Securing the Plate with Forensics Science: Clamping Down on Food Fraud in Ghana

Abstract

Food fraud is a critical concern for food safety and public health that has not received sufficient attention. In Ghana, food fraud is economically driven, aiming to exploit unsuspecting consumers for profit. This paper examines the literature on food fraud in Ghana, drawing from journals, online articles, social media and published reports. The findings emphasize the prevalence of food fraud, underscoring the urgent need to combat it in Ghana by leveraging forensic science. The study identifies key food adulterants, including sawdust, foam, carbide, bixa, and Sudan IV, commonly found in Ghanaian markets. These substances pose significant risks to consumers. The paper serves as a roadmap for establishing effective policies, laws, and regulations to address food fraud in Ghana. Furthermore, the paper emphasizes the importance of future directions and policies to tackle the existing food fraud situation. It recommends the prudent use of forensic technologies as a powerful approach to crackdown on food fraud. By employing forensic techniques, it becomes possible to apprehend and bring justice to those responsible for intentional acts of food fraud. In conclusion, this paper highlights the seriousness of food fraud in Ghana's food industry and public health. It emphasizes the urgent need to combat this issue by utilizing forensic science. By implementing robust policies and leveraging forensic technologies, Ghana can effectively ensure consumer safety and maintain integrity within the food supply chain.

Keywords: Food Fraud, Food Safety, Forensic Science, Ghana

Introduction

Food fraud has been a persistent problem throughout history and has no universally accepted definition. Rather, it involves intentionally deceiving or altering any food product for economic gain at any stage within the food supply chain (1). It is reported that the complexity of this phenomenon lies in the fact that only the perpetrator knows how the basic ingredients have been manipulated, putting consumers at significant risk of toxicological impacts. Food fraud can take many forms, including adding substances to consumables, replacing components, and making false claims about food products' origins (2).

Throughout history, food fraud has taken various forms, such as mixing wine with honey in ancient Greece and Rome, blending bread flour with sawdust and straw in the Middle Ages (3), and diluting dairy products in the 18th and 19th centuries (4). In the 20th century, food fraud continued with the replacement of food salt with road salt, the dilution of olive oil with soybean oil, and the labeling of non-Basmati rice as Basmati (4). Food fraud has increased exponentially in the 21st century due to the complexity of the global supply chain (5). Law enforcement efforts and the proliferation of print and multimedia have brought food fraud into the public eye. Recent examples include honey adulterated with foreign sugars imported into Canada (6), intentional mixing of horsemeat with beef products in the European market (EFSA, 2013), and adulterated milk and infant formula with melamine in China (8–11)..

Food fraud is not confined to any particular region and affects all edible substances consumed by humans and animals. Countries in the poor economic states are particularly vulnerable, with cases of tampering with food labels reported in South Africa and intentionally marketed poisonous rice, fish treated with formaldehyde-treated, and fake Coca-Cola products in most African countries (12). The intentional use of aluminum foil in place of edible silver leaf on meats has been reported in India (13), as well as the use of fake and illegal products to

produce mislabeled ketchup marketed as well-licensed products (14). This paper first highlight on the underreported issue of food fraud in Ghana and answers three research questions: What is the current status and trend of food fraud in Ghana? What are the drivers of this phenomenon in Ghana? How can this phenomenon be managed? The paper outlines the drivers of food fraud in Ghana, and suggests a step-up in the fight against food fraud with forensic science as a recommendation to mitigate the situation. The paper also provides global examples of food fraud incidents and highlights the benefits of forensic science in Ghana's food sector for ensuring food safety and promoting sustainable development.

Methodology

This article reports a review of available publications, television news, news articles, and social media-related information from Ghana, with a focus on food fraud, food adulteration, food safety, and food forensics. The study aimed to extract and categorize data from relevant sources to identify trends and issues related to food fraud in Ghana.

To identify relevant publications, a search on various credible scientific sources, including Google Scholar, PubMed, Sciencedirect, Research Gate, and African Journals Online was conducted using keywords related to food fraud, food safety, forensic science, and Ghana. The study limited the search to articles published in English between the years 2000 and 2023. Credible social media platforms such as YouTube, Facebook and Twitter, and online websites were accessed for relevant information because there is a lack of published peer-reviewed research on food fraud in Ghana.

After identifying potential articles, the titles and abstracts were screened to exclude articles that did not meet the study questions. The study excluded full texts of the remaining articles after review and duplicate articles, abstracts, posters, conference proceedings, and studies

outside Ghana were excluded. Only videos and social media information that were critically reviewed were included in this review.

Extraction and categorization of the data were done based on the selected publications, videos, and social media information by taking into consideration headings such as food fraud, food safety, forensic science, methods of identifying food fraud, food authentication, molecular methods of food authentication, news on food fraud, videos on food fraud, and food fraud cases. The collected data were managed using Mendeley and prepared for citations. The methodology ensured that the final data set was comprehensive, accurate, and relevant to the study questions.

After all of these duplicates had been eliminated, a manual search was conducted to find and eliminate any remaining copies. The internet and published data was gathered, managed, and then the citations were created using Mendeley.

Food Fraud Situation in Ghana

The food sector in Ghana depends heavily on locally produced crops, livestock, and processed foods. However, imported goods are also in high demand. The Food and Drugs Authority (FDA) and the Food Research Institute (FRI) of the Council for Scientific and Industrial Research (CSIR) carried out a survey and discovered that many food products contained various chemicals, which is a punishable offence in Ghana. Unfortunately, there is a lack of transparency in food manufacturing, leading to concerns about food fraud such as adulteration, replacement, mislabelling, substitution, and counterfeiting (15). For example, palm oil a significant locally manufactured commodity, has been contaminated with Sudan dyes especially (IV) (16,17). Honey, milk and dairy products, spices, and alcoholic beverages such as palm wine and "pito" are also highly susceptible to food fraud practices in Ghana (15,18,19).

To prevent running at a loss, sellers enhance food product shelf life. In Ghana, palm oil needs to be red for consumers to buy, and sellers' capital will be locked up with no profit earned in the palm oil business if it is not red enough. However, it was discovered that Sudan IV, an industrial dye used in the coloring of plastics and other synthetic items, was added to palm oil that was sampled from several markets in Accra and Tema (15,18,20). This adulteration of palm oil has led to the loss of significant revenue for the country. In recent times palm oils exports without certification is frowned upon in Ghana as there are strict regulations set by the European markets to check products from Ghana (21). Additionally, the use of cancer-causing Sudan IV dye presents a health threat to consumers.

Food scientists at the Kwame Nkrumah University of Science and Technology (KNUST) have revealed that food adulteration is not limited to palm oil; other products like groundnut paste, fish, pepper, and tomato powder have also been compromised (22). In most markets in Ghana, low-grade fish, condiments, and spices are used to produce fish powder. "Dawadawa," a local kitchen spice made from the seeds of Parkia biglobosa, "kuli kuli," and "kuli kuli zim," made from groundnuts, are also highly adulterated with low-grade cereals, spices, and other condiments to either increase the quantity to gain undue profit or enhance the taste with different materials without consumers' awareness, which could likely expose them to toxicological effects (19).

In 2019, fraudulent and intentional substitution and mislabelling of imported rice as local rice and local rice as imported rice became a sensitive issue of concern in Ghana (23). This is because most products on the local Ghanaian market are not labelled, licensed, or certified for public consumption. The Ghana Standards Authority (GSA) and the Greater Accra regional crime office worked together to conduct an investigation and recover alcohol from counterfeiters. These erroneously labeled goods included 90 cartons of empty Herb Afrique and Mandingo bottles and 120 cartons of Castle Bridge drinks purportedly from GIHOC

distilleries at Kpeshie in Nungua, Greater Accra (24). Investigations by the Ghana Revenue Authority (GRA) revealed that criminals had access to original stamps. This case shows the level of mislabelling occurring in the alcoholic industry in Ghana. Nowadays, people can gain access to product labels using digital equipment to deceive unsuspecting consumers.

The FDA issued a report in November 2021 warning Ghanaians about the availability of fake, expired, and adulterated goods and services as festive seasons approached. The FDA and the Ghana Police Service (GPS) worked together to retrieve 270 cartons of Charme Sparkling Non-Alcoholic Red and White Grape Juice that had gone bad (25–28).

Furthermore, the food fraud situation in Ghana is not limited to local products. Imported goods such as canned foods, beverages, and dairy products are also susceptible to adulteration and mislabelling. Some imported products are repackaged and sold in smaller quantities to unsuspecting consumers. This makes it difficult for consumers to determine the origin and quality of these products, which could lead to health hazards.

The prevalence of food fraud in Ghana (Table 1.0) has significant economic implications as the cost of enforcing regulations and combating food fraud is high, placing a burden on the government's resources. The health implications of food fraud are also a cause for concern. Adulterated and mislabelled products pose a health risk to consumers, especially when the adulterant is toxic or harmful. The use of industrial dyes such as Sudan IV in palm oil is a cause for concern as it is a known carcinogen. Consumption of such products could lead to long-term health effects such as cancer. Furthermore, the addition of harmful substances to food products could also lead to foodborne illnesses and other health complications (29).

Table 1.0

Prevalence of Food fraud in Ghana

Sources	Type of Incident
https://panafricanvisions.com/2021/09/food-fraud-and-food-safety-ghanaian-scientists-embrace-novel-technology-to-reduce-trends-of-fraud/ scijgh.com/content/food-fraud-and-food-safety-ghanaian-scientists-embrace-novel-technology-reduce-trends-fraud https://www.ghanabusinessnews.com/2021/10/20/food-fraud-on-the-rise-fda/ https://www.myjoyonline.com/food-and-drug-integrity-research-group-at-ucc-wants-fda-equipped-with-modern-rapid-detection-techniques-to-fight-food-fraud/	**Repackaging and false labelling of food**
https://fdaghana.gov.gh/img/reports/FDA%20NEWSLETTER%20Vol%2001%20No-%2001%20-%20March%202016-min.pdf https://citinewsroom.com/2022/03/30-of-palm-oils-on-ghanaian-markets-fail-fdas-nationwide-zero-sudan-dye-test/ https://www.myjoyonline.com/30-of-palm-oil-on-ghanaian-markets-fail-fdas-sudan-dye-test/ https://fdaghana.gov.gh/news-media.php?page=133 https://web.facebook.com/watch/?v=687012392731819 https://www.youtube.com/watch?v=84Hwz9Ijepo	**Palm oil Adulteration**

https://fdaghana.gov.gh/img/press/Expired%20Charme https://www.ghanaweb.com/GhanaHomePage/business/Do-not-drink-Charm-Non-alcoholic-Grape-Juice-FDA-1411363 https://starrfm.com.gh/2021/11/fda-warns-public-over-expired-charme-juice-distributor-arrested/ https://www.classfmonline.com/business/Don-t-drink-expired-Charm-sparkling-non-alcoholic-wine-FDA-warns-public-28915 https://newsghana.com.gh/fda-arrest-distributor-of-expired-charme-non-alcoholic-wine-warns-public/	**Fake and Expired beverages**
https://fcwc-fish.org/other-news/ghana-chemical-adulteration-of-fish-widespread-research https://www.graphic.com.gh/news/general-news/chemical-adulteration-of-fish-widespread-research.html https://myinfo.com.gh/2020/12/chemical-adulteration-of-fish-widespread-research/ https://www.businessghana.com/site/news/general/228569/Chemical-adulteration-of-fish-widespread-Research https://www.youtube.com/watch?v=hylj4dYL9lI	**Adulterated Fish**
https://fdaghana.gov.gh/img/press/PRESS%20RELEASE%20-%20COA%20FS%20PRODUCT.pdf	**Adulterated Food supplements**

https://fdaghana.gov.gh/img/press/TOMATO%20PASTE%20Press%20Release.pdf https://www.ghanaweb.com/GhanaHomePage/NewsArchive/FDA-bans-16-tomato-paste-products-824227	**Adulterated Tomato paste**
https://www.youtube.com/watch?v=Sc8qy7FZ4XM https://www.modernghana.com/amp/news/528894/fake-natural-honey-sold-in-ghanawatch-out-for-sugar-mixed.html https://www.modernghana.com/news/528894/fake-natural-honey-sold-in-ghanawatch-out-for-sugar-mixed.html	**Honey Adulteration**
https://wire.farmradio.fm/farmer-stories/3-ghana-use-of-harmful-food-additives-on-the-rise-public-agenda-ghanaian-chronicle/ https://newsghana.com.gh/stop-using-chemicals-hasten-ripening-fruits-farmers-warned/ https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9859701/ https://www.modernghana.com/amp/news/682186/chemicals-in-vegetable-growth-fruit-ripening-and-health-eff.html	**Hastening fruit and vegetable ripening**
https://www.modernghana.com/news/523110/1/fda-arrests-man-for-faking-alcoholic-drinks.html https://anapuafm.com/fda-arrests-man-for-faking-alcoholic-drinks/ https://www.ghanamma.com/2014/02/14/fda-arrests-man-for-faking-alcoholic-drinks/	**Fake alcoholic drinks**

https://ama.gov.gh/news-details.php?n=cXA1czM0ODE4cTg3ODY5NDkxczZycjA3MDZucjMxODBwc TBuMXIzbg%3D%3D https://www.gbcghanaonline.com/general/court-fines-bar-operators-for-selling-adulterated-alcoholic-beverage-expired-eagle-lager-beer/2019/ https://web.facebook.com/AccraMetropolis/posts/2540646182695497/?_rdc=1&_rdr https://newslinegh.com/category/news/court/	**Fake alcoholic beverages**
https://www.modernghana.com/amp/news/966101/fake-gihoc-syndicate-busted-at-nungua.html https://www.primenews.com.gh/general-news/accra-four-arrested-for-producing-fake-gihoc-distillery-products.html https://www.youtube.com/watch?v=Pv5J91Og-d4 https://www.theghanareport.com/police-confiscates-120-cartons-of-fake-alcoholic-beverages/ https://mobile.ghanaweb.com/GhanaHomePage/NewsArchive/Nungua-Police-arrest-four-persons-for-producing-fake-alcoholic-beverages-797818	**Fake alcoholic beverages**
https://www.ghanabusinessnews.com/2016/08/23/fda-cautions-against-deceptive-tomato-powder/ https://www.modernghana.com/news/714267/fda-cautions-against-deceptive-tomato-powder.html https://newsghana.com.gh/fda-warns-public-on-fake-tomato-powder/	**Fake tomato powder**

https://www.pulse.com.gh/ece-frontpage/public-safety-alert-fda-exposes-fake-tomato-powder-on-the-market/pwng373	
https://www.modernghana.com/amp/news/191813/chemicals-used-to-enhance-bread-palm-oil.html https://www.ghanaweb.com/GhanaHomePage/NewsArchive/Food-adulteration-is-injurious-to-human-health-Survey-149216	**Adulterated bread, palm oil**
https://www.modernghana.com/amp/sports/66390/palm-wine-dying-a-painful-death.html https://www.pulse.com.gh/lifestyle/food-travel/heres-why-you-probably-shouldnt-be-drinking-palm-wine/5svb8z7 https://www.modernghana.com/news/871527/palm-wine-you-drink-could-be-dangerous.html https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4048608/	**Adulterated palm wine & pito**
https://cgspace.cgiar.org/handle/10568/796 https://ugspace.ug.edu.gh/handle/123456789/6455?show=full https://dric.ucc.edu.gh/news/fingerprinting-rice-fighting-food-fraud-saving-lives	**Adulteration of milk** **Rice fraud**
https://www.modernghana.com/amp/news/180684/food-adulteration-on-the-increase-fdb-survey.html	**Food adulteration**

https://allafrica.com/stories/200809011420.html	**Rising trend of Food Adulteration**
https://www.modernghana.com/news/1137964/insight-the-wegdam-food-fraud-case-presented.html	**Document fraud**

Cases

The following at typical cases of food fraud that have occurred in Ghana in the past decade

Case 1

Case of adulterated honey in Ghana

There have been several accounts from victims of fake honey products on the local Ghanaian markets. In a YouTube video, two accounts from Ghanian individuals whose identities are unknown claim to purchase honey products from Ghana to abroad for consumption. On both accounts, these products passed airport security assessments. They also confirmed tasting the honey at the sales point and testified it was honey until the honey solidified in their containers after a few months of storage at both normal and cold weather temperatures at their destinations. One victim claimed he had unusual reactions after a few months of continuously consuming the product. Under normal circumstances, honey can remain in its original state for years. But in this case, the honey hardened like fresh bread or gum. One victim claimed that upon subjecting this solid substance to heat it converted back to the liquid state in which it was purchased.

Source:

Available from: https://www.youtube.com/watch?v=shh1oVm0Cjc

Available from: https://www.youtube.com/watch?v=Sc8qy7FZ4XM

Case 2

Case of artificial ripening of fruits in Ghana

In an interview on Somanya based Rite FM, a market woman commented that the fraudulent activity has taken over the market as a result of the greedy nature of the new generation of

sellers. She also blamed the farmers for introducing most of the sellers to this illegal activity which has negative consequences on consumers. Farmers are highly involved in this criminal act of transporting fruits and vegetables with high levels of residual agrochemicals on them into the markets just to prevent spoilage on their farms and also to maintain the freshness of these farms' produce. Even though this situation is rampant nowadays, in the case of the Tema mango market, Miss Vivian Narh, the mango market queen reports that the consumers of the Tema community are more aware of their safety. This makes them insist on naturally ripened fruits. They also put in measures to control the number of fruit sellers in the market per day to avoid the hastening of the fruit ripening process.

Source*: Available from: https://ritefmonline.org/tackling-unregulated-fruit-ripening-in-ghana/*

Case 3

Case of FDA's intervention against palm oil adulteration

The FDA reported that about 30% of palm oils found on Ghanaian market were adulterated with Sudan IV dye popularly known among the market women as "shuudin" after a market survey conducted in 2021. Due to the possible adverse health effects on consumers and the implications on exportation and trade, the FDA developed a traceability system in collaboration with The Artisanal Palm Oil Millers and Out-growers Association and The Solidaridad Network - West Africa to identify culprits engaging in the adulteration of palm oil along the supply chain. The Director of the Food Industrial Support Services Department of the FDA indicated in relation to this intervention that, it was high time the FDA with help from law enforcers used some people as scapegoats for adulterating palm oil just for getting a reddish oil. President of the Palm Oil Millers Association, Mr Paul Amaning also indicated that as part of the traceability system, the FDA would register all palm oil dealers and they

would be given an identification card where the barcodes will be scanned periodically for tracing. Furthermore, effective July 1, 2022, the FDA also introduced new conditions for palm oil export. The conditions require all consignments of palm oil exports to be accompanied by official certificates from the FDA indicating absence of Sudan IV dye in the palm oils. Consignments that are not accompanied by official certificates from the FDA will be rejected on arrival in the EU. These interventions by the FDA would help in enhancing food safety issues as far as palm oil fraud related activities are concerned and safeguard the health and safety of the consuming public.

Source: http://www.fdaghana.gov.gh/news-media.php?page=133

https://www.gna.org.gh/1.21526246

Drivers of Food Fraud in Ghana

Food fraud is a prevalent issue in Ghana but is highly underreported (19), and it is driven by several factors, including globalization, financial incentives, and the low risk of being caught and penalized (18,30). Understanding the fundamental causes of food theft in Ghana is essential to effectively combating the issue. This can be achieved by examining the integrity of the food sector from various perspectives, such as product, process, people, and data across the entire food supply chain.

The economic motive is the primary driver of food fraud in Ghana, with individuals or organizations acting as the sole perpetrators. Food fraud is expected to cost the world's economy €49 billion yearly and impacts 10% of all commercially available foods (31). Therefore, understanding the drivers of food fraud in Ghana holistically is necessary to address the issue.

Supply Pressure and Consumer Preference

The proliferation of food fraud in Ghana can be attributed to the country's economic vulnerabilities (32), which create pressure for both producers and consumers to prioritize financial gain over product integrity. This pressure is compounded by the scarcity of raw ingredients, which drives up production costs and prices due to high demand and limited supply. As a result, many producers resort to using alternative ingredients in food production to generate extra income, compromising the quality and safety of the food supply. Consumers are also driven by the desire for affordable and desirable food, often overlooking the potential health risks associated with consuming adulterated food. This lack of vigilance on the part of consumers motivates perpetrators to continue engaging in fraudulent activities.

Supply Chain Complexities

Food fraud is becoming more and more of a problem in Ghana, in part because of the increase in food imports, which include anything from dairy and vegetable goods to beverages and cigarettes. However, the complexity of the supply chain can make it challenging to trace the origin of these goods, leaving room for fraudulent activities to occur. Products such as tea, coffee, spices, and herbs that come through various routes are particularly vulnerable to mislabelling or lack of proper labelling. As a result, detecting and preventing food fraud in Ghana becomes more difficult, making traceability a significant challenge in this regard.

Globalization and Technology

In Ghana, people involved in food fraud are becoming increasingly sophisticated, using technology and the internet to carry out their illegal activities. They often masquerade as legitimate food businesses and infiltrate the supply chain with counterfeit or adulterated products. In some cases, they deceive those in the food sector by providing fake documents in exchange for money. The proliferation of these substandard and counterfeit products, including consumables, has had a significant negative economic impact and poses health hazards to unsuspecting consumers.

Low Probability and Severity of Penalties

In Ghana, food safety measures tend to prioritize microbial contamination over food fraud, resulting in a proliferation of fraudulent activities in the food sector. The penalties for violating food safety laws, including the Food and Drug Law 1992, PNDCL 305B (33), are not severe enough to deter perpetrators from engaging in fraudulent activities. Traders caught committing food fraud are often allowed to reopen their shops after a short closure period, enabling them to continue their illegal activities. To prevent food fraud, law enforcement agencies should increase their focus on this issue, with penalties that outweigh the financial

gain of fraudulent activities. Regulatory agencies should establish efficient mechanisms for monitoring and reporting food fraud cases to help prosecute perpetrators.

Low Probability of Detection and Discovery

In Ghana's food supply chain, the problem of food authenticity is very important. Although food fraud is a serious issue, microbiological contamination is frequently brought up in debates about food safety. Most food retailers are unaware of simple household tests that can be used to authenticate certain products and imported and exported food products often bypass scientific and compositional standard tests at immigration and security checkpoints. To address these issues, there is a need for greater education and awareness among food retailers, as well as the strengthening of the enforcement of food safety laws and penalties. To guarantee the integrity and safety of the food supply chain, the Ghanaian government must act swiftly.

Finding the weak points in the food supply chain and putting precautionary measures in place are essential for combating food fraud. This can be achieved by promoting transparency, accountability, and integrity throughout the food sector. By doing so, consumers can have access to safe and authentic food products. Ultimately, comprehending the factors that drive food fraud is essential to tackling the issue and safeguarding public health.

The Impact of Food Fraud

Consumer Impact

Food fraud is a pressing global issue that poses serious economic and health risks to consumers. Adulteration of food products occurs when substances are added to increase volume or weight, deceive consumers, or cut costs. The adulteration can involve substitution of high-quality ingredients with lower-grade ones, dilution of products, or the addition of

harmful substances. The end result is a product that is lower in quality than advertised, potentially dangerous, and misleading to consumers (29).

Globally, food fraud has led to food safety issues such as the addition of battery chemicals to black pepper (34), which can be deadly, and the death of people from dairy anaphylaxis after drinking adulterated coconut water (35). Melamine in baby formula also caused kidney damage to some infants (11). Moreover, some spices such as turmeric and cinnamon contain harmful amounts of lead, which can pose significant health risks to consumers over time (36).

The indirect dangers linked to consuming modest dosages of pollutants over an extended period of time are sometimes unknown to consumers. Consumers who consume adulterated food products may be exposed to toxic chemicals, pathogenic bacteria, and allergens, which can pose significant health risks. Mislabelling of products may lead to people consuming food that they are prohibited from consuming due to religious reasons or consuming food that poses a significant threat to their health.

Food goods can include allergens such milk, eggs, peanuts, tree nuts, fish, shellfish, wheat, and soy without being properly labeled, which can result in severe allergic responses, including potentially fatal ones. Religious beliefs also play a crucial role in food consumption among different populations, and adulteration of halal foods with forbidden substitutes leads to disobedience of religious obligations and commandments.

Economic Impact

Food fraud poses significant risks to both consumers and producers, resulting in serious consequences such as financial losses, closure of factories, job losses, and reputational damage. The discovery or detection of food fraud may lead to hefty fines and the shutdown of factories, causing severe economic consequences. Additionally, the reputation of producers, companies, and retailers may be severely damaged, leading to a loss of consumer

trust and loyalty. Producers who engage in fraudulent practices risk losing their businesses and customers, leading to a significant decrease in profits and potential job losses.

Moreover, food fraud may lead to increased prices of certain food products due to the need for high-quality and safe ingredients, which may have significant economic implications for both consumers and producers. As such, it is crucial to ensure that food products are authentic, safe, and of high quality to prevent potential economic and health risks associated with food fraud.

Food Fraud Related Challenges in the Food Safety Industry

Food fraud is a complex global issue with far-reaching impacts on nations across the world. However, defining food fraud remains a challenging task, which makes it difficult to assess the extent of the problem. In Ghana, the current approach to testing food authenticity through the analysis of compositional standards appears inadequate in tackling food fraud (18). Consequently, unqualified individuals are producing and selling food products that do not meet established standards. Regulatory bodies play a vital role in enforcing food safety regulations, but face challenges in sharing information with the general public, which requires urgent redress.

Every incidence of food fraud is different, and creative techniques and resources are needed for effective action. However, compared to the volume of food fraud cases and the population of the nation, Ghana's official laboratories, which are administered by the Food and Drugs Authority (FDA) and the Ghana Standards Authority (GSA), have a limited testing capacity. As such, the state's capacity to meet the potential increase in demand for authenticity testing is relatively low (18,30).

The prevalence of food fraud in Ghana is increasing due to several factors, including inadequacies at border and immigration point laboratories, as well as regional and district-

level control laboratories. Additionally, limited funding and technical expertise are hindering the development of effective countermeasures (18).

Given the significant challenge posed by food fraud in Ghana's food industry, a comprehensive strategy is required to mitigate its impact. Addressing the driving factors of food fraud, such as inadequacies at border and immigration point laboratories and regional and district-level control laboratories, will also go a long way in reducing the incidence of food fraud in Ghana.

Role and Interventions of National Institutions

Ghana's fight against food fraud calls for more work than usual investigative techniques. Although the Food & Drugs Authority (FDA), Ghana Standards Authority, the Ministry of Health, and the Ghana Police Service (GPS) have been collaborating to address this issue, instances of phony food products continue to make headlines.

Thousands of kilograms of improper fruits and vegetables have been destroyed over the years by the FDA, which was founded and given the responsibility of assuring the production and consumption of safe food in Ghana (37). The FDA built a cutting-edge micro lab at the Tema Harbour in 2018 to increase its capacity for ensuring food safety. This lab will assist speed up operations related imported food commodities by using quick testing methods to ensure product conformity, safety, and quality before it reaches the consumer. To strengthen their ability to combat food fraud, they have also developed a cutting-edge micro lab and a food safety supervisor's training. The Ghana Standards Authority has also been involved in the fight against food fraud, with their Forensic Laboratory working with the Ghana Police to conduct forensic investigations.

In order to create rules and regulations and raise awareness of food fraud among the nation's food industry, a National Conference on Food Fraud was convened in 2015. At a workshop

on rice integrity, Prof. Elvis Asare Bediako, dean of the UCC School of Agriculture, noted that "knowledge of food fraud is quite low in Ghana and Africa." This has provided numerous crooks with the opportunity to defraud naïve customers." Despite these efforts, more needs to be done to combat food fraud in Ghana, including increased education and awareness among consumers and food retailers, as well as stronger enforcement of food safety laws and penalties.

Clamping Down on Food Fraud with Forensic science

Forensic science is an interdisciplinary field that utilizes various scientific disciplines to provide evidence for legal proceedings (38). It involves the gathering, examination, interpretation, and presentation of physical, chemical, or biological evidence to provide investigatory leads or make sense of an event. Forensic science has evolved significantly since its establishment as a scientific discipline about 100 years ago, progressing from basic fingerprinting techniques to advanced DNA analysis of air samples (49). Today's forensic scientists collaborate with experts from a wide range of disciplines, including engineering, microbiology, psychology, entomology, pathology, dentistry, economics, and computer science (38).

Despite criticisms from the public, forensic science has found ways to increase public confidence in its methods and approaches. While it is not a panacea, forensic science has brought an end to many criminal and civil issues, making it a reliable source for solutions to issues of criminal nature. Forensic science plays a crucial role in most criminal prosecutions through basic to complex cutting-edge scientific analysis. Its evolution has allowed for the closure of many criminal cases and has expanded to become a multidisciplinary approach for investigating and solving contemporary social and environmental issues (38).

Forensic science, initially developed for criminal investigations, has been increasingly applied to address issues of food integrity and safety, which are often prone to falsification. This application is known as food forensics, which involves the verification of food composition, processing, and origin to identify issues that affect the quality and safety of food. Food forensic investigations provide scientific support in urgent situations related to food, ingredients, materials, and processing (40).

Food fraud cases can be highly complex due to the use of analytical expertise to orchestrate the crime. Food forensics seeks to determine the root causes of these issues and how to prevent them from recurring. Investigations frequently concentrate on problems including foreign material, consumer complaints, financial adulteration, packaging material, ingredient issues, off-flavors, and other issues. Aside from looking for foreign objects, food forensic scientists also look for allergies, concerns with off-color, off-flavor, and off-odor, as well as changes in viscosity, texture, and other physical aspects (29,41).

In addition to identifying problems, food forensics can also clear the names of producers (41). For instance, misleading results may occur due to errors in equipment or devices, which could lead to the closure or banning of a company or individual's business. Food forensics can determine whether such results are due to technical failures in equipment or devices and can distinguish between different types of foreign materials.

To solve issues in the food supply chain, forensic scientists in the field of food use a variety of microscopic, physical, and spectroscopy methods as well as cutting-edge technologies like time-of-flight mass spectrometry, liquid chromatography, mass spectrometry, lateral-flow and ELISA immunoassays, gas chromatography, and optical microscopy (40).

Food fraud is a pervasive problem in Ghana, with reports dating back to at least 2018 highlighting its prevalence in the region (42). The seriousness of the situation has been

underscored by food technologist who warned that eating food in Ghana could mean consuming something that one should not (18). A multidisciplinary approach is necessary to tackle this crime, and part of that approach include having food inspectorate department staff members receive training in and follow basic forensic science methods.

Traceability is a fundamental requirement in the food supply chain, as the source of most of the food we consume is often unknown. Lack of knowledge about food origin can have severe health implications, including fatalities, which could be prevented by incorporating forensic science procedures into the training and practices of employees responsible for food inspection, supervision, and scientific analysis. These steps entail gathering, inspecting, analyzing, interpreting, and evaluating the evidence, as well as presenting it to the court or other relevant authority (40).

Through the use of scientific/technical tools like DNA analysis and databases (43), soil/microbial analysis (44), trace evidence analysis (45), chemical and toxicological analysis (46), and digital evidence analysis (47), forensic science practices also involve the identification and association of people and things, the prediction of events and activities, and the protection of society and systems. These techniques can be used to help find those who commit food fraud and uncover illegal activity in the food sector (48).

Food fraud is an economically driven crime with severe health implications. Countermeasures that address the root causes of food fraud, including inadequate testing procedures, insufficient laboratory facilities, limited funding, and technical expertise, are necessary. Combining forensic science principles and techniques with traditional regulatory and law enforcement measures is essential to combat food fraud effectively in Ghana.

Stable isotope ratio analysis and nucleic acid analysis are noteworthy aspects of food forensics. Stable isotope ratio analysis identifies the country and region of origin of a food

sample and provides insight into production methods. Nucleic acid analysis uses mitochondrial DNA to determine genetic differences among species, making it effective in detecting meat containing unspecified animal DNA. These technologies have proven effective in the authentication of halal meat products, enforcement of food labeling regulations, and assuaging consumer concerns (40).

Proteomic/metabolomic studies, DNA barcoding, and mass spectrometry-based analysis are examples of cutting-edge food forensics technologies that have important implications for the assurance of the food supply chain, consumer trust, and food safety. It is critical to incorporate these methods into the instruction and daily routines of those working in the food sector, including food scientists, managers, and inspectors, in order to maintain the credibility of the evidence and guarantee the openness of forensic investigations (40,43,46,49).

Proteomic and metabolomic analyses have become essential techniques for performing biological and chemical profiling of food components (50). These methods offer significant advantages in enhancing product tracking and traceability, verifying processing methods, and determining the authenticity, quality, and safety of food products. By identifying and quantifying proteins and small molecules in complex samples such as food products, scientists can compare the profiles of different samples and determine the origin and quality of food products.

DNA barcoding is a modern approach used for identifying food and wildlife species. This genetic analysis relies on specific segments of DNA that are unique to each species. By comparing an unknown species' DNA sequence to a database of known sequences, DNA barcoding can identify unknown species (51). This method can be used to process, finish, and package goods across the supply chain and is particularly helpful for plant-based items like

spices. DNA barcoding is a precise and trustworthy method for finding diseases and microbes in animal-based goods like milk, meat, or fish (43).

Mass spectrometry-based analysis is a valuable tool for analyzing the quality, authenticity, and safety of food products (52). This technology is especially useful for vulnerable goods like cheese that may be contaminated with mycotoxins or other dangerous compounds during preparation. Mass spectrometry-based analysis allows for non-targeted approaches, novel compound identification, and retrospective data analysis of minimal samples across as many chemical categories as possible. High-resolution mass spectrometers have been designed for use in food safety and forensic toxicology applications, providing high sensitivity, selectivity, and accurate quantitative analysis. These instruments are equipped with artificial intelligence, enabling them to detect both existing and emerging trends in food safety and quality (53).

Future Developments in Ghana

The use of forensic science in situations involving food fraud has the potential to speed up the investigative process, increase effectiveness, and produce solid, transparent, and trustworthy scientific evidence to support legal claims. Additionally, forensic science techniques can raise the standard of professionalism and accountability needed in food fraud investigations. It would be advantageous to increase forensic resources in organizations charged with preventing food fraud, including the creation of well-equipped food forensic laboratories across the country and instruction of food scientists and related professionals in forensic science practices, procedures, and relevant technologies.

The use of digital technologies to design trackable third-party apps for food deliveries can assist in identifying the origin of specific food products purchased or ordered online. In the future, establishing a national food protection and defense center that integrates data from a unified network of experts, organizations, and producers sharing food data from diverse

sources could help bridge gaps in the food supply chain. A central food fraud institution is necessary to provide independent regulation of fraudulent activities, conduct additional investigations in Ghana's food supply chain and hold accountable those responsible for committing such crimes.

To mitigate food fraud, a more coordinated national approach is required, involving law enforcement agencies, scientific laboratories, universities, research institutes, food regulatory bodies, industry players, consumers, and relevant stakeholders. Behavioral change interventions can also be used to reduce the motivation to commit food fraud in Ghana. The government of Ghana must prioritize the procurement and availability of authenticity and specialist instrumentation, enabling the food industry, immigration, and border checkpoints to verify the standards of food products entering and leaving the country.

Finally, advocating and educating the public about the effects of food fraud is critical to prevent such crimes. The public must be fully informed about the institutions and tools available to fight food fraud, and reporting incidents to the authorities should be encouraged. Security checkpoints should be well-guarded nationwide to prevent the admission of subpar, contaminated, and counterfeit goods that could jeopardize the health of Ghanaians who are not vigilant.

Conclusion

In recent years, the global food industry has experienced substantial growth, making it more vulnerable to fraudulent activities. These activities jeopardize the health and economic well-being of billions of people, compromising the integrity of the food supply chain. Food fraud can occur with almost any sort of food, and it has been estimated that the profits from food fraud outpace those from the drug trade. The whole food supply chain, from basic production through wholesaling and retailing, is susceptible to fraudulent activity. Given that food fraud

is one of the most sophisticated criminal activities, it necessitates the implementation of appropriate checks and measures, including proper food regulations and auditing for both small businesses and large industries.

Managing and minimizing food fraud is a multifaceted global challenge that requires a global effort. While forensic support for food fraud investigations is encouraged in the developed world, where most of the food we eat is processed, equal prioritization and importance should be given to the developing world, where food safety and fraud issues are prevalent. A stable nexus between policies, laws, and regulations is crucial in strengthening food control systems and providing authentic information about the food people consume across the world.

In summary, food fraud is a global challenge that requires the concerted efforts of all stakeholders in the food supply chain to mitigate its effects. By instituting appropriate checks and measures, leveraging forensic support, applying digital technologies, instituting national food protection and defense centers, coordinating national efforts, and prioritizing education and advocacy, we can achieve a safer and more secure food supply chain for all.

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