Emerging Contaminants in Food and Food Products

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Emerging Contaminants in Food and Food Products

In recent years, a wide variety of new chemicals have continued to be developed as a result of industrial development and associated anthropogenic activities. The microbial contaminants in the environment, more precisely, antibiotic-resistant genes/bacteria produced as a result of mutation due to antibacterial drugs, are also considered emerging contaminants and specifically called emerging microbial contaminants such as sapoviruses, *Waddlia chondrophila* and *Streptococcus parauberis*. Additionally, pharmaceuticals and personal care products are a diverse group of compounds that include ibuprofen, diclofenac, triclosan, antibiotics, anti-inflammatory agents, steroidal hormones and active ingredients in soaps, detergents and perfumes which could find their way into food materials, are tagged as emerging contaminants.

Given this, *Emerging Contaminants in Food and Food Products* discusses issues around the emerging contaminants in food and food products. Different types of contaminants, such as biological, chemical, organic, inorganic and microbial contaminants in foods, ways of detecting them and regulations surrounding global food safety, are all covered.

Key features:

- Discusses all the categories of contaminants in food and food products. Biological, chemical, organic, inorganic and microbial contaminants.
- Provides full information on emerging food contaminants, their effect on human and animal health, and how it affects global food security and emerging technological applications in solving this global problem.
- Gives detection and prevention strategies and guideline policies on emerging contaminants of foods.
- Brings into account global perspectives on food contaminants and health implications.

This volume will serve as an information hub of emerging contaminants for scientists/researchers and professionals globally. This book is a good collection of independent chapters, which presents full insights into the study of emerging contamination in food and the effects of these contaminants in humans and animals.

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Foreword

In the recent years, a wide variety of new chemicals continue to be developed as a result of industrial development and associated anthropogenic activities. The microbial contaminants in the environment, more precisely, antibiotic-resistant genes/bacteria produced as a result of mutation due to antibacterial drugs, are also considered emerging contaminants and specifically called emerging microbial contaminants such as sapoviruses, *Waddlia chondrophila* and *Streptococcus parauberis.* Pharmaceuticals and Personal Care products are a diverse group of compounds that includes ibuprofen, diclofenac, triclosan, antibiotics, anti-inflammatory agents, steroidal hormones, and active ingredients in soaps, detergents and perfumes which could find their way into food materials are tagged emerging contaminants. Endocrine-disrupting chemicals are extremely heterogeneous and are classified as synthetic chemicals and natural chemicals. Natural chemicals are found in food of humans and animals, for example, phytoestrogen: genistein and coumestrol. Synthetic chemicals can be further grouped into industrial solvents, lubricants, plastics, pesticides and some pharmaceuticals. Exposure to these are virtually unavoidable, and these contaminants have thus become ubiquitous, leading to a growing concern that such living conditions could result in adverse health effects such as early puberty and infertility. Having known all these, this book provides a guide for every human being in every country to be aware of the types of these contaminants, and how to detect, prevent and/or control them. Also, this volume will serve as an information hub of emerging contaminants for scientists/researchers and professionals globally.

This book *Emerging contaminants in food and food products* is a good collection of independent chapters which presents full insights in the study of emerging contamination in food and the effects of these contaminants in humans and animals. In an expansive form, this book focuses on the understanding the emerging contaminants in foods, types, sources and effects, soil-plant interaction in heavy metal uptake and crop quality, international regulations in food contaminants, emerging contaminants in drinking water, biological and chemical food contaminants: challenges and solutions, emerging microbial food contaminants, cases of micro and nanoplastics in food and food products, emerging contaminants from pesticide, Bio solids, and manure, effects of emerging pharmaceutical contaminants on human, natural contaminants in infant foods:, effects of biotransformation of PFCs, PBDEs and Ps in human and food products, detection of microbial food contaminants, distribution, prevention and control of emerging food contaminations, current trends and future research in emerging food contaminants,heavy metals and emerging contaminants in foods linked with neurotoxicity and current trends and future research in emerging food contaminants . I therefore have no doubt that the above focused areas provide adequate information on emerging contaminants in food and food products and do fill the expected scientific knowledge gaps in this area.

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Preface

Nutrients are needed from the environment (soil) for plants growth. When growing, plants absorb contaminants in their tissues in form of nutrient constituting possible vectors of introducing emerging contaminants into the food chain; an issue that is presently considered of high priority, hence, needing intensive and critical reviews. International bodies and Government agencies worldwide are intensifying efforts to improve food safety, which are coming in response to an increasing number of food-safety problems and rising consumer concerns. This book titled *Emerging Contaminants in Food and Food Products* has been designed to give current scientific information on unnoticed but yet important contaminants called emerging contaminants in food and food products.

Emerging contaminants may be present in food and food products because of the various stages of production such as harvesting, transport, processing, packaging or storage. In addition, new emerging contaminants in food are rapidly increasing due to new industrial processes, agricultural practices, environmental pollution and climate change. Emerging contaminants denote a more recently detected wide group of families of naturally or synthetically occurring compounds, such as pharmaceuticals, flame retardants, endocrine-disrupting chemicals, nanoparticles, personal care products, plastics materials, biological and microbial contaminants. These compounds are omnipresent (including food products) and pose risks to human health and the environment. Prolonged exposure to some emerging contaminants like parabens, bisphenol A, alkylphenols or phthalates can impact the reproductive system in humans and wildlife. Nanoparticles, commonly used in industrial and consumer products, can cause cytotoxicity and cell damage; flame retardants can cause neurotoxicity and impact the normal routine of the endocrine system. These concerns have led the scientific community across the globe to shift its focus from conventional "priority" pollutants to "emerging" or "new generation" contaminants. In addition, many medical drugs used for human disease treatment, such as antibiotics, endocrine disruptors and chemotherapy drugs, are excreted domestically and discharged into the environment. Some of these pharmaceutical compounds have strong sorption characteristics and low solubility and are likely to be concentrated in biosolids. When such biosolids are used for land application, it can take years for the emerging contaminants to get removed from the environment and they can eventually end up accumulated by plants and found their way into the food chain causing critical health concerns.

This volume is aimed to discuss issues around the emerging contaminants in food and food products. Different types of emerging contaminants, such as biological, chemical, organic, inorganic and microbial contaminants in foods, current ways of detecting them and regulations surrounding global food safety, will be discussed. This proposed book has been designed to provide recent information on emerging contaminants of different kinds of food and food products. In light of this, this volume was divided into three sections comprising 15 chapters in all. The purpose of Section 1 is to introduce emerging contaminants in foods, Section 2 focuses on emerging food contaminants and food insecurity, while Section 3 reviewed the application of emerging technology in food contaminants mitigation. Chapter 1 summarizes the emerging contaminants in foods: types, sources and effects. Chapters 2, 3, and 4 revealed the soil-plant interaction in heavy metal uptake and crop quality, international regulations in food contaminants and emerging contaminants in drinking water, respectively. The second section of the book comprises five chapters which include biological and chemical food cntaminants: challenges and solutions, emerging microbial food contaminants: types, effects and detection, cases of micro- and nanoplastics in food and food products, emerging contaminants from pesticide, bio solids, and manureand effects of emerging pharmaceutical contaminants on human were critically discussed. The third section of this book with six chapters laid emphasis on the natural contaminants in infant foods: case study, effects of biotransformation of PFCs, PBDEs and Ps in human and food products, detection of microbial food contaminants, distribution, prevention and control of emerging food contaminations, Heavy metals and emerging contaminants in foods linked with neurotoxicity and current trends and future research in emerging food contaminants were examined. The chapters were contributed by 65 Academicians/Scientists/Researchers from ten different countries (Ethiopia, Denmark, India, Nigeria, Canada, South Africa, Brazil, the USA, the UK, Hong Kong) across the globe.

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Section I

Introduction to Emerging Contaminants (ECs) in Foods

1 Emerging Contaminants in Foods

Types, Sources, and Effects

C.E. Elenwo, A.I. Gabasawa, E.T. Alori, and O.O. Babalola

1.1 INTRODUCTION

Inherently occurring chemicals that could also be human-made or any microorganism that are not commonly observed in the environment but have the capacity to penetrate the environment and initiate known or presumed adverse ecological and/or human health effects are known as emerging contaminants. Pharmaceuticals, pesticides, industrial chemicals, surfactants, and personal care products that are constantly being found in groundwater, surface water, municipal waste water, drinking water, and food sources can be seen as contaminants. They also comprise endocrine-disrupting compounds, analgesics, antibiotics, hormones, and a whole range of other pharmaceutical compounds, including anti-inflammatory, anti-diabetic, and anti-epileptic drugs (Rosenfeld and Feng 2011; Amobonye *et al.* 2023). Guaranteeing food safety and quality is a major public health concern. Toxic metals, pesticides, and veterinary drug residues, as well as organic pollutants, radionuclides, and mycotoxins, can regularly pollute food. Radiometric and related processes, designed to local desires, are used in supporting national programs to control such pollutants (Siwila *et al.* 2022). Farré *et al.* (2013) opined that dangers of contamination in the agricultural food chain can stem from a range of sources such as remains of agrochemicals and natural toxins. Despite important public health interests, the economic impact of food contamination can be remarkable and might unpleasantly transform international trade. The enormous use of pesticides and agrochemicals is a fundamental part of agricultural practices and public health. There is evidence that children are particularly at risk from foodborne pollution from chemicals like pesticides. Even with the implementation of highest residual levels and a ban on certain chemical pollutants, the risk of diseases still continues as such chemicals remain in the physical environment. Furthermore, Garvey (2019) mentioned that the existence of antimicrobial resistance amid foodborne pathogens highlights the importance of avoiding this path of disease spread.

Contaminants may remain in food due to numerous steps of its manufacture, packaging, transport, or storage. Also, new toxicant deposits or emerging contaminants in food are on the increase as an outcome of new industrial techniques, agricultural formalities, environmental pollution, and climate change. While contamination, generally, has an adverse effect on the quality of food and may imply danger to human health, measures to reduce contaminants in foodstuffs have been taken in most developed countries (Farré *et al.* 2013). They can also be spotted from an undisclosed source, a new contact to humans, or a novel discovery method or technology and also comprise an extensive array of synthetic chemicals in global use, which include perfluorinated compounds, water disinfection by-products, gasoline additives, pharmaceuticals, human-made nanomaterial, and UV-filters, which are important for the advancement of modern society (Richardson 2007). Emerging contaminants can be broadly classified into several categories of such chemicals as pharmaceuticals and personal care products, cyanotoxins, nanoparticles, and flame retardants, among others. However, as new contaminants (or effects) are discovered, these classifications are constantly changing, and emerging contaminants from past years become less of a priority (Kárászová *et al.* 2020). These contaminants have only

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recently been discovered and investigated as contaminants, but their environmental effects were not fully fathomed or already known contaminants that have new reports arising about their risks in the environment (Kárászová *et al.* 2020). A group of substances with different properties including their molecular weights and their saturated vapor pressures would generally be referred to as emerging contaminants in foods. This chapter mainly focuses on the major types and causes of emerging contaminants in foods that impair food quality which would be appropriate in increasing consciousness, creating awareness, and increasing programs in environmental monitoring and regulations.

1.2 TYPES OF EMERGING CONTAMINANTS IN FOOD

According to Maggiore *et al.* (2020) and FAO (2022), among many others, there are several types of emerging contaminants that can be found in food. Some of the most common types include the following:

1. ***Chemical Contaminants***: Chemical contaminants include pesticides, veterinary drugs, industrial chemicals, persistent organic pollutants (POPs), mycotoxins, heavy metals (such as Pb, Cd, Ag), and per- and polyfluoroalkyl substances (PFAS). These contaminants can enter the food chain through various pathways such as contaminated soil, water, air, or through direct application during agricultural practices (Delcour *et al.* 2015; Aransiola *et al.* 2022).
2. ***Microbiological Contaminants***: Microbiological contaminants include bacteria (such as *Salmonella* spp., *Escherichia coli*), viruses (such as *norovirus*), parasites (such as *Cryptosporidium*), and fungi (such as *Aspergillus*). These contaminants can contaminate food during production, processing, handling, or storage if proper hygiene practices are not followed.
3. ***Nanomaterials***: Nanomaterials are engineered particles with dimensions in the nanometer range. They can be intentionally added to food as additives or unintentionally generated during food processing or packaging. Nanomaterials have unique properties that can potentially pose risks to human health, although their specific effects are still being studied (Babaniyi *et al.* 2023).

1.3 SOURCES OF EMERGING CONTAMINANTS IN FOOD

Emerging contaminants in food can originate from various sources, as seen in Table 1.1 (Abdolshahi and Yancheshmeh 2020).

1. ***Environmental Pollution***: Environmental pollution, such as air and water pollution, can lead to the contamination of crops, livestock, and seafood. Industrial activities, improper waste disposal, and the use of certain chemicals contribute to environmental pollution and subsequent contamination of food.
2. ***Agricultural Practices***: The use of pesticides, fertilizers, veterinary drugs, and growth promoters in agriculture can result in the presence of residues in food products. Improper application or excessive use of these substances can lead to contamination (Abioye *et al.* 2021).
3. ***Food Processing and Packaging***: Contaminants can also enter food during processing and packaging stages. Migration of chemicals or microorganisms from packaging materials into food, cross-contamination during processing, or the use of contaminated ingredients can introduce emerging contaminants into the final food product.
4. ***Natural Occurrences***: Some emerging contaminants occur naturally in the environment or are produced by microorganisms. For example, mycotoxins are naturally occurring toxins produced by certain fungi that can contaminate crops under specific conditions.

Table 1.1 depicts some of the sources and causes of emerging contaminants, vis-à-vis the consequent health repercussions thereof, as follows.

TABLE 1.1
Causative Agents, Sources, and Health Implication of Emerging Contaminants in Food

Causative Agents	Sources	Health Implications	References
Bacteria *Bacterium Listeria monocytogenes, bacterium Clostridium botulinum, Campylobacter jejuni, Shigella, Staphylococcus aureus, Vibrio vulnificus, Escherichia coli*	Intestines of birds, reptiles, and mammals. Soft cheeses, unpasteurized milk, meat, and seafood. Improperly canned foods, lunch meats, and garlic. Undercooked chicken or food contaminated with the juices of raw chicken, raw meat, and undercooked liquid or moist food that has been handled by an infected person. Contamination from food handlers, meat and poultry, egg products, cream-filled pastries, tuna, potato and macaroni salad, and foods left unrefrigerated for long periods of time. Found in raw oysters and other kinds of seafood, raw vegetables, minimally processed ciders and juices, and contaminated drinking water.	They invade the bloodstream and complications, such as high fever and severe diarrhea; cause a disease called listeriosis in pregnant women, newborns, older adults, cancer patients, and people with compromised immune systems. Cause botulism; symptoms are nerve dysfunctions, such as double vision, inability to swallow, speech difficulty, and progressive paralysis of the respiratory system. Cause campylobacteriosis; symptoms include diarrhea, stomach cramps, fever, and bloody stools. Cause shigellosis; symptoms include stomach cramps, diarrhea, fever, and vomiting. Another common symptom is blood, pus, or mucus in stool, including diarrhea, vomiting, nausea, stomach pain, and cramps. Other symptoms include chills, fever, nausea, and vomiting. It can result in fatalities, especially in people with underlying health problem. Other results include watery and bloody diarrhea, severe stomach cramps, dehydration, colitis, neurological symptoms, stroke, hemolytic uremic syndrome, kidney failure, and death in children.	Calabrese *et al.* (2017); Abdolshahi and Yancheshmeh (2020)
Viruses *Norovirus*	Raw shellfish from polluted water and food handled by an infected person.	Cause gastroenteritis symptoms, such as nausea, vomiting, diarrhea, stomach pain, headache, and a low-grade fever.	Lei *et al.* (2015); Abdolshahi and Yancheshmeh (2020)
Parasitic Protozoa *Giardia lamblia, Anisakis, Cryptosporidium, Toxoplasma gondii*	Found in contaminated drinking water, also lives in the intestinal tracts of animals, and can wash into surface water and reservoirs. Include raw fish. Lives in the intestines of infected animals. Common source is drinking water, when heavy rains wash animal wastes into reservoirs. The feces of a cat with an acute infection. Sources also include raw or undercooked meat and unwashed fruits and vegetables.	Cause giardiasis, with symptoms that include abdominal cramping and diarrhea. Symptoms of anisakis infection begin within a day or less and include abdominal pain that can be severe. Cause cryptosporidiosis; symptoms include watery stools, loss of appetite, vomiting, a low-grade fever, abdominal cramps, and diarrhea. Cause toxoplasmosis which can be carried without showing symptoms. The body's immune system keeps the parasite from causing disease.	Nabil *et al.* (2021); Akoolo *et al.* (2022); Siwila *et al.* (2022)

(*Continued*)

TABLE 1.1 (*Continued*)
Causative Agents, Sources, and Health Implication of Emerging Contaminants in Food

Causative Agents	Sources	Health Implications	References
Fungi *Aspergillus*, molds, toxic mushrooms	Peanuts, tree nuts, and corn. Fruits, vegetables, grains, meats, poultry, and dairy products, and typically appear as gray or green "fur." Diversities of fatal mushroom.	Produce mycotoxins that is called aflatoxins causing aflatoxicosis. Symptoms include vomiting and abdominal pain. Possible complications include liver failure, liver cancer, and even death. Produce mycotoxins that cause allergic reactions and respiratory problems. Cause severe vomiting and other symptoms.	Fisher *et al.* (2012); Tanjina Hasnat (2021); Sullivan (2022)
Pesticides	Agricultural food produce such as peaches, apples, bell peppers, celery, nectarines, strawberries, cherries, pears, spinach, lettuce, and potatoes contain high levels, while avocados, pineapples, bananas, mangoes, asparagus, cabbage, and broccoli contain lowest levels.	Cause certain health problems and difficulties, including cancer. Influence soil and water pollution and can be hazardous to farm workers.	Stefanakis and Becker (2020); Intisar *et al.* (2022)
Pollutants	Fish from dioxin-polluted waters. Lead contained in drinking water, soil, and air. Methyl mercury absorbed by fish. Polychlorinated biphenyls (PCBs) found in predatory fish.	Dangerous health problems. Physical and mental developmental delays in children. Health problems in physical and neurological growth in children. Carcinogenic effect, affect the immune, reproductive, nervous, and endocrine systems.	Meador (2008); Morin-Crini *et al.* (2022)

1.4 EFFECTS OF CHEMICAL CONTAMINANTS ON FOOD AND FEED

Presence of high concentration of chemicals in food and feed poses serious health risks (Thompson and Darwish 2019). Chemicals can enter the environment through feed production processes, leading to water and soil contamination, thereby negatively impacting ecosystems and wildlife (Naidu *et al.* 2021). Food and feed contaminants can cause acute and/or chronic toxic effect on human and animal health and environment, depending on the type and concentration of the contaminant, route of exposure, dose of contaminant, and such personal characteristics as age and health condition of the individual (World Health Organization [WHO] 2022). The harmful effects of chemicals in food and feeds range from minor gastric problems to major health fatalities (Rather *et al.* 2017). At high concentrations, certain chemicals, such as pesticides and heavy metals, can cause acute poisoning (WHO 2022). This can lead to symptoms such as nausea, vomiting, diarrhea, abdominal pain, organ damage, or even death in severe cases. In the long run, low levels of certain chemical contaminants can also cause chronic health problems (Alengebawy et al. 2021). Prolonged exposure to pesticide residues may contribute to the development of cancer, reproductive disorders, endocrine disruption, neurological disorders, or developmental issues (Alori and Babalola 2018; Alori *et al.* 2022).

Accumulation of heavy metals like lead, mercury, or cadmium over time can lead to organ damage, impaired cognitive function, developmental problems, and other chronic health conditions (Mitra *et al.* 2022). Some chemical contaminants, such as certain food additives or processing agents, can trigger allergic reactions in susceptible individuals. This can range from mild symptoms like hives or itching to severe allergic reactions like *anaphylaxis* (Andreozzi et al. 2019). Some chemical contaminants, including certain pesticides or industrial chemicals, can interfere with the endocrine system, disrupting hormone balance in humans or animals. This can lead to reproductive problems, developmental abnormalities, or hormonal imbalances. (Endocrine Society 2022). Exposure to certain chemical contaminants, such as certain mycotoxins (e.g., aflatoxins), some food additives, or environmental pollutants, may increase the risk of developing cancer over time (Ekwomadu *et al.* 2022). Chemical contaminants in feed can have detrimental effects on livestock and wildlife. Pesticide residues in feed may harm animals' health and reduce productivity (Choudhary *et al.* 2018).

1.5 EFFECTS OF CLIMATE ON FOOD SAFETY

Emerging contaminants in food are such types of substances that are not traditionally monitored or regulated but have the potential of posing risks to human and environmental health (Maggiore *et al.* 2020; Duchenne-Moutien and Neetoo 2021; FAO 2022). These contaminant types can readily enter the food chain through such diverse sources as environmental pollution, agricultural practices, food processing and packaging materials, and even via natural occurrences (Miraglia *et al.* 2009; Duchenne-Moutien and Neetoo 2021). They can have multitude of effects on human health, through toxicity (acute and/or chronic), carcinogenicity, endocrine disruption, neurotoxicity, reproductive toxicity, and immuno-toxicity (Nichols and Lake 2012; Alori *et al.* 2022).

Climate change has far-reaching effects on food safety throughout the entire food supply chain (IPCC 2023). Every stage from agricultural production to food processing, storage, transportation, and distribution is vulnerable to the impacts of climate change. Addressing these challenges requires a multi-faceted approach that includes sustainable agricultural practices, robust infrastructure, improved monitoring systems, and effective adaptation strategies (Vermeulen *et al.* 2012). Hence, climate change has a significant impact on various aspects of our planet, including food safety. The changing climate patterns are altering the conditions under which food is produced, processed, transported, and stored, leading to potential risks and challenges for food safety (Hjort *et al.* 2023). This part of the chapter attempts to delve into the effects of climate change on different stages of the food supply chain and highlights the key concerns that are associated with each stage as made clear by (Palade *et al.* 2023).

1. ***Agricultural Production***: Climate change affects agricultural production in multiple ways, which subsequently impacts food safety (Rodriguez *et al.* 2020; FAO 2022). Here are some key effects:
   a. ***Shifts in Growing Seasons***: Rising temperatures and changing precipitation patterns can alter the timing and duration of growing seasons. This can disrupt crop growth cycles, affecting yields and potentially leading to changes in pest and disease dynamics.
   b. ***Water Availability***: Changes in rainfall patterns can result in water scarcity or excessive rainfall, both of which can impact crop growth and quality. Droughts can reduce crop yields and increase the risk of contamination due to inadequate water for irrigation and sanitation purposes. Conversely, heavy rainfall events can lead to soil erosion, waterlogging, and increased runoff, potentially carrying contaminants into agricultural fields.
   c. ***Pest and Disease Dynamics***: Climate change can influence the distribution and abundance of pests and diseases that affect crops (Russell *et al.* 2010). Warmer temperatures may expand the range of certain pests, while altered precipitation patterns can create favorable conditions for disease outbreaks (Morand *et al.* 2013). These factors can lead to increased pesticide use or the emergence of new pests that pose risks to food safety.
   d. ***Crop Quality and Nutritional Content***: Elevated carbon dioxide levels in the atmosphere can affect the nutritional composition of crops. Studies suggest that rising CO_2 concentrations may reduce the protein content of grains while increasing their carbohydrate content. Changes in nutrient composition could have implications for human health if not properly managed.

1.6 FOOD PROCESSING AND STORAGE

Climate change also impacts food processing and storage, which are critical stages in ensuring food safety. Here are the key effects:

a. ***Temperature Control***: Rising temperatures can pose challenges for maintaining proper temperature control during food processing and storage. Higher ambient temperatures can accelerate bacterial growth, potentially leading to increased risks of foodborne illnesses. It becomes crucial to implement robust cooling systems and monitor temperature conditions closely.
b. ***Energy Supply and Infrastructure***: Climate change can disrupt energy supply and infrastructure, affecting the reliability of refrigeration systems and cold chains. Power outages or inadequate cooling infrastructure can compromise the safety of perishable foods, leading to spoilage or microbial growth.
c. ***Foodborne Illness Outbreaks***: Changes in climate patterns can influence the prevalence and behavior of foodborne pathogens. Warmer temperatures may enhance the survival and growth of certain bacteria, such as *Salmonella* and *Listeria*, increasing the risk of foodborne illness outbreaks (Jiang *et al.* 2015). Additionally, extreme weather events like floods or hurricanes can contaminate food processing facilities, leading to widespread contamination if not properly addressed (Herrera *et al.* 2016).

1.7 FOOD TRANSPORTATION AND DISTRIBUTION

Climate change impacts transportation and distribution systems, which play a crucial role in maintaining food safety. Here are the key effects:

a. ***Infrastructure Disruptions***: Extreme weather events associated with climate change, such as storms, floods, or heat waves, can damage transportation infrastructure. This can lead to delays in food shipments, compromising their quality and safety.
b. ***Supply Chain Vulnerability***: Climate-related disruptions in one region can have cascading effects on global food supply chains. For example, droughts or floods in major agricultural regions can lead to reduced crop yields or increased prices, affecting the availability and affordability of safe food.
c. ***Cold Chain Integrity***: Maintaining the integrity of the cold chain during transportation is crucial for preserving food safety. Rising temperatures can strain refrigeration systems and increase the risk of temperature excursions during transit. Such excursions can compromise the quality and safety of perishable foods.

1.8 HEALTH IMPLICATION OF EMERGING CONTAMINANTS IN FOOD

The effects of emerging contaminants in food on human health can vary depending on the type and level of exposure. Some potential effects according to Alori *et al.* (2022) include the following:

1. ***Acute Toxicity***: Exposure to high levels of certain contaminants, such as pesticides or heavy metals, can cause immediate toxic effects on human health. Symptoms may include nausea, vomiting, diarrhea, abdominal pain, dizziness, or even organ failure.
2. ***Chronic Toxicity***: Long-term exposure to low levels of contaminants may lead to chronic toxicity, which can manifest as various health problems over time. Chronic exposure to certain pesticides or POPs, for example, has been associated with increased risk of cancer, developmental disorders, neurological impairments, and hormonal imbalances.
3. ***Endocrine Disruption***: Some emerging contaminants have the ability to interfere with the endocrine system, which regulates hormone production and function. Endocrine-disrupting

chemicals (EDCs) can disrupt normal hormonal balance and potentially lead to reproductive disorders, developmental abnormalities, and other health issues.
4. ***Neurotoxicity***: Certain contaminants, such as heavy metals or some pesticides, can have neurotoxic effects on the central nervous system. Prolonged exposure to these substances may result in cognitive impairments, behavioral changes, or neurological disorders.
5. ***Reproductive Toxicity***: Emerging contaminants can also affect reproductive health and fertility. Exposure to certain chemicals or toxins during critical periods of development can lead to reproductive disorders, infertility, or adverse effects on fetal development.
6. ***Immuno-toxicity***: Some contaminants have the potential to suppress or alter the immune system's normal functioning. This can increase susceptibility to infections, impair immune responses, or lead to autoimmune diseases.

Emerging contaminants in food, therefore, pose potential risks to human health and the environment. These contaminants can enter the food chain through the various sources highlighted above, which include, although not limited to, environmental pollution, agricultural practices, food processing, packaging materials, and natural occurrences. These can have various effects on human health, including acute and chronic toxicity, carcinogenicity, endocrine disruption, neurotoxicity, reproductive toxicity, and immuno-toxicity. It is, therefore, very important for regulatory bodies, food producers, and consumers to be aware of these emerging contaminants and take appropriate measures to ensure food safety (Christensen *et al.* 2023).

1.9 DETECTION AND MONITORING OF FOOD CONTAMINANTS

Food contaminant detection and monitoring play a crucial role in ensuring the safety and quality of the food we consume (Russell *et al.* 2010; Chen *et al.* 2021; Hjort *et al.* 2023). Various methods and technologies are employed to detect and monitor contaminants in food, ranging from traditional techniques to advanced analytical tools. These methods can be categorized into physical, chemical, and biological approaches. Each of these categories will concisely be explored in this part of the chapter, as follows:

1. ***Physical Methods***: Physical methods involve the use of physical properties or phenomena to detect and monitor food contaminant (Chiou *et al.* 2015). Some commonly used physical methods include the following:
    a. ***Visual Inspection***: Visual inspection is a simple yet effective method for detecting visible contaminants such as foreign objects mold or discoloration in food products. Trained personnel visually examine the food samples for any abnormalities (Christensen *et al.* 2023).
    b. ***X-ray Inspection***: X-ray inspection utilizes X-ray technology to detect foreign objects, such as metal fragments or stones, in food products. X-ray machines generate images that can be analyzed by trained operators to identify potential contaminants.
    c. ***Metal Detection***: Metal detection systems use electromagnetic fields to identify metallic contaminants in food products. These systems are commonly used in the food industry to detect metal fragments that may have accidentally entered the production process.
    d. ***Magnetic Separation***: Magnetic separation involves the use of magnets to attract and remove magnetic contaminants from food products. This method is particularly useful for removing ferrous metals from raw materials or finished products.
    e. ***Ultraviolet Light***: Ultraviolet (UV) light can be used to detect certain types of contaminants, such as fluorescent dyes or residues, in food products. This light causes these substances to emit fluorescence, which can be detected using specialized equipment.

2. ***Chemical Methods***: Chemical methods rely on chemical reactions or interactions between contaminants and specific reagents to detect and quantify their presence in food samples (Silva *et al.* 2013; Hjort *et al.* 2023). Some of the commonly used chemical methods include the following:
   a. ***Chromatography***: Such chromatography techniques as gas chromatography (GC) and liquid chromatography (LC) are extensively used for the separation and analysis of food contaminants. These methods can detect a wide range of contaminants, including pesticides, mycotoxins, and veterinary drug residues.
   b. ***Mass Spectrometry (MS)***: MS is a powerful analytical technique that can identify and quantify contaminants based on their molecular weight and fragmentation patterns. Coupling MS with chromatography techniques (GC-MS or LC-MS) allows for highly sensitive and selective analysis of food contaminants.
   c. ***Immunoassays***: Immunoassays utilize the specific binding between antibodies and target contaminants to detect their presence in food samples. Enzyme-linked immunosorbent assays (ELISA) and lateral flow devices are commonly used immunoassay techniques in food contaminant analysis.
   d. ***Polymerase Chain Reaction (PCR)***: PCR is a molecular biology technique that amplifies specific DNA sequences, allowing for the detection of pathogens or genetically modified organisms (GMOs) in food samples. Real-time PCR enables rapid and sensitive detection of target DNA sequences.
3. ***Biological Methods***: Biological methods involve the use of living organisms or their components to detect or monitor food contaminants (Eyvazi *et al.* 2021). Some commonly used biological methods include the following:
   a. ***Microbiological Testing***: Microbiological testing involves the cultivation and identification of microorganisms present in food samples. This method is primarily used to detect pathogens such as *Salmonella*, *E. coli*, or *Listeria monocytogenes* (Liu *et al.* 2013).
   b. ***Biosensors***: Biosensors are analytical devices that combine biological components, such as enzymes or antibodies, with transducers to detect specific contaminants in food samples. Biosensors offer rapid and sensitive detection capabilities for various contaminants (Dominguez *et al.* 2016; Eyvazi *et al.* 2021).
   c. ***Whole Genome Sequencing (WGS)***: WGS is a cutting-edge technology that allows for the complete sequencing of an organism's DNA (Eyvazi et al. 2021). WGS can be used to identify and trace the source of foodborne outbreaks by comparing the genetic profiles of pathogens isolated from food samples and patients.

1.10 SUMMARY AND CONCLUSION

Emerging contaminants are those substances that are traditionally not monitored or regulated in the food supply although been identified as potentially hazardous. These contaminants may include many chemicals such as pharmaceuticals, personal care products, pesticides, industrial chemicals, and environmental pollutants. They can enter the food chain via diverse pathways, such as agricultural practices, environmental contamination, food processing, packaging materials, and even intentional adulteration.

Their effects in food range from acute toxicity to long-term chronic health complications. Specific effects can generally depend on the type of contaminant and its concentration in the food consumed. To mitigate the risks associated with emerging contaminants in food, it is essential to identify their sources and implement appropriate control measures. This includes monitoring, surveillance, and detection of their presence in different food commodities. Regulatory agencies should also play a vital role in establishing maximum residue limits (MRLs), critical limits, or tolerances for these contaminants to ensure safety standards of food products.

The chapter, therefore, provides an overview of the presence of emerging contaminants in food, their different types and sources, as well as their possible potential health effects on consumers. Emerging contaminants in food pose significant concerns for their potential adverse effects on human health. They can originate from various sources and can have diverse types, making it crucial to understand their presence, sources, and effects to ensure food safety and public health protection.

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