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Research Paper

Database of Food Fraud Records: Summary of Data from 1980 to 2022

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ABSTRACT

Food fraud prevention and detection remains a challenging problem, despite recent developments in regulatory and auditing requirements. In 2012, the United States Pharmacopeial Convention created a database of food ingredient fraud. The objective of this research was to report on updates made to the database structure and to provide an updated analysis of food fraud records. The restructured database was relational and included four tables: ingredients, adulterants, adulteration records, and references. Four adulteration record types were created to capture the variety of information that can be found in public food fraud reports. Information was searched and extracted from the peer-reviewed scientific literature, media publications, regulatory reports, judicial records, trade association reports, and other public sources covering 1980-present. Over an almost seven-year data entry period, a total of 15,575 records were entered, sourced primarily from the peer-reviewed literature and media reports. The percentage of records that included at least one potentially hazardous adulterant ranged from 34% to 60%, depending on the record type. The ingredients with the highest number of incident and inference records included fluid cow's milk, extra virgin olive oil, honey, beef, and chili powder. The ingredient groups with the highest number of incident and inference records included Dairy Ingredients, Seafood Products, Meat and Poultry Products, Herbs, Spices, and Seasonings, Milk and Cream, and Alcoholic Beverages. This database was created to serve as a standardized source of information about publicly documented occurrences of food fraud and other information relevant to fraud risk to support food fraud vulnerability assessments, mitigation plans, and food safety plans. These data support the contention that food fraud presents a public health risk that should continue to be addressed by food safety systems worldwide.

The risks to food safety, public health, and consumer confidence created by food fraud have been well-documented over recent years (Everstine et al., 2013; Gossner et al., 2009; Spink & Moyer, 2011). Both regulatory agencies and industry-driven food safety initiatives have developed additional requirements specifically targeting food fraud prevention (Center for Food Safety and Applied Nutrition, 2023c; Tackling Food Fraud Through Food Safety Management Systems, 2018). Nonetheless, food fraud remains a challenging problem due to the global nature and complexity of food supply networks, difficulties in testing and detection strategies, and the often-unconventional nature of fraud-related adulterants (Everstine, Hellberg, et al., 2021).

Various definitions of food fraud exist, along with related terms such as economically motivated adulteration (EMA) (Gussow & Mariët, 2022; Johnson, 2014). Generally speaking, food fraud is the intentional misrepresentation of the true identity or contents of a food ingredient or product for economic gain (Jijon, 2017). A United States Pharmacopeial Convention (USP) Expert Panel defined the intentional and 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" (Moore et al., 2012). One frequently cited definition of food fraud is "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 & Moyer, 2011). A recently proposed definition is "food fraud is committed by any actor who is intentionally involved in illegal acts for economic advantage, thus causing or facilitating illegal food to be laundered into the supply chain or for food to be fraudulently value-enhanced" (Gussow, 2020).

Regulatory attention to food fraud, especially fraud that does not result in acute illness, can be limited by the need to focus limited

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resources on known food safety risks. Public reports of food fraud likely represent only a fraction of the true incidence of fraud in the food supply (Everstine, Hellberg, et al., 2021). Making meaningful use of publicly available data can be challenging. For that reason, in 2012, USP created a database of food ingredient fraud and economically motivated adulteration (Moore et al., 2012). This database was intended to systematically collect and report public information about fraud in food ingredients and additives, associated analytical detection methods, and to analyze the information for useful trends. It contained just over 1,300 records and included fields capturing information about the ingredient and ingredient category, adulterant, type of fraud, reported detection method, publication year, and report type. Since that time, the need for resources to support regulatory and food industry efforts to mitigate food fraud risks has increased (Everstine, Popping, et al., 2021).

The objective of this research was to use learnings gleaned since the creation of the food fraud database in 2012 to make it more comprehensive and to make improvements to the structure and function of the database in support of food fraud vulnerability assessment requirements. This research resulted in the creation of new record types, additional fields, and standardization of nomenclature for ingredients and adulterants. A team of analysts began entering data using the revised structure in May 2016 and data entry proceeded continuously through January 2023. During this time, ownership of the database was transferred from USP to FoodChain ID, but the primary team of analysts remained the same. The updated data were used for this analysis.

Materials and methods

For the purposes of this database, the authors and analysts generally aligned to the broad definition of food fraud cited above, the "intentional misrepresentation of the true identity or contents of a food ingredient or product for economic gain." To qualify for entry in the database, there had to be (or likely be) intent, misrepresentation, and economic advantage. Intent was determined by the analysts to the best of their ability through the information provided in each primary source reference. If the intentional nature of the adulteration was not explicitly stated in the primary source reference, it could be inferred from the nature of the adulterant and its behavior in the food product or ingredient (e.g., a color additive known to improve the appearance of spices). The analysts focused primarily on information relevant to legitimate food supply chains (in contrast with informal or unregulated food production). They included information about illegal production sold to the general public and diversion of waste streams back into the food supply chain (so-called "food laundering") (Gussow & Mariët, 2022). We generally did not include "food-adjacent crimes" such as tax fraud involving food unless a downstream purchaser was misled as to the true identity of the product. The primary goals of the revised database structure were to include additional information relevant to food fraud vulnerability (such as the geographic location of production/distribution and illnesses or deaths associated with the fraud), to increase the amount of structured data, to minimize free-text data entry, and to maximize grouping of related information to support searching and the ability to examine trends.

Database structure and fields. The database was structured to be a relational database with four tables: ingredients, adulterants, adulteration records, and references (see Fig. 1). Distinct tables for ingredients and adulterants were created to allow standardization of nomenclature, grouping of related information, and inclusion of additional identifying information (such as CAS Registry numbers, if relevant; see Table 1) (CAS REGISTRY | CAS, n.d.). Each adulterant was classified with respect to whether it could be potentially hazardous using a scheme previously reported (Everstine et al., 2018). A synonym field was included within both the ingredient table and the adulterant table to support searching by multiple names. Ingredient groups were created to enable grouping and simultaneous searching of related ingredients.

Ingredients, adulterants, and references were linked through the adulteration records. Four adulteration record types were created to capture the variety of food fraud-relevant information that can be found in public reports: incident, inference, method, and surveillance records (see Table 2). Incident, inference, and surveillance records were structured so that they were associated with only one ingredient but could be associated with multiple adulterants. Method records were created based on distinct ingredient-adulterant combinations;

Table 1
Associated data fields for Ingredient, Adulterant, and Reference tables

Table	Data Fields
Ingredients	Ingredient Name
	Regulatory Classification (Food Ingredient or Animal Food Ingredient)
	Synonym(s)
	CAS#
	INS#
	UNII#
Adulterants	Adulterant Name
	Synonym(s)
	Potential Hazard
	CAS#
References	Title
	Description (full citation)
	Type (Scholarly, Judicial, Media, etc.)
	Publication Year
	DOI

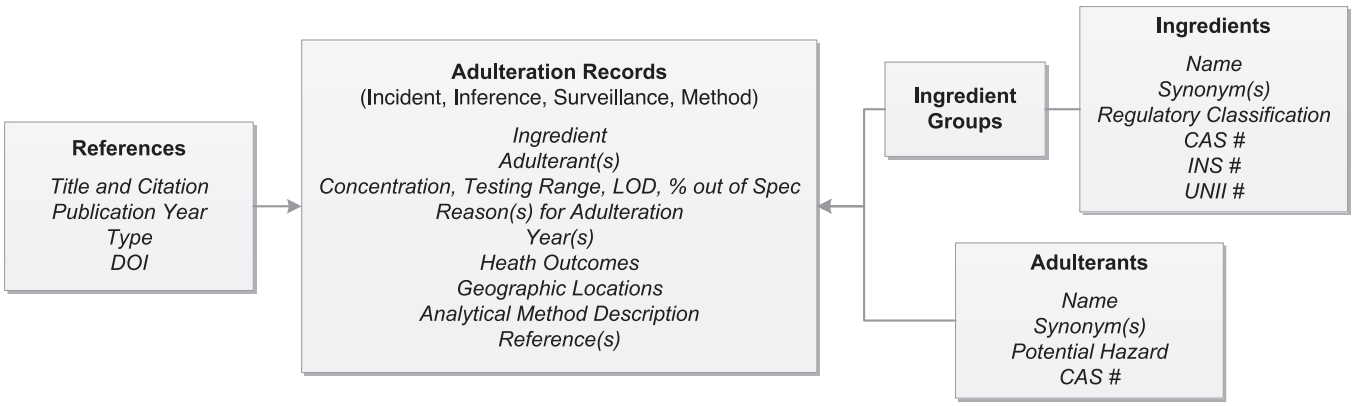

Figure 1. Database elements and structure.

Table 2
Adulteration record table – record types and associated data fields (fields in italics are relational)

Record Type	Description	Data Fields
Incident	A documented occurrence of food fraud in a food ingredient or product within a defined timeframe. Incidents are often reported in the media and tend to include contextual and supporting information about the perpetrator, motive, geographic location, and/or other characteristics.	*Ingredient* *Adulterant*(s) Adulterant concentration(s) detected (lower/upper) Fraud Type(s) Year Began Year Ended / Reported Weight of Evidence Produced Location Distributed Location(s) Health Outcomes (deaths and/or illnesses) *Reference*(s)
Inference	Documentation of probable knowledge of food fraud risk without sufficient contextual information to be classified as an incident. May be created from published research to develop methods for authentication or adulteration detection, or to document ingredient-adulterant combinations identified in market-based surveillance.	*Ingredient* *Adulterant*(s) Adulterant Estimated Testing Range(s) (lower/upper) Fraud Type(s) *Reference*
Surveillance	Documentation of market sampling and testing of foods or ingredients in specified geographic locations that informs estimates of the prevalence and scope of fraud. Sampling may be conducted by regulatory agencies, trade organizations, or other interest groups, or occur as part of analytical method development.	*Ingredient* *Adulterant*(s) Year Began Year Ended / Reported Surveillance Location(s) Sample Population Percentage out of specification *Reference*(s)
Method	A method record provides information on an analytical method for detecting food adulteration or authenticating food ingredients that has been published in a scholarly report.	*Ingredient* *Adulterant* Adulterant Estimated Testing Range (lower/upper) Adulterant Estimated Detection Limit Fraud Type(s) Analytical Method Description *Reference*

therefore, each method record was structured to contain only one ingredient and one adulterant. Review of one primary source reference could result in the entry of multiple records and record types, depending on the type of information included. Data entry conventions were designed to help ensure that distinct information relevant to food fraud vulnerability was included in either an incident record or an inference record but not duplicated within those two record types.

Literature Search. Food fraud information was searched and extracted from the peer-reviewed scientific literature ("scholarly" references), media publications, regulatory reports, judicial records, trade association reports, and other relevant public sources published from 1980 to the present using the methods and keywords outlined previously (Everstine et al., 2018). The search was broadened from food ingredients produced and sold with the intention of incorporation into finished food products to include all food ingredients or products (including finished food products) intended for human or animal (either companion or food producing) consumption that were reported to be associated with food fraud. This included some dietary and botanical ingredients that may be used in both dietary supplements and conventional food products. Searches were conducted primarily in English, with targeted searches conducted in other languages (Mandarin, Cantonese, Portuguese, and Spanish) by analysts fluent in those languages. The analysts also used Google Translate, when necessary, to enable extracting of information from non-English sources. In addition, all information was extracted from the previous database and entered into the restructured database using the new format.

Data entry. Ingredients included foods, food ingredients, and substances allowed for use in foods (such as direct and secondary direct food additives) and were initially created based on existing sources, including the previous database, the *Food Chemicals Codex* (United States Pharmacopeial Convention, n.d.), the FDA Seafood List (Center for Food Safety and Applied Nutrition, 2023b), Substances Added to Food (Center for Food Safety and Applied Nutrition Safety and Applied Nutrition, 2023a), and others. In addition, both ingredients and adulterants were created and curated as needed during data entry, oftentimes at the request of food industry users of the database. Synonyms were used to capture multiple names for the same ingredient, including binomial nomenclature, when applicable.

Incident, inference, and method records included a field called "fraud type," which was intended to classify the type of adulteration and the means by which it occurred. The categories were created to be distinct (to provide differentiation among the records) and clearly defined to support the grouping of related fraud information in the database (see Table 3). Multiple fraud types could be cited for each record. Data analysts relied on information provided in the reference, previous knowledge of food fraud, and their best judgment when assigning this classification. Due to the fact that market-based surveys generally include limited or no information on the possible intent of adulteration or how it may have occurred, surveillance records did not include this field.

Information was pulled from a wide variety of public sources which varied in terms of the type of information and validity of information provided. Incident records included fields for the location of production and distribution ("produced location" and "distributed location (s)" in Table 2). The produced location was intended to reflect the location where the fraud occurred. This may be the same as the country of origin (COO) for products such as spices or honey but may not be the same as the COO for seafood products since misrepresentation may occur downstream in the supply chain (at retail, for example). Each of these fields was entered by a data analyst based on the context of the source reference and they were left blank if the information was not provided in the original source. In addition, incident records included a field titled "weight of evidence" (WOE) to allow analysts to provide an assessment of the credibility of information provided in the source

Table 3
Fraud types

Fraud Type	Definition	Subcategories	Examples
Dilution or substitution with an alternate ingredient	Partial or full substitution of foods or food ingredients in any form (whole fillets, liquid, ground, powdered, etc.) with the intent to increase weight or volume	Misrepresentation of geographic origin	Tunisian-origin olive oil labeled as Italian
		Misrepresentation of botanical origin	Partial substitution of olive or myrtle leaves in dried oregano
		Misrepresentation of animal origin	Horse meat inclusion in ground beef
		Misrepresentation of varietal origin	Intentional mislabeling of grape varietals used in wine production
		Use of a substance that is not approved for use in food	Reintroduction of discarded "gutter oil" into the food supply
		Other (forms of dilution/substitution that are not included in the above subcategories)	Dilution of honey with sugar syrups and replacement of milk fat products with vegetable fats
Artificial enhancement	The undeclared, unlabeled, or non-permitted addition of a substance to artificially improve perceived quality through color, nutritional content, or organoleptic qualities. These substances are added for functional effect (not to increase weight or volume).	Use of color additives	Addition of Sudan dyes to spices
		Use of non-authentic protein sources or non-protein nitrogen sources	Melamine or soy protein addition to milk
		Use of substances that enhance organoleptic qualities	Chemical ripening agents in fruit or artificial "aging" chemicals in cheese products
Use of non-declared, unapproved or banned biocides	Fraudulent use of unapproved pesticides, antibiotics, fungicides, or other biocides or preservatives during production	N/A	Chloramphenicol use in honeybee populations and malachite green use in aquaculture
Misrepresentation of nutritional content	Fraudulent and intentional mislabeling of nutritional content, often related to foods consumed by vulnerable populations	N/A	Infant formula that does not meet nutritional requirements as labeled
Fraudulent labeling claims	Misrepresentation of a label attribute that implies a particular production technique	N/A	Fraudulent labeling of designations such as organic, kosher, halal, cage free, and tampering with expiration dates
Removal of authentic constituents	Removal of a component of an ingredient or food that characterizes and authenticates it	N/A	Sale of "spent" spices that have had lipids and flavor compounds removed to produce spice-derived flavoring extracts
Formulation of a fraudulent product through the use of multiple adulterants and techniques	Creation of an entirely fraudulent food product through a combination of methods	N/A	Sale of "100% apple juice" that consists of water, sugar, flavoring and coloring agents, and acid
Other	Fraudulent methods not included above	N/A	Intellectual property infringement (fraudulent branded packaging or "counterfeit" products), smuggled and/or stolen goods, and other forms of distribution of products that should have been removed from the market

references. The WOE field was intended to convey an assessment of the credibility of the sources that supported the incident record; it was not intended to convey information about the severity of the incident (see Table 4).

The data analysts developed a process of quality control to ensure that each record entered by one analyst was reviewed by a second analyst before it was included in the analysis. Data were entered into a custom-built web-based database platform.

Data analysis. Data were extracted into.csv format on February 3, 2023 and analyzed using Microsoft Excel.

Results and discussion

A total of 15,575 records were entered into the updated database structure including a total of 7,238 incident and inference records. The highest number of references came from scholarly articles followed by media reports. Additional details about the data are provided in Table 5. Twelve hundred twenty (46%) of the 2,628 adulterants were classified as potentially hazardous, 1,338 (51%) as not potentially hazardous, and the remainder as unknown. The percentage of records that included at least one potentially hazardous adulterant ranged from 34% to 60%, depending on the record type (see Table 5). It is important to note that all allergens, as defined by Codex Alimentarius, were classified as potentially hazardous adulterants regardless of the ingredient with which they were associated. Therefore, for example, cow's milk used as an adulterant in goat's milk was classified as potentially hazardous even though the substitution would not present a health risk to those who can safely drink milk. It is also likely that fraud-related adulteration with hazardous substances is over-represented in the database, particularly in incident records, since incidents that result in consumer illnesses are the most likely to be detected and reported. Nonetheless, these data challenge the common perception that food fraud rarely introduces a safety threat to food systems. Food fraud presents a public health risk that should continue to be addressed by food safety systems worldwide.

Almost 29% of incident records were classified as a high WOE while 38% were classified as a medium WOE (Table 4). The ingredients with the highest number of incident and inference records included fluid cow's milk, extra virgin olive oil, honey, beef, and chili powder (see Table 6). The ingredient groups with the highest number of incident and inference records included Dairy Ingredients, Seafood Products, Meat and Poultry Products, Herbs, Spices, and Seasonings, Milk and Cream, and Alcoholic Beverages (see Table 7). Fish and seafood, dairy products, honey, olive oil, and spices were also cited as fraud-prone ingredients in previous work, although the methods of categorizing records differed (Everstine et al., 2013; Moore et al., 2012). Fruit juices, coffee, and grains were cited less frequently in this database (by proportion) than in previous work. There may be various reasons for this decrease. In the case of fruit juice, the global fruit juice industry has undertaken efforts over the past 40+ years to address problems with authenticity, including the creation of additional standards, test methods, and increased testing at all levels of the supply chain. Research and method development also tends to follow high-profile reports of fraud incidents; for example, research in the detection of melamine (and its analogs) in milk products increased substantially in the years following the melamine incident and continues to this day. The same appears to be true for honey. This may have the effect of reducing the proportion of records for commodities that have not experienced a high-profile food fraud event in recent years.

The most common adulterants reported for the top 15 ingredient groups are shown in Table 8. When looking at the fraud types, dilution/substitution (all forms) was cited most frequently (in 5,875 of 7,238 records, or 81%). Notably, dilution/substitution with a sub-

Table 4
Weight of evidence (WOE) criteria

WOE Designation	Criteria[a]	No. (%) of Incident Records[b]
High	Regulatory documentation from a credible agency Legal documentation indicating ongoing litigation or a completed conviction/settlement Scientific documentation Multiple media reports from credible sources	596 (29)
Medium	Multiple media reports Reference to regulatory/government involvement (may be unverified) Legal/court documents (if applicable) indicating a lack of conviction or settlement	783 (38)
Low	Single media report Unverified credibility of media outlet No reported illnesses/deaths which could prompt regulatory investigation No references to regulatory/government involvement	672 (33)

[a] These were used as guidelines to make a determination of the weight of evidence; not all criteria were required.
[b] $N = 2,051$.

Table 5
Overview of database contents

Table and Fields	Total and Subtotals	No. (%) of Records with a Potentially Hazardous Adulterant
Records	15,575	
Method	7,287	2,512 (34)
Inference	5,187	2,333 (45)
Incident	2,051	1,212 (59)
Surveillance	1,050	628 (60)
Ingredients	5,523	N/A
Adulterants	2,696	N/A
References	5,022	N/A
Scholarly	2,618	
Media	1,962	
Regulatory	282	
Judicial	91	
Other	69	

Table 6
Twenty-one most represented ingredients from Incident and Inference Records

Ingredient	No. of Records (No. of Incident Records)	Percentage of Total Records ($N = 7,238$)
Milk (Fluid, Cow)	348 (89)	4.8
Olive Oil (Extra Virgin)	207 (49)	2.9
Honey	202 (55)	2.8
Beef Meat	97 (34)	1.3
Chili Powder	87 (33)	1.2
Olive Oil	84 (20)	1.2
Turmeric Powder	78 (23)	1.0
Milk Powder	75 (8)	1.0
Vodka	60 (49)	0.8
Ghee (Milk Fat)	57 (27)	0.8
Orange Juice	57 (5)	0.8
Milk (Fluid, Goat)	50 (0)	0.7
Wine	48 (46)	0.7
Chicken Meat	44 (21)	0.6
Beef (Ground)	40 (11)	0.6
Whiskey	43 (29)	0.6
Liquor (Unspecified)	41 (36)	0.6
Honey (Acacia)	40 (2)	0.6
Olive Oil (Virgin)	37 (4)	0.5
Saffron	37 (7)	0.5
Sesame Oil	37 (2)	0.5

Table 7
Number of Incident and Inference records by Ingredient Group[a]

Ingredient Group	Description	Total No. of Records	No. of Incident Records	No. of Inference Records	% of Total Records (Incident and Inference, N = 7,238)
Dairy Ingredients	Cow, buffalo, water buffalo, donkey, yak, goat, and sheep milks and products produced from these milks	1,059	206	853	14.6
Seafood and Seafood Products	Fish and shellfish	894	195	699	12.4
Meat and Poultry Products	Meat and poultry (livestock or wild) and products produced from these animals, not including seafood products	755	248	507	10.4
Herbs, Spices, and Seasonings	Herbs, spices, and seasoning blends (other than salt) in various forms (whole, dried, diced, ground, etc.)	569	145	424	7.9
Milk and Cream	Fluid milk and cream products from all sources (as listed in Dairy Ingredients)	550	96	454	7.6
Beverages (Alcoholic)	Wine, beer, liquors, and other alcoholic beverages	531	337	194	7.3
Botanical Ingredients	Botanical Products and ingredients, including those addressed in Botanical Adulterants Prevention Program documents (Botanical Adulterants Prevention Program, n.d.)	464	80	384	6.4
Honey	Honey and honeybee products (such as beeswax, propolis, and royal jelly)	461	72	389	6.4
Vegetable Oils	Oils from vegetables, fruits, and seeds other than olive oil	448	79	369	6.2
Olive Oil	All grades and varietals of olive oil	364	77	287	5.0
Beverages (Nonalcoholic)	Juices, sodas, artificially flavored beverages, dairy-based beverages, and other beverages (does not include coffee and tea, unless blended into a finished product)	287	64	223	4.0
Dairy Ingredients (from Animals other than Cows)	Buffalo, water buffalo, donkey, yak, goat, and sheep milks and products produced from these milks	258	7	251	3.6
Fruit and Vegetable Juices and Concentrates	Liquid juices and concentrates from fruits and vegetables	254	31	223	3.5
Organic Labeled Products	Products labeled and sold as “Organic” under local requirements and/or regulations	249	213	36	3.4
Fruits and Vegetables	Fruits and vegetables unprocessed or minimally processed (does not include juices or purees)	241	132	109	3.3
Essential Oils, Oleoresins, and Natural Extractives	As listed in 21CFR 182.20 (CFR - Code of Federal Regulations Title 21, n.d.)	195	16	179	2.7
Animal Feed and Pet Food	Foods and food ingredients intended for consumption by animals (livestock or pets)	194	48	146	2.7
Wines	Grape wines, all varietals (does not include wine grapes or wine vinegars)	193	111	82	2.7
Grains	Cereal grains and pulses and products made from these (does not include oilseed grains)	180	51	129	2.5
Cheeses	Cheeses from all milk sources (as listed in Dairy Ingredients)	152	34	118	2.1
Tree Nuts and Peanuts	Tree nuts, peanuts, nut flours, nut “butters,” nut “milks,” and nut oils (does not include nut extracts or coconut products)	149	32	117	2.1
Coffee	Coffee, coffee beans (whole or ground), and coffee extract	145	17	128	2.0
Butter and Milkfat Products	Butter and milk fat from all sources (as listed in Dairy Ingredients)	119	32	87	1.6
Milk Powders	Powdered milk from all sources (as listed in Dairy Ingredients)	119	13	106	1.6
Flavors (Natural)	Flavor compounds, extracts, and essential oils represented as naturally derived	102	6	96	1.4
Tea	Tea from *Camellia sinensis* or other dried plant products labeled as “tea”	91	40	51	1.3
Beans and Legumes	The edible seeds of leguminous plants and products thereof	80	44	36	1.1
Sweeteners (Nutritive)	Sugars and syrups used as nutritive sweeteners (does not include honey)	70	32	38	1.0
Rice	Rice (all varieties), crisp rice, rice bran, and rice flour	62	20	42	0.9
Cocoa and Cacao-Based Products	Cocoa powder, chocolate, cocoa butter, cocoa liquor, and other cacao-based products	41	17	24	0.6
Eggs and Egg Products	Shell eggs, liquid eggs, and powdered eggs from fowl	40	30	40	0.6
Plant-Based Protein Ingredients	Protein products from nonanimal sources	34	8	26	0.5
Vanilla Products	Vanilla pods, seeds, extract, and other naturally derived vanilla-based products	34	20	14	0.5
Vinegars	Solution containing acetic acid and other substances produced through fermentation; may be produced from a variety of sources	29	2	27	0.4

[a] For groups with at least 25 records.

Table 8
Example adulterants by ingredient group (includes the 10 most represented groups, excluding groups with substantial ingredient overlap)

Ingredient Group	Example Adulterants (Incident Records)	Example Adulterants (Inference Records)
Dairy Ingredients	Water, detergent, vegetable oils, urea, formaldehyde, milk powder, sodium hydroxide	Melamine, milk (from alternate species), urea, starch, water, sugar, soy protein isolate, salt, vegetable oils
Seafood and Seafood Products	Seafood product (alternate species), formaldehyde, chloramphenicol, water, gelatin, expired products	Seafood product (alternate species), malachite green, chloramphenicol, formaldehyde, seafood product (farm-raised), escolar
Meat and Poultry Products	Meat product (expired), meat product (alternate species), meat product (unfit for human consumption), bleach, clenbuterol, formaldehyde, meat (nonhalal or nonorganic)	Meat product (alternate species), soy protein, offal, sulfur dioxide, color, gluten, water
Herbs, Spices, and Seasonings	Colors, lead chromate, Sudan dyes, various plant materials (leaves, husks), corn meal, starches	Sudan dyes, metanil yellow, para red, rhodamine B, lead chromate, plant material (alternate botanical origin), grain flours, nut husks/shells
Beverages (Alcoholic)	Methanol, counterfeit spirits, alcoholic beverages (alternate geographic or varietal origin), isopropyl alcohol, water, colors	Water, methanol, alcoholic beverages (alternate geographic or varietal origin), ethanol, sugar, ethylene glycol, isopropyl alcohol, propyl alcohol
Botanical Ingredients	Colors, botanical products (alternate botanical source), chlorophylls, starches, and husks	Botanical products (alternate botanical source), colors, corn starch, active pharmaceutical ingredients, exogenous sources of bioactive compounds
Honey	Honey (alternate geographic origin), chloramphenicol, corn syrup, sugar syrup (unspecified), cane sugar syrup	Honey (alternate geographic origin), corn syrup, high-fructose corn syrup, sugar syrup (unspecified), glucose
Vegetable Oils	Cottonseed oil, Sudan 4 dye, recycled waste cooking oil, palm oil, animal fats/oils	Recycled waste cooking oil, soybean oil, palm oil, sunflower oil, argemone oil
Olive Oil	Sunflower oil, vegetable oil, canola oil, olive oil (alternate grade), olive oil (alternate geographic origin)	Sunflower oil, soybean oil, corn oil, hazelnut oil, canola oil
Beverages (Nonalcoholic)	Beverage product (counterfeit), sugar, water, orange pulpwash, colors, and flavors	Water, high-fructose corn syrup, sugar, apple juice, fruit juice (alternate botanical origin)

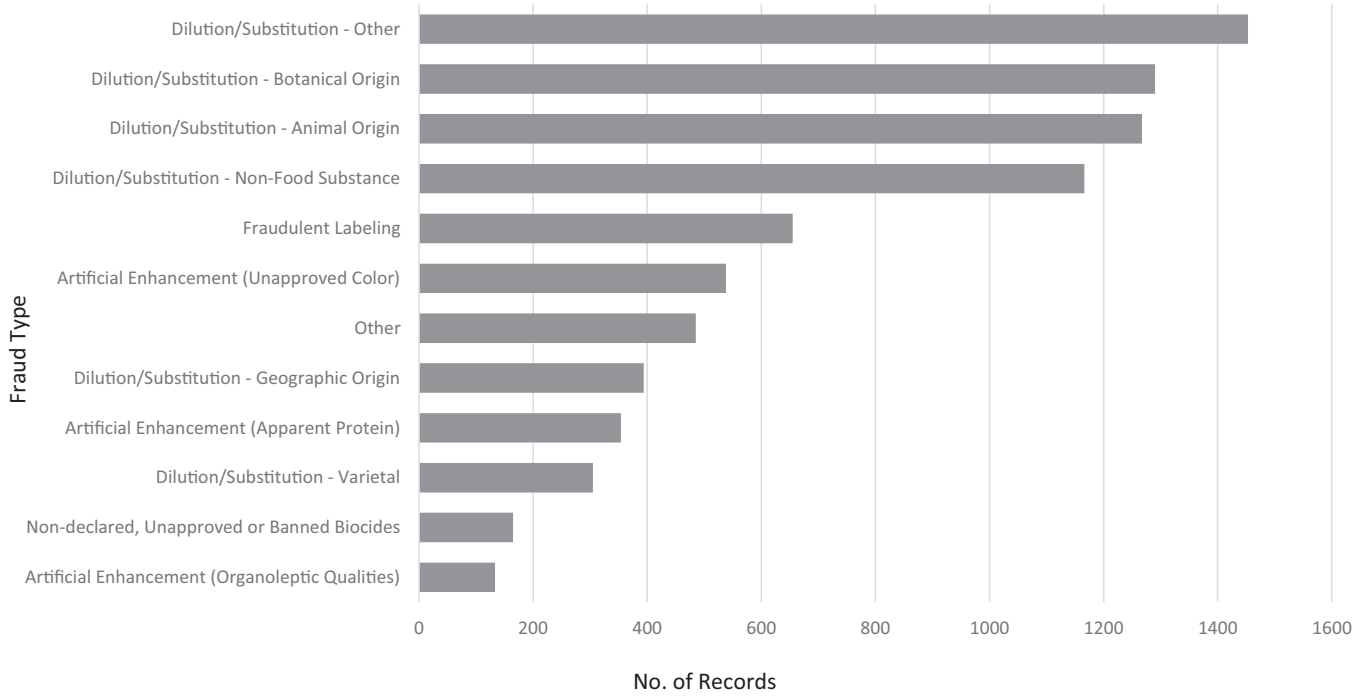

Figure 2. Number of records for each fraud type (each record could have multiple fraud types selected); 521 records were excluded due to being classified as "unknown" (N = 6,717).

stance not approved for use in foods was the second most cited fraud type (see Fig. 2). Artificial enhancement (all forms) was cited in 1,025 (14%) of records. As illustrated in Figure 3, the highest number of incident records was associated with a production location of India (363 records), followed by China (208), the U.S. (161), Italy (128), the U.K. (114), and Pakistan (97). Looking only at incidents classified as high or medium weights of evidence, the highest number of incidents was associated with a production location in China (159), the U.S. (150), India (134), Italy (92), the U.K. (88), and Spain (58).

While this database represents an improvement in both the comprehensiveness of the information and the structure of the data, it is important to note that there are limitations to these data. Due to the nature of food fraud, publicly available records likely represent only a fraction of the true incidence of fraud. Within business-to-business transactions, there are likely instances where fraud is suspected, and the ingredient is rejected by purchasers without the incident being reported publicly. This database was compiled using public sources of information on fraud, including media reports, which can vary in

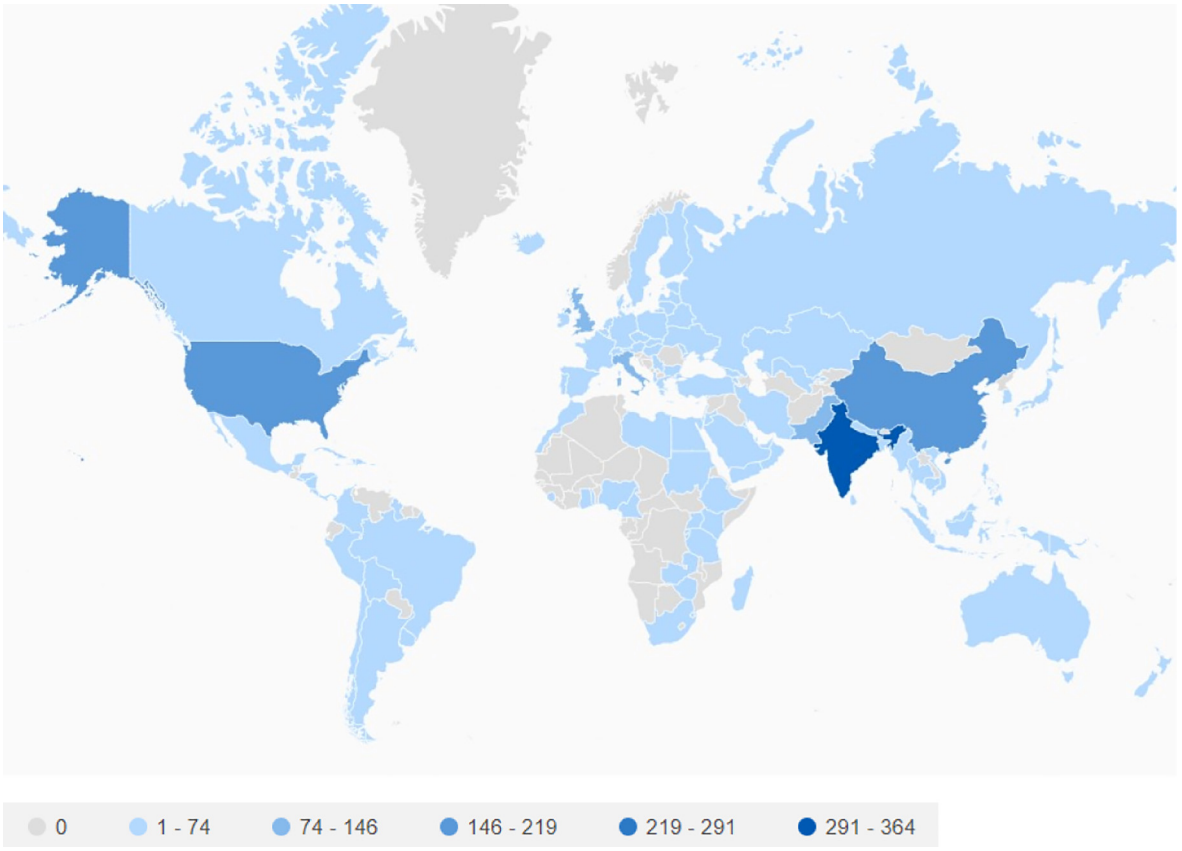

Figure 3. Geographic distribution of incident records (N = 2,051).

accuracy and validity. Data entry also relied on the judgment of the data analysts and the creation of standardized processes and conventions. As noted by Gussow, evaluating a nonpublic source of data such as enforcement actions may give a different picture of our understanding of fraud (Gussow & Mariët, 2022). This database was designed with a specific purpose, and the results presented in this paper should not be interpreted to represent the known scope of fraud globally. In addition, there is wide variation in the surveillance and reporting mechanisms for both food safety and fraud issues around the world. A low incidence of fraud reports from a particular country should not necessarily be interpreted as representing low risk. Finally, although the data analysts used every means necessary to conduct searches for information globally, there is undoubtedly a bias toward English-language reports since this work was based in the U.S. and that the analysts had the most familiarity with English-language food safety reporting mechanisms. Recognizing the limitations above, this work represents a significant advance and a useful estimate on the scope of fraud reported in publicly available sources.

Publicly available food fraud reports vary widely in the specificity and validity of the information provided and, therefore, provide a challenge in creating a database that would provide structure to diverse and nonstandardized information. The use of multiple record types was one way the authors attempted to address this challenge. In addition, the authors felt that excluding information deemed not to be credible would be problematic since we could unintentionally bias the resulting data. Therefore, the database was structured such that a determination of data relevance would be left to the food safety stakeholders (for example, by creating the "weight of evidence" field and geographically tagging incident records). In contrast with the methods used in the previous paper, the authors in this case did attempt to classify information into incident records, where applicable. It is true that many food fraud reports do not have enough information to facilitate classification into distinct *incidents*. However, when they do, the authors found it to be helpful to the understanding of food fraud risk to provide an incident record (Everstine et al., 2013) that summarized the contextual details and provided multiple references, if applicable.

This database was created to serve as a standardized source of information about publicly documented occurrences of food fraud and other information relevant to fraud risk to support food fraud vulnerability assessments, mitigation plans, and food safety plans. Based on the language in the U.S. FDA Preventive Controls Draft Guidance for Industry (Center for Food Safety and Applied Nutrition, 2023c), an evaluation of EMA risk should take into account a "documented history of EMA" in a particular ingredient as well as geographic origin of the ingredient (among other factors). This database was designed to differentiate between documented occurrences of fraud (incident records) and documentation of potential fraud risk (inference records). It was also designed to be searchable by geographic location, to further assist the food safety community in identifying the information most relevant to their supply chains.

Most food fraud mitigation frameworks recommend an evaluation of historical records of food fraud as part of a holistic vulnerability assessment (Barrere et al., 2020; Food Fraud Mitigation Guidance—Appendix XVII General Tests and Assays, 2016; IFS Standards Product and Fraud—Guidelines for Implementation, 2018; Tackling Food Fraud Through Food Safety Management Systems, 2018). The database described herein enables efficient identification of relevant historical information in support of those efforts. On a broader scale, it can be useful for informing the prioritization of resources by regulatory agencies and other stakeholders.

Food fraud history is an important source of information on potential future risk, but it is one of multiple factors that can affect vulnerability (Food Fraud Mitigation Guidance—Appendix XVII General

Tests and Assays, 2016). Publicly available reports on food fraud likely represent only a fraction of the true incidence. There remain many opportunities for future research and development in food fraud risk mitigation. One promising area is the development of tools to make use of economic data as an early warning mechanism for detecting increased food fraud risk or detecting inconsistencies that indicate fraud may be happening. Databases of information sourced from non-public laboratory detections of possible fraud could also be a powerful supply chain protection resource. As stated in a white paper evaluating legal and policy strategies to address food fraud, authentic food is both a social good that benefits consumers and good governance (Roberts & Turk, 2017).

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Karen Everstine reports financial support and article publishing charges were provided by FoodChain ID. Karen Everstine reports a relationship with FoodChain ID that includes: employment. Karen Everstine and Jeffrey Moore were employed by USP at the time the database was created.

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References

Barrere, V., Everstine, K., Théolier, J., & Godefroy, S. (2020). Food fraud vulnerability assessment: Towards a global consensus on procedures to manage and mitigate food fraud. *Trends in Food Science & Technology, 100*, 131–137. https://doi.org/10.1016/j.tifs.2020.04.002.

Botanical Adulterants Prevention Program. (n.d.). American Botanical Council. Retrieved January 8, 2024, from https://www.herbalgram.org/resources/botanical-adulterants-prevention-program/.

CAS REGISTRY | CAS. (n.d.). CAS: A Division of the American Chemical Society. Retrieved January 8, 2024, from https://www.cas.org/cas-data/cas-registry.

Center for Food Safety and Applied Nutrition. (2023a, March 22). *Substances Added to Food (formerly EAFUS)*. U.S. Food and Drug Administration; FDA. https://www.fda.gov/food/food-additives-petitions/substances-added-food-formerly-eafus.

Center for Food Safety and Applied Nutrition. (2023b, September 6). *Guidance for Industry: The Seafood List FDA's Guide to Determine Acceptable Seafood Names*. U.S. Food and Drug Administration; FDA. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-seafood-list-fdas-guide-determine-acceptable-seafood-names.

Center for Food Safety and Applied Nutrition. (2023c, September 26). *Draft Guidance for Industry: Hazard Analysis and Risk-Based Preventive Controls for Human Food*. U.S. Food and Drug Administration; FDA. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/draft-guidance-industry-hazard-analysis-and-risk-based-preventive-controls-human-food.

CFR - Code of Federal Regulations Title 21. (n.d.). U.S. Food and Drug Administration. Retrieved January 11, 2024, from https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=182.20.

Everstine, K., Abt, E., McColl, D., Popping, B., Morrison-Rowe, S., Lane, R. W., Scimeca, J., Winter, C., Ebert, A., Moore, J. C., & Chin, H. B. (2018). Development of a hazard classification scheme for substances used in the fraudulent adulteration of foods. *Journal of Food Protection, 81*(1), 31–36. https://doi.org/10.4315/0362-028X.JFP-17-173.

Everstine, K., Hellberg, R. S., & Sklare, S. A. (2021). Chapter 1—Introduction to food fraud. In R. S. Hellberg, K. Everstine, & S. A. Sklare (Eds.), *Food fraud* (pp. 1–7). Academic Press https://doi.org/10.1016/B978-0-12-817242-1.00010-5.

Everstine, K., Popping, B., & Gendel, S. M. (2021). Chapter 3 - Food fraud mitigation: Strategic approaches and tools. In R. S. Hellberg, K. Everstine, & S. A. Sklare (Eds.), *Food Fraud* (pp. 23–43). Academic Press https://doi.org/10.1016/B978-0-12-817242-1.00015-4.

Everstine, K., Spink, J., & Kennedy, S. (2013). Economically Motivated Adulteration (EMA) of Food: Common Characteristics of EMA Incidents. *Journal of Food Protection, 76*(4), 723–735. https://doi.org/10.4315/0362-028X.JFP-12-399.

Food Fraud Mitigation Guidance—Appendix XVII General Tests and Assays. (2016). United States Pharmacopeial Convention. https://www.usp.org/sites/default/files/usp/document/our-work/Foods/food-fraud-mitigation-guidance.pdf.

Gossner, C.-M.-E., Schlundt, J., Ben Embarek, P., Hird, S., Lo-Fo-Wong, D., Beltran, J. J. O., Teoh, K. N., & Tritscher, A. (2009). The Melamine incident: Implications for international food and feed safety. *Environmental Health Perspectives, 117*(12), 1803–1808. https://doi.org/10.1289/ehp.0900949.

Gussow, K. E. (2020). *Finding food fraud: Explaining the detection of food fraud in the Netherlands* [PhD-Thesis – Research and graduation internal]. https://research.vu.nl/en/publications/finding-food-fraud-explaining-the-detection-of-food-fraud-in-the-.

Gussow, K. E., & Mariët, A. (2022). The scope of food fraud revisited. *Crime, Law and Social Change, 78*(5), 621–642. https://doi.org/10.1007/s10611-022-10055-w.

IFS Standards Product Fraud—Guidelines for Implementation. (2018). IFS Management GmbH. https://www.kin.de/wp-content/uploads/2018/05/FoodFraud-Guide_1805.pdf.

Jijon, A. (2017, September 14). *Food Fraud: The Role of Standards and the Litigation Implications*. Food and Drug Law Institute Annual Conference. https://www.fdli.org/wp-content/uploads/2017/09/Alissa-Jijon-Food-Fraud_09_14_2017-1.pdf.

Johnson, R. (2014, January 10). *Food Fraud and "Economically Motivated Adulteration" of Food and Food Ingredients*. Congressional Research Service. https://sgp.fas.org/crs/misc/R43358.pdf.

Moore, J. C., Spink, J., & Lipp, M. (2012). Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010. *Journal of Food Science, 77*(4), R118–R126. https://doi.org/10.1111/j.1750-3841.2012.02657.x.

Roberts, M. T., & Turk, W. (2017). White paper: The pursuit of food authenticity – Recommended legal & policy strategies to eradicate economically motivated adulteration (Food Fraud). *UCLA Law – Resnick Center for Food Law and Policy* https://law.ucla.edu/news/white-paper-pursuit-food-authenticity.

Spink, J., & Moyer, D. C. (2011). Defining the public health threat of food fraud. *Journal of Food Science, 76*(9), R157–R163. https://doi.org/10.1111/j.1750-3841.2011.02417.x.

Tackling Food Fraud Through Food Safety Management Systems. (2018). The Consumer Goods Forum and GFSI. https://mygfsi.com/wp-content/uploads/2019/09/Food-Fraud-GFSI-Technical-Document.pdf.

United States Pharmacopeial Convention. (n.d.). *Food Chemicals Codex (FCC) | FCC | Online*. Retrieved January 8, 2024, from https://www.foodchemicalscodex.org/.