Food Chain Contaminants: How Pollution Infiltrates Our Diet

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Abstract

The food we consume is greatly impacted by environmental degradation. This chapter examines the complex relationships between contaminants in the food chain, such as how pesticide residues on fruits and vegetables, industrial pollutants in meat and dairy products, and heavy metals in seafood enter our diet and impact human health. Food chain contaminants have negative effects on human development, immune function and disease risk. By tracking pollutants from source to plate, this chapter aims to raise readers' awareness of the connections between environmental health, food safety, and human well-being, foster a more sustainable and healthy food system, and empower them to make educated decisions about their diet and lifestyle.

Keywords: Food chain contaminants, Environmental pollution, Food safety, Human health, Sustainable food systems

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Introduction

1.1 : Overview of Food Chain Contamination

Food chain contamination refers to a condition whereby there are unacceptable hazardous substances or pathogenic micro-organisms in the food chain which are potentially harmful to man and the environment (Odeyemi et al., 2020). Food borne diseases (FBD) courses through at least two billion people every year globally (Draeger et al., 2018).

1.2 : Pollution and its Sources

Pollution is largely caused by industrial activities (Rundlöf & Lundin, 2018). Vehicle emissions are well known to contribute significantly to the incidences of pollution (Arnold, 2019). Another cause of pollution is farming activities (Vergara & Silver, 2019). Garbage disposal is another significant menace to the wellbeing of the environment. Environment and natural calamities such as wildfires, volcanic eruptions are examples of polluting events (Singh et al., 2020).

1.3: How Contaminants Enter the Food Chain

Pollution of the environment is most common way for pollutants to get into food chain. Contaminated soil and water for instance can be ingested by plants while contaminated food and water can for instance be ingested by animals (Singh et al., 2020). Polluters can infiltrate the food system through agriculture or farming methods themselves. Droughts and floods are two instances of extreme weather that can cause contaminants to spread into the food chain (Rundlöf & Lundin, 2019).

2: Types of Pollutants Affecting the Food Chain

2.1 : Chemical Pollutants

Chemicals have the potential to harm both people and ecosystem when they are discharged into the environment (Wang et al., 2019).

Some of the components of interest are heavy metals and synthetic compounds which include pesticides as well as pharmaceuticals (Fischer et al., 2013).

2.2 : Biological Contaminants

There are serious health risks to humans from biological pollutants in the food chain. Pathogenic bacteria (Salmonella), Viruses (norovirus), parasites (Cryptosporidium), fungi (Aspergillus) and prions are examples of biological contaminants (Arnold, 2019).

2.3 : Microplastics

Microplastics are tiny pieces of plastic that are smaller than five millimetres (mm). Crawford and Quinn define microplastics as particles that range in size from 5 mm to 1 µm, whereas particles that fall between 1 mm and 1 µm are known as mini-microplastics (Crawford & Quinn, 2017).

Numerous infections have been discovered to be present in microplastics, such as Acinetobacter, which attacks humans, animals, and fish, and plants are attacked by Pseudomonas syringae (Wright et al., 2013).

3: Air Pollution and Food Chain Contamination

3.1 : Impact of Airborne Pollutants on Crop Growth

Air pollution has become a major danger to high-quality crop products found due to rapid urbanization and industrialization of the world (Shrestha et al., 2022).

Leaves are the most vulnerable plant portion. Significant alterations in foliar morphology, decreased root growth, and altered translocation patterns are all brought on by air pollution. Increased concentration of air pollutants is connected with a delay in spring phenology which impacts the CO_2 uptake via stomata and onset of pollination (Saini et al., 2019).

3.2 : Deposition of Heavy Metals and Toxins on Edible Plants

The metals accumulate in the soil over time and plants absorb these toxic metals through root systems and transport them to other plant parts including grains, fruits and vegetables (Nagajyoti et al., 2010).

Heavy metals acidify the soil, and interfere with microbial activity and nutrient cycling. This has serious economic ramifications since tainted products would not be fit for sale, with losses for farmers and shortages of food for the local population.

Methods such as phytoremediation and soil remediation can be used to manage contaminated soils (Nagajyoti et al., 2010).

3.3 Long Term Effects of Smog and Acid Rain on Agricultural Products

Acid rain (low pH) is any precipitation that has high concentrations of hydrogen ions and is abnormally acidic. The main receptors of acid deposition are soil and vegetation. Both natural and artificial acid rains have an impact on a range of plant species' germination, growth, biomass, budding, blooming, leaf abscission, photosynthesis, metabolic processes, enzyme activity, cytoplasmic characteristics, pollen behavior, and yield (Lal et al., 2016).

Smog is a mixture of air pollutants that results in lower crop yields and lower quality products (Arnold, 2019). Ozone and particulate matter (PM) from smog damage plant cells, retard growth, and reduce photosynthesis. Ozone damage is due to the entry of ozone into plant leaves. It can result in lower crop yields and lower quality products (Sillmann et al., 2021). Smog also lowers nutritional value by lowering the production of vital vitamins and minerals (Baráth & Fertő, 2017).

4: Water Pollution and Aquatic Food Contamination

4.1 : Contaminated Water Sources and Impact on Fish and Seafood

Contaminated water sources have huge and far-reaching impacts on fish populations, aquaculture and finally human health (fig:1). The heavy metals naturally accumulate in sediments and then are taken up by aquatic organisms that in turn become bioaccumulated in fish. For instance, at very high levels of mercury in the fish, it can create neurological2024lell as developmental issues in humans (Babuji et al., 2023).

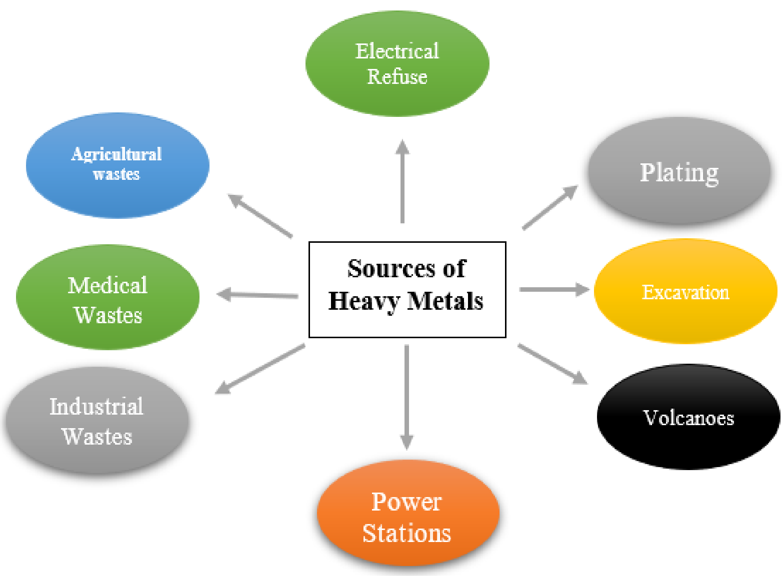


Fig. 1: Sources of heavy metal contamination in aquaculture and water

By better waste management, pollution load in aquatic settings can be reduced (Babuji et al., 2023).

4.2 : Mercury Accumulation in the Marine Food Chain

Mercury has neurotoxic effects when flashed in larger quantities, and the central nervous system is the element's primary target for its fumes. Higher levels of mercury absorbed by pregnant women are associated with involuntary abortion. They have identified many different types of sensory, motor, personality, and cognitive problems. Impaired vision, tremulous speech, poor focus, unsteady walking, and decline in psychomotor skills have been caused by some long term exposures to elemental mercury vapour. Subjects exposed to elemental mercury vapour for a few weeks have developed a persistent cough (Sonone et al., 2020).

4.3 : Agricultural Runoff and Eutrophication: Impacts on Aquaculture

Global aquaculture is seriously threatened by agricultural runoff, which is a major cause of eutrophication. Too many nutrients from fertilizers, manure and pesticides in runoff encourages too many algae to grow, which lowers dissolved oxygen and kills aquatic life (Wang et al., 2019).

Eutrophication reduces aquaculture productivity by reducing yields and causing financial losses. Eutrophication makes seafood unfit for human consumption. An example of the disastrous effects of agricultural runoff on commercial fisheries is the roughly 14,000 square kilometre Gulf of Mexico Hypoxic Zone. Aquaculture innovations are needed including recirculating aquaculture systems for waste reduction and water conservation (Martìnez et al., 2010).

5: Soil Pollution: The Silent Infiltration

5.1 : Contaminants in Agricultural soils: Fertilizers, Pesticides and Industrial Waste

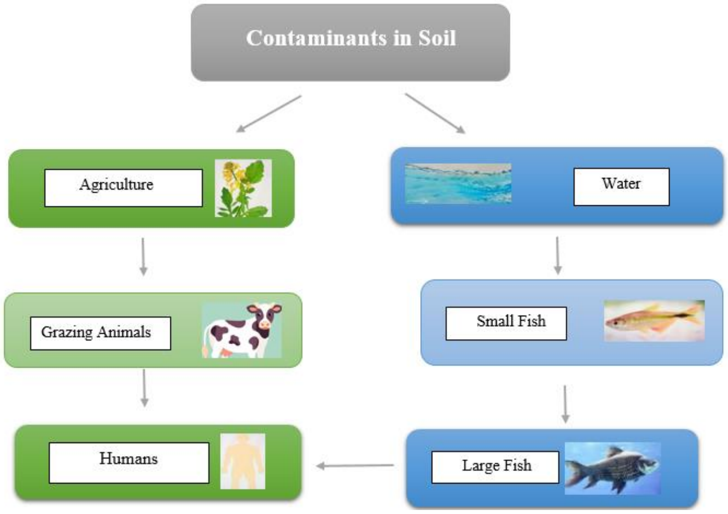
Soil contamination is frequently found to be associated with the careless application of agricultural chemicals. Pesticides seep into the ground and cause potentially negative repercussions. This could ironically lead to crop poisoning if dangerous compounds in fertilizers (such as cadmium) build up above hazardous thresholds. Industrial waste is one of the means to soil pollution (Arnold, 2019).

5.2 : Uptake of Pollutants by Crops: how Contamination Enter our Diet

Soil to plant transfer refers to when pollutants in the soil are taken up by the plant's roots and end up as edible sections of the plant. Food chain transfer occurs when pollutants accumulate in animals that consume contaminated water or graze on contaminated vegetation (Stachinuk et al., 2017). A serious risk is directly consuming tainted seafood, meat, dairy products or crops (Baráth & Fertő, 2017). Tainted food can cause a number of health problems. To reduce contamination in farming methods, sustainable farming methods should be used (Linke et al., 2018).

5.3: Impact of Soil Degradation on food Safety and Nutrition

Soil degradation reduces the quantity and quality of food produced. Global hunger, estimated at 854 million people today, is aggravated by reduced crop and agronomic yields and quality, and malnutrition and "hidden hunger", affecting 3.7 billion people including children, worsened by low protein and micronutrient density levels such as Zinc, Iron, Selenium and iodine. Soil degradation weakens crop yields because it influences susceptibility of crops to drought stress and compactness of elements. Human health is also determined by soil and environment sustainability as shown in (fig. 2) (Melnick et al. 2005).



Keshan and Kaschin-Beck diseases are found where there is Low level of Se content in the soil (Yang et al., 2007).

Brick production in the two east Indian states of Haryana and Punjab consumes topsoil at a rate of one meter annually and contributes 0.5%-0.7% of total farmland area in India. Deficiency in micronutrients is associated with food crops that grow on scalped soils (Lal et al., 2009).

6: Bioaccumulation and Biomagnification in Food Chain

Bioaccumulation is described as the method by which a material, especially a pollutant, for example, a heavy metal or any pesticide, progressively accumulates in a living organism. These substances in living organisms are more rapidly accumulated and are slow to be metabolized or excreted out of the system (Ali & Khan, 2019). The process by which a material, such a poison or pollutant, becomes more concentrated in the tissues of organisms as it ascends the food chain is known as biomagnification (Ali & Khan, 2019).

6.1 : Case Studies: DDT, PCB and Mercury in Marine Ecosystem

6.1.1 : Dichlorodiphlorotrichloroethane (DDT)

The bioaccumulation and biomagnification of Dichlorodiphenyltrichloroethane (DDT) has disastrous effects on the Gulf of California. DDT, a common insecticide in the 1940s and 1960s, harmed many species by contaminating the marine food chain.

DDT was taken up by phytoplankton from the water and moved up the food chain to zooplankton (0.4 ppm), small fish (4 ppm), large fish (40 ppm), seabirds (400 ppm), and marine mammals (4,000 ppm). When contaminants accumulate in organisms and are transferred to higher trophic levels, a process known as biomagnification takes place (Risebrough, 1972).

DDT caused reproductive issues, eggshell thinning, and decreased fertility in the reproductive systems of seabirds and marine mammals (Risebrough, 1972). The US Environmental Protection Agency (EPA) banned DDT usage in 1972 after Mexico did so in 1970.

6.1.2 : Polychlorinated Biphenyls (PCB)

Between 1947 and 1977, General Electric's (GE) transformer manufacturing facilities released polychlorinated biphenyls (PCBs) into the Hudson River, which runs 507 km across New York State. This resulted in significant environmental damage (Fitzgerald et al., 2007).

PCBs were taken up by phytoplankton from the water and turned into 0.01 ppm. These were subsequently consumed by people, marine animals, zooplankton, small fish, and large fish (0.1 ppm, 1 ppm, 10 ppm, and 100 ppm, respectively). This bio magnification process happens when contaminants accumulate within organisms and are transferred to higher trophic levels (Ali & Khan., 2019).

6.1.3 : Mercury

A well-known instance of bioaccumulation and biomagnification is the mercury contamination in Minamata Bay, Japan (Yokoyama, 2018). Mercury entered the bay in the 1950s and 1960s as a result of industrial wastewater discharge from a nearby chemical factory. There, it accumulated in sediment and was taken up by zooplankton and phytoplankton (Hachiya, 2020). Biomagnification occurred when larger fish and shellfish, dined on these polluted microbes. High quantities of mercury were exposed to locals who ate tainted fish and shellfish, leading to serious health consequences such as Minamata sickness (Yorifuji et al., 2010).

7. The role of Industrial Agriculture in Food Chain Contamination

7.1 : Pesticides use and Residue in Food Crops

From the fruits and vegetables of all over the world and particularly Indo-Pakistan, pyrethroid insecticides has been found. A majority of samples contained toxic substance above maximum residue limits.

Fruits and vegetables purchased from Karachi's (Sindh, Pakistan) whole sale market between July 1988 to June 1990 were studied for the presence of pyrethroid, organochlorine and organophosphorus pesticides. Amongst the 250 samples that were examined, 93 came out with different pesticides. Residues were found in 45 samples that exceeded the FAO/WHO proposed maximum residue limits (MRLs) and in 48 samples that were within acceptable bounds. The remaining samples were free of pesticides residues (Tariq et al., 2007).

7.2: Growth Promoters and Antibiotics in Livestock

More antibiotics are used to raise cattle for growth than for human illnesses, which develop antibiotic resistance—that can be a problem for both resource conservation and world health (Teillant et al., 2015).

While both Veterinary antibiotics (VAs) and synthetic growth promoters (SGP) play a fundamental role in the livestock business, their use undermines the sustainability of diets and they build up residues in the animals (meat, milk and eggs) and in the environment (pollution of water and soil). Additionally, wastewater systems offer a crucial pathway for hormones and antibiotics to enter the ecosystem and have destructive effects. In the perspective of a more sustainable feeding, possibly aimed at lowering allergies and antibiotic resistance, a major goal is of curtailing the use of artificial growth boosters and antibiotics (Ronquillo & Hernandez, 2017).

7.3: The Rise of Genetically Modified Organisms (GMOs) and their Contaminant Risks

Organisms that have their genetic makeup changed by genetic engineering methods are known as genetically modified organisms (GMOs), in order to generate organisms having traits that differ from those possessed by their parent (Prakash et al., 2011).

In 1994 the first commercial GMO crop, the Flavr Savr tomato, was released and created to resist rotting. GMOs have been implanted in spots since, in crops like canola, cotton, soybeans, and maize. The difficulties in avoiding cross-border GMO contamination were brought to light in 2006 when LibertyLink rice, a genetically modified strain not permitted for sale in the region, was found in U.S. rice imports from Europe. This episode illustrated the worldwide concerns connected with genetically modified organisms (GMOs) and resulted in the implementation of more stringent controls on U.S. rice exports to Europe (Prakash et al., 2011).

8. Impact on Human Health

8.1 : Short term and long-term Health Effects of food Contaminants

Exposure to food pollutants can have immediate and long-term health consequences. Short term consequences such as nausea, vomiting, diarrhea, and cramping in the abdomen can occur hours to days after eating contaminated food. Short term consequences can be more severe in susceptible groups like the elderly, the young and people with weakened immune system (Detwiler, 2020).

Prolonged exposure to food toxins can result in chronic illness, like cancer, neurological diseases and reproductive problems. For instance, risk of liver cancer was increased in people exposed to aflatoxins, mycotoxins made by certain molds (Trakoli, 2012).

8.2: Heavy Metal Toxicity: Neurological and Developmental Risks

Toxic metals can cross the blood- brain barrier and affect the brain leading to neurodegenerative ailments. Several other neurological disorders such as Parkinson's and Alzheimer's illness erode memory and generates cognitive disorders can occur (Agnihotri & Kesari, 2019).

Modern prevalence of neurobehavioral disorders such as autism spectrum disorders, increasing in frequency, is being attributed to industrial pollutants particularly heavy metals. Heavy metals can be very much disastrous to foetal development and cause behavioral disorders, learning disabilities and developmental delays (Agnihotri & Kesari, 2019).

8.3: Endocrine Disruptors in Food: Impacts on Hormonal Health

Rossi (2009) and Slama et al. (2016) defined endocrine disruptors as exogenous substances that disrupt endocrine functions, leading to endocrine dysfunction, exhibiting clear cause- and-effect links in exposed individuals, or progeny, or subpopulations (Rolfo et al.; 2020).

Heavy metals, phthalates, bisphenol A (BPA), industrial (dioxins, polychlorinated biphenyls, or PCBs), pharmaceutical (mitotane, ketoconazole, cardiac glycosides, nitrofurans, carbamazepine, astazene), and agricultural (pesticides, herbicides, fungicides, and insecticides) are all endocrine disruptors (Khetan et al., 2014).

BPA, has recently been found to function as an agonist when it targets oestrogen receptors (ERs) or as an antagonist when it binds to androgen receptors or androgen receptors (AR). Recent studies showed that EDC exposure is associated with type 2 diabetes; metabolic syndrome and obesity (Guarnotta et al., 2022).

8.4: Antibiotic Resistance and its Links to Food Chain Contamination

An antibiotic refers to a minimal natural or artificial substance that cannot allow the bacteria's growth and survival. Thousands of people are said to be dying from antibiotic resistant diseases every year in the US, India, Thailand and the EU respectively (Marshall & Levy, 2011). Human associated pathogens can get antibiotic resistance genes (ARG) from human and animal sources. Strains of Salmonella, Campylobacter, and E coli that are resistant to normal treatment are likely to have been developed due to the feeding of fluoroquinolones (enrofloxacin) to animals meant for human food, worldwide (Marshall & Levy, 2011). Timeline of discovery of different antibiotics is shown in (Table 1) below.

Table 1: Antibiotics discovery timeline

Year	Antibiotics discovery
1920	Penicillin
1945	Cephalosporin
1950	Tetracycline
1960	Methicillin
1962	Fluoroquinolone
1967	Gentamicin
1972	Vancomycin
1985	Imipenem
	Ceftazidime
	Carbapenum
1996	Levofloxacin
2000	Linezolid
2003	Daptomycin
2010	Ceftaroline

9. Contamination in Processed and Packaged Foods

9.1 : Additives, Preservatives and Chemical Processing Agents

Processed foods frequently contain additives including artificial sweeteners (like aspartame or saccharin), flavour enhancers (like monosodium glutamate or MSG), and artificial colourants (like tartrazine or Red 40). Studies show that these compounds are linked to a number of negative health outcomes. For example, artificial colourants may make youngsters more hyperactive, and MSG has been connected to headaches, nausea, and possible neurotoxicity in sensitive individuals (Gütler et al., 2020).

9.2 : Packaging Material and Microplastic Infiltration in Packaged Foods

Most food these days sell in packages. Food contains trace levels of minor residues from the production of epoxy resins, including bisphenol A, cyclo-di-BADGE, and bisphenol A diglycidyl ether (BADGE). (Cabado et al., 2008).

Migration within the glass jars comes from the copper lids used to close them (Pedersen et al., 2008). Many different products come in paper and board packaging. Ticking the box of migration into foods paperboard additives or printing inks is possible (Nerin et al., 2007).

9.3: The Impact of heat and food Storage on Contaminant Release

By heating, baking, roasting, grilling, canning, hydrolysing, or fermenting food, substances like acrylamide, nitrosamines, chloropropanols, furans, or polycyclic aromatic hydrocarbons (PAHs) can be produced. Interactions of fatty acids and protein during frying generate mutagenic polycyclic aromatic heterocycles such as polycyclic aromatic hydrocarbons (PAH) and heterocyclic aromatic amines (HAA). Acrylamide is genotoxic and carcinogenic (Nerin et al., 2016).

- **Food Storage**

Storage circumstances such as high temperatures and humidity can affect the qualities of a packaging materials. Migrations and sorptions of internal and external contaminants which can be discharged from the packaging to the food take place at any time. In particular, the packing material used for long term storage should have excellent barrier qualities to prevent organoleptic changes under described storage conditions (Kato et al., 2021).

10. Solutions and Strategies to Mitigate food chain Contamination

10.1 : Sustainable Agricultural Practices to Reduce Chemical usage

Sustainable agriculture blends current technologies with traditional conservation- minded farming practices. Crop rotation, soil improvement, livestock and crop diversification, and natural pest management are all prioritized. Crops that are grown in rotation often yield

10–15% more than those grown in monoculture. Integrated pest management IPM is a general approach of reducing pesticides use. Biological control methods have been employed in over 250 projects worldwide to manage pests, particularly insects (Hassan et al., 2018).

10.2 : Organic Farming and its Role in Reducing Contaminants

Around 186 countries, have adopted organic farming due to its greater ecological and health benefits (Ramakrishnan et al., 2021).

The health of the soil is greatly enhanced by organic farming. Furthermore, by stopping synthetic agrochemicals from flowing into rivers, lakes, and groundwater systems, organic farming preserves water quality and lowers hazards to aquatic and human health. Organic farming promotes 30% more species diversity than conventional systems (Ramakrishnan et al., 2021).

10.3 : Public Awareness and Consumer Choices: Buying Contaminant Free Food

Consumer preferences for safer, contaminant-free food options have been influenced by the steady increase in public knowledge of the risks presented by food contaminants (Willer et al., 2024). Awareness can be spread through:

1. Rising Awareness Through Education and Media
2. Importance of Certification and Labeling
3. Health Benefits of Choosing Contaminant-Free Food
4. Environmental Considerations
5. Market Trends and Consumer Behavior

11. Global Case Studies

11.1 : Contaminated Rice in Asia: Arsenic and Cadmium Exposure

- **Arsenic Contamination in Rice**

According to a study conducted in Bangladesh, concentrations of arsenic in rice can surpass the WHO's safety guidelines; in certain areas, they can reach 0.5 mg/kg, while the recommended maximum is 0.2 mg/kg (Rahman et al., 2019). Arsenicosis, a disease characterised by skin lesions and internal organ damage, occurs particularly in people that consume big amounts of rice.

- **Cadmium Contamination in Rice**

In 2014, the Chinese government conducted a comprehensive investigation and discovered that 44% of rice samples had cadmium levels higher than the 0.2 mg/kg national safety guidelines (Zhao et al., 2015). Osteoporosis, renal failure, and Itai-itai disease—a painful ailment initially identified in Japan as a result of cadmium-contaminated rice (Suwatvitayakorn et al., 2022).

11.2 : The impact of Mercury Contamination in the Arctic Food Web

During springtime episodes known as mercury depletion events, permafrost melting and ocean Currents are sources of Arctic mercury contamination (Fitzgerald et al., 2007a).

Fish, seals, and whales—all of which are vulnerable to mercury contamination—are staple foods for indigenous Arctic populations. Prolonged exposure to methylmercury has detrimental effects on health:

- Neurological Effects
- Cardiovascular Diseases
- Cultural Implications

11.3 : Industrial Farming and Food Chain Contamination in the US and Europe

Industrial farming model in the US first emerged during the Green Revolution in the middle of 20^{th} century. For instance, the fresh spinach *E. coli* outbreak in 2006 caused more than 200 hospitalizations and three fatalities (Lacombe et al., 2022). In 2018, a similar outbreak linked to romaine lettuce killed five people and affected 210 people across 36 states (Canning et al., 2023).

Another significant food safety incident was the 2011 *E. coli* outbreak in Germany, which was brought on by imported fenugreek sprouts from Egypt. This incident claimed 53 lives and caused over 3,950 cases of illness, many of which involved haemolytic uremic syndrome (Buchholz et al., 2011). More recently, the 2017 fipronil egg scandal revealed regulatory compliance gaps when millions of tainted eggs were dispersed around Europe as a result of the unapproved use of the pesticide fipronil in poultry farms. Widespread recalls and public worries about food safety resulted from the incident (Nayak et al., 2022).

12. The Future of Food Safety

12.1 : The role of Artificial Intelligence in Predicting and Managing food Chain Risks

Numerous advantages result from the use of AI in food chain risk management. (Mishra et al., 2020). The following actions can be taken to successfully incorporate AI into food chain risk management:

- Data collection
- Data analysis
- Decision-making
- Stakeholder collaboration
- Constant observation

AI-powered food chain risk management solutions have been successfully used by a number of businesses. Walmart, forecasts demand and avoids stockouts by using predictive analytics driven by AI. (Aljohani, 2023).

Conclusion

In conclusion, because pollution enters our diets through a variety of interconnected environmental channels, food chain contamination is a serious and complex worldwide issue. Environmental pollutants seep into plants, animals, and eventually human food sources through the land, water, and air.

Ecosystem contamination jeopardises global food security by reducing agricultural, altering food webs, and affecting biodiversity. Local, national, and international cooperation is needed to solve food chain contamination. We can preserve the integrity of our ecosystems and guarantee the security and well-being of future generations by cutting pollution, implementing sustainable practices, and raising awareness.

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