Analysis of the economically motivated food adulteration in China based on 6477 events from 2000 to 2020

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Abstract

In order to investigate the epidemic characteristics of economically motivated food adulteration (EMA) in China, we analyzed the frequency and/or percentage of parameters of EMAs from 2000 to 2020. A total of 6477 EMAs were collected from a portal based in China and evaluated, the results showed that 69% of the EMAs were identified through supervisions and 95.7% EMAs were discovered in the sale process. The top three specifications of EMA information were listed as follows: the regions were Guangdong, Shandong, and Henan; the fraud means were illegal addition, substitution or dilution, and unqualified hygiene; the food types were meat, vegetable, and fruit. Our findings indicated that supervision of the production process of the main food types is of utmost importance to prevent EMA, according to adulterating phase, fraud means, and adulterer type.

Keywords: economically motivated food adulteration; food fraud; food type; fraud means; adulteration; discovery source

Introduction

Economically motivated food adulteration (EMA) has become a global issue that needs to be addressed. The definition of EMA was formally proposed by the Food and Drug Administration (FDA) at a seminar in April 2009 (US 2009). The FDA defines EMA as, to obtain high profits, deliberately replacing or adding a certain substance to improve the appearance of food, using falsehood to achieve the purpose of reducing production costs and earning high price differences (Robson *et al*., 2021). Food adulteration has existed since the beginning of food production. Adulteration methods are constantly changing with the progress of detection methods, thus making EMA difficult to be discovered and supervised. At present, there is no international consensus on the detection methods of EMAs, and an effective detection method outside professional laboratories is rare (Esteki *et al*., 2019).

Rocchi *et al*. (2020) reported that food fraud costs more than 1.8 billion Euros per year in the lost output, and more than 20,000 jobs, with a serious adverse impact on the national and global economy. Most EMAs did not cause severe food safety problems; therefore, these incidents did not increase consumers' awareness. The discovered EMAs have only represented a small fraction of all EMAs, which really needs to be addressed by regulatory authorities (Bene *et al*., 2020). The negative impacts of EMAs have damaged consumers' confidence and may also produce seriously adverse effects on public health and international trade (Lin *et al*. 2020a; Theolier *et al*., 2021; Wang, 2021).

In order to rapidly respond to EMAs, several countries have established food fraud databases (FFDs), such as the National Center for Food Protection and Defense (NCFPD) in the USA (Cai *et al*., 2019). The

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United States Pharmacopeia Commission (The United States Pharmacopoeia Convention, USP) established an FFD by collecting information from academic journals and media articles (Wang *et al*., 2019). The European Union set up a rapid alert system for food and feed (Pigłowski, 2020). Although such databases exist, globalization increased the complexity and vulnerability of the food chain, making EMAs more likely to occur. Thus, it is important to establish a more comprehensive and applicable data system to effectively record and report EMA (Pavlidis *et al*., 2019). In recent years, several FFDs have been utilized for EMA characterization, prediction, and prevention.

In recent years, the food industry has developed rapidly in China (Tan and Zhang, 2019; Theolier *et al*., 2021). The increasing demand for food consumption has spawned an increasingly long and complicated food supply chain, which offers many susceptible points of attack for food fraud (Zhang and Xue, 2016). Food safety issues in China have been a frequent public concern in recent years, resulting in decreased consumer confidence and impediment of the development of the Chinese food industry (Kendall *et al*., 2019; Spink *et al*., 2015). The "melamine" event in China in 2008 was a more typical EMA case, and it ended 14 years ago. Its influence on consumer confidence still exists and the losses to Chinese dairy industry are incalculable (Bouzembrak and Marvin, 2016; Yang *et al*., 2020). Tibola *et al*. (2018) finds that management practices in developing countries have critical flaws to effectively regulate EMAs after analyzing Brazil's EMAs based on academic journals from 2007 to 2017. China does not have an official EMA database, and the development of an EMA database has been lagging (Li *et al*., 2016). Zhang *et al*. (2020) reported 961 cases based on molecular database of food adulteration in China from 1998 to 2019. Because of enormous amounts of food industry and complicated adulteration situations, such a database can't reflect the entirety of EMA in China.

The present study aimed to collect EMA events from a portal based in China to establish a database. Using the database, we further discovered epidemic characteristics of these events to provide a scientific basis for the prevention and control of EMAs in China.

Materials and Methods

EMA definition

Based on the Product Quality Law of the People's Republic of China (PQLPRC) – 2019 (National People's Congress, 2019), EMA is defined as, to obtain high profits, an event meeting one of the following criteria: using food quality marks, counterfeiting food origin, faking factory name and address, adulteration in food producing and sale process, shoddy food, and passing substandard food as qualified food to achieve the purpose of reducing production costs and earning high price differences.

EMA collection and screen

According to the definition of EMA, EMA events were collected via central and local governmental websites (the State Administration for Market Regulation, China FDA, Chinacourt, etc.), online media (China Food Safety Net, Chinanews, Foodmate, Baidu, Sina, etc.), and the literature (CNKI), from 2000 to 2020. The keywords included: food or edible agricultural products (EP) and any combination of origin fraud, mislabeling, illegal addition, illegal sale, illegal production, false advertising, substitution or dilution, counterfeiting, and unqualified hygiene to search EMA events. Duplicate and incomplete information was removed. The uniform resource locator (URL) was ranked according to the number of EMAs collected from highest to lowest (Table 1).

EMA information category

Details of the EMA events were divided into two classes consisting of discovery information (source, stage, region, and time) and fraud information (food type, adulterating, and fraud means). Furthermore, discovery stages categorized five types; discovery region included 34 provinces and municipalities directly under the central government, and 2 others; discovery time included year and month; food types referenced to "Classification catalogue of food production license" (State Administration for Market Regulation, 2020); adulterating included adulterer type and adulteration phase (Table 2).

EMA fraud means category and definition

The classes were categorized into six types according to PQLPRC (National People's Congress, 2019); classes were subdivided into 10 subclasses based on the present database and literature (Wang *et al*., 2019) (Table 3).

Economic data collection

Economic data, including expenditure of consumer goods (ECG), gross domestic product (GDP), citizen amount, ECG per capita, resident amount, and GDP per capita for each province, were obtained from National Bureau of Statistics, the website of which is http://www.stats.gov.cn.

Table 1. Partial URL of the main discovery source of information for China's EMA database.

Rank	URL	Rank	URL
1	http://www.sfda.gov.cn	17	http://info.tjkx.com
2	http://www.cfqn.com.cn	18	http://www.lawtime.cn
3	http://www.cfsn.cn	19	http://dl.cnr.cn
4	http://www.china12315.com.cn	20	http://www.21food.cn
5	http://bbs.foodmate.net	21	http://zj.cnr.cn
6	http://gkml.samr.gov.cn	22	http://nx.cnr.cn
7	https://wenku.baidu.com	23	http://www.kj-cy.cn
8	https://www.sina.com.cn	24	http://www.legaldaily.com.cn
9	https://www.sogou.com	25	http://js.cnr.cn
10	http://www.360doc.cn	26	http://www.chinanews.com
11	https://www.tech-food.com	27	http://o.news.hbu.cn
12	http://www.cnfoodnet.com	28	http://jsnews2.jschina.com.cn
13	http://www.39yst.com	29	http://www.xinhuanet.com
14	http://www.ce.cn	30	http://www.people.com.cn
15	http://www.cnr.cn	31	http://jiangxi.jxnews.com.cn
16	https://baijiahao.baidu.com	32	https://www.chinacourt.org

URL, uniform resource locator.

Table 2. The parameters and specifications of EMA.

Class	Subclass	Content
Discovery information	Discovery source	Supervision, media, literature.
	Discovery stage	Process of Producing, transportation, storage, sale, consumption.
	Discovery region	Beijing, Tianjin, Shanghai, Chongqing, Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Taiwan Province, Inner Mongolia, Guangxi, Xizang, Ningxia, Xinjiang, Hong Kong, Macao, import and the Internet.
	Discovery time	Years from 2000 to 2020, months from January to December.
Fraud information	Food type	Processed grain products, edible oils/fats and their products, condiments, meat products, dairy products, beverages, convenience food, biscuits, canned food, frozen beverage, quick-frozen foods, potatoes and puffed foods, confectionary products, tea-related products, liquor, vegetable products, fruit products, roasted seeds and nuts products, egg products, cocoa and roasted coffee products, canteens, aquatic products, starch products, cakes, soy products, bee products, health food, formula food for special medical purposes, infant formula food, food additives, other food.
	Adulterating	Adulterer type: enterprise (A limited liability company and a joint stock limited company authorized by Chinese company law.), individual producer (A person or family that has been approved by the commercial law), other. Adulterating phase: farming/planting, producing/packaging, transportation, storage, sale, consumption, other.

Data analysis

The collected EMA data were organized and classified using Excel. Entry items were double-checked during the data input stage to reduce errors. A Spearman correlation with regional amount of EMA was conducted. In order to reflect the distribution characteristics of EMA events, we used area chart and line graphs for discovery time, clustered column chart and stacked column chart for discovery region and fraud means, clustered column chart for discovery source and stage, food type, and pie chart for fraud means and adulterating (Cai *et al*., 2019; Wang *et al*., 2019). In order to predict EMAs' developing trend with year, a three-period exponential smoothing model was employed.

Results

Discovery information

Discovery source and stage

The main discovery source of EMA was supervision from the local government, which accounted for 69.6%, followed by media reports accounting for 30.4% (Figure 1A).

Table 3. EMA fraud means category and definition.

Class	Subclass	Definition
Counterfeiting food origin Faking factory name and address	Origin fraud	Counterfeiting the origin of food, counterfeiting or illegally using another's factory name or address.
Adulteration in food producing and sale process	Mislabeling	Changing the product date, etc., including mismarking of food origin information, counterfeiting trademarks, etc.
	Illegal addition	Adding unapproved or prohibited additives to food, including overuse, over-range use, and artificial enhancement.
	Illegal sale	Without obtaining selling license.
	Illegal production	Without obtaining food production license.
	False advertising	Exaggerating the effects of products and deceiving consumers.
Shoddy food	Substitution or dilution	Substituting high-grade products with low-grade products, or substituting genuine or new products after assembling defective products. Diluting the real food ingredients with a certain food ingredient partially to increase weight or volume.
Passing substandard food as qualified food Fraudulent using food quality marks	Counterfeiting	Unqualified products being presented as qualified products, also including unqualified production conditions, out of range production license, unqualified production process.
	Unqualified hygiene	Hygienic indicators, including microbiological indicators, and physical and chemical indicators, exceed standards.
	Others	Food fraud in restaurants, inedible food, etc.

The database management system had been established for Chinese EMA, the website http://food-ffd.com (in Chinese) can be freely accessed.

A total of 95.7% EMAs were discovered during the sale process, while 4.3% of EMAs were discovered during the process of production, consumption, transportation, and storage (Figure 1B).

Discovery region

The EMAs occurred in all provinces with substantial differences between provinces. The top 14 provinces account for 68.2% of the total EMA. Among the provinces, Guangdong, Shandong, Henan, Beijing, and Zhejiang ranked among the top five, accounting for approximately 35.1% of all the EMAs (Figure 2A). Illegal addition was the main means of fraud in the top five provinces (Figure 2B). The top three food types varied among provinces. For example, in Guangdong province, the top three possible fraudulent foods were fruit products (FP), meat products (MP), and beverage; in Shandong province, they were MP, FP, and vegetable products (VP); while in Henan province, the top three were pastries, aquatic products (AP), and VP (Figure 2C). The correlation analysis results showed that EMA amount was a positively correlating factor included in ECG, GDP, citizens, ECG per capita, residents, and GDP per capita (Table 4).

Discovery time

In time characteristics, four peaks of food adulterations appeared in 2006, 2010, 2018 and 2020 (Figure 3A). The fraud means changed over the years. For example, in 2006, illegal addition was the main means of fraud, while substitution or dilution was the top means of fraud in 2018. In both 2017 and 2020, unqualified hygiene increased rapidly, while mislabeling predominantly occurred in two small peaks in 2008 and 2010 (Figure 3B). The peak of incidents was usually found in January and December, which were just before the Spring festival, with smaller fluctuations in other months (Figure 3C). The prediction model results revealed that the incidence of EMA would be still at high levels from 2021 to 2024 (Figure 4).

Fraud information

Food type

The 14 food types that were top fraudulent items were MP 10.7%, VP 10.1%, FP 8.0%, pastries 7.3%, beverage 6.7%, AP 6.6%, EP 5.7%, alcohol 5.5%, condiments 5.0%, edible oils/fats and their products (EFP) 4.0%, health care products (HCP) 3.9%, others 3.5%, processed grain products (PGP) 3.2%, and starch and its products (SP) 2.9%. These food types accounted for approximately 83.1% of the all EMAs (Figure 5).

Fraud means and adulterating

Among the 6477 incidents of the 10 categories, illegal additions were the main type of EMA, accounting for more than 58.7% of all incidents, followed by substitution or dilution, unqualified hygiene, and mislabeling

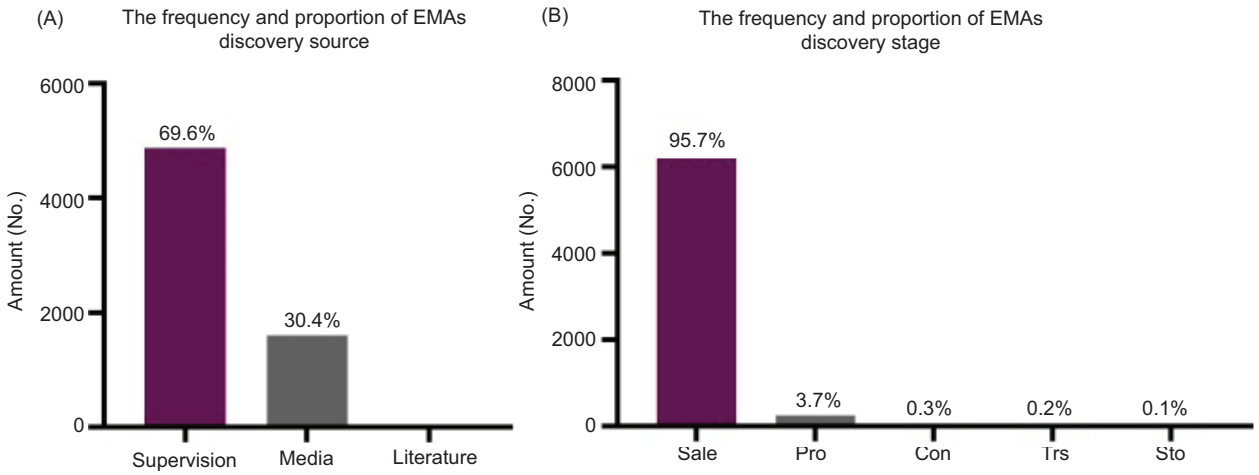

Figure 1. Discovery source and stage distribution characteristics of EMA. Pro, producing; Con, consumption; Trs, transportation; Sto, storage.

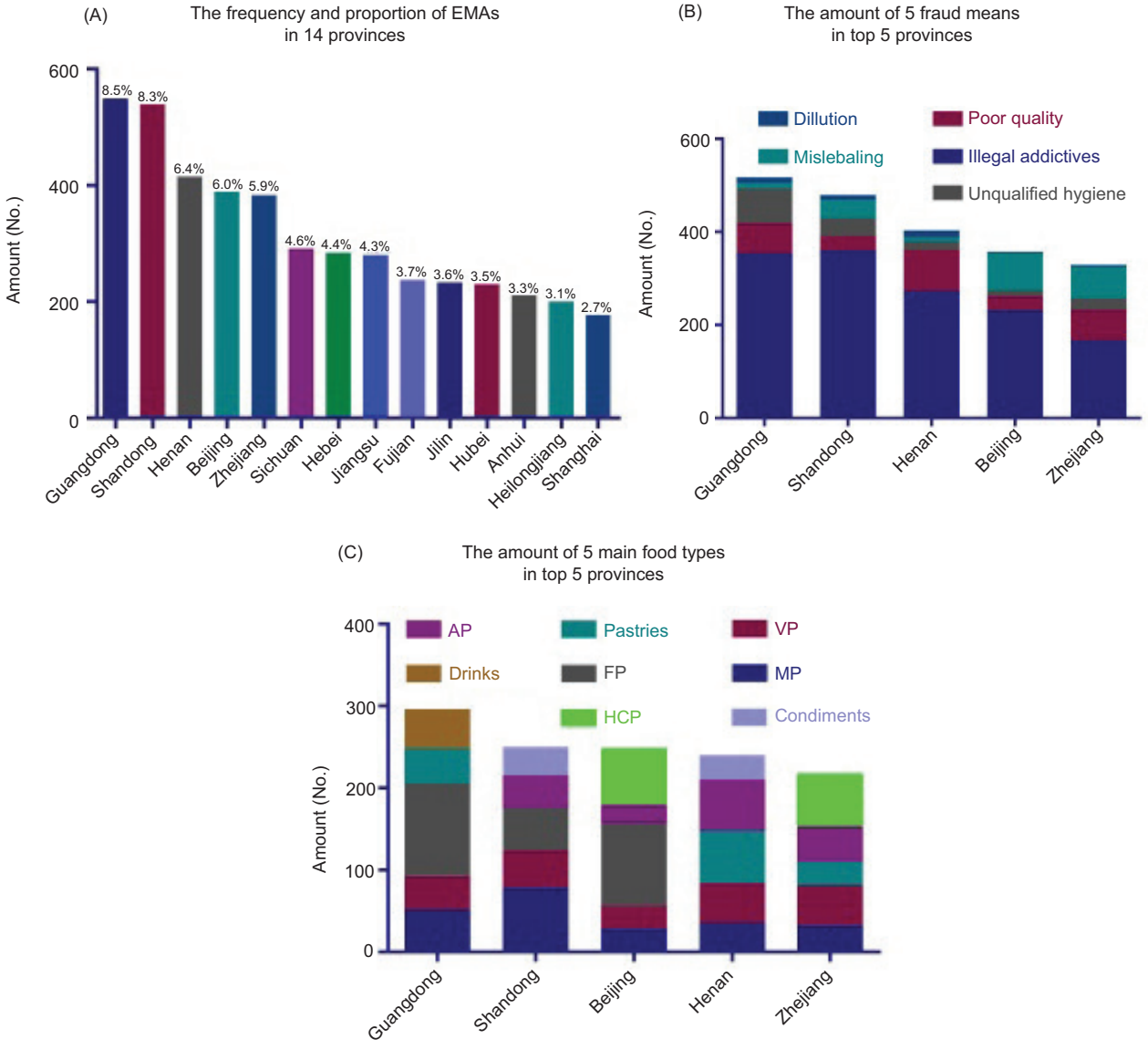

Figure 2. Regional distribution characteristics of EMAs.

Table 4. Correlation between economic factors and regional amount of EMAs.

	ECG	GDP	ECG/capita (¥/person)	Citizen (10k)	Resident (10k)	GDP/capita
Spearman correlation	0.782**	0.728**	0.673**	0.609**	0.526**	0.506**

Note: ** means P < 0.01.
ECG, expenditure of consumer goods; GDP, gross domestic product.

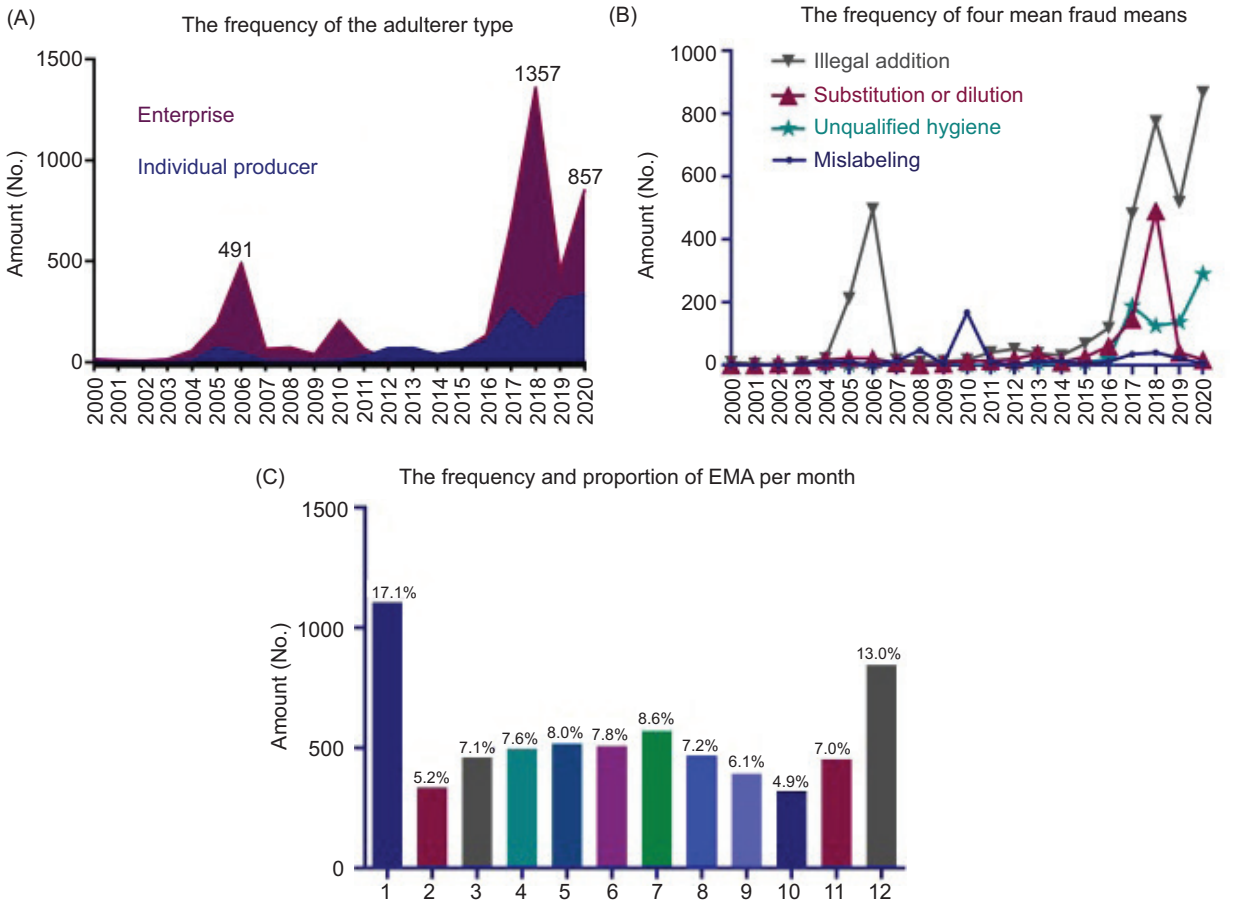

Figure 3. Time distribution characteristics of EMA.

(Figure 6A). The ratio of enterprise and individual producers who were involved in EMA were 75.2 and 24.7%, respectively (Figure 6B). The adulteration primarily occurred in the producing/packaging process (78.6%), followed by the process of sale (7.5%), farming (4.8%), and storage (4.0%) (Figure 6C).

Discussion

In the FFD-EMA, the ratio of EMAs sourcing from literature, media, and supervision, respectively, accounts for 59.5, 31.0, and 5.7% (Figure 7A) (Wang *et al*., 2019). However, food safety supervisory systems are different in China and the USA (Yang, 2019). The present study found that EMAs in China are mainly discovered from government supervision and media reports while the EMAs in the USA are from literature and media (Figure 7B).

Countries are divided into four categories according to different income levels: lower-income countries (LICs), lower-middle-income countries (LMICs), upper-middle-income (UMICs) countries, and high-income countries (HICs) (Miller *et al*., 2016). Unlike the HICs, there are also many food transition issues in developing countries. For example, in Colombia, the dominant food transition is different between northeast and south-central region (Quintero-Lesmes and Herran, 2019). In China, the geographical agricultural farming, food production, and food consumption habits show great variations among

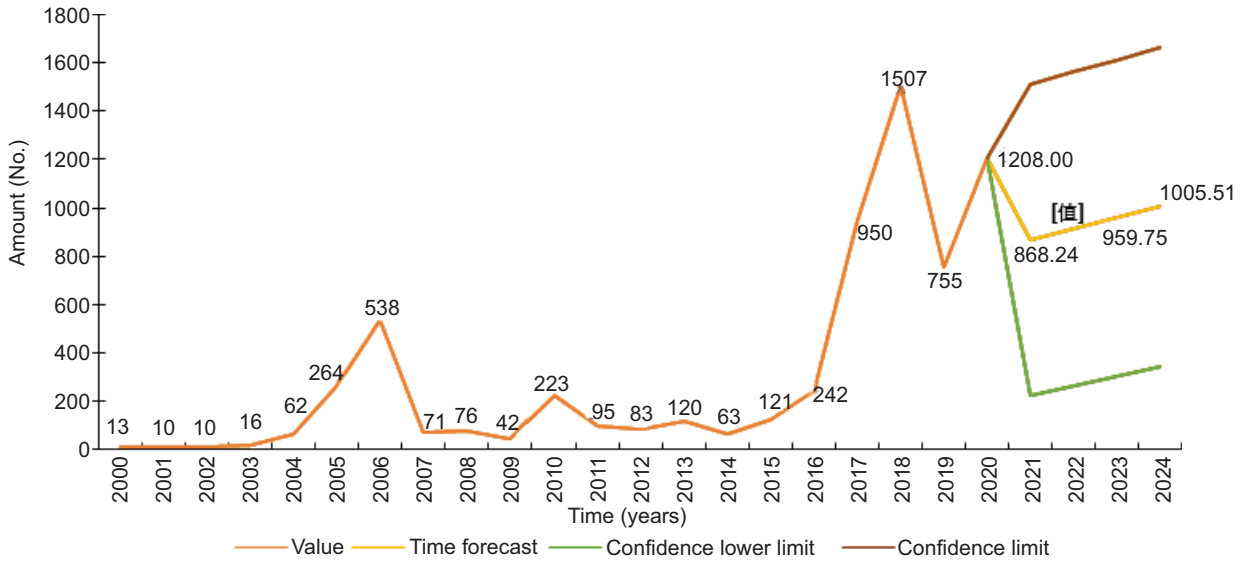

Figure 4. Trend forecast lines of the EMA for 2021 to 2024.

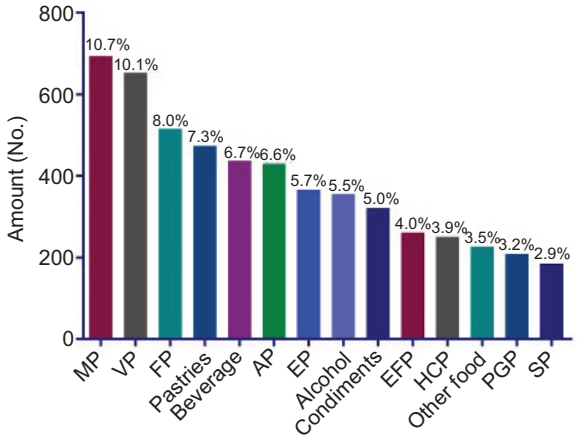

Figure 5. The frequency and proportion of top 14 food types.

provinces (Zhang *et al*., 2019). The current research also shows that the frequency of EMA is higher in economically developed regions, such as Guangdong, Shandong, Henan, Beijing, and Zhejiang provinces where fraud food types are consistent with regional food industrial structure.

In terms of comparisons at country levels, food fraud issues in developing countries are more complicated than those in the developed countries. China had been a LMIC since 2001 and transformed to an UMIC since 2010; however, development of China had been slowing down since 2010 (Chen *et al*., 2021). In the present study, EMAs are still in a high incident stage based on exponential line of this study. The incidence of EMA shows four peaks in 2006, 2010, 2018, and 2020. Also, the orders of positively correlated factors with EMAs are acceleration of urbanization, growth of ECG, GDP, citizen amount in China. The above studies suggest that EMA impacts GDP.

The types of fraudulent foods in developing countries are different from those in developed countries. Edible oils, dairy products, MP, alcohol, condiments, beverages, and bee products encompass 90% of EMAs in the FFD-EMA database (Wang *et al*., 2019). Meat and milk are the most frequent fraudulent food types in Brazil (Tibola *et al*., 2018). Meat consumption has increased with per capita income growth in recent decades in China (Tan and Zhang, 2019). In present study, the top-ranked adulterated food in China is MP, which indicates that adulterated food types are similar to Brazil, a developing country, and different from the USA, a developed country, wherein it is dairy products.

Food safety in countries at different income levels needs to prioritize their strategies against different EMAs. For example, food quantity and security are still a big issue in LICs, thus developing a sound regulatory system is an urgent task for middle-income countries (Shen *et al*., 2021). On the other hand, nutrition and consumer participation is the focal work in HICs (Shen *et al*., 2021). Substitution or dilution (more than 40%), artificial enhancement, mislabeling, origin fraud, and illegal additions are top adulteration types in the FFD-EMA database (Wang *et al*., 2019; Cai *et al*., 2019) (Table 5). In Europe, substitution or dilution (44.5%), mislabeling, counterfeiting, artificial enhancement, transshipment or origin masking, theft and resale, and intentional distribution of contaminated products are top means of fraud according to NCFPD-EMA (Cai *et al*., 2019). Based on the information above, substitution or dilution is the top-ranked adulteration type in both the USA and Europe (Li *et al*., 2016) while illegal addition is the main adulteration method in developing countries. For example, mango adulteration frequently

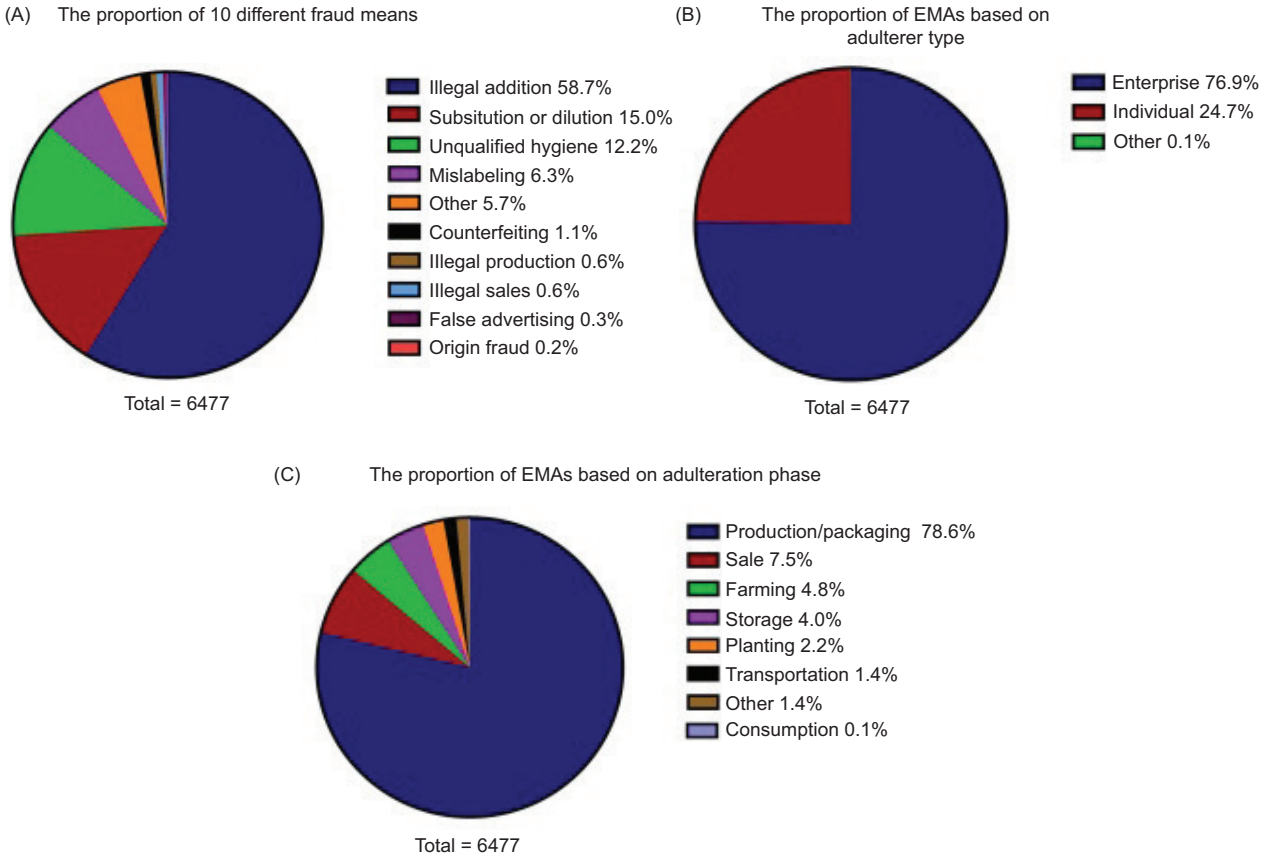

Figure 6. Fraud means and adulterating distribution characteristics of EMA.

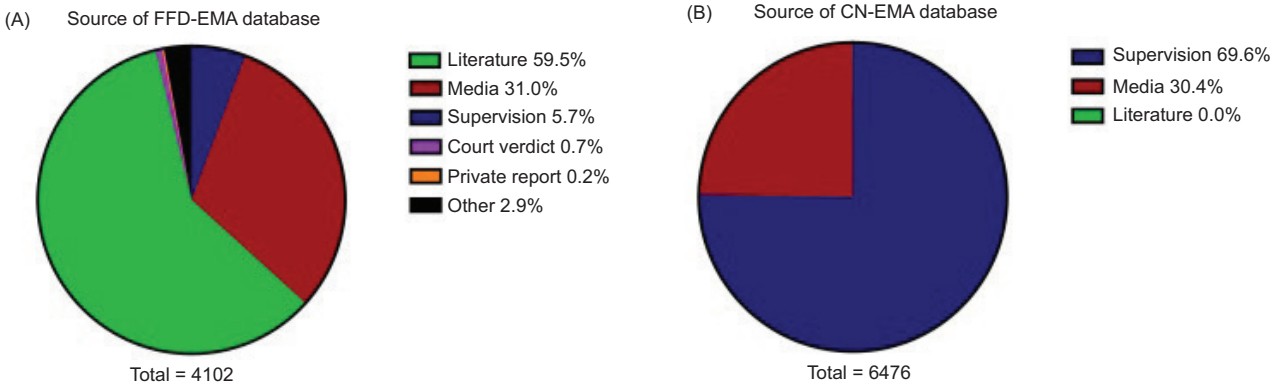

Figure 7. Sources of CN-EMA and FFD-EMA database.

occurred in India where ripening mango with calcium carbide containing trace amounts of arsenic was employed, which is harmful to human health (Lakade *et al*., 2018). In China, top food fraud means rank with illegal addition, substitution or dilution, unqualified hygiene, mislabeling, others, counterfeiting, illegal production, illegal sale, false advertising, and origin fraud based on present study. The health risk associated with illegal addition is significantly higher than substitution or dilution (Lakade *et al*., 2018).

Developed countries, such as USA, possess relatively sound systems for food supervision. In 2013, the FDA owned 2.8 supervisors per enterprise, while in China, the rate of supervisors per enterprise was only 0.022 in 2015, with a substantial imbalance between the number of supervisors and the enterprises (Li *et al*., 2016). After analyzing 1553 media reports related to food safety issues and scandals, insufficient food safety supervision is the main factor leading to frequent EMA events in China (He *et al*., 2019; Zhang and Xue, 2016). In addition, the government

Table 5. Adulteration types in four EMA database.

Rank	CN-EMA	FFD-EMA	NCFPD-EMA
1	Illegal addition	Substitution or dilution	Substitution or dilution
2	Substitution or dilution	Others	Mislabeling
3	Unqualified hygiene	Artificial enhancement	Counterfeiting
4	Mislabeling	Mislabeling	Artificial enhancement
5	Others	Origin fraud	Transshipment or origin masking
6	Counterfeiting	Illegal additions	Theft and resale
7	Illegal production	—	Intentional distribution of contaminated products
8	Illegal sale	—	—
9	False advertising	—	—
10	Origin fraud	—	—

EMA, economically motivated food adulteration; FFD, food fraud database; NCFPD, National Center for Food Protection and Defense.

not only needs to optimize the supervisory systems but also the enterprises should improve food quality at the self-administration level (Niu *et al*., 2021). Lin *et al*. (2020b) revealed that state-owned enterprises are more active in food safety certification than smaller enterprises. In order to avoid food fraud in the production process, it is necessary to strengthen training of front-line workers in productive enterprises (Taha *et al*., 2020; Zanin *et al*., 2017). Both enterprise and individual producers engage in food fraud (Quan 2020). This study shows that enterprises accounting for 75.2% are the main adulterer type. In China, production license and end product supervision are main supervisory regulation, 95.7% of Chinese EMAs are discovered in the sale process, while 78.6% EMAs happen in the producing/packaging process based on this study. Thus, it is necessary to strengthen supervision in producing/packaging process (Wang 2021).

This article collected information of 6477 Chinese EMA including: discovery region, discovery time, discovery source, discovery stage, food type, fraud means, and adulterating. Food fraud is closely related to the local food industrial structure, consumption habits, and economic development. The EMAs will still be at a high level in the next 4 years based on the trend forecast line; therefore, production process supervision should be strengthened in high-incidence regions such as Guangdong, Shandong, Henan, Beijing, and Zhejiang, especially before the Spring Festival. About the food types of meat, vegetable, fruit, as well as the fraud means of illegal addition, substitution or dilution and unqualified hygiene should be paid more attention.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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