Development and Application of a Database of Food Ingredient Fraud and Economically Motivated Adulteration from 1980 to 2010

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Abstract: Food ingredient fraud and economically motivated adulteration are emerging risks, but a comprehensive compilation of information about known problematic ingredients and detection methods does not currently exist. The objectives of this research were to collect such information from publicly available articles in scholarly journals and general media, organize into a database, and review and analyze the data to identify trends. The results summarized are a database that will be published in the US Pharmacopeial Convention's *Food Chemicals Codex*, 8th edition, and includes 1305 records, including 1000 records with analytical methods collected from 677 references. Olive oil, milk, honey, and saffron were the most common targets for adulteration reported in scholarly journals, and potentially harmful issues identified include spices diluted with lead chromate and lead tetraoxide, substitution of Chinese star anise with toxic Japanese star anise, and melamine adulteration of high protein content foods. High-performance liquid chromatography and infrared spectroscopy were the most common analytical detection procedures, and chemometrics data analysis was used in a large number of reports. Future expansion of this database will include additional publically available articles published before 1980 and in other languages, as well as data outside the public domain. The authors recommend in-depth analyses of individual incidents.

Keywords: analytical procedures, economically motivated adulteration, *Food Chemicals Codex*, food fraud, food ingredients

Practical Application: This report describes the development and application of a database of food ingredient fraud issues from publicly available references. The database provides baseline information and data useful to governments, agencies, and individual companies assessing the risks of specific products produced in specific regions as well as products distributed and sold in other regions. In addition, the report describes current analytical technologies for detecting food fraud and identifies trends and developments.

Introduction

New and challenging risks have emerged as food supply chains have become increasing global and complex (Food and Drug Administration 2009; Spink 2010; Grocery Manufacturers Association 2010). One of the risks gaining attention from industry, governments, and standards-setting organizations is fraud conducted for economic gain by food producers, manufacturers, processors, distributors, or retailers. Food fraud recently was defined in a report commissioned by the Dept. of Homeland Security and funded by the Natl. Center for Food Protection and Defense (Univ. of Minnesota) as a collective term that encompasses the deliberate substitution, addition, tampering, or misrepresentation of food, food ingredients, or food packaging, or false or misleading statements made about a product for economic gain (Spink 2011b). Addressing a more specific type of fraud, the USP Expert Panel on Food Ingredient Intentional Adulterants, which operates under the aegis of the Food Ingredients Expert Committee in the Council of Experts, defined the intentional or economically motivated adulteration of food ingredients as "the fraudulent addition of nonauthentic substances or removal or replacement of authentic substances without the purchaser's knowledge for economic gain of the seller" (DeVries 2009). Additional terms commonly used to describe food fraud include economic adulteration, economically motivated adulteration, and food counterfeiting.

Food fraud often has been considered to be foremost an economic issue and less a concern of the traditional food safety or food protection intervention and response infrastructure. However, any adulteration results in a change of the identity and/or purity of the original and purported ingredient by substituting, diluting, or modifying it by physical or chemical means. By the very nature of such adulteration, the criminal engineers fraudulent ingredients so that he or she can evade existing quality assurance (QA) and quality control (QC) systems implemented by purchasers, including GMP testing and hazard analysis and critical control points (HACCP) plans. As a consequence, only the criminal knows how the food ingredient has been manipulated and is, thus, the only one with the information, but not necessarily the expertise, to assess whether such a manipulation poses any toxicological or hygienic

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risks to the purchaser or the consumer. Because most criminals are focused on economic gain and evading QA systems and likely do not have the resources or the knowledge to carry out a suitable risk asssement, the public health risk of adulterated ingredient often is unknown until it is too late. Thus, only the ethics and knowledge of the criminal determine the hazard that an adulterated ingredient poses. In essence, the safety of the whole food supply chain collapses into a singular factor, the criminal. Only he or she has enough information to know the extent of the hazard introduced into the food supply chain.

The melamine incidents of 2007 and 2008 show how adulteration can cause the safety of food to collapse and the hazards that can be introduced by economically motivated adulteration. In this case criminals were focused on fooling total nitrogen measurements for protein for economic gain and were not likely interested in assessing the safety of the fraudulent ingredients (Moore and others 2010). The toxicological profile of melamine and its related compounds was not fully appreciated until it was too late (Codex Alimentarius 2010).

There is a growing concern that in some ways food fraud may be more risky than traditional threats to the food supply (Layton 2010; Spink 2011a 2011b; Spink and Moyer 2011b). The adulterants used in these activities often are unconventional. Melamine, for example, was considered neither a potential contaminant nor an adulterant in the food supply before 2007 and hence was not included in routine QA/QC analyses (Spink 2011a; Moore and others 2011). In addition, current food protection systems are not designed to look for the nearly infinite number of potential adulterants that may show up in the food supply (Spink 2011a; Moore and others 2011).

Although there is a wide range of food products and risks, food ingredients and additives present a unique risk because they are used in so many food products and often do not have unique visual or functional properties that enable easy discrimination from other and similar ingredients or adulterants throughout the supply chain. Glycerin, for example, is a sweet, clear, colorless, viscous liquid and is visually and organoleptically difficult to differentiate from other sweet, clear, colorless, viscous liquid syrups—including toxic diethylene glycol that in the past has been substituted for glycerin with deadly consequences (Schier and others 2009).

Traditional food protection plans involve prevention, intervention, and response with a process cycle back to prevention (Acheson 2007; Food and Drug Administration 2007; United States Government Accountability Office 2008). For food fraud specifically, some have proposed that food protection should begin with a focus on understanding the new risk at the intervention step (Figure 1) (Spink and Moyer 2011b). In the case of food fraud, understanding this new risk must begin with a review of previous incidents.

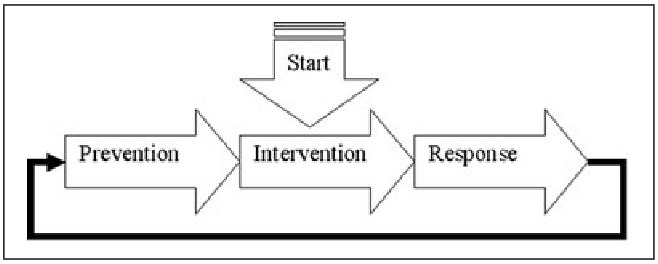

Figure 1–Food protection plan progression (reprinted with permission from Spink and Moyer 2011b).

Although reports of previous food fraud are widespread in scholarly and media reports, no systematic effort has been reported to collect and analyze this information. The objectives of this research were therefore to systematically collect reports of food fraud (food ingredients specifically), to record analytical technologies used in these studies, and to analyze the reports for trends to may be useful for developing new response tools to prevent future food fraud.

Materials and Methods

Literature search

To research incidents of food ingredient fraud or economically motivated adulteration, the authors performed 2 literature searches. The first was a comprehensive literature search of peer-reviewed scientific journal articles published in English from 1980 to 2010. This review used databases including the Web of Science, Google Scholar, and PubMed. Keywords used for this search included: "food," "adulterat*" (* used as a wildcard to include adulteration, adulterant, adulterated, etc.), "fraud," "authentic," "authentication," and their combinations. Primary articles identified by these searches also were reviewed for relevant secondary (cited) references.

A second search was carried out for media and other non–peer-reviewed scientific journal articles written in English from 1980 to 2010. Sources included Google searches, trade press articles, food media outlets (for example, FoodNavigator.com), governmental publications, and trade association publications. Keywords included "food," "adulterat*," "fraud," and "counterfeit."

Articles were limited to food ingredients that are produced and sold with the intention of incorporation into a finished food product. Some products considered foods (such as olive oil and milk) were included because they also are used as food ingredients. Finished or processed food products (for example, breakfast cereal or canned soup) were not included in this search.

Database assembly

Literature search information was analyzed and coded into a database by the authors and other supporting researchers. Table 1 indicates the types of information collected from each article and the coding used to create an organized database with fields relevant to food fraud. Considerations were given to the most appropriate and useful characteristics that could be extracted into a concise format for tabular and database presentations that allow further data analysis and insights for understanding and predicting food fraud and identifying analytical detection methods. The database will be available in tabular format in the 8th edition of the *Food Chemicals Codex* (United States Pharmacopeia 2012), and the full database will be available online at www.usp.org and www.foodfraud.org in 2012.

Database analysis

Database information was analyzed using Microsoft Excel.

Results and Discussion

Scope and interpretation the database

The intention of this research was to create a database that captures publically available articles published in English from 1980 to 2010 reporting fraudulent activities related to food ingredients. *Food ingredient* for purposes of the project included substances that can be legally added to food products such as food additives, functional food ingredients, and foods that also are used as ingredients such as olive oil and milk. Each record in the database is a publically reported unique combination of food ingredient, adulterant, and literature reference. Individual entries in the database should not be interpreted as unique adulteration *incidents* because this is not the intention of the database.

A total of 1305 database records for food ingredient fraud have been identified to date based on a total of 660 scholarly, media, and other publically available reports (Table 2). Each record in the database includes the type of article (scholarly or media), the common or usual name of the ingredient, ingredient category, common or usual name of the reported adulterant, type of fraud reported, and publication year and reference (Table 1). Scholarly articles also included information about analytical detection methods when available. Each record in the database was categorized by the type of food fraud using the following 3 broad categories: replacement, addition, or removal. A description, including the specific types of fraud included in each broad category, is listed in Table 3.

Learnings from research applicable to future literature database searches

The process of searching for food fraud literature revealed a lack of consistency in the terminology used in scholarly and media articles. Use of the keywords *food* and *adulteration* and their variants was not found to be a reliable way to search comprehensively for scientific and media articles focused on economically motivated adulteration of food and food fraud. For example, a scholarly report by Downey and others in 1997 regarding a method to detect fraudulent coffee substitution did not mention the term *adulteration* in the title, abstract, or keywords and was identified only by the keyword *authentication*. Other terms such as *counterfeiting*, *fraud*, and *fake* were helpful for more comprehensive searches but also resulted in more false search results. Searching media articles was even more problematic. For example, an article in *The Guardian* newspaper, "From Mumbai to your supermarket: on the murky trail of Britain's biggest food scandal," highlighted fraudulent addition of Sudan Red dyes to chillis without mentioning *adulteration*, *fraud*, or *authentication* but did use the term *contaminated* (Ramesh and others 2005). Although contaminants are not consistent from a regulatory perspective with the concept of food fraud or economically motivated adulteration, researchers should consider the use of this keyword for literature searches.

This lack of consistent terminology makes comprehensive literature searches for food fraud difficult and necessitates the use of researchers familiar with the field to carefully review articles identified by literature databases and search engines. It also indicates the need for food fraud to be more clearly defined and differentiated from other related issues such as food defense, food safety, and food contamination (Spink 2011b). The challenge of ambiguous or inconsistent terminology is not constrained just to food fraud. To address the challenge, one of the first working groups in ISO Technical Committee 247, Fraud Countermeasures and Controls, addresses vocabulary and defines and harmonizes basic fraud terms for a global audience (International Standards Organization 2010).

Note that the authors decided not to limit the database to one entry per fraud *incident* and did not collect *incident* details in the database. Many articles collected in the database do not have enough information to facilitate classification into specific *incidents*. There are several possible explanations for this. Many articles about food fraud are focused on analytical methods and provide little information to connect the tested adulterants to specific documented or verifable cases of adulteration. This could be a result of several factors: some fraud issues are general knowledge within specific industry sectors; some cases of adulteration are speculative or are based on insider information and thus are not traceable to documented cases; and research efforts are hampered by a general lack of government survelleance reports and a similar lack of information from criminal prosecution cases for some types of food fraud. In addition, there is no commonly accepted definition for what constitutes a single fraud *incident*. For example, the 2007 to 2008 melamine adulteration events could be considered one *incident* that occured over several years, but others may consider melamine in wheat gluten, melamine in pet food, melamine in infant formula, and melamine in other food products as separate *incidents*. Others may consider each fraud case prosecuted in a court of law to be individual *incidents*. Because a meaningful and systematic classification of incidents could not be

Table 2–Database scope.

	Scholarly	Media and other records	Total
Number of records	1054	251	1305
Number of ingredients	250	147	361[a]
Number of references	575	85	660

[a]The total number of discrete food ingredients present in the database. This number does not equal the sum of the previous 2 columns because some ingredients were common to both the "scholarly" and the "media and other records" datasets.

Table 1–Data fields used to create the database from the literature search.

Field	Description, criteria, and terms used
Ingredient	The common or usual name for the food ingredient that was subject to the reported adulteration or fraud. Names were harmonized where appropriate, for example paprika and paprika powder were both entered using the common name of paprika.
Adulterant	The common or usual name for the reported adulterant or fraudulently added material. The term nonauthentic was commonly used in the database to describe reports about broad categories of adulterants or nonspecific adulterants. For example, to describe the adulteration of tuna with other fish species, the adulterant was described as fish of nonauthentic species.
Ingredient category	Food ingredient category names were determined retrospectively as a way to capture similar types of food ingredient with common adulteration or analytical challenges. For example, all types of milk (from cow, sheep, or goat) were categorized as milk.
Type of fraud	Descriptor used to describe the nature or type of adulterant or fraud reported. Three options were used: replacement, addition, or removal. See Table 3 for a further explanation of these terms.
Publication year	The publication year of the article or report.
Reported detection method[a]	The detection technology, analyte(s), and data analysis.
Report type	Scholarly was used to describe articles from peer-reviewed scientific journals. Media or other was used to describe articles from mainstream or food media outlets or other publications such as reports from trade associations or government agencies.

[a]Collected only from scholarly journal articles.

made for many articles in the databse, the authors did not include this information.

Database analysis: trends and insights

The authors analyzed the database by sorting all records into 2 datasets by report type, and then they determined top ingredients and ingredient categories in each dataset. The scholarly records dataset included a total of 1054 records based on 584 literature references, and the media and other reports dataset included 251 records based on 93 articles (Table 2).

The authors analyzed the scholarly reports dataset to determine the 25 food ingredients with the greatest number of records or hits (Table 4). Of these 25 ingredients, the top 7 ingredients represented more than 50 percent of the scholarly records in the database and included:

- olive oil
- milk
- honey
- saffron
- orange juice
- coffee
- apple juice

For further analysis, the scholarly dataset was organized by ingredient category (Figure 2). Of the 18 ingredient categories in the database, oils, milk, fruit juices, concentrates, jams, purees and preserves, and spices represented more than 50% of the scholarly records.

Similar analyses were carried out on the media and other reports dataset as shown in Table 5 and Figure 3. Comparing the media and other reports dataset to the scholarly dataset showed some similarities: both contained a large number of records for honey and olive oil ingredients. Also, the food ingredient category of spices was mentioned in more than 10% of the records in each dataset. There were important differences in the datasets as well. Natural flavoring complexes and seafood represented 42% of the records in the media and other dataset but only 6% of the scholarly dataset. Orange juice and coffee represented 7% of all ingredient records in the scholarly dataset, but the media and other dataset contained no records for these ingredients. These differences could be attributed to either the less comprehensive nature of the media or to the difficulty of searching for these types of articles. Alternatively, it could

Table 4–Top 25 ingredients in the scholarly records dataset.

Ingredient	Number of records	Percentage of total records
Olive oil (all)[a]	167	16
Milk (all)	143	14
Honey	71	7
Saffron (*Crocus sativus* L.)	57	5
Orange juice	43	4
Coffee (all)	34	3
Apple juice	20	2
Grape wine (*Vitis vinifera*)	16	2
Maple syrup	16	2
Vanilla extract (all)	16	2
Rice (all)	14	1
Cheese (all)	13	1
Milk fat (all)	13	1
Turmeric	12	1
Vegetable oil (all)	11	1
Chili powder	10	1
Sesame oil	10	1
Cocoa powder	9	1
Strawberry puree	9	1
Beeswax	8	1
Chinese star anise (*Illicium verum* Hook. f.)	8	1
Durum wheat (*Triticum durum*) pasta	8	1
Guar gum	7	1
Palm oil	7	1
Paprika	7	1

[a]All indicates that multiple ingredient subtypes were combined. For example, different types of olive oil (virgin and extra virgin) were combined into Olive oil (all) for this table.

Table 3–Categories and explanations for type of fraud field in Table 2.

Type of fraud	Definition	Subtypes included	Examples
Replacement	Complete or partial replacement of a food ingredient or valuable authentic constituent with a less expensive substitute without the purchasers' knowledge	Addition, dilution, or extension of an authentic ingredient with an adulterant or mixture of adulterants	Addition of melamine to milk to artificially increase apparent protein contents measured by total nitrogen methods. Addition of water and citric acid to lemon juice to fraudulently increase the titratable acidity of the final juice product. Overtreating frozen fish with extra water (ice)
		False declaration of geographic, species, botanical, or varietal origin	Substitution of cow's milk for sheep or goat's milk. Substitution of common wheat for durum wheat Substitution of Greek olive oil for Italian olive oil.
		False declaration of the raw material origin or production process used to manufacture an ingredient	Substitution of synthetically produced vanillin for botanically derived (natural) vanillin
		False declaration of origin to evade taxes or tariffs	Import into the United States from Vietnam of catfish labeled as grouper to avoid antidumping duties or transshipment of Chinese shrimp through Indonesia to avoid antidumping duties
Addition	The addition of nonauthentic substance to mask inferior quality ingredient without the purchasers' knowledge	Color enhancement	Addition of Sudan Red dyes to enhance to the color of poor-quality paprika
		Taste enhancement	Addition of sugar to mask the astringent taste of poor-quality pomegranate juice
Removal	Removal of an authentic and valuable constituent without the purchasers' knowledge	NA	Removal of nonpolar constituents from paprika (for example, lipids and flavor compounds) to produce paprika-derived flavoring extracts. The sale of the resulting defatted paprika, which lacks valuable flavoring compounds, as normal paprika is a fraudulent practice

be attributed to the fundamentally different motivations for publication of scholarly articles versus media articles on food fraud. Further research might reveal how incidents are nominated or selected for treatment in the media, government, and scholarly articles.

Analytical detection methods

Analytical detection methods are an important first line of defense for both detecting and deterring food ingredient fraud. The authors examined the analytical detection technologies reported in the scholarly dataset to determine the most common instrumental approaches used to detect food fraud and to identify trends. Database records reported the use of 16 commonly used instrumental technologies for detecting food adulteration. Liquid chromatography, infrared spectroscopy, gas chromatography, isotope ratio mass spectrometry, and hyphenated mass spectroscopy were the top 5, as shown in Figure 4. Such information could be useful to organizations assessing future QA analytical needs for monitoring food fraud or for those setting up new laboratories for this purpose. Liquid and gas chromatography and infrared spectroscopy are already common instrumental platforms available in most QA laboratories, and based on this research they will continue to provide value for food fraud prevention. Mass spectrometry and especially isotope ratio mass spectrometry are not as common in QA laboratories, but because of the demonstrated power and increasing use of mass spectrometry, it may become more important in routine QA testing.

An emerging trend in food fraud analytics: chemometrics

Chemometrics is a multivariate data analysis tool often coupled with data-rich instrumental methods such as infrared spectroscopy, mass spectrometry, or nuclear magnetic resonance. In respect to food fraud, chemometrics is a powerful data reduction tool used qualitatively for grouping or classifying unknown samples with similar characteristics and quantitatively for determining adulterant analytes in samples (Moore and others 2011). Recent reports demonstrate the use of principal component analysis and partial least squares multivariate models of the infrared spectra of honey to classify samples as authentic or adulterated (Zhu 2010) and also to predict the levels of specific adulterants (Wang 2010). The earliest records in the database reporting the use of chemometrics for food fraud analytics were published in 1988, and from that year until 2010 a total of 306 scholarly records (30%) included the use of chemometrics. This suggests increasing use of chemometric data analyses for food fraud detection during the past 2 decades and and suggests the need for their expanded use in routine QA testing (Moore and others 2011).

Table 5– Top 25 ingredients in the media and other records dataset.

Ingredient	Number of records	Percentage of total records
Fish (all)[a]	23	9
Honey	15	6
Olive oil (all)	10	4
Chili powder	9	4
Milk (all)	7	3
Black pepper	6	2
Caviar (all)	5	2
Cooking oil	5	2
Paprika	5	2
Rice (all)	5	2
Saffron	5	2
Turmeric	5	2
Patchouli oil (*Pogostemon cablin*)	4	2
Pulses	4	2
Apple juice	3	1
Bergamot oil (*Citrus bergamia*)	3	1
Ghee	3	1
Juice	3	1
Lavender oil (*Lavandula angustifolia*)	3	1
Wheat flour	3	1
Wheat gluten	3	1
Wine (all)	3	1
Anise oil (Pimpinella spp.)	2	1
Asafoetida	2	1
Chicken meat	2	1

[a]All indicates that multiple ingredient subtypes were combined. For example, different types of fish were combined into Fish (all) for this table.

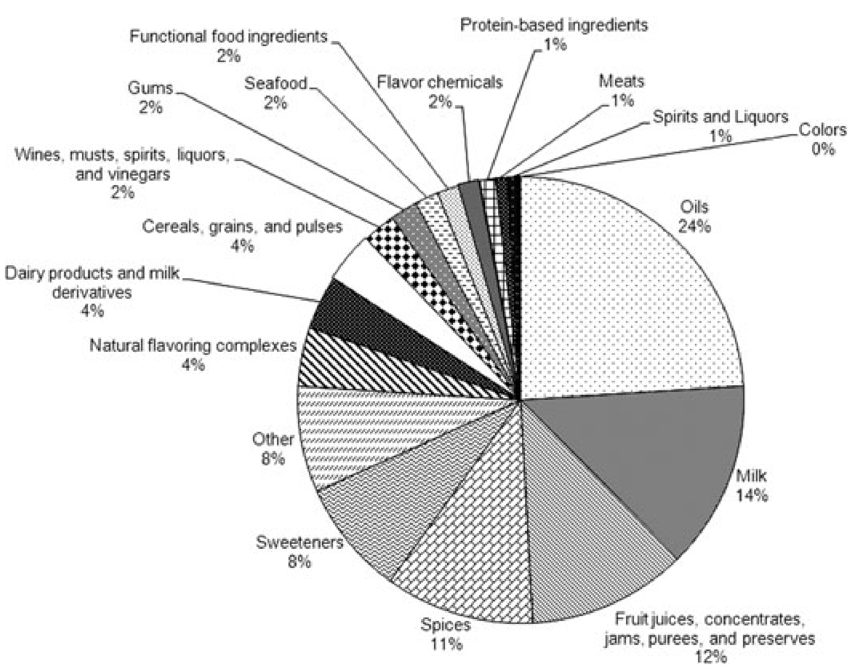

Figure 2–Percent of scholarly records by food ingredient category.

Types of food fraud and implications for analytical detection methods

The next analysis was devoted to the type of fraud. Three categories were created, including replacement, addition, and removal, as described in Table 3. The replacement category represented 95% of the records in the database, followed by less than 5% for addition and less than 1% for removal. The term *replacement* was used to describe reports of authentic material being replaced with another, less expensive, substitute without the purchaser's knowledge and for the seller's economic gain. Substitution of part or all of an olive oil ingredient with hazelnut oil is an example of this type of fraud.

One interesting implication of the extensive replacement-type in food fraud involves the analytical testing strategy best suited to detect this type of adulteration. In principle, there are 2 analytical strategies for detecting adulteration. Testing for the absence of specific adulterants is a commonly used approach, but it has critical limitations: by its nature it cannot detect unknown adulterants, and it seeks only one specific adulterant and not others. This approach does, however, excel at detecting adulterants at very low concentrations. The second approach is the compendial strategy that specifically tests for the identity, authenticity, and purity of a food ingredient (that is, what is supposed to be present and in what quantity) instead of what should not be present. This approach has the advantage of detecting both known and unknown adulterants but may detect only relatively high levels of adulteration and not always the low levels possible with the first approach (Moore and others 2011). Because a majority of the records in this database are categorized as the replacement-type, compendial testing approaches are an important tool for detecting and deterring food fraud.

Because of the nature of our supply chains and the monetary drivers behind economically motivated adulteration, one surmises that the compendial strategy will be most effective when used as close as possible to the supply chain node where the adulteration occurred. At this point, the criminal has incorporated a relatively large amount of foreign material into genuine material (or has otherwise adulterated the material). The amount added or changed is driven by the efforts to maximize profits and hence in most cases

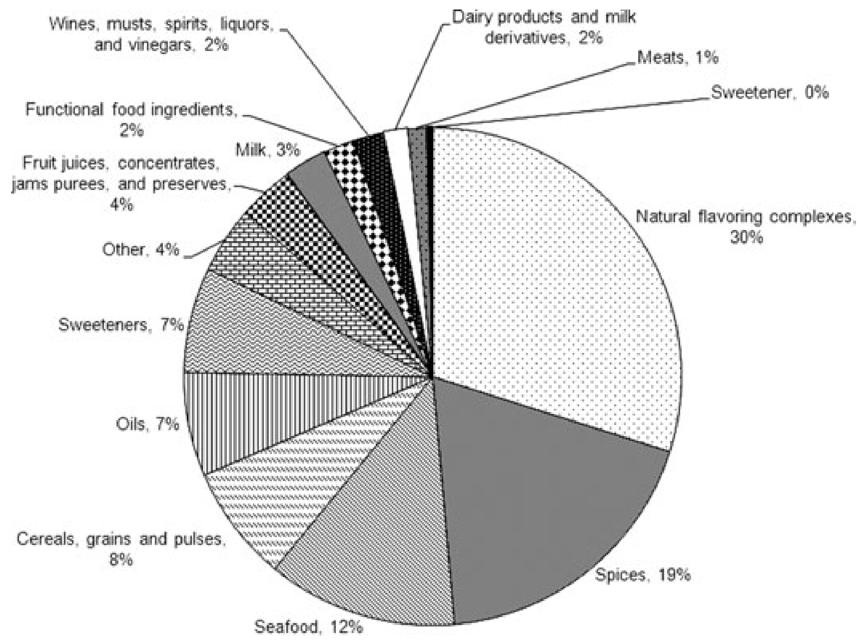

Figure 3–Percent of media and other records by food ingredient category.

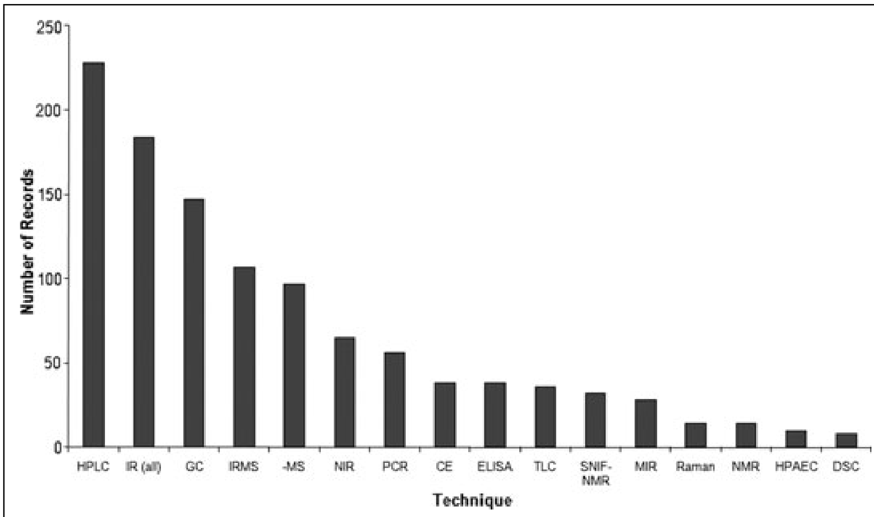

Figure 4–Top detection technologies in the scholarly database. HPLC stands for high-performance liquid chromatography; IR standards for infrared spectroscopy; GC stands for gas chromatography; IRMS stands for isotope ratio mass spectrometry; -MS stands for hyphenated mass spectrometry methods; NIR stands for near infrared spectrscopy; PCR standards for polymerase chain reaction; CE stands for capillary electrophoresis; ELISA stands for enzyme linked immunosorbent assay; TLC stands for thin-layer chromatography; SNIF-NMR stands for site-specific natural isotope fractionation NMR; MIR stands for mid-infrared spectroscopy; Raman stands for Raman spectroscopy; NRM stands for nuclear magnetic resonance spectroscopy; HPAEC stands for high-performance anion exchange chromatography; DSC stands for differential scanning calorimetry.

will be large enough to allow detection with compendial testing. However, as the adulterated material moves through the supply chain it is likely to be aggregated with genuine material, and hence the adulteration is diluted to the extent that it occurs at very low levels.

These considerations highlight the needs and benefits of testing throughout the supply chain because the compendial-based testing for authenticity almost always is more cost-efficient compared to targeted testing for a trace level of a myriad of possible adulterants. In addition, the amount of material that will be quaranteed and eventually destroyed is much smaller if the adulteration is detected as close as possible to the node in the supply chain where it occurred. Two important examples show the economic impact of adulterated material that is detected too late in the supply chain. An incident that persisted from 2003 to 2005 in the United Kingdom involved the fraudulent addition of harmful Sudan red dyes to spices such as chili powder. This led to the largest recall of food in the United Kingdom to that date and involved more than 580 products (Smith 2010). A second example is the 1985 fraudulent addition of diethylene glycol to Austrian wines that affected 10 countries and devastated the €20 million per year export wine trade in Austria (Barnes 1996). As these examples show, when selecting an analytical method to detect the absence of a genuine ingredient or the presence of an unauthorized adulterant, analysts must have an insight into the nature of the fraud and the nature of the criminal.

Utility of the database

The database provides information that can be useful for risk assessors evaluating current and emerging risk for food fraud. Beyond listing known food fraud adulterants, it provides a baseline understanding of the susceptibility or vulnerability of individual ingredients to fraud. This information may not be well known in the food science community or extensively reported in mainstream media. The substitution of Chinese star anise (*Illicium verum* Hook. f.) with Japanese star anise (*Illicium anisatum* Linn) is an illustrative example. The latter is unsafe for human consumption. It contains highly toxic sesquiterpenes and has been implicated in cases of infants suffering seizures and other acute neurological effects following consumption of herbal teas made with Japanese star anise that had been substituted for Chinese star anise (Joshi 2005). Chinese star anise has been in short supply in China following drought conditions and because of its use as a raw material for oseltamivir, an antiviral medicine (Hongyi 2009; Watson 2011). In another example from the database, highly toxic diethylene glycol has received notoriety in the food arena because of its fraudulent addition to wines (Molotsky 1985) and also as an adulterant of glycerin used in pharmaceuticals (Schier and others 2009). Leveraging USP's activities in the pharmaceutical area for the later issue, USP has recently published newly revised standards for food-grade glycerin in its *Food Chemicals Codex*, and the new standards are capable of detecting this type of adulteration (United States Pharmacopeia 2012).

The database also provides information about potential adulterants that could reappear in the supply chain for particular ingredients. For example, records in the database regarding melamine as an adulterant for high-protein-content ingredients date back to 1979 to 1982 (Cattaneo and Cantoni 1982). Perhaps if this information had been readily available to risk assessors before the 2007 to 2008 incidents of melamine-adulterated wheat gluten and milk powders, it could have helped risk assessors anticipate these adulteration possibilities. This information also could have stimulated research aimed at developing new methods for the determination of total protein content that are selective enough for proteins to not be influenced by the presence of these adulterants like melamine—an effort that has only recently gained substantial interest (Moore and others 2010).

Beyond aiding in risk assessment, information contained in the database may be useful for risk management. The database provides information about analytical detection approaches in scientific journal articles. Such information could be used as a starting point for organizations investigating different analytical methods already developed for specific food ingredients. This ultimately could help an organization decide which methods to use based on their individual risk–benefit analysis and analytical capabilities assessment.

Future research

The database was intended to be a baseline of publically reported food ingredient fraud issues. Future work could make it more comprehensive. Intentionally missing from the database are publically available articles published before 1980 or published in languages other than English. Such reports could provide useful insights about previously used adulterants that could reappear in the food supply, as well as insights into issues in non–English-speaking countries. Beeswax, for example, is not commonly reported to be adulterated based on mainstream English-language media and food science scholarly sources, but it does appear in the SciFinder database for Chinese scholarly articles that had English abstracts. Because of the global nature of food ingredient production, this example suggests that further research into scholarly articles written in Chinese could prove useful for identifying other ingredients susceptible to adulteration.

Also intentionally missing from the established database are publically reported issues fitting the broad definition of food fraud but for finished food products involving tampering, over-run theft, diversion, simulation, or counterfeit (Spink 2011b). Finally, issues of food ingredient fraud that have never been publically reported (or suspicious activity reports) are missing from the current database. The amount of such insider information that may be available from industry and government enforcement organizations such as customs is unknown. This information would provide a valuable addition to the publically available reports, and the authors recommend exploration of mechanisms for the collection of such information.

Collection of additional information about food fraud may aid in more thorough risk assessment. The public health threat associated with potential adulterants is an important factor for risk assessment. Work should be undertaken to assess exposure and safety consequences for specific ingredient/adulterant combinations to address this gap. For example, the database includes several records of lead-based adulteration, including lead chromate substitution to replace turmeric (Jaiswal 2008; Mishra 2010) and use of lead tetroxide to replace paprika (Doka 1998). Recent safety assessments of lead have concluded that no level of lead contamination in foods can be considered safe (Joint Expert Committee on Food Additives 2011). Other fraud such as replacement of vegetable oils may not pose an extensive public health threat, but safety concerns related to allergens should be carefully considered (Arlorio 2010). Again, only the ethics and knowledge of the criminal will determine the extent to which public health is threatened. To follow the example above, if food-grade vegetable oils are used as the adulterant, the impact on public health may be small and limited only to those who suffer from allergies, which would cause a problem if peanut oil or other allergenic nut oil were used. However, throughout history cooking oil adulteration with a variety of mineral oils has led to serious threats for public health, for example, the toxic oil syndrome in Spain in 1981 (Mayeno and others 1995), ortho-cresyl phosphate in Moroccan cooking oil (Travers 1962) in 1959, and the presence of dioxins in meat following the use of PCBs in feed in Belgium (Bernard and others 2002). A more recent example is the use of "gutter oil" (made from discarded kitchen oil) disguised as vegetable oil (Rui and Yan 2010). All of these examples point to the incalculable health hazards introduced by these oils that are not fit for human consumption.

Information about the exact nature of food fraud incidents also could aid in risk assessment and should be further explored. This includes how, where, and why the fraud incidents have occurred from criminal, economic, legal, and trade perspectives. Knowledge of the QA systems or methods that were evaded by the criminal in the past could be useful to determine if a current QA system or method is at risk and can help predict other at-risk ingredients based on their use of similar QA analytical methods. Assessments of the QA analytical issues associated with recent melamine adulteration incidents, for example, have highlighted the risk for melamine adulteration of other high protein content ingredients such as soy and rice protein concentrates for which analysts typically use the nonspecific Kjeldahl method for estimating total protein (Moore 2010). This level of additional information pertaining to the exact nature of fraud was not attainable in the present database research because of the limited amount of information provided by single articles. A more through or meta-analysis of related incidents could be undertaken using articles reported in this database. Finally, although several survey studies have been published by governmental agencies, for example, GAO reports on fruit juice and seafood fraud (GAO 1995 and 2009), additional surveys would be useful in the future to help better characterize the true extent and scope of food fraud in the marketplace.

Supply chain analytics

The food industry traditionally has focused on supply chain efficiency and on food safety incidents. Improvements in supply chain logistics have led to cost-effective and timely shipment of products around the globe. Supply chain managers are aware of product safety and security risks that could disrupt the supply chain, but their focus has been on large-scale and common events or terrorist attacks (Helferich and Cook 2002; Closs and McGarrell 2004; Roth and others 2008). There also is a growing awareness of the need to select trusted and reliable suppliers (Voss and others 2009). Supply chain managers are becoming more aware of the risks of complex supply chains and susceptible products, including the operational complexity of the full supply chain, risk for disruption including food product recalls, and coupling of a series of activities such as just-in-time inventory (Speier and others 2011).

Every node in the supply chain presents an opportunity for food fraud. Each aggregator, shipper, or wholesaler who collects, blends, or repackages can change the identity, purity, and authenticity of the ingredient. Integration of the database information described in this research into supply chain analytics systems is a potential opportunity to help manage food fraud risks. The information in the database provides supply chain managers with a scholarly assessment of vulnerabilities that are often not understood or considered.

Conclusion

The database of food fraud presented in this research offers a starting point to better understanding the scope, scale, and threat of food fraud issues that have been publically reported in English from 1980 to 2010. Analysis of the information in this database can help identify problematic ingredients including poorly publicized issues and can facilitate the development of innovative countermeasures and analytical methods to protect the food supply. Future research should include collecting and analyzing additional publically available articles about food fraud beyond the scope of this work (for example, before 1980, in other languagues, etc.) as well as insider information not available in the public domain. Further analysis will help identify trends that can help reveal weaknesses in existing quality control systems.

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