



# Environmental and Health Impacts of Pesticides and Microplastic Interactions: Types, Sources, Uses, Bioavailability, and Mechanism

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## Abstract

The intersection of microplastics and pesticides in the environment poses a significant and underrecognized threat to ecosystems and human health. Microplastics, pervasive in soils, sediments, and aquatic systems, interact with pesticides through adsorption, altering the fate, mobility, and bioavailability of these chemicals. This interaction can increase the persistence and toxicity of pesticides, disrupt soil and aquatic ecosystems, and facilitate the transport of both pesticides and heavy metals through food webs. The combined presence of microplastics and pesticides amplifies ecological stress, affecting non-target organisms, impairing soil health, and increasing the risk of bioaccumulation and biomagnification. Furthermore, these pollutants threaten food safety and public health through contamination of crops, water, and animal products. This review synthesizes current knowledge on the sources, environmental behavior, and toxicological impacts of microplastics and pesticides, with a focus on their synergistic effects, mechanisms of interaction, and implications for ecosystem and human health. The urgent need for integrated research and policy approaches to mitigate the risks posed by this toxic combination is highlighted.

## 1. Introduction

Pesticides and microplastics work in deadly tandem to increase environmental toxicity, disturb ecosystems, and jeopardize food security. The behavior and bioavailability of pesticides are changed by the adsorption of microplastic particles, which are smaller than 5 mm and come from synthetic fabrics and deteriorated plastics, according to recent study. Because of this interaction, pesticides are more persistent, less effective in agriculture, and more hazardous to humans, crops, and soil organisms. Given that 74% of soils and 50% of aquatic ecosystems are contaminated by microplastics at medium-to-high risk levels<sup>6</sup>, immediate policy action is required [33].

Microplastics, composed of diverse chemicals and polymers, are widespread pollutants found in sediments, water, and other environments, these ecosystems are often studied separately, overlooking the interconnected impacts of microplastics. Environmental interactions such as absorption, settling, biofouling, degradation, and entry into the food web enable microplastics to transport harmful substances, including heavy metals, throughout ecosystems. The frequent use and poor management of plastics contribute to the release of heavy metal-laden microplastics, which can spread toxic metals through the food chain and increase ecological stress. The affinity of microplastic surfaces for toxic metals exacerbates their impact, posing significant threats to organism survival. To effectively address these risks, it is crucial to understand the origins and interactions of microplastics with metal contaminants in water and sediments, focusing on their toxicity, accumulation, and ecological harm [10].

The term "pesticide" is derived from the Latin words "pestis," meaning plague, and "caedere," meaning to kill. Weeds, plant pathogens, insects, mollusks, nematodes (roundworms), birds, fish, mammals, and microbes that compete with humans for food, damage property, spread or aid in the spread of diseases, or are deemed a nuisance are all included in this broad category of chemicals used to manage and control pests. Pesticides are used in a wide range of applications, from public health campaigns to decrease disease-carrying insects like mosquitoes to agriculture, where they shield crops from pests. Herbicides, insecticides, fungicides, rodenticides, and more are among the many types of pesticides that are used to target particular pests or purposes. The necessities of contemporary civilization have led to the development of a wide range of pesticides. Nonetheless, pesticides are sometimes categorized into three main groups: insecticides with a primary focus on the chemical composition of the pesticide, pesticides that target particular pest species, and pesticides that target pest entry sites [38].

## **2. Interactions between pesticides and microplastics**

MPs can alter the distribution and bioavailability of pesticides and other organic pollutants found in soil settings. In order to address the ultimate behavior when pesticides and MPs coexist in soils, it is crucial to comprehend how they interact in aqueous systems. A new area of study is the processes governing pesticide-MP interactions in aqueous phases. Using kinetic and isotherm data, recent research has evaluated the processes governing the adsorption behavior of pesticides on MPs. The process would mostly take place via surface adsorption and subsequent pore filling by diffusion, since the adsorption kinetics of pesticides on MPs often suit the pseudo-second-order and intraparticle diffusion models well [31].

Recent research has started to look at the interactions between pesticides and microplastics in soil ecosystems. Pesticides can adhere to the surface of microplastic particles, a process known as adsorption. The mobility, availability, and degradation of pesticides can all be impacted by this adsorption. Microplastics, for instance, might slow down the pace at which pesticides break down in the soil, resulting in extended exposure to these substances. This may raise the possibility of pesticide toxicity and accumulation. On the other hand, pesticides may change the characteristics of microplastics, such their chemical makeup or surface charge, which might change how they interact with soil and other pollutants. The coexistence of insecticides and microplastics in soil might result in

intricate relationships that are yet poorly understood. The specific effects of each pollutant may be amplified by these interactions, increasing toxicity and environmental danger [37].

### 3. Types of Pesticides

Chemicals used in agriculture to control undesirable species, including insects, weeds, fungus, and other things that might harm crops, are referred to as pesticides. These chemicals are classified based on their chemical composition, mode of action, and the kind of pests they target [41].

**3.1 Insecticides:** Insecticides are used to control pests and typically include neonicotinoids, such as imidacloprid and thiamethoxam, pyrethroids, such as cypermethrin and permethrin, and organophosphates, such as malathion and chlorpyrifos [36].

**3.2 Herbicides:** Eliminate or hinder the development of weeds. While non-selective herbicides, like paraquat, destroy all plants, selective herbicides, like glyphosate, target certain weeds. Atrazine is a prominent example of a pre-emergent herbicide, which is applied before weeds start to sprout [36].

**3.3 Fungicides:** Avoid or eradicate fungus-related illnesses. Fungicides include things like mancozeb, tebuconazole, and azoxystrobin. Another way to classify pesticides is by their method of action. Targeting pests that consume plants, systemic insecticides like imidacloprid are absorbed by plants and moved throughout their tissues. Pyrethroids and other contact insecticides kill bugs when they come into direct contact with them. Certain stable pesticides can continue to affect pests for a long time because of their long-lasting effects [4].

The usage of pesticides has steadily grown worldwide during the last ten years. The global use of pesticides was estimated to be 3.69 million metric tons by 2021. By 2022, the average pesticide application rate per hectare of agricultural was 2.37 kg, compared to 1.23 kg in 1990. Due to the development of farming methods and rising agricultural needs, this is a notable increase over previous years. Region-specific usage patterns show that nations with large agriculture, such as China and Brazil, have greater rates of pesticide application [39].

### 4. Sources and exposure patterns

One of the main places where people are exposed to pesticides from farming is the environment. Water is scattered throughout the atmosphere, and around 47% of the applied product is deposited at or near soil. The direction and intensity of the rain and wind, the kind of soil and geology, the existence of water currents, and other elements like the product's formula, presentation (liquid, powder, gel, gas, etc.), and application method (air, land, etc.) all affect this scenario. Strong winds, hot weather, and uneven ground all contribute to the product's drag. Powder, aerosol, or smoke presentations, as well as, of course, aerial applications, are all favored. Processes including photodegradation, volatilization, leaching, and runoff, particularly after rains, speed up the spread of pesticides in the environment. Workers in the chemical and agricultural industries who produce, handle, and apply pesticides are especially exposed at work, increasing their risk of acute poisoning from frequent and intensive contact with these

chemicals. On the other hand, low levels of pesticides are continuously present in the general population from a variety of sources, mainly tainted food (plant and animal products), water, air, and soil. Common industrial items could potentially be a factor in this exposure. Because of this, almost no group of people is completely immune to the harmful health consequences of pesticides [11].

## **5. Benefits and harmful effects of pesticides**

The use of pesticides has benefited mankind in many ways over the years. The use of pesticides on agricultural fields prevents undesired plant growth while shielding crops from insect and pest assaults. Controlling agricultural pest infections, managing plant disease vectors, and battling animal disease vectors and other nuisance species are some of the main advantages of pesticides. Due in great part to the use of pesticides, which have decreased crop losses, the world's agricultural output has grown rapidly in recent years. In addition to being widely utilized in agriculture, pesticides are also used to manage insect vectors that spread illnesses like leishmaniasis, dengue, malaria, and Lyme disease, which continue to be major health and economic problems on a worldwide scale.

Although it would be ideal for pesticides to just destroy hazardous pests and not harm other creatures, most pesticides actually endanger people, wildlife, and the environment. Inappropriate use of pesticides can contaminate soil and water, disrupt ecosystems, and leave poisonous residues in food. Some pesticides, such as DDT and ethylene dibromide, have been banned due to worries about their mutagenic and carcinogenic properties. There are also persistent worries about food safety since certain fruits and vegetables, referred to as the "dirty dozen," are discovered to have notably high levels of pesticide residues [12].

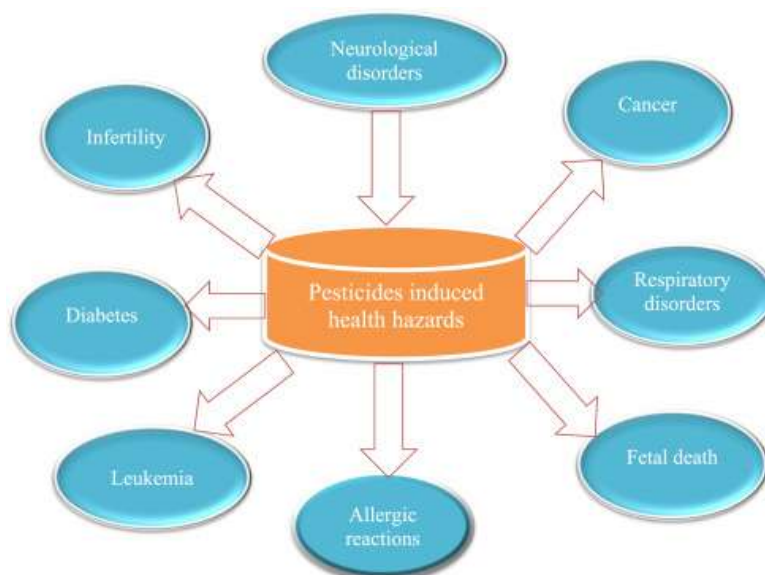
### **5.1 Effect on the Environment**

Following their application, pesticides contaminate turf, water (both surface and groundwater), soil, and other plants. Pesticides are hazardous to a wide range of creatures, including fish, birds, helpful insects, and non-target plants, in addition to killing insects and weeds. Herbicides can be harmful to creatures that are outside their intended target, but insecticides are the most intensely toxic type of pesticides [17]. Because they may alter the metabolism of beneficial microbes found in soil, herbicides can damage these microorganisms [28], [16].

### **5.2 Effect on the Human Health**

There are serious health risks for people as a result of the extensive usage of pesticides. Because of their growing bodies and the possibility of both acute and long-term exposure repercussions, infants and children are particularly susceptible to their negative effects. According to estimates, over 44% of farmers worldwide are poisoned by pesticides each year, and there are approximately 385 million cases of accidental, acute pesticide poisoning globally each year, including approximately 11,000 fatalities. Because of their high toxicity, organochlorines (OCs) and organophosphates (OPs) have an impact on the nervous system and can cause serious health problems, such as

cancer and damage to several organs. Dietary consumption and environmental contact are two exposure pathways that carry the risk of cytotoxic effects and different organ damage (Fig: 1) [52].



**Fig: 1 Pesticides Effect on Human Health**

### 5.3 Effect of pesticides on plants

Farmers now often employ chemical pesticides on agricultural land to manage weeds, insects, bacteria, fungi, mollusks, rodents, and other pests. The purpose of pesticides is to increase agricultural yields. In addition to protecting crops on agricultural land, the pesticide reduces the possibility of harm occurring during post-harvest storage. It is highly beneficial in managing a variety of human and plant illnesses, including typhoid and malaria. However, it also degrades the soil quality of agricultural land, which is why its adverse effects are taken into consideration. The majority of technologically sophisticated nations prohibited or outlawed the use of pesticides in 1960. A synthetic or chemical pesticide should ideally be poisonous or fatal to the species it is intended to kill. Due to the widespread use of pesticides, insects and other pests will become resistant to modified pesticides, such as DDT, and will be able to avoid them [44].

### 5.4 Effects of pesticides on aquatic animals

Exposure to pesticides impacts a wide range of non-target organisms, the most prominent of which being fish, in addition to the target species. In several instances, fish that were exposed to multiple pesticides acutely died, but fish exposed to the same chemicals at lesser levels died. Histological abnormalities affecting the liver, kidneys, gills, muscles, brain, and gut are caused by changes in hematological parameters, such as red blood cells, white blood cells, or plasma and serum level variations, in many fish species exposed to different pesticides. Additionally, several incidences of genotoxicity brought on by various herbicides have been reported. Because they are at the

bottom of the aquatic food chain, fish reflect the pollution and quality of the water. Because fish consume more pesticide-contaminated algae, phytoplankton, and other aquatic plants, harmful poisons gradually build up in the fish's tissues and organs. The fish's gills, skin, and alimentary canal absorb different contaminants, which spread to different organs and tissues and change physiological and natural phenomena. The gills are the most contaminated organs because they are in constant contact with water. The gills allow toxins to enter the body, raising the need for oxygen. Therefore, it is crucial to keep an eye out for any harmful stress in the aquatic environment [30].

## 5.5 Effects on Pesticide Bioavailability

The degree to which a pesticide is available for absorption, uptake, or interaction by living things, including microorganisms, plants, and animals, is known as its bioavailability. It affects a pesticide's potential for toxicity and environmental pollution, as well as how well it may achieve its desired results, such as eliminating pests or suppressing weeds. The bioavailability of pesticides may be impacted by their sorption or desorption from MPs. Consequently, the variables affecting MPs' capacity to sorb pesticides also affect their bioavailability. These parameters include ambient conditions including pH, temperature, ionic strength, and dissolved organic matter, as well as the physicochemical properties of MPs, such as surface area, aging extent, hydrophobicity, and polymer type. The bioaccumulation of pesticides in target species under the effect of MPs is another indicator of bioavailability [45].

## 6. Use of pesticides

With 85% of global output, agriculture is the biggest consumer of this kind of compound, which is used to chemically control numerous pests that lower the quantity and quality of food crops and other vegetables [5]. 10% of all insecticides used in public health initiatives to prevent and treat vector-borne illnesses including dengue, malaria, and Chagas disease, among others. also used to eradicate crops whose final products are illicit substances, purify water, and control rodents [13]. They are also employed to keep pests out of big buildings, malls, trains, aircraft, and boats. Use in recreational parks, gardens, and decorative landscaping to manage the growth of weeds, grass, and insects as well as fungus. They are dispersed along roads, railroads, and high-voltage power line towers for the same reason. In manufactured water or natural reserves, pesticides are used to stop the growth of bacteria, fungus, algae, and weeds. are frequently used in industry to prevent the growth of bacteria, fungus, algae, and yeast, as well as to prevent damage from insect pests and/or rodents. Examples of these items include electrical equipment, refrigerators, paints, carpets, paper, cardboard, and food packaging materials.

## 7. Type of MPs

Plastics have mostly been made from petroleum-based materials, such as polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), polyethylene terephthalate (PET), and polypropylene (PP). These polymers have been employed in a variety of settings based on their physical and chemical properties. (Fig: 2)

## Common Plastic Types

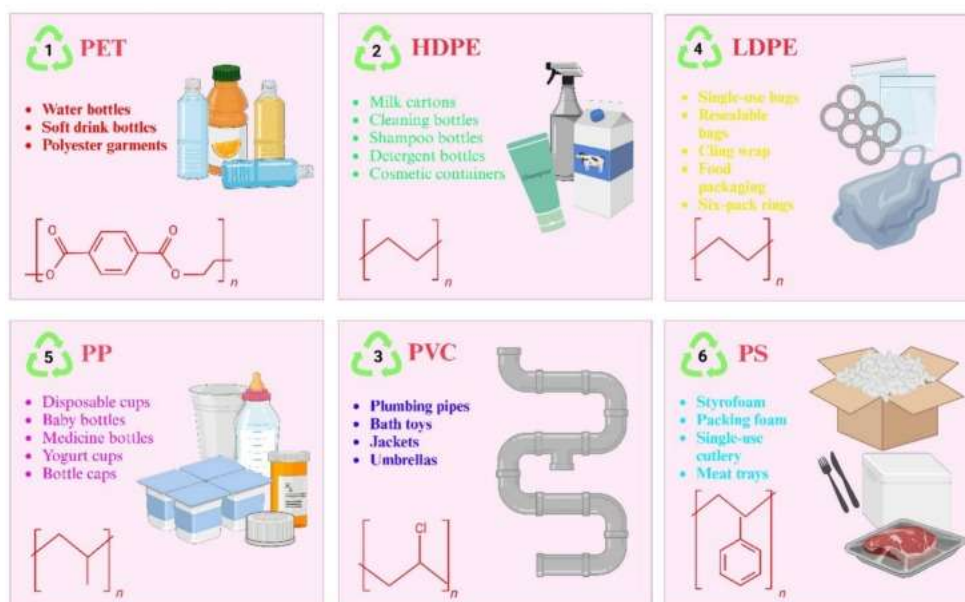


Fig: 2 Types of Plastics

### 7.1 Polyethylene (PE)

Because of its flexibility, polyethylene (PE) is used extensively in packaging; different varieties, such as low-density (LDPE) and high-density (HDPE), provide distinct features. HDPE is lightweight and has a high breaking strength, but LDPE is long-lasting and resistant to chemicals. PE's impact strength and resistance increase with density and crystallinity, however it is not extremely resistant to ripping or stress-cracking. PE is frequently used in commonplace products like milk jugs, plastic bottles, and grocery containers. Because of this, a large amount of waste is produced, most of which is disposed of incorrectly. Due to its chemical stability, PE breaks down and interacts with soil, water, and animals over time after being discharged into the environment. It can also be carried by streams or seep into groundwater.

### 7.2 Polystyrene (PS)

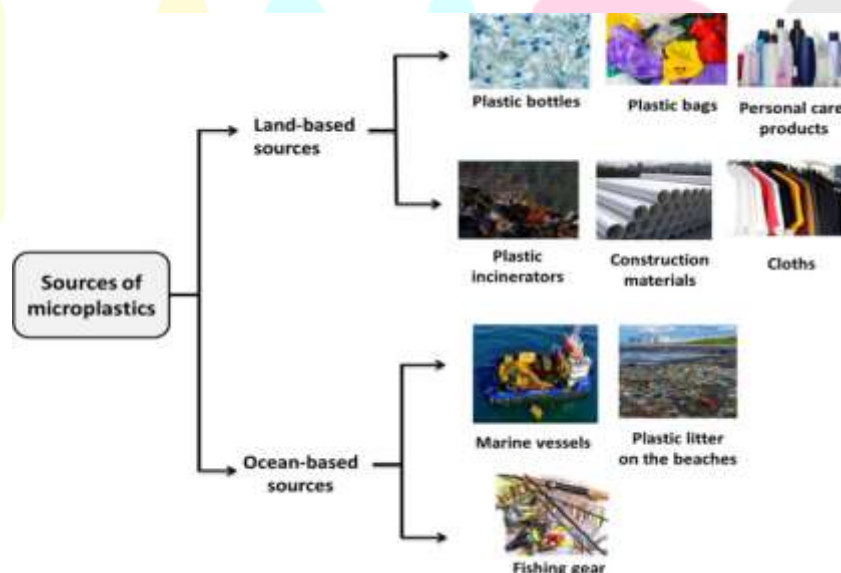
The most manufactured plastic in the world, polystyrene (PS) is frequently found in items like electronics housings, jewelry and CD cases, and toy packaging. Because contaminants like pesticides, antibiotics, heavy metals, and surfactants can hasten its aging and degradation, its environmental persistence is a cause for worry. There are serious worries about the effects of PS waste on ecosystems, animals, and human health since large volumes of it wind up in marine settings. Particles smaller than 1,000 nanometers, known as polystyrene nano-plastics (PNPs), are emitted from a variety of sources, such as medicines, electronics, varnishes, and personal care items. The mechanical breakdown of PS also produces these nano-plastics, which adds to their environmental presence and possible hazards.

### 7.3 Polypropylene (PP)

The most popular plastic in the automotive sector and several consumer goods is polypropylene (PP), which is inexpensive, strong, heat-resistant, and physically stable. It is shielded from environmental oxidation by its structure, which includes lengthy carbon chains and a large molecular weight, as well as other stabilizers. Over 20% of all polymers used in the EU in 2019 were PP, and during the Covid-19 pandemic, their use increased significantly for products like masks, gloves, and packaging. PP microplastics (MPs) are currently one of the most prevalent contaminants in aquatic environments as a result of inappropriate disposal and increasing manufacturing, which has seriously contaminated the environment. Despite being resistant to biodegradation due to its lengthy chains, PP can be broken down by photooxidation, which can lead to the creation of microplastics that contaminate the environment and endanger ecological health [32].

### 8. Sources of Microplastics

Microplastics (MPs) are a persistent and subtle environmental concern that has already been found to have a major impact on human health and aquatic environments. Despite the widespread presence of MP pollution in the air, water, and land, these environments are frequently seen as distinct yet interconnected. In order to establish future research goals, this study attempts to give a thorough overview of MPs that cause pollution, their prevalence, and possible routes for these pollutants. It also intends to highlight research gaps. The study found that low temperatures and UV light help break down common plastic into microscopic particles called MPs, which are then carried into the marine environment by runoff. Furthermore, it has been shown that other water pollutants, including chemicals, dyes, and heavy metals, stick to MPs easily. As a result, MPs are used as a carrier of several other contaminants in aquatic animals' bodies. Therefore, the present study looks at: i) MPs and where they are found; and ii) how they harm the environment and marine biodiversity (Fig: 3) [6].



**Fig: 3 Sources of Microplastics**

## 9. Microplastic transformation mechanisms

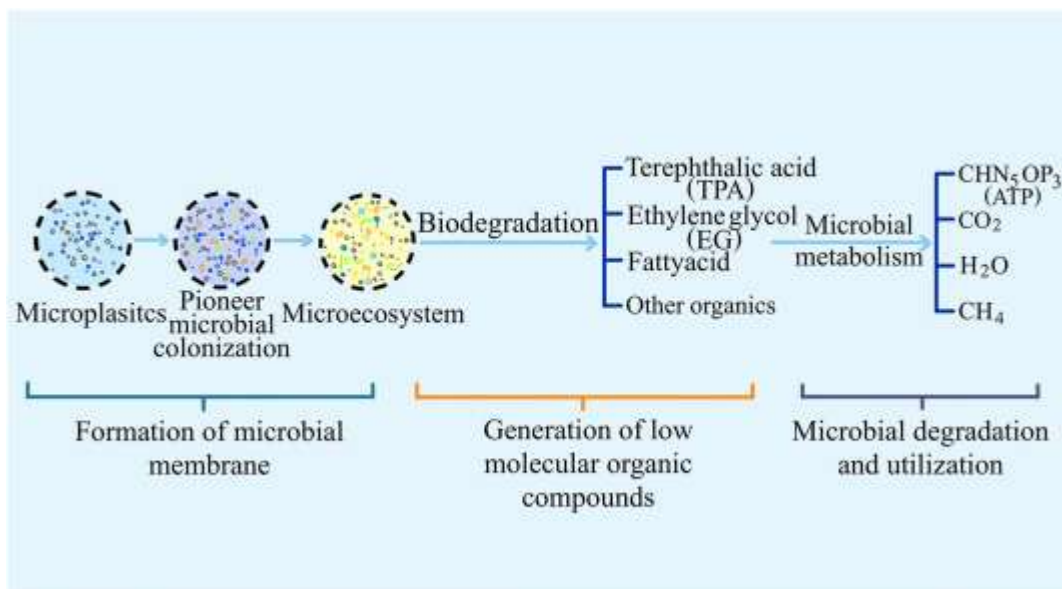
Due to a variety of physical, chemical, and biological processes, such as exposure to light, heat, biological activity, wind, and water currents, plastic eventually degrades into micro- and even nanoscale particles once it enters the environment. Microplastics experience significant changes in their surface characteristics, thermal characteristics, molecular weight, wettability, zeta potential, and crystallinity when compared to their original forms. These changes have an impact on the plastics' migration, environmental fate, ecological impact, and toxicity in soil, water, and air. According to studies, photodegradation and microbiological activity are the two main processes that lead to plastic aging.

### 9.1 Photodegradation mechanism

Alkoxy radicals ( $RO\cdot$ ) further encourage the creation of smaller molecules with functional groups like olefins, ketones, and acids, whereas hydroxyl radicals ( $\cdot OH$ ) are essential in rupturing the major polymer chains during the photoconversion and aging of microplastics. UV radiation and reactive oxygen species (ROS) drive this photo-oxidation process, which progressively lowers the molecular weight of plastics, modifies their characteristics, and causes the release of microplastics. The kind of polymer, particle size and shape, exposure to UV radiation, and environmental variables like the presence of organic carbon, minerals, or acids in soils and water all affect how quickly photodegradation occurs. Although commercial plastics sometimes have chemicals that slow down deterioration, such as UV stabilizers and colors, these compounds ultimately lose their efficacy and polymers still break down, releasing microplastics into the environment.

### 9.2 Biodegradation mechanism

Secondary plastic particles separate from surfaces when polymers deteriorate, forming rough, porous structures that enhance their capacity to absorb pollutants from the environment and facilitate microbial colonization. By adhering to these surfaces, microorganisms change their characteristics and create intricate microbial communities that may use plastics as carbon sources. Three phases of microbial breakdown of plastics include absorption or conversion into compounds such as water, carbon dioxide, methane, and nitrogen; attachment and enzyme secretion; and bio-fragmentation into tiny molecules. Some plastics, like PLA and PHAs, biodegrade quickly in composting, whereas others, like PET, decay very slowly in natural settings. The pace of biodegradation varies significantly depending on the kind of polymer and environmental factors. Microplastics decompose further to produce nano-plastics, which are particles smaller than  $1\ \mu m$ , have high reactivity and mobility, may pass through biological membranes, and operate as pollutant vectors, increasing the hazards to the environment and human health (Fig: 4) [24].



**Fig: 4 Mechanism of Microplastics Transformation**

## 10. Toxic Effects of Microplastics

The intricate mechanism by which microplastics produce harmful effects depends on a number of variables, such as their physical and chemical characteristics, exposure duration, additives, etc. In addition to being poisonous in and of themselves, microplastics may also carry a variety of contaminants into biological tissues and organs. In order to investigate the toxicity mechanism, we want to methodically outline their possible toxicity at the "individual-tissue-cell-subcellular" level.

### 10.1 Factors Affecting the Toxicity of Microplastics

Numerous elements, such as size, form, surface charge, weathering/aging process, adsorption, etc., might affect how harmful microplastics are. Larger particles cause less oxidative stress because they are less likely to penetrate cells. Randomly shaped pieces have greater detrimental physical effects than spherical microplastics. The primary factor influencing the effectiveness of cellular absorption is the surface charge of microplastics. The number of absorbed particles has a positive correlation with zeta potential. The physical and chemical characteristics of plastic, including color, surface morphology, crystallinity, particle size, and density, will alter during a weathering or aging process. In addition, materials made of polymers and additives are commonly found in microplastics. Additives in microplastics may be released and cause toxicity when the environment changes.

Microplastics may serve as the vector adsorbing other contaminants, particularly heavy metals and hydrophobic organic compounds (HOCs), which may increase toxicity because of the surface energy created by their tiny size. Depending on their hydrophobicity, microplastics can absorb organic contaminants and heavy metals with concentrations ranging from 10–1 to 10<sup>4</sup> µg/g in marine and coastal settings. After further breaking down into nano-plastics, they can rapidly create a biomolecule corona upon coming into contact with different biomolecules (such

proteins), which can further change their ecotoxicity, persistence, and bioavailability. The nature of the protein corona can also be changed by aging processes [23].

## **11. Exposure route for microplastics**

MPs are ubiquitous in the environment because they are found in all ecosystem components. How microplastics enter the bodies of humans, animals, and plants is covered in the section that follows.

### **11.1 Pathways of microplastics in humans**

Ingestion, inhalation, and skin contact are some of the ways that microplastics can get into our systems. The main exposure pathway in humans is oral intake [20]. Living creatures, including food, drink, and other necessities, consume microplastics [25],[14],[35],[50]. Plastic food containers and utensils, tainted seafood, and drinking water can all include microplastics. After being ingested, microplastics may build up in the digestive system and other organs [9]. Furthermore, microplastics in our environment can absorb persistent organic pollutants (POPs), which build up in the tissues of marine creatures and may potentially reach people through the ingestion of contaminated seafood.

Microplastics can also enter the human body by inhalation after coming into touch with other sources such as manufacture, transportation, and disposal. People who work in industries that generate or use plastic products are particularly susceptible to microplastic exposure by inhalation [21]. Between 26 and 130 particles of airborne microplastics may be consumed by an individual each day [19]. Roads are the source of 84% of the microplastics in the atmosphere [18]. However, utilizing personal care products like face cleansers and body washes that include microbeads might expose the skin to microplastics [34],[48]. Because they can emit microfibers when washed and worn, synthetic fabrics and clothing may potentially contain microplastics [8].

#### **11.1.1 Detrimental effects of microplastics ingestion on human health**

Fig: 5 summarizes the related molecular pathways that underlie the effects of microplastics on human health. Human health hazards such as cancer, immunotoxicity, intestinal, pulmonary, cardiovascular, and inflammatory disorders, as well as pregnancy and maternal exposure to offspring, may arise from exposure to the human body through the consumption of food containing plastic particles. The harmful processes and consequences of microplastics that might endanger human health are outlined in this section.

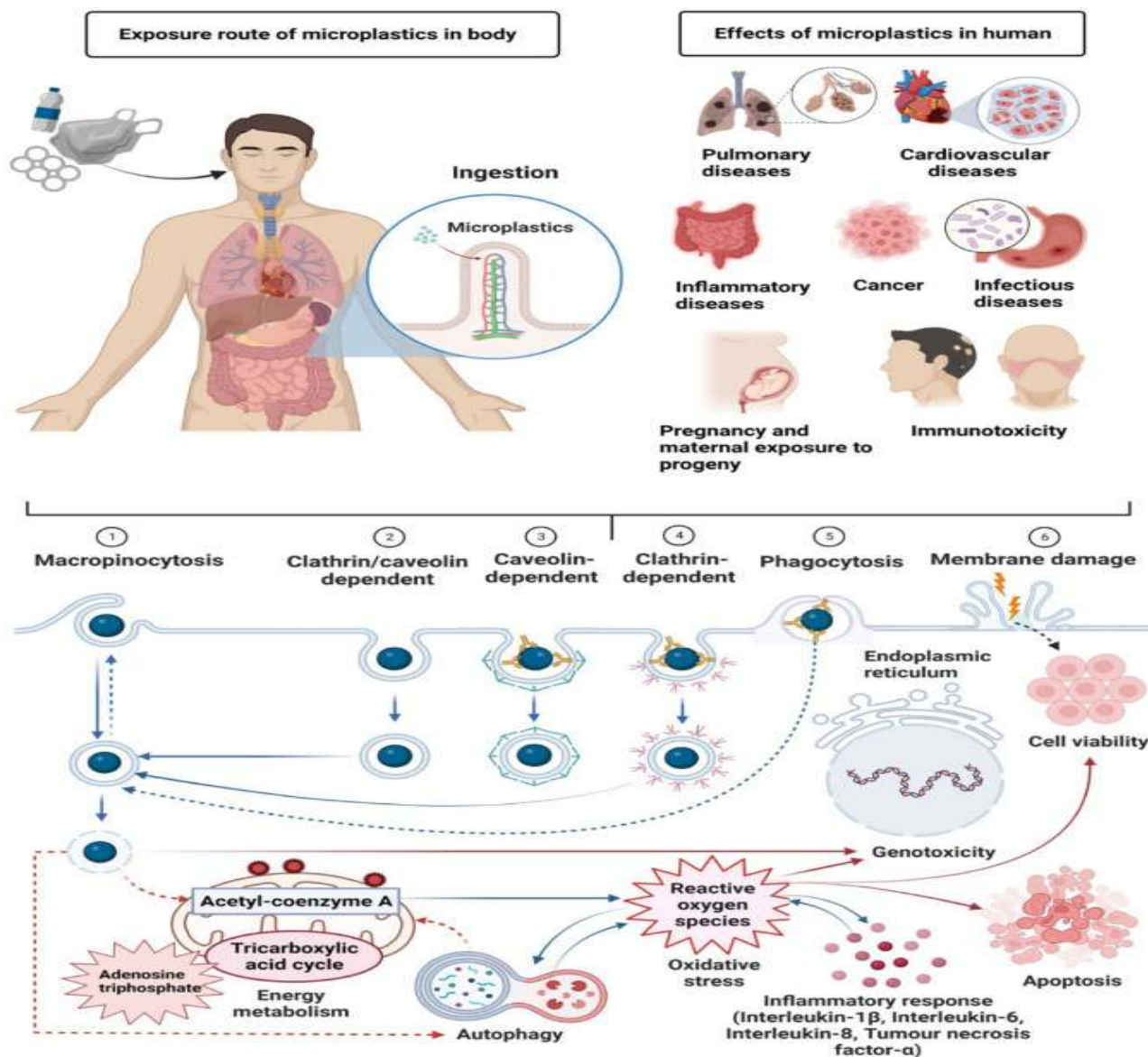


Fig: 5 Effect of Microplastics in Human

### 11.1.1.1 Microplastic-induced cancer

When consumed by humans, microplastics have been connected to a number of health hazards, including as toxicity and cancer, because of their small size and huge surface area. They are especially harmful to cells and DNA because of their large surface area, which can result in mutations and cancer. Their health concerns are further increased by the ability of microplastics in water to absorb heavy metals like arsenic, cadmium, and lead as well as organic contaminants that can cause cancer. Long-term microplastic exposure is strongly linked to cancer in both people and animals, according to epidemiological research. Research suggests that Europeans may ingest up to 11,000 microplastics annually via shellfish like bivalves. These particles can enter the food chain through marine species and build up in people. There are worries over the potential health effects of microplastics smaller than 2.5 mm as they can enter the digestive system through certain cellular mechanisms after being consumed.

### 11.1.1.2 Immunotoxicity

Supported by immune cells and secretory immunoglobulin A, the intestinal immune system strikes a careful balance between reacting to invaders and allowing commensal microorganisms. Through immunotoxicity, which results in cytokine dysregulation, immune cell death, and changed receptor expression, microplastics upset this equilibrium. These exchanges may result in:

- **Immunosuppression** (reduced defense against infections and tumors)
- **Immune hyperactivity** (increased allergy and autoimmune risks)
- **Chronic inflammation** (Tissue damage and Dysfunction) Studies show microplastics attach to intestinal epithelial cells, particularly in Peyer's patches, with ~0.3% penetrating the epithelium. This enables systemic distribution, triggering local inflammation and potentially significant systemic immune responses [29].

## 11.2 Pathway of microplastics in animals

Through ingestion and entanglement, animals—including marine and soil organisms—are exposed to microplastics (MPs). One of the primary reasons why some marine species ensnare or consume microplastics is because of the formation of biofilm on their surface. Biofilm-forming activities on virgin microplastic particles begin as soon as they come into contact with ambient water [27],[2],[3],[46],[40].

Additionally, it is known that different soil organisms, such as isopods, oligochaeta (e.g., earthworms), collembolans, and nematodes, interact with one another and eat soil plastic trash [2], [46]. Additionally, because the majority of land animals, including goats, cows, and herbivores, may be exposed directly or indirectly by consuming tainted water or animal feed, carnivores, including tigers, lions, and others, may be exposed through the food chain process or trophic transfer by consuming or feeding on the tissues and biosystems of herbivores. The food chain exposure mechanisms are often seen in the aquatic ecosystem; for example, MPs may have been devoured by whales or sharks that prey on smaller marine species, or the amphipod *Gammarus duebeni* may have swallowed PE-laden *L. minor* [1].

## 11.3 Pathway of microplastics in plants

Through contact (from MP fallout, polluted water, or irrigation water) and absorption in the plastic-soil matrix through the rhizosphere, MPs are consumed by plants [43], [7], [8]. Furthermore, MPs may build up in plants in two ways: through root uptake and foliar absorption [15]. Despite their inability to penetrate the physical barriers of intact plant tissue due to their size, MPs are easily detected on the surface of plant seeds and roots [49]. For example, MPs have been seen to build up in the pores and roots of garden cress (*Lepidium sativum*) and broad beans (*Vicia faba*) [42], [47] respectively. Furthermore, the buildup of microplastics on plants might negatively impact growth, contingent on the kinds of MPs, oxidative activities, and exposure concentration. Overall, after

extended exposure to the treatment, aquatic plants' adhesion to MPs in water rose indicating that they may be utilized to monitor MP pollution in freshwater settings [22], [1].

## 12. Solutions to Reduce Microplastic Pollution

The environmental microplastics cannot be eradicated with current technical capabilities. As a result, action must be taken at several levels, specifically at the macro and mesoblast levels. In order to address some of the numerous issues with traditional plastics, the area of bioplastics has evolved. Biobased and biodegradable polymers are examples of bioplastics. Renewable sources of plastic monomers have supplanted non-renewable ones in the case of bioplastics.

Bio-based plastics, such as bio-PE, help cut down on the usage of fossil fuels since they are made from renewable resources like sugarcane starch rather than petrochemicals. But there are drawbacks to this change as well, such as the necessity for intensive chemical processing, increasing pesticide use, and deforestation. The characteristics and chemical additions of traditional polymers are comparable to those of biomass-based plastics. Microbial activity allows biodegradable polymers, whether derived from fossil or renewable resources, to break down into carbon dioxide and water in certain environmental settings. The primary short-term uses for these biodegradable polymers are in food packaging, throwaway goods, and some agricultural applications.

The plastics industry's transition to more environmentally friendly, sustainable solutions is highlighted by the rising interest in bioplastics. Recycling is helpful, but it cannot eliminate plastic pollution on its own. Therefore, it is crucial to lessen dependency on plastics derived from fossil fuels. Bio-based plastics are becoming more and more popular as substitutes since they can function on par with traditional plastics. Notably, using microalgae, such as *Chlorella* and *Spirulina* species, to produce bioplastics offers a novel and promising way to make biopolymers and plastic blends, opening up new possibilities for the creation of sustainable materials [51].

## 13. Uses of Microplastics

Because of their widespread distribution and possible ecological effects, microplastics tiny plastic particles smaller than five millimeters have sparked environmental concerns on a global basis. They come from a variety of sources, and depending on how they are produced, they can be classified as primary or secondary microplastics. Primary microplastics are purposefully made and utilized in the textile, personal care, and cosmetics sectors. Another important source of primary microplastics is synthetic fibers found in clothes, such as polyester and nylon, which are released into the environment directly through washing machines and wastewater treatment facilities. However, the major plastic-based items break down to produce secondary microplastics owing to a variety of environmental factors [26].

## Future prospect

- There is an urgent need for integrated research, policy, and management strategies to address the combined threat of microplastics and pesticides.
- As microplastics accumulate in agricultural soils and ecosystems, their interactions with pesticides are expected to increase the persistence, bioavailability, and toxicity of these chemicals, posing greater risks to soil health, crop productivity, and biodiversity.
- Comprehensive studies are needed to better understand these interactions and their long-term ecological impacts.
- Developing sustainable alternatives, such as biodegradable plastics and eco-friendly agrochemicals, should be a priority.
- Strengthening global regulations to limit the intentional use of microplastics in agriculture and improving waste management practices are critical steps.
- Technological innovation in remediation and increased public awareness will be essential for mitigating the impacts of this toxic combination and protecting ecosystem and human health in the future.

## Conclusion

The combination of microplastics and pesticides in the environment poses a growing threat to ecosystems and human health, as microplastics act as carriers that increase the persistence, bioavailability, and toxicity of pesticides. This interaction disrupts ecological balance, harms non-target organisms, and facilitates the spread of contaminants through food webs, ultimately threatening biodiversity, soil health, and food security. The potential for bioaccumulation and biomagnification further raises concerns about human exposure through contaminated food and water. Despite increasing awareness, the mechanisms of microplastic–pesticide interactions are not fully understood, and current regulations are inadequate. To address these risks, there is an urgent need for integrated research, stronger policies, sustainable alternatives, and improved waste management, requiring coordinated efforts across scientific, regulatory, and societal sectors.

## References

1. A Mateos-Cárdenas, D.T. Scott, G. Seitmaganbetova, N.A.M. van Pelt Frank, J.M. AK, Polyethylene microplastics adhere to *Lemna minor* (L.), yet have no effects on plant growth or feeding by *Gammarus duebeni* (Lillj.), *Sci. Total Environ.* 689 (2019) 413–421.
2. A.W. Verla, C.E. Enyoh, E.N. Verla, K.O. Nwarnorh, Microplastic-toxic chemical interaction: a review study on quantified levels, mechanism and implications, *SN Appl. Sci.* 1 (2019) 1400.

3. A.W. Verla, C.E. Enyoh, E.N. Verla, Microplastics, an emerging concern: a review of analytical techniques for detecting and quantifying microplastics, *Anal. Methods Environ. Chem. J.* 2 (2) (2019) 13–30.
4. Abubakar, Y.; Tijjani, H.; Egbuna, C.; Adetunji, C.O.; Kala, S.; Kryeziu, T.L.; Ifemeje, J.C.; Patrick-Iwuanyanwu, K.C. Chapter 3—Pesticides, History, and Classification. In *Natural Remedies for Pest, Disease and Weed Control*; Egbuna, C., Sawicka, B., Eds.; Academic Press: Cambridge, MA, USA, 2020; pp. 29–42. [[Google Scholar](#)]
5. Al-Saleh I A (1994). Pesticides: a review article. *J Environ Pathol Toxicol Oncol*; 13:151-161.
6. Ashrafy, Asifa, Afroza Akter Liza, Md Nazrul Islam, Md Morsaline Billah, Shaikh Tareq Arafat, Md Moshir Rahman, and Sheikh Mustafizur Rahman. "Microplastics pollution: a brief review of its source and abundance in different aquatic ecosystems." *Journal of Hazardous Materials Advances* 9 (2023): 100215.
7. C.E. Enyoh, A.W. Verla, E.N. Verla, F.C. Ibe, C.E. Amaobi, Airborne microplastics: a review study on method for analysis, occurrence, movement and risks, *Environ. Monit. Assess.* 191 (668) (2019) 1–11
8. C.E. Enyoh, L. Shafea, A.W. Verla, E.N. Verla, W. Qingyue, T. Chowdhury, M. Paredes, Microplastics exposure routes and toxicity studies to ecosystems: an overview, *Environ. Anal., Health Toxicol.* 35 (1) (2020) e2020004, <https://doi.org/10.5620/eaht.e2020004>.
9. Campanale, C. Massarelli, I. Savino, V. Locaputo, V.F. Uricchio, A detailed review study on potential effects of microplastics and additives of concern on human health, *Int. J. Environ. Res. Public Health* 17 (4) (2020) 1212.
10. Crispin, Augustine, and Purushothaman Parthasarathy. "Microplastics and the Environment: A Review." In *International Conference on Civil Engineering Innovative Development in Engineering Advances*, pp. 229-237. Singapore: Springer Nature Singapore, 2023.
11. Garcia, F. Prieto, Sandra Yazmin Cortés Ascencio, John Carlos Gaytán Oyarzún, Alejandra Ceruelo Hernandez, and Patricia Vazquez Alavarado. "Pesticides: classification, uses and toxicity. Measures of exposure and genotoxic risks." *J. Res. Environ. Sci. Toxicol* 1, no. 11 (2012): 279-293.
12. Garud, Aishwarya, Satyajeet Pawar, Monika S. Patil, Shivani R. Kale, and Satish Patil. "A scientific review of pesticides: Classification, toxicity, health effects, sustainability, and environmental impact." *Cureus* 16, no. 8 (2024).
13. Goldman LR (1998). Linking research and policy to ensure children's environmental health. *Environ Health Perspect*; 106:857-862.
14. H. Li, Z. Yang, F. Jiang, L. Li, Y. Li, M. Zhang, Z. Qi, R. Ma, Y. Zhang, J. Fang, et al., Detection of microplastics in domestic and fetal pigs' lung tissue in natural environment: A preliminary study, *Environ. Res.* 216 (2023) 114623.

15. H. Sun, C. Lei, J. Xu, R. Li, Foliar uptake and leaf-to-root translocation of nanoplastics with different coating charge in maize plants, *J. Hazard. Mater.* 416 (2021) 125854.
16. Imidacloprid application changes microbial dynamics and enzymes in rice soil. Mahapatra B, Adak T, Patil NK, et al. *Ecotoxicol Environ Saf.* 2017;144:123–130. doi: 10.1016/j.ecoenv.2017.06.013. [DOI] [PubMed] [Google Scholar]
17. Impact of pesticides use in agriculture: their benefits and hazards. Aktar MW, Sengupta D, Chowdhury A. *Interdiscip Toxicol.* 2009;2:1–12. doi: 10.2478/v10102-009-0001-7. [DOI] [PMC free article] [PubMed] [Google Scholar]
18. J. Brahney, N. Mahowald, M. Prank, G. Cornwell, Z. Klimont, H. Matsui, K.A. Prather, Constraining the Atmospheric Limb of the Plastic Cycle, *Proc. Natl. Acad. Sci. U. S. A.* 118 (16) (2021) No. e2020719118.
19. J.C. Prata, Airborne microplastics: consequences to human health? *Environ. Pollut.* 234 (2018) 115–126, <https://doi.org/10.1016/j.envpol.2017.11.043>.
20. J.C. Prata, J.P. da Costa, I. Lopes, A.C. Duarte, T. Rocha- Santos, Environmental exposure to microplastics: an overview on possible human health effects, *Sci. Total Environ.* 702 (2020) 134455.
21. K. Kannan, K.A. Vimalkumar, Review of human exposure to microplastics and insights into microplastics as obesogens, *Front. Endocrinol.* 12 (2021) 724989.
22. L. Li, Q. Zhou, N. Yin, C. Tu, Y. Luo, Uptake and accumulation of microplastics in an edible plant, *Chin. Sci. Bull.* 64 (2019) 928–934.
23. Li, Yue, Le Tao, Qiong Wang, Fengbang Wang, Gang Li, and Maoyong Song. "Potential health impact of microplastics: a review of environmental distribution, human exposure, and toxic effects." *Environment & Health* 1, no. 4 (2023): 249-257.
24. Liu, Jianfu, and Liang Zheng. "Microplastic Migration and Transformation Pathways and Exposure Health Risks." *Environmental Pollution* (2025): 125700.
25. M. Kumar, V. Chaudhary, V. Chaudhary, et al., Impacts of microplastics on ecosystem services and their microbial degradation: a systematic review of the recent state of the art and future prospects, *Environ. Sci. Pollut. Res* 31 (2024) 63524–63575, <https://doi.org/10.1007/s11356-024-35472-3>
26. Mathew, John Tsado, Abel Inobeme, Babatunde Oluwafemi Adetuyi, Charles Oluwaseun Adetunji, Oluwabukola Atinuke Popoola, Falana Yetunde Olaitan, Olalekan Akinbo et al. "General introduction of microplastic: uses, types, and generation." In *Microplastic pollution*, pp. 3-21. Singapore: Springer Nature Singapore, 2024.
27. N.U. Benson, O.D. Agboola, O.H. Fred-Ahmadu, G.E. De-la-Torre, A. Oluwalana, A.B. Williams, Micro (nano) plastics prevalence, food web interactions, and toxicity assessment in aquatic organisms: a review, *Front. Mar. Sci.* 9 (2022) 851281.

28. Non-target Impact of dinotefuran and azoxystrobin on soil bacterial community and nitrification. Yamaguchi T, Mahmood A, Ito T, Kataoka R. *Bull Environ Contam Toxicol.* 2021;106:996–1002. doi: 10.1007/s00128-021-03163-1. [DOI] [PubMed] [Google Scholar]
29. Osman, Ahmed I., Mohamed Hosny, Abdelazeem S. Eltaweil, Sara Omar, Ahmed M. Elgarahy, Mohamed Farghali, Pow-Seng Yap et al. "Microplastic sources, formation, toxicity and remediation: a review." *Environmental Chemistry Letters* 21, no. 4 (2023): 2129-2169.
30. Pathak, Vinay Mohan, Vijay K. Verma, Balwant Singh Rawat, Baljinder Kaur, Neelesh Babu, Akansha Sharma, Seeta Dewali et al. "Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review." *Frontiers in microbiology* 13 (2022): 962619.
31. Peña, Aránzazu, José Antonio Rodríguez-Liébaná, and Laura Delgado-Moreno. "Interactions of microplastics with pesticides in soils and their ecotoxicological implications." *Agronomy* 13, no. 3 (2023): 701.
32. Prasath, Arunagiri Ragu, Chinnappan Sudhakar, and Kandasamy Selvam. "Microplastics in the environment: Types, sources, and impact on human and aquatic systems." *Bioresource Technology Reports* (2025): 102055.
33. Qiu, Yifei, Shenglu Zhou, Chuchu Zhang, Wendong Qin, and Chengxiang Lv. "A framework for systematic microplastic ecological risk assessment at a national scale." *Environmental Pollution* 327 (2023): 121631.
34. S.M. Bashir, S. Kimiko, C.-W. Mak, J.K.-H. Fang, D. Gonçalves, Personal care and cosmetic products as a potential source of environmental contamination by microplastics in a densely populated Asian City, *Front. Mar. Sci.* 8 (2021) 683482
35. S.M. Praveena, S. Laohaprapanon, Quality assessment for methodological aspects of microplastics analysis in bottled water - a critical review, *Food Control* 130 (2021) 108285.
36. Sabzevari, S.; Hofman, J. A worldwide review of currently used pesticides' monitoring in agricultural soils. *Sci. Total Environ.* 2022, 812, 152344. [Google Scholar] [CrossRef] [PubMed]
37. Schell, Theresa, Rachel Hurley, Nina T. Buenaventura, Pedro V. Mauri, Luca Nizzetto, Andreu Rico, and Marco Vighi. "Fate of microplastics in agricultural soils amended with sewage sludge: Is surface water runoff a relevant environmental pathway?." *Environmental Pollution* 293 (2022): 118520.
38. Shekhar, Chander, Reetu Khosya, Kushal Thakur, Danish Mahajan, Rakesh Kumar, Sunil Kumar, and Amit Kumar Sharma. "A systematic review of pesticide exposure, associated risks, and long-term human health impacts." *Toxicology Reports* (2024): 101840.
39. Statista. Agricultural Consumption of Pesticides per Area of Cropland Worldwide from 1990 to 2022. Available online: <https://www.statista.com/statistics/1263369/global-pesticide-use-per-area/> (accessed on 20 December 2024).

40. Sun, J.W. (2020). Characteristics of biofilms and resistance genes o microplastic surfaces in waste water treatment plant. Shandong University
41. Sun, S.; Sidhu, V.; Rong, Y.; Zheng, Y. Pesticide Pollution in Agricultural Soils and Sustainable Remediation Methods: A Review. *Curr. Pollut. Rep.* 2018, 4, 240–250. [Google Scholar] [CrossRef]
42. T. Bosker, L.J. Bouwman, N.R. Brun, P. Behrens, M.G. Vijver, Microplastics accumulate on pores in seed capsule and delay germination and root growth of the terrestrial vascular plant *Lepidium sativum*, *Chemosphere* 226 (2019) 774–781
43. T. Roy, T.K. Dey, M. Jamal, Microplastic/nanoplastic toxicity in plants: an imminent concern, *Environ. Monit. Assess.* 195 (2023) 27, <https://doi.org/10.1007/s106>
44. Tomer, N. (2013). Determination of chlorinated pesticide in vegetables, cereals and pulses by gas chromatography in east national capital region, Delhi, India. *Res. J. Agric. Sci.* 1, 27–28.
45. Tang, Kuok Ho Daniel. "Effects of Microplastics on Bioavailability, Persistence and Toxicity of Plant Pesticides: An Agricultural Perspective." *Agriculture* 15, no. 4 (2025): 356
46. X. Chang, Y. Fang, Y. Wang, F. Wang, L. Shang, R. Zhong, Microplastic pollution in soils, plants, and animals: a review of distributions, effects and potential mechanisms, *Sci. Total Environ.* 850 (2022) 157857.
47. X. Jiang, H. Chen, Y. Liao, Z. Ye, M. Li, G. Klobučar, Ecotoxicity and genotoxicity of polystyrene microplastics on higher plant *Vicia faba*, *Environ. Pollut.* 250 (2019) 831–838.
48. Y. Wang, A. Baynes, K.O. Renner, M. Zhang, M.D. Scrimshaw, E.J. Routledge, Uptake, Elimination and Effects of Cosmetic Microbeads on the Freshwater Gastropod *Biomphalaria glabrata*, *Toxics* 10 (2022) 87.
49. Z. Li, Q. Li, R. Li, Y. Zhao, J. Geng, G. Wang, Physiological responses of lettuce (*Lactuca sativa* L.) to microplastic pollution, *Environ. Sci. Pollut. Res.* 27 (24) (2020) 30306–30314
50. Zhang, X. Yang, L. Chen, J. Chao, J. Teng, Q. Wang, Microplastics in soils: a review of possible sources, analytical methods and ecological impacts, *J. Chem. Technol. Biotechnol.* 95 (8) (2020) 2052–2068.
51. Ziani, Khaled, Corina-Bianca Ioniță-Mîndrican, Magdalena Mititelu, Sorinel Marius Neacșu, Carolina Negrei, Elena Moroșan, Doina Drăgănescu, and Olivia-Teodora Preda. "Microplastics: a real global threat for environment and food safety: a state of the art review." *Nutrients* 15, no. 3 (2023): 617.
52. Zhou, Wei, Mengmeng Li, and Varenayam Achal. "A comprehensive review on environmental and human health impacts of chemical pesticide usage." *Emerging Contaminants* (2024): 100410.