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From Contamination to Climate Change: Emerging Risks at the Nexus of Food Safety and Nutrition, and their Implications for Public Health

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Food shoppers are confronted with an extensive amount of information. Most often, consumers focus mainly on the price, brand, the type and extent of nutrition offered, and, potentially other food production or processing attributes, such as kosher or organic certifications. In most developed countries, it is taken for granted that the human and pet foods available for sale are safe for consumption. However, this is not always the case. Every week, news reports detail new cases of food contamination, usually from microbes (especially bacteria and viruses) but also from a variety of parasitic, chemical, or physical contaminants such as plastics or metals.

The volume and often complex nature of food risk information can be overwhelming and lead some consumers to either become hypervigilant or to largely ignore food safety risks. Additionally, food safety concerns become more complex when nutrition considerations are also considered. To offer further insight into these issues, this article begins by introducing food safety and some of the important linkages between food safety and nutrition. Following this, several contemporary food safety issues with nutrition implications are discussed.

What Food Safety Is… and Isn't

While there is no generally accepted definition of food safety (Oyarzabel and VanRenterghem, 2020), food safety broadly refers to the growing, handling, preparation, and storage of ingredients and foods in a way that prevents contamination and reduces the risk of foodborne illness. Food safety may, but does not necessarily, overlap with the concepts of food quality, food fraud, and food defense. Food quality considerations apply to products that may still be safely consumed but because of spoilage or mishandling may offer less nutrition, changed texture or flavor, or become less visually appealing (e.g., due to bruising or wilting). Importantly, both food safety and food quality challenges are unintentional and are often due to mishandling and made worse with time. In contrast, food fraud is the deliberate deception of consumers using food products, ingredients, or package labeling for economic gain (GFSI, 2014). While not intended to affect a food's safety or available nutrition, certain types of fraud can detrimentally affect these attributes. The present discussion explores food safety and the overlapping area of food fraud which can negatively impact a food's safety and nutrition.

So, why is this important? The economic cost of food safety failures and the burden to public health cannot be overstated. Despite extensive efforts to keep the U.S. food system safe, foodborne illness is still prevalent. The Centers for Disease Control and Prevention (CDC) estimate that one in six people living in the United States will be sickened by their food each year. Most of these cases are short-lived and successfully treated at home. More severe cases will require medical intervention. Each year, foodborne illnesses lead to 128,000 hospitalizations and approximately 3,000 deaths (FDA, 2023). Individuals with compromised immune systems, those who are pregnant, are elderly, and the unborn, are at particular risk from foodborne illnesses.

Foodborne disease outbreaks are defined as an incident in which two or more people experience the same illness from the same contaminated food or drink (CDC, 2015). As most cases of foodborne illness are remedied at home, the cause of the illness is not confirmed and is, therefore, not considered part of an outbreak. Between 2008 and 2015, among confirmed outbreaks where the source food was identified, chicken, turkey, pork, and beef products collectively accounted for 39% of outbreak-associated illnesses. Other commonly identified causes of outbreaks include fruits and vegetables (26% of outbreaks), animal products including eggs and dairy (12% of outbreaks), and fish

and mollusks (9% of outbreaks) (CDC, 2023).

The economic cost of foodborne illness is substantial. Hoffman and Ahn (2021) estimated the economic burden of illness resulting from 15 pathogens that cause 95% foodborne illness cases. Using 2018 data to consider medical costs, productivity loss, and—in the case of deaths—the Value of a Statistical Life (VSL), it was estimated that these pathogens impose an economic burden of $17.6 billion annually. Given high inflation since this analysis was completed, and as medical care prices generally increase faster than overall consumer prices, this cost would now likely be substantially higher.

Linkages between Food Safety and Nutrition: Evolving Contemporary Issues

While often studied separately, food safety and nutrition are deeply interconnected. To achieve good health, individuals need to be both well-nourished as well as free from illness. The following discussion explores several evolving issues at the nexus between food safety and nutrition: changes in our understanding of diet-related disease, the nature and incidence of food fraud, and the implications of climate change on food safety.

Individual Food Safety Risk and Diet-Related Disease

When it comes to food, what is safe for some individuals may not be safe for all. Food allergies are a significant and growing health concern in the United States and several other nations that have adopted a Western lifestyle (Tang and Mullins, 2017). The most common type of food allergies occur when an allergen binds to specific immunoglobulin E (IgE) antibodies which, in turn, triggers the release of histamine and other chemical substances that cause an allergic reaction. While mild food allergies may be inconvenient but tolerable (itchy mouth, hives, facial swelling), more severe allergies can be life-threatening (throat tightening, difficulty breathing, hypertension, circulatory collapse) or, in the most severe cases, are fatal. The economic burden of food allergies is significant. The cost of foodborne allergies among U.S. children alone has been estimated to be $24.8 billion ($4,184 per child) annually (Gupta et al., 2013); importantly as well, the financial burden to individual households has been found to vary by socioeconomic status (Bilaver et al., 2016).

In addition, several other disorders can be triggered by food. Oral allergy syndrome and eosinophilic esophagitis occur alongside food allergies (NIAID, 2018). Food intolerance is an abnormal response to food that does not involve the immune system, but rather, may occur due to malabsorption, enzyme deficiency, or other digestive issues. Food sensitivities do not yet have an official definition or medical diagnosis but are generally thought to result from inappropriate activation of the immune system (in this case Immunoglobulin G) to a particular food. Finally, autoimmune disorders, in which the body mistakenly attacks itself, can also be triggered by food. Celiac disease, which can be triggered by the ingestion of gluten (a protein found in barley, rye, and wheat) is, perhaps, the best-known example of this.

Estimates indicate that 33 million Americans, approximately one in 10 adults and one in 13 children, exhibit some degree of food allergy (FARE, 2023). As most food allergy research is focused on children, much more is known about prevalence and effects on this population subgroup. Among children with food allergies, 39% are reported to have experienced severe reactions, and about 30% have multiple food allergies (Gupta et al., 2011). Importantly, data suggest that the incidence of food allergies differs by race and ethnicity. Black Americans are at the greatest risk of developing a food allergy (Keet et al., 2014). Moreover, compared to White children, Black and Hispanic/Latino children are at higher risk of adverse outcomes due to food allergies, including having increased rates of life-threatening reactions (e.g., anaphylaxis), emergency department visits, and associated morbidities (Mahdavinia et al., 2017).

Avoiding specific foods in one's diet requires great care and information. The Food Allergen Labeling and Consumer Protection Act of 2004 (FALCPA) requires labeling of eight major food allergens milk, eggs, tree nuts, peanuts, wheat, soy, fish, and crustacean shellfish. When FALCPA was passed, these eight allergens accounted for 90% of food allergies and serious allergic reactions in the United States. FALCPA requires allergens to be indicated in a food's ingredient list either in parentheses following the name of the ingredient (e.g., "flour (wheat)" or in a "contains statement" (e.g., "contains wheat") placed immediately after or next to the ingredient list. The list of ingredients that require labeling was expanded to include sesame seed in the Food Allergy Safety, Treatment, Education, and Research (FASTER) Act which was implemented in 2023. In addition, recognizing that there are many more foods that can cause allergies or other reactions, the FDA issued draft guidance in 2022 concerning how the agency intends to evaluate the public health importance of lesser-known food allergens (FDA, 2022).

Avoiding specific foods also comes at an additional cost in both searching for and the expense of "free-from" foods. Families, particularly those in rural areas, face significant obstacles in finding appropriate foods and often need to travel significant distances to do so. Additionally, foods needed to address (or prevent) food-related illnesses are more expensive than their standard equivalents. Indeed, a gluten-free diet has been found to cost twice as much as a standard diet (Lee et al., 2019). Compounding this challenge, those with food allergies and other diet-related illnesses are also more likely to be from lower income households and have a higher

prevalence of food insecurity than the general population. While these families may be eligible for nutrition assistance programs, these do not help with this additional expense. The largest nutrition program, the Supplemental Nutrition Assistance Program (SNAP), does not fully consider the increased cost burden on families with food allergies (Brown et al., 2020). Other programs, such as the Summer Feeding Program and the Senior Farmers' Market Nutrition Program, do not adjust reimbursement to accommodate meal modifications for those with food-related conditions (USDA-FNS, 2024). Emergency food assistance efforts, such as food pantries and soup kitchens, also offer little help; nationally, only a handful of sites offer allergy-free options (Brown et al., 2020).

Food Fraud as a Food Safety and Nutrition Concern

Given the potential health impacts and geographic reach of food fraud, it is worth considering the risks posed by various types of food fraud and their food safety implications. Spink and Moyer (2011) classified several common types of food fraud. *Adulteration* occurs when all or some component of a food product, such as a high-cost ingredient, is not what is claimed on the product label. *Tampering* refers to instances in which a legitimate product and packaging are used in a fraudulent way. *Over-run* occurs when a legitimate product is made in quantities which exceed a production agreement; in such cases the excess product is sold, often through illegitimate marketing channels. This differs from *theft*, in which legitimate products are stolen and later sold as if they had been legitimately procured. This can occur when, for example, loaded tractor trailers are stolen and the food contained in them is redistributed through standard (often discount) food retailers. *Diversion* is the sale or distribution of products outside of intended markets. Food products that are illegitimately made but designed to look exactly like or very similar to the authentic versions of a product are considered *counterfeit* or *simulated*, respectively.

While food fraud is not a widely discussed topic, it has significant economic and public health implications. It has been estimated that, globally, food fraud costs the food industry $30–$40 billion annually (MSU CVM, 2019) and that a single food fraud incident can cost a company 2%–25% of its annual revenue (GMA, 2010). Particularly relevant to the present discussion, though, are the potential public health consequences of food fraud. To be sure, not all cases of food fraud will have food safety or nutrition implications: Fraud through theft or diversion may not pose any additional risk to consumers. But nutrition and food safety impacts are possible in instances where the fraud involves the sale and consumption of illegitimate products or legitimate products that are not properly handled. Products adulterated with toxic substances—such as food coloring containing lead or unapproved color additives—pose a direct health threat. Instances where legitimate foods are stolen and temperature controls are not maintained during redistribution or when "best before" date labels are changed (extended), increase the likelihood that food products will become unsafe for consumption.

Other types of food fraud may have adverse health impacts for vulnerable population segments. As one example, fraud in spices is common and often occurs through the addition of filler material, which can easily be disguised as the spice to increase volume and thereby reduce the seller's input cost. When the bulking agent is a benign plant material the fraud has purely economic implications. But should the bulking materials be an allergen, such as when ground peanut shells or almond husks are added to ground cumin, these fraudulent products can pose a life-threatening risk. There can also be nutritional impacts can when the labeled amount of nutrition is not contained in a product. This can occur, for example, when ingredients containing important macro- or micro-nutrients are substituted with other (often lower cost) ingredients with lower nutrient availability. Here again, for some food consumers this may not be a problem. However, for those consumers depending on the nutrition offered by these foods, such as infant formula or nutritional drinks for older adults, this can have grave health implications.

The challenge of food fraud is not limited to markets with lax regulatory or inspection oversight; rather, this is a global problem affecting all countries where there is an economic incentive (and insufficient deterrent) to doing so. In the United States, there were at least 153 identified cases of food fraud between 2015 and 2021.[1] While this number may seem low, the value and damages of each of these incidents is significant. Because of the obscure nature of this crime, these identified cases are certain to be a lower bound of the actual prevalence of U.S. food fraud. Importantly as well, the reported number of cases has generally been trending upward; however, it is unclear whether this is due to an actual increase in the number of cases or to improvements in surveillance and reporting. The distribution of these cases across raw agricultural commodities and prepared foodstuffs varies considerably. Seafood animals and products, meat, cereals, flour, and starch products are the products most subject to fraud in the United States. Among these U.S. cases, most of the food fraud consists of adulteration (46.1%) or fraudulent documentation (39.1%). Many fewer cases are due to food processing or manufacturing without inspection (6.2%), in unapproved premises (5.0%), due to expiration date changes, or the unauthorized or unsuitable transport of food (0.9%).

[1] Author calculation using data from *HorizonScan (https://horizon-scan.fera.co.uk/)*.

Linkages between Climate Change, Food Safety and Nutrition

Several studies have considered questions concerning the impact of climate change on food security; in general, these studies have concluded that climate change will affect food security by disrupting food production and access. Relatively less is known about the complex and important linkages and implications of climate change for food safety and human nutrition. To address this, national and multinational efforts are considering these issues (FAO, 2020).[2] To date, studies suggest that climate change is likely to increase the risk of foodborne illness and chemical hazards in food (Ziska et al., 2016). Elevated temperatures and volatility in precipitation are expected to increase exposure to some pathogens, toxins, and chemical contaminants. Many food and water pathogens - including *E. coli*, *Vibrio* spp., and nontyphoidal *Salmonella* spp.- favor warmer and wetter growing conditions which, in turn, could increase the pathogen load in soils and the potential for crop contamination. In addition, altered and extended summer seasons are expected to affect the frequency and severity of seasonal foodborne diseases (FAO, 2020). Cucurbits - which include cucumbers, melons, squashes, and pumpkins - may be particularly vulnerable to this contamination as they are grown in direct contact with soil.

Increases in extreme weather events, changing sea and ambient air temperatures, and elevated carbon dioxide levels are also expected to have a profound impact on exposure to chemical contaminants, the prevalence of naturally occurring toxins, and nutrient availability in food. Elevated sea surface temperatures can contribute to a greater accumulation of mercury in fish (Ziska et al., 2016). This poses food safety risks as consumption of methylmercury (the form of mercury that can be absorbed by humans) can have adverse neurological effects and affect the development of children. The risk of mycotoxin accumulation in fields and in the storage of harvested products is also expected to increase. Mycotoxins are produced by some fungi, exposure to which can have toxic effects on the kidneys and the reproductive and immune systems (FAO, 2020), is known to be a primary cause of liver cancer (WHO, 2015, and has contributed to micronutrient deficiencies in children in developing countries (Watson et al., 2016). Finally, it is anticipated that climate change will also affect the nutrient availability in foods. Due to increasing levels of atmospheric carbon dioxide, the concentrations of protein and essential minerals in many plant species will decrease (Ziska et al., 2016). As such, the nutritional value of many important food crops, including rice and wheat, may fall below current norms.

In addition to these detrimental impacts, studies have explored a variety of other linkages between climate change and food safety and nutrition. Among these are the impacts of increasing water and air temperatures. Algal blooms occur when there is an abundance of one or more of the 300 harmful species of algae in an area; warmer seas, ocean acidification, and other food impacts of overfishing have led to a global increase in the number and duration of these blooms FAO (2020). Phycotoxins produced by these algae can accumulate in fish and shellfish and can induce a variety of seafood intoxications - including Diarrhetic Shellfish Poisoning, Neurotoxic Shellfish Poisoning, and Amnesic Shellfish Poisoning - in those who consume them (Grattan et al., 2016).

Climate change will also pose increased challenges for the safe storage of temperature-sensitive ingredients and foods as the rise of ambient temperatures will likely require expanded or upgraded chilling or freezing technologies. The economic burden of this technology upgrading will be disproportionately felt by those in developing countries, who will be most in need of upgrading their current cooling capacity due to their lower initial stock of this equipment and who will likely experience the largest temperature changes (James and James, 2010). Many other emerging food safety issues that will be affected by climate change have been identified, including emerging pollutants, novel food production systems, novel food sources, geoengineering measures, and digitization and other technological advancements (FAO, 2020).

Conclusions

Despite significant investment in efforts to reduce the prevalence and increase the monitoring and prediction of food safety hazards, foodborne illness continues to pose very significant public health and economic burdens. Evolving environmental and human health conditions, and changing markets and incentives, continue to create new food safety challenges and opportunities. These changes, in turn, have direct and indirect linkages and often negative implications to access and availability of safe food, and the nutritional quality of it. Anticipating, understanding, and meeting these emerging challenges will require sustained, creative, and transdisciplinary research, significant private and public sector investment, and innovative policy development.

[2] One such initiative was led by the U.S. Global Change Research Program (https://www.globalchange.gov/), which facilitates collaboration and cooperation across 15 federal agencies.

For More Information

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