Journal of Environmental Protection, 2024, 15, 1035-1055
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

The Detrimental Influence of Heavy Metals and Contaminants on Food Production and Consumption

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How to cite this paper: Alabi, O.D., Gounden, A., Naidoo, K.K., Mellem, J.J. and Paul, V. (2024) The Detrimental Influence of Heavy Metals and Contaminants on Food Production and Consumption. *Journal of Environmental Protection*, **15**, 1035-1055.
https://doi.org/10.4236/jep.2024.1512062

Received: October 30, 2024
Accepted: December 24, 2024
Published: December 27, 2024

Abstract

Contaminated foods with pesticide residues, mycotoxins, and heavy metals pose significant health risks to humans. Fungal mycotoxins, which are organ toxins and cancer-causing agents, can cause long-term diseases like cancer and acute poisoning. Natural preservatives like essential oils or preservatives were tested for safety. Heavy metals, such as cadmium, lead, and mercury, are the most dangerous pollutants, causing long-term diseases like cancer and acute poisoning. Moreover, extreme weather events increase fungal infestation, thereby increasing the levels of mycotoxins in meals and posing a threat to human life through unsafe food consumption. Bioremediation and phytoremediation techniques use microorganisms and plants to clean water and soil, but have limitations due to applicability limits. Gene modification can solve these limitations. Composted sewage sludge with CuO nanoparticles may improve plant tolerance against metal stress, but high levels may increase As content in crops like rice. Technological advancements have made it easier to detect these pollutants, but strict rules should be in place to limit their presence. Sustainable plant protection methods and biomass-derived materials can be an eco-friendly alternative to conventional pesticides in large-scale farming systems. A holistic approach is needed to address these issues, including comprehensive strategies like quality control measures and mitigation approaches. These should reduce emission rates and monitor pollution levels in food crops grown across different regions. Policymakers should established guidelines to ensure that safe production processes are followed at every stage, from planting to harvesting, processing, and transportation. Failure to follow these steps may lead to more problems than solutions.

Keywords

Contamination, Heavy Metal, Mycotoxin, Food, Harvest, Diseases, Control

1. Introduction

Humans depend on staple foods, fruits, and vegetables as their most important sources of nutrition. They represent a well-balanced diet. However, agriculture still faces significant challenges, such as postharvest diseases and mycotoxin contamination, also known to affect global food security [1]. Mycotoxins produced by fungi are secondary metabolites that can infect fruits and vegetables at different stages from pre- to postharvest periods. These compounds include trichothecenes (TCs), ochratoxin A (OTA), patulin (PAT), and Alternaria toxin (ATs). Apart from causing spoilage in appearance and taste, they can also pose serious health risks to animals and humans [2]. Another major threat to food safety is heavy metal contamination of agricultural soils, affecting crop quality during storage or processing and compromising wholesomeness and consumer well-being [3]. Lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) are the most common metals associated with this problem [4]. The sources of these pollutants may be natural or anthropogenic, that is, industrial emissions, use of fertilizers/pesticides, sewage irrigation, mining activities, vehicle exhaust gases, and coal combustion [4]. Chlorinated hydrocarbons (CHCs) constitute organic environmental pollutants that are widely distributed globally, mainly owing to insecticides/herbicides, industrial waste, etcetera [4] [5]. Carbon tetrachloride polychlorinated biphenyls (PCBs), chloroform perchloroethylene (PCE), and trichloroethylene (TCE) are just but some examples of typical solvents used for CHC. Pesticides widely used in agriculture for pest control contribute to CHC pollution through compounds such as hexachlorocyclohexane and 2,4-dichlorophenoxyacetic acid [5]. The primary way heavy metals enter the food chain is through polluted soils. Plants absorb these substances in their systems in such areas. Within crops, these lethal chemicals can build up to levels that are dangerous to humans [6] [7]. Many different studies have shown that being exposed to heavy metals may lead to other adverse health results, including but not limited to damage of kidneys; bones become affected as well as fractures occur due to cadmium; mercury causes harm to the nervous system while increased cancer risks come from arsenic [6]. Various methods are employed to deal with postharvest diseases and mycotoxin contamination, as well as reduce heavy metal pollution [7]. These include, among others, adoption of better agricultural practices, provision for proper storage facilities, utilization of biological control agents, and use of fungicides/preservatives during the processing stage, coupled with strict enforcement measures on food safety regulations so that they can act as deterrents against organic farming methods which may increase chemical inputs [7]-[9]. Moreover, recent endeavours have concentrated on controlling industrial emissions and waste disposal sites where heavy metals are disposed of into the environment, thereby posing great danger to public health through the consumption of unsafe foods, while at the same time enlightening stakeholders about different hazards associated with exposure to heavy metals during this period, highlighting the need for safe handling practices for foods [8]. It is also important to consider how this affects production and consumption patterns. This article aims to investigate contamination and its effect on the various stages involved in food production, from the planting season until it eventually reaches the final consumer.

2. The Agricultural Sector and Food Security Face the Challenge of Mycotoxins

Mycotoxins are a major risk to the world's food supply, as approximately 25% of all cereals may be infected [8]-[10]. These poisons are created by certain kinds of fungi such as Aspergillus, Fusarium, Alternaria, or Penicillium and include deoxynivalenol (DON), T-2 toxin, fumonisins (FUMs), zearalenone (ZEN), ochratoxins (OTs), and aflatoxins (AFs), which can harm humans, animals, and plants alike. Factors such as fungal species present on the fruit surface and the composition of the fruit matrix itself, as well as other environmental conditions such as temperature and moisture levels, may determine whether mycotoxins are found in fruits [7] [8]. Some of the most common mycotoxins found in fruits and their processed products are aflatoxins, including B1, ochratoxin A, patulin, and Alternaria toxins [9] [10]. These diverse toxic molecules have organ toxicity, teratogenicity, carcinogenicity, mutagenicity, and genotoxicity characteristics; hence, they can cause severe acute or chronic health problems leading to cancer and even leukaemia in some cases, especially when consumed over long periods without control measures being taken against them by authorities responsible for public health safety [10]. There can be many entry points for mycotoxin contamination into foods from farm to table with different factors affecting each stage such as temperature, humidity level, oxygen availability, etc., while climatic factors also play significant roles since there is variation between regions based on different climate zones across these areas [11]. Economic losses due to mycotoxin contamination during trade transactions could be substantial, similar to what happened after the Hungarian wheat epidemic, where about 100 million euros were lost alone through this eventuality [12]. The relationship between climate change, agro-ecological conditions, fungal colonisation, and mycotoxin production is well documented; however, this nexus has not been fully explored in Africa, which remains highly vulnerable to weather variability driven by El Niño Southern Oscillation events that cause severe droughts across the continent, hence adversely affecting agricultural productivity, especially if they coincide with planting seasons or other critical stages of crop development where moisture stress may increase susceptibility towards such mycotoxigenic fungi [12] [13]. Temperature variations together with available moisture content within soil types during different storage periods also have significant effects on cereal growth as well as mycotoxin accumulation potentials under pre- and postharvest conditions similar to drought stress, further increasing the risks associated with maize production systems in Sub-Saharan Africa [14] [15], which rely more on rainfed agriculture than any other region globally [16]. Due to increased temperatures and frequent droughts associated with climate change impacts in Africa, there will be higher levels of mycotoxin contamination, particularly among staple crops such as maize grown under hotter drier environments or humid areas where they are stored for long periods without adequate ventilation systems, thereby creating conducive conditions necessary for mould growth accompanied by subsequent toxin formation [17]-[19].

The southern area of Africa faces a number of problems with regard to mycotoxin contamination in basic food crops such as maize and groundnuts, which are important for sustenance as well as livelihoods [13] [16] [20]. Current weather conditions are mainly subtropical or tropical, coupled with irregular rainfall patterns and inadequate storage facilities, resulting in favourable environments for the growth of toxigenic fungi that consequently leads to widespread mycotoxin contamination [17] [19]. Restricted research activities, together with limited laboratory equipment and financial resources, prevent wide-ranging surveillance efforts from occurring within this region, thereby compromising the enforcement of regulatory standards [17]. Developed countries have good knowledge about mycotoxins found in food and feedstuffs due to their high-level awareness as well as strong regulatory frameworks characterised by various rules and regulations, but they still face challenges associated with controlling these contaminants [21]. They experience huge losses caused by significant crop contamination resulting from changes in climatic conditions, leading to restrictions on the use and processing of crops [11]. Moreover, extreme weather events increase fungal infestation, thereby increasing the levels of mycotoxins in meals and posing a threat to human life through unsafe food consumption [12]. The detection of mycotoxins in agricultural products, including grains, is very difficult because it requires highly sophisticated instruments, which most countries lack, making it impossible for them to monitor these toxins effectively, thus putting people's health at risk [12] [13] [20]. Fusarium toxins, which are common in temperate cereals, especially in developed nations, are mainly found in grains used in both animal feeds, where trichothecenes, such as DON, are frequently detected [18]. Among many such mycotoxins, deoxynivalenol (DON) has been identified as one of the most important, especially in Europe, where this compound causes severe acute toxic effects that can also become chronic over time among humans and animals, leading to symptoms such as abdominal pain, nausea, or vomiting [22].

There are still poor control measures against DON contamination, even within European countries themselves, since some researchers have discovered high levels exceeding the limits set for wheat samples collected from different parts of Europe [23]. The occurrence of DON is influenced by weather, which means that extreme events worsen the situation [24]. In developed countries, efforts to fight mycotoxin contamination are based on data-orientated approaches that can identify vulnerable crops with regard to food safety and create awareness among the public [25]. Research has been conducted to determine where major mycotoxins are distributed and how much of them can be found to allow those involved to know what they are dealing with as far as intervention is concerned [26]. Prevention measures focus on anti-mildew practices during different stages of grain production and detoxification through physical, chemical, and biological methods to ensure the safety of food and human health [27]. In addition, it is worth noting that geographical variations together with climate preferences exhibited by fungi have a great impact on mycotoxin formation, whereby DON tends to be most common in cereals like wheat or oats across different parts of the world [28]. Therefore, any intervention that targets specific areas must consider such facts about distribution patterns because they help effectively deal with mycotoxins associated with Fusarium species depending on prevailing temperatures [29]. Even though these regions have put strict laws as well as monitoring systems against this problem, DON contamination still continues to pose serious threats to our meal safety; hence, there is a need for more investigations while providing comprehensive measures that will not only protect but also save lives through the prevention of diseases caused by toxins [30].

3. Pesticides Usage in Harvested Crop, Residual Effect and Monitoring

Moreover, human health cannot be improved if pesticides are used or chemical bioaccumulation in food substances. The importance of this issue in relation to the conservation of stored fruits and vegetables can hardly be overestimated; it includes different aspects such as the synthesis of mycotoxins by pathogenic fungi [25]-[27], application of essential oils as natural preservatives [21], risk evaluation connected with pyrethroids [31], and use of biomass-derived carbon nanomaterials for sensor applications aimed at detecting impurities [12]. Photodynamic inactivation technology may help to keep microorganisms in check without affecting food quality [8], while bacteriocins have potential as biopreservatives [6]. The presence of bisphenol in packaging materials raises concerns about food safety, thus creating a problem for those who want their products to be packaged safely but at low cost [26] [28]. Fungi and mycotoxins indirectly endanger feed chain security through silage management systems which leads to various challenges, such as storage losses or cattle diseases caused by these toxins themselves appearing later during the digestion process [31]. It should also be noted that bioselenium nanoparticles exhibit antibacterial properties that are beneficial for food preservation; therefore, they can be used as an effective method against bacteria, which cause spoilage during storage [12]. Additionally, ozone technology has been found to be highly effective in maintaining freshness standards while prolonging the shelf life of fresh-cut produce items packed under controlled atmospheric conditions [23] [32]. Throughout the entire supply chain, there is a significant health risk due to contamination with mycotoxins, which calls for sensitive detection methods such as chromatography, electrochemical biosensors, or immunoassays to ensure public safety [24]. Essential oils are regarded as one of the most environmentally friendly alternatives to synthetic preservatives because they have strong antimicrobial properties; however, there is fear that these may also contain residues from pesticide use, thereby limiting their application range [15].

Conventionally, pyrethroid residues in fruits and vegetables have been assessed, which have shown different degrees of risk from dietary exposure, indicating non-hazardous levels generally, although concerns have been raised about acute intake [28]. New sensor technologies are being developed using biomass-based carbon nanomaterials to detect harmful substances present in preserved fruits and vegetables [29]. Photodynamic Inactivation (PDI) is an environmentally friendly way to control microbes without affecting the quality of food or promoting bacterial resistance, thereby overcoming some limitations of traditional chemical preservation techniques [26]. Bacteriocins act as potent biopreservatives by killing closely related microbial species that cause spoilage but leaving other useful bacteria unharmed. When industrial chemicals leach into packaging materials from where they come into contact with food items, bisphenol A (BPA) analogues can disrupt hormones; hence, stringent monitoring should be implemented, particularly within Europe because concentration values seem higher than those found in Northern Europe [22]. Besides direct contamination, fungi also affect animal products consumed by humans through mycotoxins carried in silage used for livestock feed, thus highlighting that it is necessary to control fungal growth at all stages of agriculture, including storage practices [32]. Bioselenium nanoparticles increase the amount of selenium in food while killing foodborne pathogens, thereby helping to prolong safety during storage periods [6]. Fresh-cut produce can be preserved without biological contamination by ozone technology, which does not leave behind any harmful residues on plants or ecosystems [29]. Significant crop losses due to pests and diseases [30] [31], especially in developing countries where these are more prevalent than anywhere else, call for the global use of chemical pesticides for pest control. India ranks seventh highest among pesticide users worldwide because the country relies heavily on them to mitigate such losses [30] [31]. However, poor use of pesticides can have harmful health effects and account for 33% of all pesticide poisoning cases across the globe, causing serious illnesses such as cancer or liver disease in particular. The presence of pesticide residues in food commodities depends on the type of pesticide used, type of food treated, and environmental conditions prevailing at the time. Sustainable plant protection through carbohydrate biopolymers as fungicides or carriers for active ingredients is one of the approaches that has been suggested to minimise ecological damage caused by conventional chemical pesticides [15]. Different thermal processing methods, such as blanching, cooking, and canning, among others, may reduce the levels of these chemicals in foods, but to varying extents depending on several factors [14] [33]. It has been found that some types of washing can remove certain proportions of pesticide residues from fruits and vegetables, while other types show different degrees of effectiveness. Most residues on fruits and vegetables are localised on their outer skins, although some may also be present elsewhere within them [28]. These can typically be eliminated by washing, peeling, or treating with chemicals; however, a few remaining compounds penetrate deeper into fruit flesh or grain which makes elimination more difficult [9] [14] [28] [33]. Various procedures such as washing, peeling, cooking, milling, etc., are employed during the processing stage aimed at reducing the levels of contaminants in any given product, but this does not always hold true, especially when it comes down to lipid affinity or concentration effects that could even increase them instead. Therefore, it is important that we know the different ways of dealing with these substances if safety regarding our meals is to be guaranteed [9].

4. Heavy Metal Pollution in Processed Food

Industrialisation, improper waste disposal, and unsustainable agricultural practices have made heavy metal pollution a global problem. Cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), chromium (Cr), and nickel (Ni) are the most common heavy metals of concern since they pose various health risks [15] [29]. Contaminated foods are associated with many health problems, such as cancer, ranging from acute poisoning to long-term diseases [24]. Nutrient-packed seafood products may contain dangerous substances, including toxic metals, which create a health risk when considering the benefits associated with their intake [17]. Studies have shown that Latin America alone has canned sardines and tuna with very high levels of mercury (Hg) content that go beyond what is considered safe by regulatory bodies in different regions. [28] emphasised that stricter quality control measures should be taken where necessary. The pathway for human beings into whom these heavy metals enter from seafood involves fish accumulating methylmercury, which can cause potential neurological damage, especially among pregnant women who are discouraged from consuming large amounts of certain fish species [24]. On the other hand, vegetables such as Sichuan pickles have exhibited varying degrees of Cr, Cu, Zn, As, Pb, and Cd, showing regional differences in contamination levels, perhaps induced by local industrial activities or natural geochemical conditions [7]. Health risk assessments using target hazard quotients (THQs) and incremental lifetime cancer risk (ILCR) models indicate that non-carcinogenic risks increase, while carcinogenic risks decrease with higher levels of consumption of heavily contaminated foodstuffs [7] [28]. Children have an underdeveloped immune system and lower body weight than adults, which makes them more susceptible to toxicant effects during their growth stage [21]. Additionally, they have higher ingestion rates than adults, increasing their vulnerability [7] [28]. In children, the potential toxicity of trace metal elements highlights the need for the prompt monitoring of harmful substances in food crops consumed by different populations [26]. Similarly, assessments of the environment have shown high levels of mercury (Hg) in Pakistan, which poses a great ecological threat to aquatic life among other things [29] [30] [33]-[35]. There are also significant risks to human health through diet, such as seafood consumption, among others. These findings, therefore, indicate that Hg emissions into ecosystems should be reduced urgently [36]. Moreover, artisanal honeys originating from areas such as the Canary Islands depict observable amounts of Al and Pb, indicating that environmental pollution affects even apparently natural products, hence underscoring the importance of wide-range food surveillance for consumer safety [7]. As well, heavy metals, including Cd and As, have been recognised as major contaminants in rice among other crops [6] [37] conducted an elaborate study on the bio-concentration ability of heavy metals using 50 rice varieties under identical test conditions [37]-[39]. According to these findings, all types of rice had cadmium content above the safe limits set by food standards for consumption all over the world; it is worth noting that there was not much difference between conventional rice, two-line hybrid rice, and three-line hybrid rice with respect to their capacities to accumulate lead or cadmium [10]-[12]. Absorption takes place when contaminated soil or water used for irrigation is absorbed into plants through roots before being consumed by humans, but mostly enters the human body via ingestion, although it can also be inhaled or enter through skin contact [10]. Once taken into the body, toxicants can bring about several negative health outcomes in children due to Pb exposure [6]; As is associated with the development of cancerous cells [6], while Cd has been linked to cardiovascular diseases [37], among others. There have been concerns over rice-fish culture systems that they may increase the carcinogenic risk (CRs) and non-carcinogenic risk (non-CR) associated with toxic metal contamination. Nevertheless, it can be seen that under certain circumstances where there are multiple heavy metals working together, there could be an increase in non-CR, but CR still remains within acceptable limits based on current guidelines, thus suggesting that such systems may not present significant CR but require proper management considering TM pollution levels [4]. Measures to prevent heavy metal contamination recommended included strict controls over emissions from industries known to be sources of such pollution by [13] [20], safe farming methods which minimise the usage of chemical fertilisers and pesticides causing pollution, and recycling promotion for reduction in Cd-containing product waste mainly but not limited to environmental discharge [38].

5. Impact of Glyphosate on Farms and Consumption

In Residue build-up, crop quality effects, livestock health implications as feed, human health impacts through consumption, and environmental considerations are some of the aspects involved in the multifaceted problem of glyphosate residue on harvested crops [16] [17] [19]. Glyphosate is commonly used as an herbicide for weed control and pre-harvest desiccation in agriculture [39]. This has raised concerns about its wide use, leading to residues in harvested produce as well as their consequences thereafter [18] [22]. The mode of action of glyphosate is such that it inhibits the shikimate pathway, which is essential for aromatic amino acid synthesis in plants but also present among certain microbial species [38] [39]. Residual accumulation remains irregular depending on when applications are made relative to harvest time, degradation rates influenced by environmental conditions, type of crop involved, and part(s) analysed, that is, leaves versus roots [14] [34]. Some studies have found that not only targeted but also non-target plants near treated fields show detectable levels of this chemical compound [40], indicating that there might be wider ecological implications associated with its use [41] [42]. With regards to animal health risks posed by contaminated feeds consumption; some evidence suggests that dietary intake may alter composition of microbiota within animal's gastrointestinal tract thereby resulting into adverse outcomes on their overall wellbeing along with productivity [35]; however most findings have been derived from "*in vitro*" trials hence need stronger "*in vivo*" tests across different physiological stages [40]. As for human beings, either directly or indirectly through eating products like meat or dairy, where animals are fed on such substances, there are concerns about dysbiosis caused by antimicrobial properties exhibited by glyphosate nutritional deficiencies due to its ability to bind essential minerals such as iron [14], besides interfering with cytochrome P450 enzymes that play a part in detoxification processes within the body, among others [33] [36] [37]. Nevertheless, critical appraisals point out major methodological flaws in existing investigations, thereby making it difficult to arrive at definite conclusions about the impact of this chemical through gut microbiome alterations or other routes [43].

Regarding the quality of crops after exposure to glyphosate from an agronomic viewpoint, germination rates might be affected and seedling vigour reduced, thereby leading to low yields in the event that seeds obtained from treated plants are used for planting the next season. [36] [37] warned against using glyphosate as a desiccant since it can contaminate non-target species, a fact which should not be forgotten during chemical application in agroecosystems. However, [44] highlighted both the antimicrobial properties and eliciting defense response functions of chitosan, showing that natural compounds can provide safer options than conventional pesticides while still improving plant health [34] [39]. Additionally, some harvest-aid herbicides may reduce milling quality necessary for secondary processing industries when tank-mixed with glyphosate, especially in legumes like lentils where dehulling efficiency becomes critical [45]. From an environmental perspective, models designed to predict bioconcentration processes have indicated wide variations influenced mainly by soil characteristics among other factors, implying that there could be regional differences with respect to metabolite levels within plants, thus adding another level of complexity towards evaluating overall impacts associated with pesticide use, including AMPA as one of the metabolites [4] [46] investigated the environmental health risks associated with urban sack gardening in Nairobi's Kibera slums [41] [43] [47]. Their results showed disparity between farmers' perception of biological contaminant risk and actual chemical contamination risk demonstrated by significant heavy metal pollution [41] [43]. This investigation highlighted the need for awareness creation among city farmers concerning potential chemical dangers present in informal settlement areas [42] [48]. In simple terms, farming activities close to sources of heavy metals produce food items that find their way into consumer markets already contaminated with these poisonous substances. The long-lasting presence of such elements as lead and cadmium within living systems leads to cumulative health hazards, thus causing chronic illnesses over time [35].

6. Heavy Metal Pollution in Soil and Plants

The overuse of pesticides can cause the Earth to become infested with heavy metals, thus disrupting food safety and human health as it passes through the food chain in a process called bioaccumulation [33] [41]. Commonly known hazardous pollutants include lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As), whose ill effects range from kidney failure, bone diseases, fractures during old age, brain damage among children, skin cancer to lung, or any other type of cancer [33]. These elements interfere with plant growth by altering membranes due to imbalances in nutrient availability caused by their toxicity towards metabolic pathways at the cellular level through osmotic stress coupled with oxidative destruction resulting from the production of reactive oxygen species (ROS) which disorganises membrane integrity, further leading to poor nutrition utilisation efficiency [41]. Bio-stimulants such as melatonin have been used as a remedy for heavy metal-stressed plants by improving redox balance along with other protective mechanisms that enhance tolerance towards them, including osmoregulation enhancement systems within cells [33]. Mercury (Mn), lead (Pb), cadmium (Cd), arsenic (As), copper (Cu), and zinc (Zn) are persistent environmental toxins because they cannot decay easily, thereby remaining in the soil and water bodies where they accumulate, causing serious harm to people's lives [48]. Heavy metals pollute agricultural products directly when they come into contact with crops themselves or indirectly through changing microbial communities within soils, thus affecting human health after consumption [42]. Hence, it is important to know how heavy metals destroy plants' normal functioning during growth, as well as the spatial extent and ecological implications associated with soil pollution around smelt plants [49] [50]. There are many ways in which plants can deal with harmful substances such as cadmium (Cd) and arsenic (As); thus, ecological health risk assessment should involve probabilistic tools such as Monte Carlo simulation methods that give a better understanding of potential impacts on human beings when exposed to them at different stages of life [51] [52]. When the maize varieties Dong Dan 80 and Run Nong 35 were subjected to combined Cd and As stress, they exhibited different antioxidant defense systems at various growth phases [51]. Heavy metals cause oxidative damage by altering antioxidant defences [50]. More also, [53], pointed out that toxic soil near smelting areas threatens not only the environment but also human lives directly because people may consume contaminated food produced in such regions [21] [53] [54]. It has been observed that a large number of heavy metals above the baseline levels come from smelting activities and farming, particularly with regard to Cd pollution [54]. Human activities such as the use of pesticides and fertilisers in agriculture, industrial and vehicular emissions, mining operations, sewage irrigation systems, and smoking are some of the sources of heavy metal pollution [21].

[55] confirmed these facts when they discovered that there is a strong positive relationship between traffic jam duration and lead (Pb), zinc (Zn), and cadmium content present in soils along roadsides, surface dusts, or films covering them together with vegetables grown within Kampala city limits, Uganda [50]. They showed that atmospheric deposition was responsible for most Pb contamination found in leafy vegetable samples collected from sites within 30 m from roadsides, hence posing a great health risk to consumers living close to such places. In addition, [56] reported high concentration levels exceeding the maximum allowable limits set by WHO/FAO standards concerning toxic metals, including arsenic (As) and lead (Pb), detected in *Celosia trigyna* leaves obtained from both the western and northern parts of Nigeria [57]. This implies that concerns over heavy metal accumulation should not only be limited to automotive exhaust gases, but should go beyond this point, taking into account other human-related factors such as discharge from industries. Moreover, [58] carried out case study in Maramureș region which revealed that anthropogenic activities significantly contributed towards soil pollution with copper (Cu), zinc (Zn), lead (Pb) chromium (Cr) among other heavy metals. Proximity to mining sites, notably mineshafts, was found to be associated with high levels of these contaminants, whereas honey originating from polluted areas had higher amounts thereof than elsewhere, according to [59] findings. Bees can be used as indicators of environmental pollution, a discovery that has great significance globally considering the large-scale consumption of honey. There are many ways in which people cause increased levels of soil heavy metals that eventually enter the food chain [37].

At the same time, it was also found that chemical compounds need to be used in conjunction with traditional breeding methods to increase wheat salt tolerance, as also stated by [14]; this is necessary for sustainable agricultural development in saline areas. Plant growth-promoting rhizobacteria (PGPR) improve nutrient availability for wheat even under metal-stressed conditions through degradation or immobilisation of toxic metals, preventing their entry into the food chain [21]. Similarly, [60] showed how plant growth-promoting rhizobacteria (PGPR) could enhance the growth and phytochemical composition of medicinal crops; thus, bio-based enhancements should be considered over synthetic chemicals, where possible. [61] gave insights on genetic modifications towards sustainable agriculture, pointing out that some genetically modified crops may reduce chemical inputs reliance while ensuring high yields across different environmental conditions. [62] suggested crop residue stabilization techniques among them biochemical processes which promote soil nutrient recycling back into soils hence lowering synthetic fertilizers demand if well managed. Cyanobacteria remediate salt-affected soils biologically but also highlight complexity involved when integrating these organisms into existing agricultural systems—a task that may benefit from complementary chemical treatments for optimal outcomes according to [14]. Olive by-product utilisation for squalene extraction not only provides economic incentives but also promotes sustainable waste management practices within agriculture, as highlighted by [63].

Additionally, merging modern biotechnological techniques with ancient phytoremediation can be practically used to fight soil heavy metal contamination, ensure food safety, and improve worldwide health [61]. The utilisation of dolomite in reducing N_2O emissions highlights the role played by environmental management in agriculture, particularly in regions highly polluted by heavy metals [64]. Heavy metal pollution within the agricultural sector is a serious threat to safe foods and human life; hence, there is a need for comprehensive knowledge about it together with its control [64]-[66]. Although there are still challenges with quantification caused by sample complexity, laser-based imaging techniques (LBITs) are essential tools for detecting toxic metals in foodstuffs [65]. Almost half of global fish consumption originates from aquaculture systems, which are also heavily polluted with heavy metals, thus making this industry unsustainable [65] [66]. Adsorption, biosorption, and phytoremediation are among some of the mitigation methods that can be employed to treat heavy metal-contaminated aquaculture systems, thereby reducing risk levels associated with these contaminants finding their way into human bodies through seafood consumption [66]. In addition, marine ecosystems suffer greatly because even short food chains have the potential for biomagnification; therefore, people should not eat fish caught from dirty waters without thorough inspection to ascertain whether they meet safety standards before being distributed to consumers who may live far away from such places [67]. Ecological effects were studied by [37] using an aquatic microcosm model [37] [38]. Their research provided insights into community-level responses of organisms towards toxic agents like HMs and therefore indicated wider ecological implications beyond individual species responses, which is important when considering risk assessment frameworks based on ecology involving different types of toxic agents, including ionising radiation [67] [68]. The historical context reminds us about continuous changes in perception towards heavy metal pollution control [68].

Throughout history, people have become increasingly aware that toxic substances, such as heavy metals, can change food [67] [68]. These findings demonstrate the complexity of dealing with heavy metal pollution in agriculture. Although detection technologies may help us keep track of and reduce this problem, we still face challenges in determining where they come from and what dangers they pose, especially when dealing with new pollutants like MNPs [50]. Given this context, we need to know more about past successes and failures if we want effective strategies against heavy metal pollution [50] [53] [54]. Phytoremediation also goes beyond cleaning up soil; it can also help purify water [56] [57]. This green idea involves using hyperaccumulator plants that take in dangerous metals from the environment or hold them down so tightly that they do not get into rivers, where fish might swallow them, or enter crops grown for food [60] [61]. Furthermore, wide-ranging studies indicate that erosion-associated transport acts as a key driver for the success of mitigation measures; therefore, future investigations must focus on understanding migration behaviour under different environmental conditions, such as global warming or land-use change [69] [70]. Also called a "green" method because it uses living organisms instead of machines or chemicals Bioremediation has emerged as an eco-friendly way to clean up sites contaminated with heavy metals by harnessing microorganisms' natural abilities along with those possessed by certain types of plants [68] [70]. Compared with traditional physical methods, this technique is cheaper, particularly in places where the level of metal toxicity is not very high [51] [52]. Microbial bioremediation makes use of bacteria that are good at coping with high levels of metals; these same bacteria can make it easier for plants to grow even when there would otherwise be too much poison, thus keeping soils fertile and crops healthy under adverse conditions [47] [52]. However, despite some exciting breakthroughs, such as patented technologies designed to help germs break down or lock up heavy metals, there are still issues regarding how safe they are for the environment and what kinds of rules should be followed when using them [55].

Bioremediation using microorganisms or plants is a green way to deal with heavy metal pollution in the environment [54]. Microbial bioremediation takes advantage of the innate biological processes of bacteria to break down metals until they become harmless [70]. On the other hand, phytoremediation involves the use of plants that can accumulate high amounts of heavy metals without showing any signs of toxicity, although effectiveness at large scales is limited due to low biomass production unless genetically modified organisms are used for better results [65] [69]. When copper oxide nanoparticles (CuO NPs) were added to composted sewage sludge as a soil amendment, some advantages and disadvantages were discovered [55]. However, rice growth was enhanced by certain levels, whereas yield and plant health were not affected negatively [71] [72]. At higher concentrations, arsenic accumulation in grains becomes a problem because it could lead to long-term human health risks through dieting [71] [72]. It has been found that nanoparticles may help crops cope with stress caused by heavy metals through hormesis, which is a process capable of enhancing plant resistance against oxidative damage brought about by these pollutants, thereby improving their adaptability in polluted areas [14] [33]. This can change conventional methods used for cleaning up contaminated sites by making them more resilient against environmental changes that might occur due to climate variations, thereby ensuring food security through increased tolerance levels among different varieties grown under adverse conditions. However, even as we make these strides forward, there still exist significant health risks associated with consumption patterns, mainly among vulnerable groups, such as children, who are more prone to toxicities based on physiological reasons and therefore should be exposed less frequently than adults [66]. Therefore, strict monitoring coupled with efficient management approaches becomes necessary if we want to prevent people from being exposed too much, thereby endangering their lives while at the same time safeguarding our environment. Research on heavy metals calls for multi-faceted methodologies that integrate sophisticated biotechnological breakthroughs alongside traditional methods of restoring ecological balance to foster collaboration between scientists, policy makers, and grassroots organisations working together towards environmental conservation, which is essential for public health protection and sustainable development [71] [72].

7. Conclusion

To summarise, the problem of heavy metal pollution is very complex and has a huge impact on ecological balance and human health. Among these metals are lead, cadmium, mercury, and arsenic, which can cause severe harm to people, such as kidney failure or different types of cancer. To prevent these diseases, we need a system, which includes strict controls over production processes combined with control devices; regular monitoring activities should also be organised to detect hazardous areas as soon as possible. Besides, it is essential to protect food supplies worldwide while taking care of people' lives globally through integration of traditional methods of treatment with more advanced ones based on biotechnology applications. As time went by, policies changed due to recognition given by governments towards risks imposed by pollution-induced threats against sustainable development goals, especially those related to ensuring healthy living environments for all children throughout their life span until they become old people, hence requiring safe nutritious diets accessible universally at every stage of growth development. It is worth mentioning that China proceeded from balancing supply safety to putting safety first, thus indicating that state awareness of dangers posed by environmental contaminants vis-a-vis national agenda security in relation to soils calls for unified approaches beforehand risk management over after supervision frames. Therefore, prevention of poisoning through food within international systems must involve collective work involving many professionals across disciplines who will help translate scientific discoveries into policies aimed at reducing risks associated not only with diet but also through various means meant to improve health status among populations residing around polluted sites.

Acknowledgements

We acknowledge the moral support and encouragement from Department of Chemistry, Faculty of Applied Sciences, Durban University of Technology.

Funding

This work was not supported by any grant. Authors did not receive research support from company.

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author Contributions

All the authors contributed to the study conception and design. Material preparation, data collection and searches were performed by (Alabi. Olusoji. David.). The first draft of the manuscript was written by Gounden, Asogan. Naidoo, Kubendran Kista. Mellem, Jason John. Paul, Vimla commented on previous versions of the manuscript. We read and approved the final manuscript.

Ethical Approval

Ethical Approval (applicable for both human and/or animal studies). Ethical committees, Internal Review Boards and guidelines are not applicable.

Data Availability

The data that support the findings of this study are available from the authors but restrictions apply to the availability of these data, which were used under license from the various research publications for the current study, and so are not publicly available.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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