, and distribution) and highlights the role of food service and retail at the end of the supply chain, establishing the connection between the entire food supply chain and the end user (consumer). Regardless of the policies, strategies, mechanisms, and processes being utilized by the food industry prior to the selling point, there is still dependency on the food service/retail sector to accurately portray the product’s claims and image. The consumer’s perception of these characteristics is affected by the manner the product is procured, stored, presented, and offered. In addition, a unique characteristic of the food service and retail segments is that they offer products to the consumer which are, to a large extent, not self-branded or self-produced. Nevertheless, the reputation and brand image of a food service/retail company are strongly affected by any failure in delivering safe and authentic products. Products may originate from domestic suppliers, international distributors, or be sourced from national and international manufacturers. They may be sold in the manufacturers’ original package or they may be assembled, further prepared, and/or packaged and served at store level. Food service and retail are also unique in those customers who have varying degrees of access to the food premises and to products being offered for sale. In the food service industry, many operators are small- to medium-scale businesses that deal with a very large number of products and ingredients but often have a limited number of suppliers (Luning et al., 2013). In addition, both the retail and food service sectors may outsource many processes related to purchasing and quality control. Food fraud risk may be higher if these processes are not directly controlled.

The global food retail industry has been experiencing steady growth in recent years, representing a compound annual growth rate of 5.9% between 2013 and 2017, largely driven by countries in the Asia-Pacific region (Food & Grocery Retail Global Industry Guide, 2019). Some of the main factors driving the industry and contributing to growth in certain areas include marked changes in customer preferences, a sharp move toward online shopping, rising global population, and an increase in the purchasing power of emerging markets. Furthermore, government investment in infrastructure and the entry of large global food companies in emerging economies has led to a boom in the food retail sectors of these markets (Research and Markets, 2016). Asia Pacific remains the largest market for food retail globally, with China and India in particular contributing to rapid growth in the global food retail industry. Indonesia and Thailand are also witnessing high levels of growth as modernization of traditional outlets is taking place. Meanwhile, the food retail market in Europe, particularly Western Europe, is thought to have already reached a saturation point (Research and Markets, 2016).

Retail food outlets take on a number of formats, shapes, and sizes and offer a wide array of products prepared and sold in a variety of formats using many different display methods (Farber et al., 2014). Consumer market companies tend to have several third-party touchpoints, such as vendors/suppliers, transporters, third-party manufacturers or subcontractors, packers, distributors, or other third-party service providers, that can significantly increase the risk of collusive frauds that are difficult to detect. The food retail sector primarily comprises businesses that sell food products through stores of various sizes to the general public. Operations in food retail are based on sourcing of products through a combination of owned manufacturing facilities, other manufacturers, small-scale producers, and local vendors. Depending on the size of the retail company, of its network and stores, there is usually inbound transportation of sourced products to a central warehouse or a depot for onward
distribution and outbound transportation to either owned stores or franchise operations for sale. Sale may be also executed through e-commerce platforms.

Consumer dynamics are affected by the changed business conditions observed today in different parts of the world: a large and growing youth population that is digitally savvy and knowledgeable, rising incomes and purchasing power that place importance on superior product quality, growing urbanization with an emphasis on a “convenient” shopping experience, emergence of organized retail that provides consistent quality in products and shopping experience, and emerging product categories such as local, ethically produced, sustainable, “free from.” These developments have prompted a change in the way food service and retail companies operate and have led to changes in the marketing and sale cycles. For example, the proliferation of online sale models in retail has resulted in increased dependence on third parties in the supply chain. Small- and medium-sized enterprises are now in competition with large established companies for market share by adopting e-commerce platforms to market and sell their products, further driving up competition. Such changes in business models and consumer preferences can increase the exposure of companies to the risk of fraud. With e-commerce emerging as a new distribution channel for consumer product companies, the supply chain has become a source of increased fraud vulnerability.

Some published figures and characteristics of the retail sector are indicative of the current conditions in it as well as the trends for future changes. According to Klynveld Peat Marwick Goerdeler (KPMG) (2019a), e-commerce retail sales were expected to account for 13.7% of retail sales worldwide in 2019. In-store shopping is still the preferred food retail channel for 82% of millennials, even the ones who also engage in online shopping. In the Retail Trends 2019 report by Klynveld Peat Marwick Goerdeler (KPMG) (2019b), it was noted that consumers are becoming increasingly educated on sales strategies and often do extensive product research before committing to a purchase. This is of particular importance when considering the access of consumers to news and announcements regarding food fraud incidents. For example, consumers that are exposed to food fraud information may decide not to spend their money on the brand or food category associated with the fraud.

19.2 Food fraud vulnerability in the food service and retail sectors

19.2.1 Fraud at the retail/food service level

Food fraud is damaging to companies and their stakeholders and is of particular concern to the food service and retail companies because of the critical nature of the brand and reputation of these companies. Similar to other sectors, the risk of purchasing and subsequently selling fraudulent products to consumers is a critical factor in the food service and retail sectors. Not only is it important to identify the risks of purchasing fraudulent products, but these risks also have to be managed dynamically in real time (Pehlivani et al., 2019). Most purchasing plans are completed 1 year prior to the related season and, if the risks are not managed in real time, suppliers that were previously approved might bring fraudulent products to the shelf undetected.

Given the sheer complexity and scale of food supply chains today, it is no surprise that food fraud poses a larger threat to the food industry than ever before. Often encompassing
an expansive network of third parties across the globe, including agents, intermediaries, resellers, and distributors, the food service and retail sectors are particularly at risk of misconduct, which is frequently committed from outside of the organization. To further the complexity, a range of differing business policies and procedures, ethical codes, food culture, and IT systems used by each external party are interwoven into the supply chain. This creates a prime environment for fraud to take place.

As food service and retail companies evolve to meet increasing consumer expectations, their supply chain operations must do so in tandem. But with the opportunity to optimize product offerings also comes risk. Companies have to meet rising consumer demand for product and price innovation. Such challenges place further pressure on companies and their business partners, which may provide opportunity and incentive for fraudsters. A recent study investigated the purchasing behavior of consumers before and after being exposed to information about food fraud (Meerza and Gustafson, 2020). The study provided an initial estimate of the effect of information about food fraud on consumers’ valuation of products implicated by this information as well as products that have not been implicated in labeling scandals. The results indicated a potentially large effect of food fraud information on consumer valuation. One of the main findings was “if consumers exposed to information about food fraud incidents come to distrust product labeling, their valuation of these products is likely to decrease, which may mean that higher quality products will not be able to compete in the market if producers are unable to effectively signal that quality to the consumers.” In other words, products with value claims will not be able to be distinguishable in the retail environment if they are incapable of proving that these claims are truly valid. Meerza and Gustafson (2020) also concluded that consumers, after receiving information about food fraud incidents in a product category, lost their trust in the entire category, not just specifically in the brand related to the fraud incident. Thus the incident itself changed consumer behavior toward all brands.

A consumer typically receives the information about a product from the package in order to evaluate a product and make a purchasing decision. Product claims, explicit or implicit, attempt to convince the buyer that the product is unique and worth its value. They also contribute to building a relationship with the consumer and serve as a connection between the brand and the buyer. Claims are usually part of a brand’s total profile strategy, not only of a specific product, and they are a tool which supports long-term trust by the consumers. Manning and Smith (2015) have demonstrated that delivering authentic and authenticated food to customers and consumers can be enhanced by designing a bespoke entrepreneurial retail marketing strategy that brings added value to products from local/regional markets, including those that are associated with national, cultural, ethical, and/or environmental characteristics. Considering these facts, the expression “a chain is only as strong as its weakest link” (Reid, 1785) illustrates the significance of preventing food fraud in the food service and retail sectors. To put it simply, even the smallest exploited food fraud vulnerability can have massive repercussions on business. The prevention of an adulteration incident, prior to retail, costs significantly less than dealing with a massive product recall or a large foodborne disease outbreak (Davidson et al., 2017). The immediate consequences of selling a fraudulent product may include financial loss stemming from the fraud itself, as well as those associated with ongoing litigation and audit requirements. Longer term repercussions may include business loss, reputational harm, and potentially a loss of market share.
Food fraud risks derive from multiple root causes and sources. The vulnerability of the food supply chain to fraud will continue as long as the potential for profit exceeds the chance of getting caught, and the potential consequences do not act as a barrier (Everstine et al., 2013). Although food fraud is generally considered to be more of an economic concern than a food safety concern, it can represent a real public health risk (Everstine et al., 2018; Spink and Moyer, 2011) and can have severe impacts on consumers and the industry in cases that cause illness or death. The latter is further intensified in the food service and retail sectors, where the consumer has a direct bond with the seller of the food product.

In the food service and retail sectors, the operators need to deal with a wide range of food products and raw materials, carrying the risks of fraud as in any other sector. An overview of food fraud risk factors that can be used to assess the product fraud risk is provided in the Product Fraud Guide (Tromp and Sechet, 2018). In the experience of the industry, products most subject to fraudulent activities are those that are the simplest to replace with passable substitutes, and whose substitutes would not be readily detected by the consumer (and sometimes the wholesalers and retailers). Tea, rice, and vodka were examples of such items provided by respondents to the Organisation for Economic Co-operation and Development (OECD) survey [Organisation for Economic Co-operation and Development (OECD), 2008; Spink, 2019].

The storage, transport, and other services (e.g., packing and labeling) involving raw materials and finished products within the logistics sector of food service and retail are areas where substitution, dilution, mislabeling, and counterfeiting could be expected as major food fraud threats. The fraudsters could use the logistic supply chain to substitute or adulterate raw materials, particularly in the case of loose or unpackaged products, or use the legitimate supply chain system to place counterfeit products onto the market.

The food service industry, especially restaurants, appears more vulnerable to food fraud than food retail due to more extensive opportunities and lack of appropriate controls (van Ruth et al., 2020). More insights into food service fraud vulnerability may be gained by evaluation of other groups of food service operators, for instance fast food operators, airline caterers, and those that cater for institutions and their direct suppliers. It has been reported that many food service operators underestimate the significance and likelihood of food fraud in their operations, although it may considerably damage their reputation (van Ruth et al., 2020). Their customers purchase the products directly from the stores and any incident of fraudulent activity (especially if customers become ill) will negatively impact the food service company with massive consequences.

Food fraud is a particular challenge to food safety stakeholders in the food service and retail sectors, given the intentional nature of the act and the variety of (often unanticipated) adulterants that are used (Everstine et al., 2013). Therefore a wide range of factors and data sources need to be included in a food fraud vulnerability assessment (FFVA).

An FFVA allows retail and food service companies to document and assess possible fraud scenarios associated with the materials and products that the company procures, produces, and sells, in order to accurately identify the potential threat, the control measures required, and the mechanisms for keeping up-to-date such assessments if the records change in the future (Manning and Soon, 2019). Therefore vulnerability is specific to the supply chain, ingredients, products, processes, and activities undertaken by a given food retailer or food service business. The vulnerability assessment process is dynamic and
needs to be revisited by retail and food service operators both routinely in line with formal procedures and also reactively in the event that FFVA outputs are out of date. It is clear that many operators in the food industry have found implementation of an FFVA to be challenging (Barrere et al., 2020). Common parameters that will incur the need for reassessing fraud vulnerability in a food company are harvest failure associated with one particular material, a new supplier, an increase in demand for a particular material when supply remains constant, price fluctuations, or changing consumer purchasing behavior. Therefore FFVA tools identify the degree of food fraud vulnerability at a given time and in a given set of circumstances (Manning and Soon, 2019).

In the food service and retail sectors, opportunities to increase profits through price control are limited in the modern global environment, while cost reduction is a strategic practice, focusing particularly on operating costs. As such, outsourcing (purchasing from independent external suppliers) of goods and services becomes increasingly important, and this is reflected as a more profitable option instead of internal operation. In the food service and retail sectors, the diversity of outsourced processes is wide and is highly reliant on the contractual arrangement between the company and the supplier, as well as the status of the raw material, ingredient, packaging, or food. Outsourcing can occur in all major operations in food service and retail, such as preparations/manufacturing, packaging, transportation/logistics, e-commerce, even quality control and quality assurance procedures. This results in a situation in which the external supplier takes responsibility for the proper execution of the outsourced services. The extent of risk control capability of a company depends on whether the company controls aspects of the purchasing and/or technical control mechanisms or completely outsources these mechanisms to the supplier. If the company has direct control of the purchasing and technical control mechanisms, the risk is reduced and the control measures relate to those specific criteria are aligned to the supplier approval and monitoring requirements. Understanding the modern complexity of global supply chains, outsourcing maps become a multilevel network of suppliers, including operators that serve only as intermediaries between the purchaser and the actual supplier of the goods or the services. By definition, this environment allows the rise of food fraud opportunities and risks, especially due to the transfer of responsibilities and the demand for cost-efficient services. Further, bilateral contracts often integrate predefined standards of quality, including food fraud risks; however, these standards do not necessarily have consistent requirements across different stakeholders and suppliers. This leads to ineffective control of existing risks in stages prior to the contractual arrangement of the food service/retail company and their direct supplier. For example, in major recent food fraud scandals that involved food service and retail businesses, the use of outsourced services led to the sale of unidentified fraudulent goods to consumers.

19.3 Historical incidents of food fraud in the food service and retail sectors

The infamous horsemeat scandal of 2013 provides a representative snapshot of the detrimental effects of food fraud on the food service and retail sectors. Although the fraudulent activities occurred in prior stages of the supply chain among several sourcing, producing, distributing, and supplying companies, many consumers associated the event...
with leading companies in the food service and retail sectors. As for the short- and mid-term financial impacts, the businesses that sold adulterated products during that period, either retailers or food service companies, experienced severe financial damages in addition to significant and long lasting brand damage (BBC, 2013; Barnett et al., 2016; Barbarossa et al., 2016; Gleeson, 2013; Williams, 2013).

Although food service companies are sometimes the actual offenders themselves, knowingly serving mislabeled or even adulterated food, more frequently they are victimized by criminals earlier in the supply chain and deliver fraudulent products to their customers unknowingly. This happened with the horsemeat-containing meatballs served in the restaurants of an international consumer goods retailer (NRC, 2013). A study by van Ruth et al. (2020) discussed numerous fraud cases in which the food service sector was involved, knowingly or not. In one study, 30% of the fish species tested in Brussels’s restaurants and canteens were determined to be mislabeled (Christiansen et al., 2018). The rates of mislabeling varied depending on the type of food service business; for instance, sushi bars presented higher rate of mislabeling (45%) than other restaurants (28%). Similarly, Horreo et al. (2019) found 37% of fish sampled in Madrid restaurants to be mislabeled and Kappel and Schröder (2016) found 50% of sole fish samples purchased in German restaurants to be cheaper species. Seafood fraud has been observed in approximately 30% of mass catering outlets across Europe as well (Pardo et al., 2018).

Van Ruth et al. (2020) state that the problem is surely global and reaches far beyond Europe. Food fraud in food service outlets has been discovered in many parts of the world, where similar investigations were conducted. For example, in the United States, 22% of grouper samples appeared to be in fact the cheaper species pangasius (Wang and Hsieh, 2016). In one of the largest global seafood fraud investigations, 1 in 5 of the more than 25,000 samples of seafood tested worldwide was mislabeled, on average (Warner et al., 2016). Similar to the investigation in Brussels, seafood mislabeling levels varied with the type of catering business: sushi venues ranked the highest (74%), followed by restaurants (38%). In China a review of media reports by Zhang and Xue (2016) revealed that 7% of seafood mislabeling cases had occurred in restaurants, 4% with street vendors, and 2% in fast food service outlets. Karimi et al. (2017) reported that 55% of the cases investigated had unfit cooking oil in food service outlets in Kenya.

There have been also numerous incidents in which retailers unknowingly sold fraudulent products in their stores. Infant formula and other products made with melamine-adulterated milk in China milk in 2008 is one example (Zhang and Xue, 2016). In the United States, Salmonella-contaminated peanut butter was knowingly passed on through the supply chain to retail outlets in 2009 (Li et al., 2014), resulting in many illnesses and widespread recalls. Deceptively marketed vanilla ice cream in the United States that actually contained “natural flavor” resulted in a class action lawsuit (e.g., Watson, 2020). Adulterated honey was withdrawn from UK retailer in 2019 (BBC, 2019), and there was a widespread recall of turmeric powder from retail stores in the United States in 2013 due to adulteration with lead chromate (Larsen, 2013).

Data published by official sources can help one to identify trends as well as differences among regions, countries, or continents. This is relevant to the evaluation of food fraud frequencies and risks historically, since food fraud characteristics differ significantly among regions, cultures, and economies. To understand how these aspects are defined in the retail sector, a filtered dataset is used herein that is based on food safety—related incidents from retailers in Europe and the United States. These incidents were announced by
official sources, including national and international food safety authorities and ministries for food, health, and the environment. They include food recalls, border rejections, food alerts, public announcements, official information announcements, information for attention, import refusals, import alerts, enforcement reports, imported food reports, and consumer advisories. The time span covered in this dataset was 5 years (2015–20) and the main points of analysis were as follows:

- the main hazards in the incidents submitted by the retail sector (fraud is considered one of them) in Europe and the United States (Fig. 19.1),
- the cases of detected food risks submitted by retailers in Europe (Fig. 19.2), and
- the food product categories identified in submitted incidents by retailers in Europe (Fig. 19.3).

At first glance, it is evident that US retailers have much lower recognition of food fraud as a hazard risk, compared to the European retailers (Fig. 19.1).

The absolute number of reported incidents of food fraud by the retail sector in the United States is low (four records in 5 years), while the European retailers seem to have more diverse content in their entries. In the FOODAKAI system the term “food fraud” covers the following cases: adulteration, counterfeit, intentional distribution of products not fit for consumption, smuggling, unauthorized ingredient (fraud), and labeling/misdescription. Taking a deeper look on the data from the food retail in Europe (Fig. 19.2), adulteration represents the second group by hazard type, following incorrect labeling and use of dates. The labeling category may also include food fraud cases (e.g., mislabeling). As for the most common product categories associated with hazards in the European retail sector during 2015–20 (Fig. 19.3), meat and confectionary hold the lead, followed by nuts, honey and syrups, dairy, and seafood.

19.3 Historical incidents of food fraud in the food service and retail sectors


Overall, the total number of food fraud records reported in retail (as published by official bodies and sources) is relatively low, in comparison to other hazard and risk sources (Fig. 19.1). Indicatively, the US retailers reported more than 100 cases of (micro)biological hazards during 2015–20, compared to only 4 records of food fraud. This observation can be explained by considering that, for the most part, the food retail sector is still in the early stages of developing food fraud assessment and evaluation strategies, in comparison to traditional food safety hazards. This progress is probably different between US and European retailers as well. It is anticipated that new available tools as well as new versions of Global Food Safety Initiative (GFSI) Certification Program Owner (CPO) standards applicable to the retail sector will help one to improve the level of understanding and evaluation of food fraud risks. Another reason for this observation could be that the US reports fraud incidents linked to producers, not necessarily the retail or food service facilities where the products were sold. On the other hand, microbiological hazards often occur at retail, so the number of those reported would naturally be much higher.

19.4 Common analytical methods used to detect fraud in the food service and retail sectors

The food service and retail sectors deal with all common types and categories of food products and commodities. Analytical methods and laboratory testing relevant to these sectors, grouped in different product types, are well described in previous chapters. In a survey conducted in the official food control authorities of the German federal states (Wisniewski and Buschulte, 2019), it was found that nearly 60% of the participants agreed that analytical laboratory methods (targeted and nontargeted) are an appropriate means to identify food fraud cases.

The food service businesses have a particular interest in self-detection, which may help one to control the vulnerabilities or at least reduce the impact when fraud is detected at an early stage. In the last 5 years, small, portable, cost-efficient analytical devices and smartphone applications have surfaced in the market and some of them are suitable for citizen science (Ellis et al., 2015; van Ruth et al., 2020). Such portable devices have accomplished, among others, detection of adulteration in milk products (Nascimento et al., 2017) and bovine dairy (Santos et al., 2013), verification of the source and origin of characteristic flavors (Gliszczyńska-Świgło and Chmielewski, 2016), and authentication chicken meat (Parastar et al., 2020).

Recent studies have been particularly focused on food fraud detection and authenticity using laboratory methods (Ellis and Goodacre, 2016). On the other hand, some authors indicate that food fraud detection by laboratory analysis can sometimes be a challenging analytical problem (e.g., Cubero-Leon et al., 2014; Oliveri and Downey, 2012). Food fraud can be also detected by inspectors of retail establishments at the point of sale (Koubová et al., 2018). Both ways of food fraud identification are equally important (Tahkapaa et al., 2015).

In general, there are two strategies for detecting food fraud by testing: (1) testing for the presence/absence of a specific known adulterant (targeted approach) and (2) testing the identity, authenticity, or purity of a food ingredient (untargeted approach) (Moore et al., 2012). There is a growing concern that in some ways food fraud may be more risky than...
traditional threats to the food supply, as the adulterants used in these activities are often unconventional (Moore et al., 2012). Because targeted tests are oftentimes not capable of identifying new or unconventional adulterants, fast and untargeted testing is developing rapidly.

A food authentication program in food service and retail needs to be implemented following some principles that derive from experience. An authentic product should have a match between its characteristics and the corresponding food product claims (CWA 17369, 2019), and laboratory testing methods are considered to be the core of such authentication programs. Comprehensive authentication programs need to be designed in order to deal properly with the emerging risks in each retail and food service business, being dynamic and including food fraud intelligence and appropriate verification methods. Each authentication program should be based on a completed FFVA and its efficiency depends, in large extent, on the use of the appropriate testing methods and a proper testing plan, as well as evaluation of results and application of posttesting actions. These steps combined will contribute to risk mitigation. With recent studies and fraud incidents demonstrating how consumer reactions to food fraud can negatively impact the food service/retail sectors (e.g., Meerza and Gustafson, 2020), verifying food authenticity is an important activity for companies to undertake that can help one to prevent the sale of fraudulent food at the retail level.

19.5 Risk mitigation strategies (other than laboratory testing)

Supply chain fraud remains a threat to the retail sector, but that does not mean all companies will fall victim. Active vigilance and strong internal controls allow companies to proactively decrease the likelihood of fraud by identifying red flags early on, so that they can be stopped before they reach the shelf. Third-party risk can also be mitigated by conducting or requesting frequent quality controls and laboratory testing of supplies prior to onboarding and during the partnership with vendors.

In general, food fraud in retail has diverse risk sources that influence the likelihood of fraud at different levels. Procurement and supplier risk with existing vendors involve conflicts of interest and dubious vendor relationships. Supply chain risk is related to diversion of goods or pilferage of stocks, quality compromise, or product substitution schemes by suppliers. Common product counterfeiting happens in a similar manner to nonfood commodities, by way of unauthorized representation of a registered trademark carried on goods with a view to deceive the purchaser into believing that they are buying the original goods. Economically motivated adulteration represents the intentional fraudulent modification of a finished product or ingredient for economic gain. Economic adulteration could take many forms, including contamination, concealment, mislabeling, dilution, and substitution of a cheaper ingredient for a high-quality ingredient. Last, the misuse of advertising and marketing tools should also be considered as influencing factors of risk source. For example, the misuse of advertising terms, promotional items with value claims, and marketing campaigns emphasizing certain promises are all risk factors that can change the value and demand for a product.

Yang et al. (2019) found in their study of the Dutch milk supply chain that producers are less vulnerable to fraud than processors or retailers. A better understanding of
perceived vulnerability is essential from a risk-management standpoint, as these perceptions will directly condition the willingness and the capacity of food operators to define risk-management plans and to implement adequate risk-management measures (van Ruth et al., 2018). According to Guntzburger et al. (2020), producers tend to be less concerned with food fraud as compared to processors, distributors, and retailers. While distributors and retailers may agree that they are responsible for the authenticity of their supply, for their final products and for the integrity of their subcontractors, they generally view their responsibility as lower than that of processors and producers. Processors were the keenest to implement preventive measures to tackle food fraud and invest in controlling it. They were the most aware of food fraud detection methods as well as being the sector that used them the most.

To avoid losses arising from fraud, a variety of activities can be carried out in the areas of fraud prevention, fraud deterrence, and fraud detection (Petrucelli, 2013). Put simply, fraud prevention is the task to stop fraud from happening in the first place, by improving technologies and risk mitigation strategies. However, this approach is not always successful and is occasionally infiltrated by fraudsters. In that case, fraud detection is the next layer of defense (Behdad et al., 2012).

Traditional risk mitigation strategies used in food retail and food service businesses, beyond laboratory testing, are based on the established practices described in most of the current commercial certification standards. Indicatively, the IFS Product Fraud Guide (Tromp and Sechet, 2018) provides some food fraud risk mitigation measures and tools:

- economical and legal status of supplier verification
- product inspection prior to delivery
- first-, second-, and third-party technical audit
- chain of custody certification
- supplier questionnaires
- legal compliance of supply chain suppliers

Although these measures and tools are mandatory for food businesses to maintain operations under the context of certification, technology offers further opportunities to develop proper alerting systems that can function as prevention measures. For example, an appropriate traceability system can have a major role in the risk mitigation strategy of food service and retail companies. According to Schwagele (2005), traceability can be divided into two key functions, tracking and tracing. Schwagele defined “tracking” as the ability to follow the path of an item as it moves downstream through the supply chain from the beginning to the end, while “tracing” is the ability to identify the origin of an item or group of items through records upstream in the supply chain (Schwagele, 2005). It is crucial that information flows readily in both directions, especially in the event of a food fraud incident or concern over a food product’s safety or integrity. Traceability of all food products can only work if there is integrity at every stage of the supply chain, not only in terms of food products, but also in terms of the associated documentation flow and personal ethics/behavior (Manning and Smith, 2015).

By creating traceable and transparent food supply chains, food operators can build better relationships with their suppliers and their customers, increase efficiency, and reduce
the risk and cost of food recalls, fraud, and product loss. Food retailers, in particular, have started to embrace a new term: digital traceability. Retailers are particularly interested in new technologies (e.g., blockchain-based) that are able to securely track the movement of information. The purpose of such traceability platforms is primarily to create transparency in the supply chain and monitor the different intermediaries to make sure that they handle a company’s product the right way. They help a food retailer to reduce errors, track the movement of products, gather real-time data to make improvements, and create trustworthy audit trails. This can be particularly important in the retail and food-service sectors that often outsource many of their processes.

A digital traceability platform has the ability to show not only the exact location of a product in real time but also where it has been, the checks and tests it has passed, and also information about the state of the product (e.g., a temperature log). All of these can be accessed by the retailer and even a restaurant customer when they scan a code on the device at the end of the chain (Bumblauskas et al., 2020). This information can help one to evaluate fraud risks as well as identify weak nodes that need to be better understood, set up, or investigated to reduce or eliminate the risk of fraud.

Although assuring food traceability with digital technologies is promising, there remain some limits to be considered. Above all is that digital platforms (including blockchain-based ones) do not have a verification mechanism to prove whether the raw data were correct. If one tampers with an entry, document, or sensor, the digital traceability platform will not be able to detect that the data have been tampered (e.g., Galvez et al., 2018). Another issue is that the overall cost of implementing such technologies is unpredictable, especially when the existing, highly mature supply chain system has been used for so long. There is also the question as to what kind of data should be public. If manufacturers keep their formulas as business secrets, they will have to decide whether to reveal them and, without a clear policy in this respect, they may provide different levels of information depending on their interpretation of transparency (Seibold, 2016). Nevertheless, digital traceability may serve as a transparent mechanism to collect information that is frequently missing, in order to evaluate risks as well as to verify claims of products in regards to their origin, ingredients, and source.

19.6 Industry standards specific to the food service and retail sectors

Food fraud prevention and risk mitigation in food service and retail sectors are governed commonly by the requirements of the GFSI CPO standards. Barrere et al. (2020) provide an overview of the global standards which describes the appropriate policies and mechanisms to be implemented in food businesses. GFSI published a 2018 position paper on mitigating the public health risk from food fraud (GFSI, 2018). With this position paper, it was described that GFSI-recognized CPO standards should include a requirement for documenting FFVAs and control plans applicable to all products. These requirements went into effect in January 2018 (Global Food Safety Initiative: Benchmarking Requirements Document v7.1) (GFSI, 2017), setting a starting point for official global harmonized guidance in food fraud prevention. Other regulatory and standardization bodies that issued guides and standards related to food fraud are the European Committee for Standardization (CEN) and the International Organization for Food Fraud.
Standardization (ISO). CEN published a document that defines concepts, terms, and definitions related to food fraud (CWA 17369, 2019). ISO includes a reference to food fraud in their standard ISO 22000 (ISO, 2018) and also has standards specific to targeted food fraud issues [such as the determination of melamine and cyanuric acid in milk (ISO, 2017)].

Aiming to develop resources that can support constructing FFVAs and fraud mitigation plans, the US Pharmacopeia (USP) as well as the joint effort between Safe Supply of Affordable Food Everywhere (SSAFE), PricewaterhouseCoopers, and Wageningen University produced tools that help food operators manage fraud risk in the food supply chain leading to an enhancement of consumer protection, compliance with regulations and GFSI requirements, and the protection of the food company and the sector. CPOs such as IFS, BRC, FSSC22000, and SQF have developed documents to support the food industry in complying with the new requirements regarding food fraud (British Retail Council, 2018; FSSC22000, 2019; International Featured Standards, 2017; SQF, 2018). Those documents present general background, definitions, and limited guidance for understanding food fraud. IFS also published a guidance document to assist industry in complying with the requirements which is comparable to those of SSAFE or USP (Tromp and Sechet, 2018). Various white papers and reports have also been published by food industry members and industry groups.

CPO standards are used by the retail sector in various stages and ways. For internal procedures, such as manufacturing own brands, the companies seek certification of their operations according to these standards. Although conducting FFVA is mandatory, retail businesses usually face difficulties due to the lack of either proper resources or access to adequate information. Nevertheless, it remains under their responsibility to fulfill the requirements and to this purpose, some organizations may also outsource the design of an FFVA. In addition, it is often required retailers that their suppliers comply with CPO standards and there is increasing demand for certified goods and procedures. This often serves as an option to reduce fraud risks that refer to ingredients and raw materials, instead of complex finished products. There should be no doubt that complying with standards that require a dedicated policy to mitigate fraud risks is key. However, CPO standards are still in an early stage of development in this field, which incurs confusion and to some extent tolerance during auditing. Better trained personnel at the retail businesses as well as improved guidance on the chapters of food fraud of the CPO standards are expected to solidify the organizational management and efficiency of the dedicated food fraud risk mitigation teams among the food business operators.

19.7 Conclusion

From the viewpoint of consumers, food retailers and food service are usually the business sectors that directly represent the food industry, delivering safety, quality, integrity, and authenticity with their food products. In principle, this by itself differentiates their role as well as their decisions in strategic planning and mitigation of the risks from food fraud. Many historic food fraud scandals and incidents resulted in the ultimate seller of the adulterated product partially or totally incurring the respective repercussions. During recent years the concept of food fraud prevention has been substantially developed in the food retail and food service sectors, either through a systemized FFVA, or by responsible
sourcing policies under frequent verification programs. Nevertheless, certain characteristics of the retail/food service sectors, such as the diversity and extent of the outsourced processes, require intensive and often exhaustive actions and programs, which are expected to develop further in the coming years through the use of new analytical technologies, operating standards, and digital traceability tools.

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FOOD FRAUD
A Global Threat With Public Health and Economic Consequences

Edited by Rosalee S. Hellberg, Karen Everstine, and Steven A. Sklare

Provides an understanding of the major food fraud challenges and mitigation strategies within specific food commodities, and the regulatory and industry standards for mitigating vulnerability to food fraud.

Food Fraud: A Global Threat With Public Health and Economic Consequences serves as a practical resource on the topic of food fraud prevention and compliance with regulatory and industry standards. It includes a brief overview of the history of food fraud, current challenges, and vulnerabilities faced by the food industry, and requirements for compliance with regulatory and industry standards on mitigating vulnerability to food fraud, with a focus on the Global Food Safety Initiative (GFSI) Benchmarking Requirements. The book also provides individual chapters dedicated to specific commodities or sectors of the food industry known to be affected by fraud, with a focus on specific vulnerabilities to fraud, the main types of fraud committed, analytical methods for detection, and strategies for mitigation. The book provides an overview of food fraud mitigation strategies applicable to the food industry and guidance on how to start the process of mitigating the vulnerability to food fraud. The intended audience for this book includes food industry members, food safety and quality assurance practitioners, food science researchers and professors, students, and members of regulatory agencies.

Key Features:
• Presents industry and regulatory standards for mitigating vulnerability to food fraud including Global Food Safety Initiative (GFSI) Benchmarking Requirements
• Provides tools and resources to comply with industry and regulatory standards, including steps for developing a food fraud vulnerability assessment and mitigation plan
• Contains detailed, commodity-specific information on the major targets of food fraud, including specific vulnerabilities to fraud, analytical methods, and strategies for mitigation

About the Editors
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ACADEMIC PRESS
An imprint of Elsevier
elsevier.com/books-and-journals

ISBN 978-0-12-817242-1