Economically Motivated Food Fraud and Adulteration in Brazil: Incidents and Alternatives to Minimize Occurrence

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Abstract: Brazil is one of the world's largest food producers. Adulteration of foods is often reported and represent an important potential threat to food safety. Because of this, reduction of the vulnerability of foods to adulteration is of high priority to Brazil. This study analyzes economically motivated food fraud and adulterations in Brazil between 2007 and 2017, based on academic journal reports. In addition, alternatives are proposed to minimize these incidents through good practices, traceability systems and the development of methods to detect food fraud and adulteration. Complex supply chains for foods of animal origin, such as milk and dairy products, were the main targets of food fraud and adulterations. Other products prone to fraudulent activities were vegetable oils, especially olive oil, which are high value products. Meat and fish, as well as their respective by-products, were also involved in some food fraud and adulteration, especially substitution. Cases of extraneous ingredient addition were also reported in the coffee and tea sectors. Comprehensive food fraud and adulteration prevention requires the enforcement of regulatory systems, increased sampling and monitoring, training of food producers and handlers, and development of precise, rapid, and cost-effective methods of fraud detection. The availability of robust methods to identify the chemical constituents of foods could be a decisive step, both to detect and prevent fraud in producer countries and to open up new markets to these products. The results of this study can be used to analyze food safety risks and prioritize target areas for food research and policy-making in order to enforce food safety regulations in Brazil.

Keywords: Brazilian food market, food fraud and adulteration, good practices

Practical Application: A food fraud and adulteration review was conducted based on scientific literature in Brazil. Milk and its products were the main targets of food fraud and adulterations. Food fraud and adulteration causes and suggestions for good practice are presented. The results can be used to analyze food safety and protect consumer rights.

Introduction

Brazil is one of the world's largest food producers. According to the World Trade Organization, it is the third largest exporter of agricultural goods behind the European Union and the United States (World Trade Organization, 2017). Brazil's grain harvest estimate for 2016/2017 was 238.01 million tons, an increase of 27.6% over the previous year (Companhia Nacional de Abastecimento, 2017a, 2017b). According to Tollefson (2010), plentiful sun, water, and land in Brazil create agricultural conditions that are not only sustainable but also prepared to meet the growing food demand on the planet. It is estimated that within 35 yr Brazil will be responsible for producing 40% of the food that will be consumed by a world population of nine billion people (Camargo et al., 2017).

In 2016, Brazil exported $85 billion (US) and imported $13.6 billion (US; Brasil, 2017a). The 10 food most produced in Brazil are: sugar cane (769 million ton), soybean (96 million ton), maize (64 million ton), sugar raw centrifugal (37 million ton), cassava (21 million ton), orange (17 million ton), molasses (15 million ton), barley (14 million ton), rice (10 million ton), and soybean oil (7 million ton; Faostat, 2014, 2016). The top five products with greater exports are soybeans, maize, sugar raw centrifugal, sugar refined, and meat chicken. The principal importers of this products in the world are Republic of Korea (soybean), Chile (maize), Canada (sugar raw centrifugal), Sudan (sugar refined), and Arabia Saudita (meat chicken; Faostat, 2013). Brazil also imports different foods including wheat, maize, malt, rice, and barley, mainly from countries such as United States (wheat and maize), France (malt and barley), and India (rice; Faostat, 2013).

Opportunities for food fraud and adulteration are great due to the large quantity of food produced, exported, and imported, and the high added value of specific products. Moyer, DeVries, and Spink (2017) reported the economic gains and impact of food frauds based on case studies and examples. According to this study, there were diverse food fraud and adulteration opportunities, and these frauds are profitable crimes.

According to the United States Pharmacopeia (USP, 2016a), geographic regions with high vulnerability to food fraud and adulteration are often developing areas with political and social instability and a large and increasing population. Brazil meets many of these conditions and is, therefore, prone to food fraud and adulteration attempts.

The loss of confidence by investors, customers, consumers, and authorities caused by food fraud and adulteration events can be far

more damaging than the direct economic impact. Food fraud and adulteration, therefore, is a direct threat to sustainability, and the reduction of food fraud and adulteration vulnerabilities is of high priority to Brazil. The objective is to reduce food vulnerability to an acceptable level while taking into account potential food safety implications and economic impacts to the business environment (United States Pharmacopeia, 2016a).

Food fraud and adulteration are the deliberate substitution, addition, adulteration or misrepresentation of food or food ingredients for economic gain (FAO, World Trade Organization, 2017). Food fraud and adulteration can be a threat to food safety or negatively affect the nutritional performance of foods. Although food fraud and adulteration are an intentional act for economic gain, a food safety incident is an unintentional act with unintentional harm, and a food defense incident is an intentional act with intentional damage (Spink & Moyer, 2011).

Food fraud and adulteration have been practiced since biblical times but has been sophisticated over time (Souza et al., 2011). In recent years, various food fraud and adulteration incidents have occurred in many countries around the world. Zhang and Xue (2016) conducted an aggregated analysis on economically motivated food frauds and adulterations in China based on 1,553 media reports on food safety scandals and concerns. Peng et al. (2017) reported the main food fraud and adulteration events and their consequences occurring in Taiwan between 2011 and 2015. In the United States, the Peanut Corp. of America (PCA) shipped peanut products known to be contaminated with Salmonella. By doing so, PCA committed food fraud and adulteration because their motivation for shipping the knowingly contaminated product was economic gain by "loss avoidance" (e.g., they did not have to destroy the product; Moyer et al., 2017). In Europe, horsemeat was illegally mixed into beef products in 2013 (O'Mahony, 2013).

These incidents have had impacts both locally and internationally, leading to significant economic losses and concern for human health. Food fraud and adulteration undermine trust in food, regulators and markets. Furthermore, food fraud and adulteration always cause immense financial losses, as most consumers simply switch immediately to other products, categories, or brands and may not return to purchasing the original items (FAO, World Trade Organization, 2017).

Studies of food fraud and adulteration are important for all types of products because these incidents can lead to public health threats and pose drastic potential impacts to the economies of the companies and/or countries involved (Moyer et al., 2017).

Food authenticity is of primary importance for both consumers and food industries in all production stages, from the purchasing of raw materials to the distribution of finished products all over the world (Dong, Luo, & Luo, 2016).

Standards for authenticity that are regularly enforced throughout the entire production chain help prevent the occurrence of food fraud and adulteration events. However, discussions at the international level on the suitability of the tools used to assess the vulnerability of supply chains to food fraud and adulteration are still underway, and it remains to be fully determined which mechanisms will be most effective for global trade and supply chains (FAO, World Trade Organization, 2017).

There is a lack of published reviews about food fraud and adulterations in Brazil, especially concerning adulterations in different categories of food products. This study examined economically motivated food fraud and adulteration incidents in Brazil, based on the analysis of academic journals between 2007 and 2017. In addition, alternatives are proposed to minimize these incidents

based on good practices, traceability systems and development of methods to detect food fraud and adulteration.

Materials and Methods

Data sources

A systematic literature review was conducted to identify peer-reviewed scientific journal articles published between 2007 and 2017 concerning food fraud and adulteration incidents in Brazil. The use of scientific journal articles allows access to legitimate data, but that data are often reported after a significant delay following the incident.

National and international publications were selected from databases such as Science Direct, Scielo, FSTA, and others. Publications were selected based on the presence of the terms "fraud," "adulteration," and "authenticity of foods" in the keywords, titles, or summaries. Only studies carried out in Brazil were included.

This study focused only on intentional food fraud and adulteration involving bad faith and motivated by economic advantages. Studies about pesticide residuals, mycotoxins, microorganisms, and other contaminants were excluded.

Food fraud and adulteration classification

Several databases exist that classify food fraud and adulteration types, including the USP Food Fraud Database, the Economically Motivated Adulteration (EMA) Incidents Database, and the European Union Rapid Alert System for Food and Feed (RASFF; Manning, 2016; Moyer et al., 2017; Zhang & Xue, 2016). This study utilized the EMA Incidents Database, which defines the following food fraud and adulteration types: intentional distribution of contaminated products, artificial enhancement, counterfeiting, substitution, mislabeling, dilution, transshipment/origin masking, and theft and resale. Descriptions of the food fraud and adulteration types used in the EMA Incidents Database are available at Zhang and Xue (2016).

Results

This review identified 42 records of food fraud and adulteration in Brazil from 2007 to 2017. These incidents were detailed in the Table 1.

Figure 1 summarizes food fraud and adulteration profile that occurred in Brazil in the period from 2007 to 2017. Figure 2 shows the main types of fraud reported in food products.

Discussion

Brazil is a leading food producer and exporter, feeding approximately 1.5 billion people worldwide. In 2016, agribusiness as a whole accounted for 23.6% of gross domestic product and accounted for 45.9% of the value of exports, generating a commercial balance of US$ 71 billion (Projeções do agronegócio, 2017). In the same year, this sector was responsible for 19 million people occupied, which accounted for almost half (9.09 million) of workers in the primary segment (Embrapa, 2018). The maintenance of the Brazilian competitiveness in the future depends on significant increases in crop yields, but also on the good reputation in the international market, which is key to protect its agriculture and economy.

Food fraud and adulteration by food category

The results of this study are representative of food fraud and adulterations that occurred in Brazil between 2007 and 2017. However, as described in Everstine, Spink, and Kennedy (2013),

Table 1–Food fraud and adulterations in different food categories reported in scientific literature in Brazil, from 2007 to 2017.

Foods	Fraud type[a]	Adulterants	Principal method applied	Region	Year	Reference
Milk and milk-based products						
Milk	Dilution	Addition of water	Cryoscopic index	Janauba city, Minas Gerais state	2009	Caldeira et al., 2010
Ultra-high temperature milks (UHT)	Artificial enhancement	Addition of urine, formaldehyde, hydrogen peroxide, and chlorine.	DNA analysis	Brazil	2010	Souza et al., 2011
Integral milk pasteurized type C	Artificial enhancement / Dilution	Addition of water, hydrogen peroxide, and sucrose.	Cryoscopic index, qualitative analysis with alcoholic solution of guaiacol, qualitative analysis with descending paper chromatography.	Brasília city, Federal district	2010	Rosa–Campos et al., 2011
Milk powder	Dilution	Other non-milk fats and oils: soybean oil, palm oil, hydrogenated soybean oil and animal fat (cow tallow and pork lard).	MALDI-QTOF MS	Brazil	2008	Garcia et al., 2012
Parmesan cheese	Artificial enhancement	Addition of starch	Qualitative analysis with lugol solution.	Ponta Grossa city, Paraná state	–	Ribeiro et al., 2012
Bulk goat milk	Dilution	Addition of cow's milk	Duplex PCR assay	Brazilian northeastern region	2012	Rodrigues et al., 2012
Raw milk	Dilution / removal	Addition of water and removal of fat.	Cryoscopic index, IR spectroscopy	Ivaiporã city, Paraná state	2010	Ribeiro, Beloti, Silva, & Tamanini, 2013
Raw milk	Dilution / removal	Addition of water and removal of fat.	Density	Piraí do Sul city, Paraná state	2012	Montanhini & Hein, 2013
Frescal goat cheese	Dilution	Addition of cow's milk.	Molecular identification (PCR)	Rio de Janeiro metropolitan area, Rio de Janeiro state	2010 to 2011	Golinelli et al., 2014
UHT milk	Artificial enhancement	Addition of starch and sodium hydroxide.	Bromothymol blue and lugol reactions.	Erechim city, Rio Grande do Sul state	2014	Rosa et al., 2015
Milk	Artificial enhancement	Addition of sodium hydroxide.	ICP-MS	Brazil	–	Buzzo et al., 2015
Parmesan cheese	Artificial enhancement	Addition of non-starch and non–protein substance, such as a gum or a fiber.	Chemical composition (moisture, ash, carbohydrates, proteins and lipids), GES content, and lugol reaction.	Paranavaí city, Paraná state.	–	Gomes et al., 2015
Parmesan cheese	–	No frauds were detected	Qualitative analysis – lugol reaction.	Paraná state.	–	Montanhini et al., 2015
Buffalo cheese	Dilution	Addition of cow's milk.	Molecular identification (multiplex PCR).	Brazilian northern region.	–	Silva et al., 2015
Buffalo mozzarella	Dilution / Substitution	Addition of cow's milk.	Molecular identification (PCR)	São Paulo city, São Paulo state.	2013–2014	Souza, 2015
Milk	Dilution	Addition of water.	Cryoscopic index	Aparecida city, Paraíba state.	2017	Silva et al., 2017

(Continued)

Table 1–Continued.

Foods	Fraud type[a]	Adulterants	Principal method applied	Region	Year	Reference
Oils and fats						
Olive oil	Dilution	Addition of other vegetable oils (rich in linoleic acid).	UV spectrophotometry, HPLC-RI	São Paulo city, São Paulo state.	2008	Aued-Pimentel et al., 2008
Encapsulated specialty oils	Dilution / Substitution	Addition of vegetable oils (soybean oil) or substitution per conjugated linoleic acid.	GC-FID, HPLC-UV	São Paulo state.	2012	Hirashima et al., 2013
Extra virgin olive oil	Dilution	Addition of other vegetable oils (rich in linoleic acid and olive pomace oil).	GC-FID, UV spectrophotometry	São Paulo city, São Paulo state.	2013	Aued-Pimentel et al., 2013
Extra virgin olive oil	Dilution	Addition of soybean oil.	STELDI-MS	Brazil –	–	Oliveira & Catharino, 2015
Coconut oil	Dilution	Addition of other vegetable oil.	GC-FID HPLC-FL	São Paulo city, São Paulo state.	2015	Aued-Pimentel, Castro, Sousa, Amaral-Mello, & Abe-Matsumoto, 2015
Cold pressed vegetable oils	Dilution / Substitution	Addition or substitution of other vegetable oil.	GC-FID	São Paulo city, São Paulo state.	2014	Silva, 2015
Olive oil	Dilution / Substitution	Addition of other vegetable oil (especially soybean oil).	GC-FID, HPLC-RI, HPLC-FL, UV spectrophotometry	São Paulo city, São Paulo state.	2014 to 2016	Aued-Pimentel et al., 2017
Extra virgin olive oil	Dilution / Substitution	Addition of other vegetable oil and refined olive oil.	HPLC-FL, GC-FID	Oils imported from various countries marketed in Brazil.	–	Tfouni et al., 2017
Linseed, safflower, evening primrose and, coconut oils.	Dilution / Substitution	Addition of other vegetable oil (especially soybean oil).	GC-FID	São Paulo city, São Paulo state.	2014 to 2016	Silva et al., 2018
Fish and seafood						
Seafood products	Substitution / Counterfeit	Highly priced species (flounder, pink cusk-eel and cod) were substituted for cheaper species (basa and Alaska pollock).	Molecular identification (PCR)	Brazilian Southern region	2014	Carvalho et al., 2015
Croaker (Sciaenidae) fillets labeled "pescada branca"	Substitution / Counterfeit	Mixture of eight species of the families Sciaenidae, Lutjanidae and Serranidae and unidentifed taxa.	Molecular identification (PCR)	Pará state	2012	Brito et al., 2015
Fish species "sardine" / Seafood products	Substitution / Substitution / Counterfeit	Other species / Substitution of a more valuable species by a cheaper one.	Molecular identification (PCR) / Molecular identification (PCR)	Rio de Janeiro state / Brazil	2014 / 2016	Leonardo et al., 2016 / Carvalho, Guedes, Gloria Trindade, Coelho, & Lima Araujo, 2017
Meat and products						
Various meat products	Dilution	Chicken DNA in pork sausage	Molecular identification (PCR)	Ponta Grossa city, Paraná state	–	Felkl, 2014
Beef hamburger	Dilution	Soy protein	IRMS	Brazil	2015	Ducatti et al., 2016

(Continued)

Table 1–Continued.

Foods	Fraud type[a]	Adulterants	Principal method applied	Region	Year	Reference
Coffee and tea						
Tea (Ilex paraguariensis St Hil)	Dilution Mislabeling	Presence of sucrose	Microscopic analysis	Chapecó city, Santa Catarina state	–	Mendes, Quadri, & Quadry, 2007
Tea (Pimpinella anisum L.)	Dilution Mislabeling	Presence of soil and sand.	Microscopic analysis	Rio de Janeiro city, Rio de Janeiro state	2012	Santos & Abrantes, 2015
Coffee	Dilution Mislabeling	Presence of barley, corn, and rice.	Real-time PCR	Coffees from various countries marketed in Brazil	2016	Ferreira et al., 2016
Coffee	Dilution Mislabeling	Presence of corn, barley, or coffee husk.	H NMR	Brazilian Southeastern region	2017	Moura Ribeiro et al., 2017
Beverages						
Orange beverages	Artificial enhancement	Addition of sucrose.	IRMS	São Paulo state	–	Queiroz et al., 2009
Passion fruit beverages	Artificial enhancement	Addition of sucrose.	IRMS	São Paulo state	–	Diniz, 2010
Beer	Counterfeit	To switch the labels and bottle caps of less expensive brands by the labels and caps of the more expensive market leader brands.	PS-MS	Brazil	2016	Pereira et al., 2016
Grape juice	Dilution	Addition of apple juice.	HPLC–DAD, HPLC-RI	Brazil	–	Spinelli et al., 2016
Other foods						
Honey	–	No frauds were detected.	Moisture, HMF, reducing sugars, apparent sucrose, proteins, Fiehe, Lugol, and Lund reactions.	São Paulo state	–	Bera & Almeida-Muradian, 2007
Honey	Dilution Substitution	Addition of honeydew, nut honey, or mixture of both.	Electric conductivity, HMF, and Fiehe reaction	Pelotas city, Rio Grande do Sul state.	2008	Richter, Jansen, Venzke, Mendonca, & Borges, 2011
Peanut sweets and pumpkin sweet.	Dilution Substitution	Addition of wheat flour to peanut sweets and sweet potato to pumpkin sweet.	Microscopic analysis	Rio de Janeiro state	–	Marques et al., 2016

[a]Fraud types according to Economic Motivated Adulterations (EMA): intentional distribution of contaminated products, artificial enhancement, counterfeit, substitution, mislabeling, dilution, transshipment/origin masking, and theft and resale. GES, fat content in dry matter; HPLC–FL, liquid chromatography with fluorescence detection; GC–FID, gas chromatography with flame ionization detection; H NMR, proton nuclear magnetic resonance spectroscopy technique; HPLC-DAD, high-performance liquid chromatography (HPLC) with a photodiode array detector; HPLC-UV, liquid chromatography with ultraviolet detection; HPLC-RI, performance liquid chromatography with refractive index; IRMS, isotope ratio mass spectrometry; IR spectroscopy, infra-red spectroscopy; PCR, polymerase chain reaction; MALDI-QTOF MS, matrix–assisted laser desorption/ionization–quadrupole time of flight mass spectrometry; PS-MS, paper spray mass spectrometry; ICP-MS, inductively coupled plasma mass spectrometry; HMF, hydroxymethylfurfural.
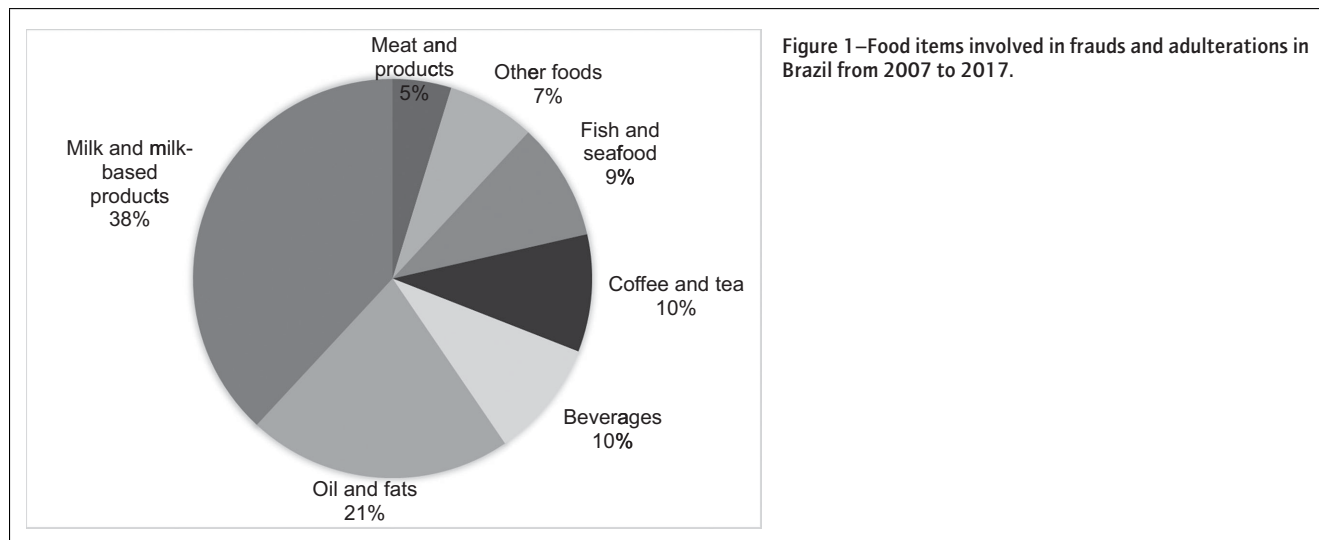
Figure 1–Food items involved in frauds and adulterations in Brazil from 2007 to 2017.
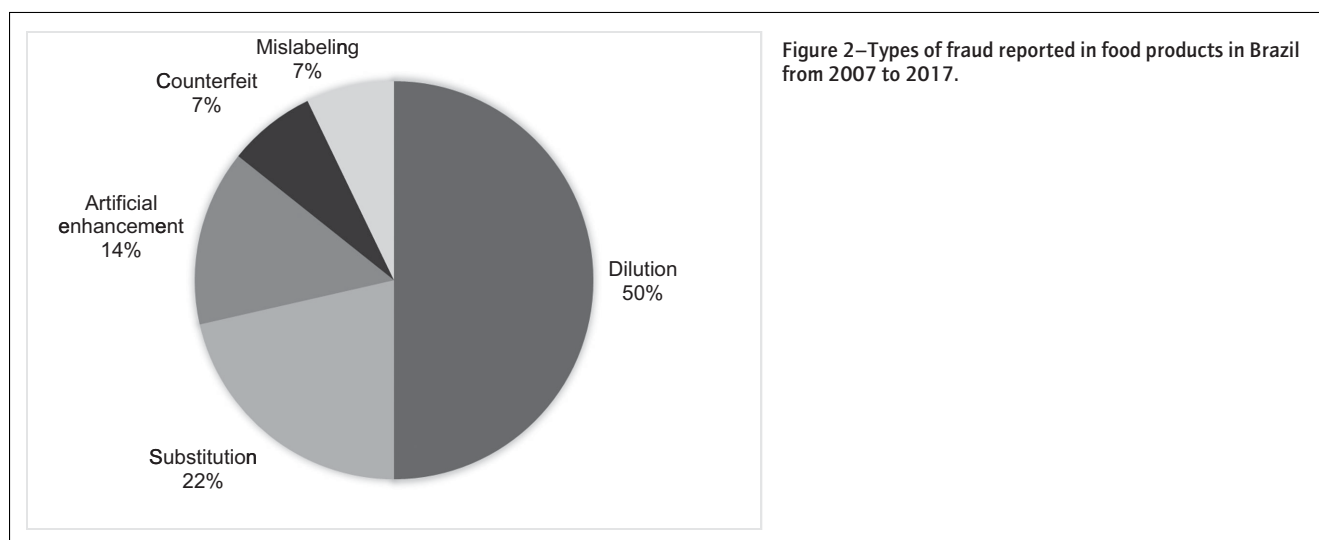

Figure 2–Types of fraud reported in food products in Brazil from 2007 to 2017.

large-scale food fraud and adulteration incidents are reported in the scientific literature, but smaller incidents are typically only reported in the media. Usually, scientifically documented incidents of food fraud and adulteration have a high degree of legitimacy, but are reported after a significant delay following the incident (United States Pharmacopeia, 2016a). In addition, the underreporting of food fraud and adulteration are common, especially when the adverse health effects are chronic with unclear evidence of cause and effect. Food fraud and adulteration deliberately designed to evade detection is also difficult to report in academic journals (Everstine et al., 2013).

Milk and milk-based products were the main targets of adulterations in Brazil (Figure 1). The most common fraud in these products was the addition of water, described in Caldeira et al. (2010); Montanhini and Hein (2013); Ribeiro et al. (2013); Silva, Oliveira, Leite, Oliveira, and Sousa (2017). Souza et al. (2011) reported an intentional contamination of ultra-high temperature (UHT) milks with urine, formaldehyde, hydrogen peroxide, and chlorine. Additions of water, hydrogen peroxide, and sucrose were found in integral milk (Rosa-Campos, Rocha, Borgo, & Mendonça, 2011). Fraudulent addition of sodium hydroxide

(Buzzo et al., 2015), starch (Ribeiro et al., 2012; Rosa, Garbin, Zamboni, & Bonacina, 2015), and other substances, such as a gum or fiber (Gomes, Alves, Pimentel, & Klososki, 2015) were also reported. Other adulterations involved the addition of cow milk to bulk goat milk (Rodrigues et al., 2012), goat cheese (Golinelli et al., 2014), and buffalo cheese (Silva et al., 2015; Souza, 2015). Furthermore, the dilution of milk powder with the addition of non-milk fats (Garcia et al., 2012). Montanhini et al. (2015), however, evaluated parmesan cheese and did not detect fraud.

The second most common target for food fraud and adulteration were vegetable oils (Figure 1). Dilution and substitution of olive oil with refined olive oils and other vegetable oils, such as soybean oil, was the main fraud reported (Aued-Pimentel, Silva, Takemoto, & Cano, 2013; Aued-Pimentel, Takemoto, Kumagai, & Cano, 2008; Oliveira & Catharino, 2015; Silva, 2015; Aued-Pimentel, Separovic, Silvestre, Kus Yamashita, & Takemoto, 2017; Tfouni et al., 2017). Encapsulated specialty oils were also adulterated with other vegetable oils (Hirashima, Silva, Caruso, & Aued-Pimentel, 2013; Silva, 2015; Silva, Torres, Almeida, & Sampaio, 2018). Aued-Pimentel, Castro, Sousa, Amaral, and Abe-Matsumoto (2015) reported the addition of other vegetable oils to coconut oil.

Fish and seafood products were also targets of food fraud and adulterations (Figure 1). The most common fraud reported was the substitution of a highly expensive species of fish for more a less priced species (Brito, Schneider, Sampaio, & Santos, 2015; Carvalho, Palhares, Drummond, & Frigo, 2015; Leonardo et al., 2016). Similarly, Carvalho, Guedes, Gloria Trindade, Coelho, and Lima Araújo (2017) reported the mislabeling of seafood products, with a substitution of a more valuable species for a less valuable one.

Felkl (2014) reported substitution of pork for chicken in sausage. Similarly, the beef hamburger was substituted for soy protein (Ducatti, Pinto, Sartori, & Ducatti, 2016; Figure 1). According to Espinoza et al. (2015) in meat products, the substitution of animal or vegetable species for similar ones with less economic value is a common fraud practice.

Brazil is the largest coffee producer in the world. In this sector, the main fraud reported was the addition of barley, corn, rice, and coffee husk (Ferreira et al., 2016; Moura Ribeiro, Boralle, Pezza, Pezza, & Toci, 2017). The fraudulent addition of sucrose (Mendes, Quadri & Quadri, 2007), soil, and sand (Santos & Abrantes, 2015) to tea was also reported.

Other frauds were reported in beverages including beer and fruit juice products (Figure 1). In beer production, counterfeiting fraud was reported. The labels and bottle caps of less expensive beer brands were replaced with the labels and caps of more expensive market leader brands (Pereira, Amador, Sena, Augusti, & Piccin, 2016). Spinelli et al. (2016) identified the fraudulent addition of apple juice to grape juice. Furthermore, the fraudulent addition of sucrose was reported in orange beverages (Queiroz et al., 2009) and passion fruit beverages (Diniz, 2010). Silva et al. (1999) studied the effect of sugar addition to fruit juices and reported that the most common adulterations were sucrose, high fructose corn syrup, cane medium invert syrup, and beet medium invert syrup.

Honey and sweets were other targets of economically motivated food fraud and adulteration (Figure 1). Richter, Jansen, Venzke, Mendonça, and Borges (2011) reported the addition of honeydew and nut honey to bee honey. Although, Bera and Almeida-Muradian (2007) evaluated bee honey and did not detect any fraud. Marques et al. (2016) reported the fraudulent addition of wheat flour and sweet potato to peanut and pumpkin sweets, respectively.

Our results demonstrated some common characteristics of food fraud and adulterations, which may encourage more research on the subject and may increase control of the food supply by inspection agencies. In general, animal-based food products involved in complex supply chains, such as milk, meat, fish, and their products, are the main targets for food fraud and adulterations. The many steps and complexity involved in the production, transportation, and processing of these products facilitate food fraud and adulteration opportunities. Furthermore, the number of food variables and parameters to be analyzed, the time to get the results and the cost of the analysis, further complicates the detection of food fraud and adulteration.

Milk and dairy products and vegetable oils had the highest prevalence and incidence of adulterations in Brazil from 2007 to 2017. These results were consistent with those found by Moore, Spink, and Lipp (2012) and Zhang and Xue (2016). In a review of 584 literature references, Moore et al. (2012) found that the top seven most commonly adulterated ingredients, representing more than 50% of the database records, were olive oil (167 records), milk (143 records), honey (71 records), saffron (57 records), orange juice (43 records), coffee (34 records), and apple juice (20 records). Zhang and Xue (2016) reviewed 1,553 media reports in China and found

that animal-based foods, further processed or mixed foods, beverages, and cooking oils were the main foods involved in frauds.

Various types of adulteration of milk have been reported, especially the addition of water, foreign proteins, whey proteins, melamine, urea, and vegetable, or animal fats (Poonia et al., 2017). One of the notable examples of the potential risk from EMA in dairy products was reported in China in 2008. In this case, dairy products, including infant formula, containing melamine were sold, causing six deaths, and thousands of cases of illness (Everstine et al., 2013; Zhang & Xue, 2016).

Other products prone to fraudulent activities are vegetable oils, especially olive oil, which have significant economic value in the market. According to Aued Pimentel et al. (2017), samples of olive oil bottled in Brazil had a higher incidence of adulteration than olive oil bottled in other countries. This finding demonstrates the need for rigorous control in the production and commercialization of this product.

International reports on adulterated or counterfeited vegetable oils are common. The main causes are related to high demand, added value, and potential profit. Olive oils and encapsulated oils are attractive targets for frauds due to the high added value of these products. The most common adulterations in oils and fats are the addition of, or substitution with, lower quality oils (refined or olive-pomace oil) or other vegetable oils (soybean oil; Everstine et al., Aued-Pimentel, Separovic, Silvestre, Kus-Yamashita, & Takemoto, 2017).

Several types of fish and seafood fraud and adulterations are reported in the literature. The most common frauds are the substitution of a higher market value species, indicated on the package label, for the lower value species; product weight increase by the addition of excess water to frozen products; change in the stated country of origin; and use of illicit chemicals in production (Everstine et al., 2013).

Types of food fraud and adulteration and regional pattern

Dilution, the partial replacement of an ingredient in a food product, was the most common food fraud in Brazil (Figure 2). Substitution, characterized by the complete replacement of a food product, was the second most prevalent fraud (Figure 2). Artificial enhancement, defined as the addition of an extraneous ingredient to a food product, was the third most common fraud in Brazil.

This study found the most prevalent types of adulteration to be dilution and substitution. A common example of dilution is the addition of water to milk to increase the volume of the final product. Examples of the fraudulent addition of extraneous substances to food products included the addition of sucrose to tea to increase the product weight and the addition of sodium hydroxide to decrease acidity and increase conservation time in milk. These frauds are serious problems in food markets that threaten the livelihood of the market traders and seriously infringe on the consumers' health and rights (Dong et al., 2016).

Brazil is a federation composed of five regions, 26 states, one federal district, and several cities. Overall, there is no regional pattern for food fraud and adulteration in Brazil. Food fraud and adulteration were distributed in all regions with no significant regional variation in the reported cases (Table 1). However, the state of São Paulo, the most populated in Brazil, reported more cases than any other individual state.

The reported cases of economically motivated food fraud and adulteration were distributed in all regions of Brazil. However, it must be pointed out that the state of São Paulo, the main consumer of food, as well as, the most industrialized state, reported

more cases than other states. It should be considered that the wide range of public and private laboratories and significant number of universities located in São Paulo may explain the large amount of research on food fraud and adulteration conducted in that state. Zhang and Xue (2016) reported that EMA was concentrated in the regions with the highest levels of industrialization and urbanization.

Analytical methods

According to Moore et al. (2012), instrumental techniques can be selected to verify the presence or absence of a particular adulterant. The techniques for this purpose tend to be more specific as it scans only a characteristic compound. However, according to the same authors, another way to detect adulterants is by evaluating various compounds, including identity, authenticity, and ingredient purity testing. Techniques coupled to the mass spectrometer have these characteristics, such as isotopic ratio mass spectrometry for the evaluation of soy protein in meat product (Ducatti et al., 2016) and the addition of sucrose in juices (Diniz, 2010; Queiroz et al., 2009).

Table 1 reported the principal instrumental techniques used in the selected studies. Chromatographic techniques and molecular identification (PCR) were the most common methods used to detect food fraud and adulteration. Sometimes, combinations of techniques were necessary to evaluate food adulterants.

Analytical methods are essential for detecting and preventing food fraud and adulterations. The choice of method(s) should be careful and appropriate to the level of concentration and type of analyte to be analyzed. According to Moore et al. (2012), the most common techniques used to detect fraud in food are chromatography and spectroscopy. The adulteration in the food may be very subtle and a combination of different techniques is often necessary. It is important to verify and validate preventive controls introduced in the food production continuously.

Liquid and gas chromatography coupled to high-sensitivity detectors, such as single and triple quadrupole mass spectrometers, can be used in the detection and quantification of fraudulent substances in food. Liquid chromatography tandem mass-spectrometry (LC-MS/MS) was used to detect nitrogen-rich adulterants, including melamine, ammeline, ammelide, and cyanuric acid, on various food matrices (Frank, Bessaire, Tarres, Goyon, & Delatour, 2017). A simultaneous quantification of caseins and whey proteins in milk was developed using an ultra-high-performance liquid chromatography-tandem mass spectrometry (UHPLC-MS/MS) method (Ke et al., 2017). Water concentration in alcoholic beverages was determined using an online pyrolysis technique for the direct determination of oxygen isotope ratios ($\delta 18O$; Wang, Zhong, Li, & Huang, 2015). Chromatography coupled with mass spectrometry continues to evolve and is a technique that produces accurate and reproducible results.

Spectroscopic techniques are very promising tools to detect and/or quantify adulteration in food because they are rapid, non-destructive, effective, reliable, and do not use chemical reagents (Kamal & Karoui, 2015). The NIRS methodology was successfully applied to identify food fraud and adulteration in the following food production chains: milk and dairy products (Carvalho et al., 2015; Gondim, Junqueira, Souza, Ruisánchez, & Callao, 2017; Kamal & Karoui, 2015; Rodrigues et al., 2016), honey and botanical origin studies (Siddiqui, Musharraf, Choudhary, & Rahman, 2017), coffee (Reis, Franca, & Oliveira, 2013), bovine meat (Nunes et al., 2016), and extra virgin flaxseed oil (Souza, Santana, Gontijo, Mazivila, & Borges, 2015). Infrared spectroscopy com-

bined with chemometrics has been used as a powerful tool for determining adulterants in milk, contributing to product quality assurance and serving as a method for cross-checking results (Nascimento, Santos, Pereira-Filho, & Rocha, 2017). Porep, Kammerer, and Carle (2015) reviewed online applications of NIR on an industrial scale, which requires different construction designs of NIR spectrometers for hyperspectral imaging, portable devices, fiber optic and direct contact probes, tube integrated probes measuring through windows, and automated sample cell loading. These alternative techniques can be used in the field for an initial inspection (screening) of the food quality.

Chemometric techniques coupled with laboratory analysis have proven to be valuable tools for monitoring food fraud and adulterations. These mathematical and statistical methods are being used for handling, interpreting, and predicting chemical data in order to gain the maximum effective information from the analysis (Indelicato et al., 2017).

Food fraud and adulteration prevention

The first step in preventing food fraud and adulteration is to determine the potential vulnerability of an ingredient to fraud by reviewing the factors known to be helpful in predicting fraud occurrence (United States Pharmacopeia, 2016a).

According to Spink, Moyer, and Whelan (2016) and Moyer et al. (2017), the best strategy to minimize food fraud and adulteration is to prevent and/or reduce the opportunity for fraud through the development of a strong control culture and risk management strategies.

The main programs to guarantee food safety are the Six Sigma and Hazard Analysis and Critical Control Point methodologies. These programs depend critically on consistent Good Agricultural Practices, Good Manufacturing Practices, and Sanitation Standard Operating Procedures, along production chains.

The primary way to reduce food fraud and adulteration is to develop industry standards and certifications (for example, Global Food Safety Initiative) and identify incidents (for example, through market surveillance to identify fraud incidents and collating the results in databases such as USP; Spink, Moyer, & Speier-Pero, 2016). Innovations in testing methods (e.g., the USP and the European Commission's Food Integrity Project), expanding law enforcement activity (e.g., Europol/INTERPOL Operation OP-SON) and the introduction of new legislative provisions (e.g., US Food Safety Modernization Act, Chinese Food Safety Laws, etc.) will also help reduce food fraud and adulteration.

USP has designed guidelines for developing and implementing a preventive management system to address intentional, economically motivated adulteration of food ingredients. These guidelines characterize the overall fraud vulnerabilities and propose a mitigation strategy (United States Pharmacopeia, 2016a).

Brazilian governmental programs for food fraud and adulteration prevention. Sanitary control of food and beverages is shared by the Ministry of Health (National Health Surveillance Agency – ANVISA) and Ministry of Agriculture, Livestock and Food Supply (MAPA).

Ministry of Health concentrates the monitoring of the sanitary quality of food products, by joint actions carried out among ANVISA, Local Sanitary Vigilance (State / Municipal), and Central Public Health Laboratories (Lacen). Besides of monitoring commercially available food products, these services also provide the monitoring of sanitary quality of commercial establishments, identifying sectors of commerce, and/or food industry that require preventive intervention. When possible food infractions was

found, Sanitary Vigilance (Visa) are responsible for the collection and sampling and the Central Public Health Laboratories (Lacen) conducts the laboratory analysis. As example, since 1995, São Paulo State are developing the "Programa Paulista de Análise Fiscal de Alimentos," in conjunction with the Sanitary Surveillance Center (CVS), the Adolfo Lutz Institute (IAL), and the Control Coordination Office (SES). Each year, a category of food is selected to be monitored, considering criteria such as: potential health risk, consumption scale, results of consumer complaints and inspection experiences. As well as, food included in ANVISA monitoring programs, such as "Pró-Iodo" (evaluation of iodine in salt), "PARA" (Program for Analysis of Pesticide Residues in Food), among others (Centro de Vigilância Sanitária, 2018).

In MAPA, there are many programs to evaluate food quality. As example "Plano Nacional de Controle de Resíduos e Contaminantes – PNCRC/Animal" that is a risk management tool adopted by MAPA with the objective of promoting chemical safety of food from animal origin produced in Brazil. In this program are included tests such as veterinary drugs, agrochemicals, inorganic contaminants, mycotoxins, and dioxins. The analyzes were carried out in laboratories of the National Network of Agricultural Laboratories, composed of National Agricultural Laboratories - LANAGROs (MAPA official laboratories) and other accredited public/private laboratories (Brasil, 2017b).

Brazilian food fraud and adulteration database. To the best of our knowledge, there is no food fraud and adulteration database in Brazil. It is important to create such a database in Brazil similar to those in other countries, such as the USP Food Fraud Database in the United states and the RASFF in the European Union (Moyer et al., 2017), to register the historic adulteration of food in order to subsidize prevention measures (Moyer et al., 2017). The USP collects food fraud and adulteration incidents data for public edification and prescribes test methods to authenticate genuine products and ingredients. The USP Food Fraud Database contains thousands of incidence entries covering a significant array of adulterants in many ingredients detected and/or monitored by different methodologies (United States Pharmacopeia, 2016a).

It should be noted that such databases also allow a temporal evaluation of food fraud and adulteration because it is possible to see the fluctuations of reported cases within different years and to design strategies to counteract frauds when there are increases.

Creation of a food fraud and adulteration database in Brazil would allow for the systematic analysis of the data, which would support actions to reduce food fraud and adulteration in the future. The main objective of the database would be to aggregate information from food fraud and adulteration cases in Brazil reported through the media, governmental organizations, and the scientific literature. It would also contain information concerning the detection and prevention of fraud and adulterations in food.

Industry associations and groups to prevent food fraud and adulteration. Many industries are careful with their brands and prioritize the delivery of authentic food to their consumers. Because of this, some producers organize themselves in groups and associations, facilitating communication, recommending standard analytical methods, and conducting frequent analysis of foods sold in the marketplace. These industry-driven associations are an option to avoid adulterations and gain consumer confidence (Everstine et al., 2013).

The Brazilian Coffee Industry Association (ABIC), an entity created in 1973, develops and implements programs focused on maintaining the purity, quality, and sustainability of coffee, as well as integrating industry, retail, and points of consumption. The

Permanent Coffee Purity Control Program (ABIC Purity Seal) certifies the purity of roasted and ground coffee by continuous monitoring of the brands in order to inhibit the action of companies that adulterate their products (Associação Brasileira da Indústria de Café, 2017).

As for olive oil, the Brazilian Association of Producers, Importers and Traders of Olive Oil (OLIVA) follows standards and guidelines of quality determined by the International Olive Oil Council (IOC), disseminates information about olive oil and carries out monitoring programs for the products marketed in Brazil (Associação Brasileira de Produtores, Importadores e Comerciantes de Azeite de Oliveira, 2017).

In the document Food Fraud Prevention (2016), the company Nestle described processes for food fraud and adulteration prevention and measures to allow the early detection of food fraud and adulterations and emerging threats (Nestle, 2016).

Food traceability and geographic certification. Food safety related incidents have led to the need to establish traceability systems that are able to identify contaminated foods and remove them from the market, thus assuring consumers of the quality of products.

Food traceability provides a high level of consumer protection by precisely targeting recalls, eliminating nonconsumable food products, and promoting the investigation of the causes of food safety issues. Food traceability, therefore, is an integral part of food safety, food quality, food defense, and the food supply chain (Badia-Melis, Mishra, & Ruiz-García, 2015). The importance of food traceability is illustrated in the study of Silva et al. (2014), in which an isotopic fingerprint of Marajó's dairy products was developed to establish a specific signature that allows the separation of Marajó's products from those of different regions.

Recently, the use of Blockchains and Internet of Things for implementation of traceability systems can provide an information platform for all the supply chain members with openness, transparency, neutrality, reliability, and security (Tian, 2017).

Conclusion

This research showed that animal-based food products involved in complex supply chains, such as milk, meat, fish, and their products, are the main targets for food fraud and adulterations. Milk and dairy products and vegetable oils had the highest prevalence and incidence of adulterations in Brazil from 2007 to 2017. The most prevalent types of adulteration in Brazil were intentionally dilution and substitution, in order to obtain economic advantages. There is no regional pattern for food fraud and adulteration in Brazil.

Addressing and preventing food fraud and adulterations require enforcement of regulatory systems, increased sampling and monitoring, training of food producers and handlers, development of effective, rapid, and cost-effective methods of fraud detection. Food monitoring is an important step for preventing fraud in producer countries and opening up new markets to these products. Complex food supply chains are the most at risk of fraud, and special measures should be in place within these industries. Monitoring results can be used to analyze food safety risks to protect the health and rights of consumers and to prioritize target areas for food research and policy-making in order to enforce food safety standards in Brazil. Other important measure is the creation of a Brazilian food fraud and adulteration database for the systematic analysis of the data, which would support actions to reduce food fraud and adulteration in the future.

Authors' Contributions

C.T. and D.P. conceived of the presented idea. C.T. and S. A. da S. wrote the manuscript with input from all authors. All authors discussed the results and contributed to the final manuscript.

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