Effects of Microplastics and Nanoplastics in Agro-ecosystems and Human Health: A review

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Abstract: Life on land and ocean is being threatened by microplastics (MPs) and nanoplastics (NPs). Despite, the fate and effects of MPs and NPs in agro-ecosystems have not been clearly understood. However, recent studies showed that these polymers can be transported and accumulated in food crops, humans, and other organisms. The introduction of plastics into terrestrial land has led to the accumulation of MPs and NPs in food crops. The bioaccumulation has been found in stems, leaves, flowers, and fruits. Thus, causes a change in physicochemical activities in plants that leads to a decline in crop production. Further, MPs accumulation in human placenta and breast milk have been evidently proven in recent studies. MPs themselves are being potential vectors of pollutants, including anti-resistance genes, harmful microbes, heavy metals, and carcinogenic compounds. Alarmingly, these pollutants can be horizontally transferred to organisms along with the MPs and remain intact throughout the food chain. Poor solid waste management, inadequacy in plastic recycling, and application of MPs contaminated compost in agricultural practices are the major entry points of MPs into the agro-ecosystem. The collection of these results in this study will help both on-going and upcoming investigations on bioaccumulation of MPs and NPs in crops and their movement through the food chain.

Keywords: *Microplastics, Crop production, Bioaccumulation, Human health, White pollution*

1. INTRODUCTION

Plastics have become an inevitable substance in life on Earth. The annual plastic production is estimated to be more than 4000 million in weight. Among them only 10 % is recycled, the rest are scattered all over the world (United Nations). The low density, low thermal and electrical conductivity, corrosion resistance including several properties, have accelerated the widespread usage of plastics in day to day life. Plastics can be classified into two groups based on their origin: fossil-based plastics and bio-based plastics. Plastics derived from fossil fuels are known as fossil-based plastics. Polyethylene terephthalate (PET), Polyethylene (PE), Polypropylene (PP), Polystyrene (PS), Polyvinyl chloride (PVC), Polyamide (nylon) and Polytetrafluoroethylene (PTFE) are some of the most widely used fossil-based plastic polymers. Meanwhile, bio-based plastics are created entirely or partially from renewable resources such as maize and sugarcane rather than fossil raw materials. Poly Lactic Acid (PLA) and Polyhydroxyalkanoates (PHA) are bio-based polymers that are slowly being utilized in the medical and food industries (Tod, 2021). Understanding the source of plastic materials is therefore essential in designing the best isolation protocol in a plastic pool. Table 1. lists the types of plastics used in different products.

The exposure of plastics to the harsh environmental conditions including ocean currents, abrasion, solar radiation, oxidation and friction allows them to break into tiny particles which are known as microplastics (Thompson *et al.*, 2004). There is no universally accepted definition for MPs. However, any synthetic substance with a solid or polymeric matrix in a size ranging from 1μm to 5 mm, having a regular or irregular shape, and being insoluble in water is considered micropalstic (Boucher *et al*., 2017) MPs can be

Types of Plastic	Applications
Polyethylene terephthalate (PET)	Plastic bottles, Food packaging
Polyethylene (PE)	Meat trays, Bottle crates
Polypropylene (PP)	Clothing, Sportswear, Food packaging materials
Polystyrene (PS)	Styrofoam, Toys, Single-use cups
Polyvinyl chloride (PVC)	Gutters, Downpipes,
Polyamide (PA)	Nylon stockings, Tents, Sports Equipment, and Medical goods.
Polytetrafluoroethylene (PTFE)	Kitchen wares, Lubricants, and Musical instruments

Table 1. Types of conventional fossil-based plastics and their application.

primary or secondary. Primary plastics originated exclusively in industries as plastic pellets, such as glitters and microbeads. Whereas, secondary MPs are tiny plastic fragments that are formed as a result of the breakdown of larger plastics. The incorporation of plastics into our ecosystem occurs in several ways. According to the studies conducted in marine environment, synthetic textiles originated on land, and account for the most (35%) of the plastic that ends up in the ocean, followed by tires (28%), city dust (24%), road markings (7%), personal care items (2%), and primary plastic pellets (0.3%). On the other hand, plastic emission on the ocean contributes to 37 % of marine accumulation including from shipwrecks, commercial fisheries, aquaculture, and recreational fishing (Lassen *et al*., 2015; Magnusson *et al*., 2016; Sundt *et al*., 2014; Essel *et al*., 2015). Due to these cumulative depositions, the North Atlantic and Artic region have become the largest plastic marine hotspots where plastics accumulation have been taken placed at higher density in marine environments (Cózar *et al*., 2017). In comparison to the marine environment, the deposition and fate of plastics in terrestrial ecosystems has received little attention. The amount of plastic garbage released into terrestrial ecosystems is estimated to be four to twenty-three times more than that released into marine ecosystem region (Horton *et al.*, 2017). Thus, a thorough understanding of plastic deposition in terrestrial ecosystems and plastic transit throughout the food chain is required. This article provides a holistic insight of plastic deposition into agro-ecosystems, migration of plastics into plants, human and other terrestrial organisms and their impacts on growth and physicochemical activities.

2. ENTRANCE AND ACCUMULATION OF MICROPLASTICS INTO THE AGRO-ECOSYSTEM

Plastics are purely synthesized for human usage. Thus, deposition of plastics both in marine and terrestrial ecosystems solely relies on anthropogenic activities. According to the recent studies on terrestrial MPs deposits, landfill refuse, sludge, and compost are the major solid sources of microplastics in agro-ecosystems. Arable lands receive approximately 1.15-2.41 MT of plastic wastes in several ways annually (Zurier *et al*., 2021). Moreover, the active and closed landfills leachates are contaminated with MPs. Therefore, the use of untreated landfill for agricultural practices enables the incorporation of MPs into arable lands. Another major modern agricultural practice that adds of MPs into cultivation land is the usage of plastic mulches. Of course, plastic mulches facilitate weed control and water retention. Yet, on the other hand, plastic mulches are continuously exposed to fragmentation by agrochemical applications, solar irradiation and thus ultimately breakdown into micro and nano plastics. Once plastics mulches are added into cultivation land, reuse and recycling of mulches are not widely practiced. And recycling plastic mulches is less effective than recycling of other plastics materials (Ramos *et al*., 2015). Thus, these mulches might be retained in soil forever as microplastics and nanoplastics. A wide range of organic and inorganic contaminants, including heavy metals, antibiotics, and pathogenic bacteria, are exposed to MPs in the environment. This means MPs are not only exposed to one type of habitat. This puts the agro ecosystem at risk since they act as transporters for hazardous contaminants (Syberg *et al.,* 2015). Different types of MPs have varying degrees of adsorption towards heavy metals; i.e, PP has the highest adsorption for cadmium, whereas PA has a greater adsorption for manganese than all other types of plastics (Selvam *et al*., 2021). In the meantime, PE and PVC adsorb lead, chromium, and zinc at significantly higher levels (Godoy *et al*., 2019). The adsorption of heavy metals relies on several factors. MPs' surface porosity and morphological characteristics govern their adsorptivity towards heavy metals. Rough surface increase the surface area thereby increases the adsorptivity. The types of heavy metals, pH, and sludge components also influence the adsorption of heavy metals. Research done by Zhao *et al*, (2021), showed that the adsorption of cadmium, cobalt, nickel, and lead increased as the pH of river water increased and the adsorption of chromium reduced and copper adsorption remained relatively constant. Munier and Bendell (2018), found that the adsorption of cadmium and lead did not differ amongst different polymers including PVC, nylon, PP, PS, and PET. However, when compared to PVC, more Zn was adsorbed by PA and PET, but not by PP and PS. Moreover, the heavy metal compositions in the environment also determine their adsorption on MPs surface. Pb, Cd, and Zn adsorption were reduced when they are present together and increased when they are present alone. This might be connected to the saturation of porosity in MPs surface. Further, Pb had the least amount of adsorption to PET MPs when compared to Cr and Zn. When these heavy metals were present in groups, the precipitation of these heavy metals was higher. These results indicate the potential of synergistic and antagonistic effects among heavy metals towards microplastics (Abbasi *et al*., 2020). The presence of organic matter in soil is also a pivotal factor, which determines the adsorption of heavy metals on MPs surface. Organic matter provides a positive charge to MPs' surface at a higher pH level. At the higher pH level, the adsorption of Pb^{2+} increases and precipitates as lead hydroxide. The precipitates provide MPs' surfaces with a heterogeneous quality, which enhances their surface area and facilitates more adsorption. The adsorption of other heavy metals is also influenced by this heterogeneous ability (Holmes *et al*., 2014). Meanwhile, the presence of carbonate, sulfate, and phosphate in irrigation water react with heavy metal and increase the precipitation of heavy metals on the surface of MPs. A study performed by Abbasi (2020), indicated that the desorption rate of heavy metals was lower than the adsorption rate of heavy metals. Thus, it causes a long-term availability of heavy metals in the root zone of plants. Furthermore, desorption of Zn from the MPs surface was greater in the earthworm intestine than in the soil (Hodson *et al*., 2017) Thus, the heavy metal-coated MPs consumed by macrofauna like earthworms would have a larger negative impact on soil biodiversity and consequently would affect soil productivity. MPs can also function as genetic carriers for antibiotic resistance. The application of animal manure, vegetable cultivation, and the subsequent weathering of MPs are all factors in the dissemination of antibiotic-resistance genes through MPs. The MPs from soil that had undergone extensive cultivation had greater concentrations of antibiotics and heavy metals (Lu *et al*., 2020). This study found that MPs with bigger sizes, more weathering, or those that were grown in the soil after long-term vegetable production: adsorbed more antibiotics and heavy metals and produced more mobile genetic components, which may have an impact on the development of antibiotic resistance in soil pathogens in environments where MPs are abundant. Because of the largest MPs had a greater surface area and a higher adsorption capacity than the smaller MPs, it was able to adsorb more heavy metals and antibiotics. Not only the MPs alone but also the Phthalate which is used for plastic polymerization plays a role in the multiplication of antibiotic resistance genes.

During plastic degradation, Phthalate is released into the environment and poses significant impacts on antibiotic resistance genes in soil, which could boost the propagation of antibiotic-resistant genes in agro-ecosystems (Lu *et al*., 2022). This scenario is posing a great threat by paving a pathway to increase antibiotic resistance in human pathogens. MPs have become a new dwelling surface for microbial colonies and making them pathogen vectors (Foulon *et al*., 2016). The adsorption of microorganisms on MPs' surface depends on the types of MPs. In a study by Zettler *et al*. (2013), biofilms developed better on PE and PP surfaces. The densities of PE and PP are equivalent to water, and they have high hydrophobicity. Thus, causing them to float in water and make contact with oxygen which facilitates biofilm formation. MPs can also be used to attract fungal colonies by acting as selective artificial microhabitats (Gkoutselis *et al*., 2021). When MPs are abundant, they can raise the temperature of the microenvironment and limit the diversity of fungal communities by providing optimum temperature for thermophilic fungal species (Zhou *et al*., 2022). In this situation, consideration should be given to the fact that the majority of thermophilic fungal species are human pathogens. On the other hand, the accumulation of MPs in the soil might inhibit the beneficial fungal population. Thus, affects the plant-fungal interaction process such as nitrogen fixation in the root zone by raising soil pH. Thus, MPs might alter plant nutrient availability and thus, affect plant growth and yield.

3. ALTERATION IN PLANT PHYSICOCHEMICAL ACTIVITIES

MPs have evolved into a significant component of terrestrial soil. As a result, different studies on MPs absorption, accumulation, and main repercussions in plants have been conducted. Since MPs could be up-taken and accumulated in plants, it is vital to investigate how these plastics change the physiology and chemical profile in plants. Several studies showed that seed germination could be affected by MPs. *Lepidium sativum* seeds grown in 4800 nm MPs suspension showed a significant difference in root growth after 24 hours of exposure, but there was no significant effect shown after 48 hours and 72 hours of exposure. This study further showed that 500 nm microplastics decreased root growth after 24 hours of exposure, to the contrary, 50 nm of MPs significantly increased root growth after 24 hours of exposure (Bosker *et al*., 2019). Continuous investigation revealed that *Lepidium sativum* seeds exposed to 4800 nm MPs for 8 hours showed a decline in germination rate from 78 % to 17 %. This study further revealed the accumulation of plastic particles particularly in the pores of seed testa. This may slow the rate of water uptake and delay germination. According to Li *et al*. (2020), wheat seedlings grown in 0.2 mM microbead solution showed adsorption of microbeads by root and accumulation in leaves at increasing concentrations. Aggregation of MPs was found mostly in the xylem and cortical cell walls. Meanwhile, Taylor *et al*. (2020), observed that MPs and NPs accumulate in the root tips of wheat and *Arabidopsis thaliana*, and that they may be detected on the root surface even after washing. Microplastics not only adsorbed and accumulated in roots but also impose a great threat to root growth. Wheat treated with 100 nm and 5 µm polystyrene NPs showed inhibition on root elongation (Liao *et al*., 2019). On the contrary, Lian *et al.* (2020), indicated that the wheat seeds showed no negative effect on seed germination when exposed to 100 nm microbeads. However, the root development rate of *Vigna radiata* (Mung bean) treated with NPs reduced the root growth (Chae *et al*., 2020). Furthermore, the above study observed the behavior of snails fed with NP-treated mung bean. The snails fed with the mung bean showed a significant decline in growth rate after 14 days (Lo *et al*., 2018). A study on accumulation and dispersion of Polystyrene Nanoplastics (PSNPs) in 100,300,500, and 700 nm size cucumbers showed; that PSNPs accumulated in the interspace tissues of roots. Moreover, PSNPs were shown to be mostly concentrated in the intercellular space between the ridges in the stem.

Though NPs particles were not discovered in the flowers and fruits for 100- and 300-nm PSNPs, NPs were detected in the interspace tissues of the calyx in cross sections of the first fruits treated with 500-nm and 700-nm PSNPs (Li *et al*., 2021). Thus, NPs and MPs have a high possibility of infiltrating the human food chain. MPs and NPs have been shown to change the biochemical pathways and biochemical profiles in plants in recent studies. Cucumbers treated with 100 nm polystyrene NPs had lower levels of chlorophyll b, soluble sugar, carotene, and proline in leaves. The fluorescence of cucumber leaves was significantly reduced by 100 nm PSNPs (Li *et al*., 2020). Wheat is grown in 100 nm and 50 nm PSMP suspensions, on the other hand, exhibited a considerable difference in photosynthetic pigment composition. High concentrations of PS-MPs (200 mg/L) strongly decreased the elongation of wheat roots and stems in a hydroponic experiment, and 5 nm PSMPs had a larger toxicity impact than 100 nm PSMPs. According to Li *et al*. (2020), MPs induced multiple glycolysis control mechanisms in barley leaves and roots, resulting in a change of metabolic profiles in leaves and roots, including an increase in hydrogen peroxide and oxygen concentrations in roots. According to this study, the phytohormone regulatory network influences the activity of key enzymes involved in glucose metabolism in barley. An investigation conducted by Wu *et al*. (2020) in paddy, indicated a significant decrease in biomass of rice leaves under the exposure of PS-MPs. Further, the activities of antioxidants including catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD) after exposure to PS-MPs were lower than those of the antioxidant enzymes in the control. Additionally, a shift in the amount of malondialdehyde (MDA) suggested that there was excessive ROS production beyond the level of scavenging. MDA concentration is a commonly used indicator as a marker of lipid peroxidation in plant tissue that rises under oxidative stress; contrary, plants create ROS in response to harsh environmental circumstances. ROS levels that are too high, lead to oxidative stress. A disparity between the formation of ROS and their neutralization, which causes harm to cellular constituents such as lipids, nucleic acids, metabolites, and proteins and ultimately cell death in plants.

A study of (Pignattelli *et al*., 2020), in *Lepidium sativum* examined the effects of PE, PP, and PVC MPs over a short (6 days) and long (21 days) period. In the conclusion of this study, all forms of MPs induced oxidative stress in plants and increased hydrogen peroxide (H_2O_2) production. Except for plants treated with PVC, the concentration of hydrogen peroxide was consistently greater in short exposure than in long exposure in each treatment. In both acute and chronic testing, PVC-treated plants maintained the same levels. PE-exposed plants produced more H_2O_2 during short-term tests, but PVC-treated plants produced H_2O_2 after a long term. Table 2. summarizes the studies conducted in terms of microplastics and nanoplastics and their effects on physicochemical functions in crop species.

4. EFFECTS OF MPS ON HUMANS AND OTHER ORGANISMS

Plastics were created to improve mankind's lifestyle; despite this, they may pose a serious threat to humans and other living organisms on

Earth. Several studies have shown evidence for MPs accumulation in marine organisms such as crustaceans and fish. Given that humans, as top predators, have the potential to consume MPs as contaminants in seafood. Thus, it might lead to serious health consequences, which should be strictly concerned in the future. Due to methodological problems, data on microplastics accumulation in insects, birds, marine mammals, sea turtles, and humans is limited. However, studies that have been done on several model organisms have revealed the bioaccumulation of MPs and their effects on functional and structural changes in animal cells.

Several model studies have been conducted to investigate the impact of MP inhalation. MPs are present in the air as tiny fibers or particles and can be directly inhaled into the human body. According to Yang's *in vitro* microarray study (Yang *et al*., 2021), polystyrene nanoparticles (PSNPs) significantly affected 770 genes in the 7.5 g/cm^2 group and 1951 genes in the 30 g/cm^2 group tissues, suggesting a significant risk to the respiratory system. PSNPs could break redox equilibrium, increase oxidative stress thus induce inflammatory effects, and trigger apoptotic pathways to cause cell death. Meanwhile, recent studies have proved the presence of MPs in human lung tissues. The presence of air-born polymeric particles and fibers have found in the respiratory system of autopsies of human lungs (*Amato et al*., 2021). All the discovered polymeric particles were smaller than 5.5 µm in size, and fibers ranged from 8.12 to 16.8 µm. Meanwhile, an FTIR spectroscopy study of digested human lung tissues revealed 1.42 ± 1.50 MPs per gram of tissue in lesser than 3µl (Jenner *et al*., 2022). Furthermore, pollutants that serve as oxidants are inhaled by humans regularly, causing oxidative stress, inflammation, and carcinogenesis. Plastic fibers were shown to be exceptionally durable in the lungs. Polypropylene, polyethylene, and polycarbonate fibers exhibited essentially no disintegration or changes in surface area or properties in a synthetic extracellular lung fluid even after 180 days of *in vitro* tests. This indicates that plastic fibers are long-lasting and likely to remain in the lungs for a longer period (Law *et al*., 1990). The size of MPs might cause different physiological changes. Smaller particles can cause a considerably higher neutrophil influx in the lungs than larger particles. Also, pro-inflammatory responses occurred in rats exposed to various sizes of polystyrene particles (Brown *et al*., 2001). A study on the effect of PSMP in *Caenorhabditis elegans* (nematode) revealed that the PSMPs at a concentration of 100 µg/L showed an increase in reactive oxygen species (ROS) production, lipofuscin accumulation, and the expression of oxidative stress-related genes.

Further, altered the expression of genes related to intestinal development and consequently caused intestinal injury (Yu *et al*., 2020). MPs, as well as the polymers which are used in plastic polymerization, can be released into the environment during the weathering process of plastics and cause harmful effects on organisms. Ingestion of Phthalate esters, that are used in the polymerization process of plastics, caused inflammation and metabolic problems in rats' guts by increasing permeability and increasing inflammation. Also, these esters alter gut microbiota by regulating genes (Deng *et al*., 2020). Another study found that polyethylene (PE) MPs in the gastrointestinal tract produced inflammatory bowel illness and generated intestinal dysbacteriosis and inflammation in C57BL/6 model mice. The microbiota community in the gut was also affected by the greater concentration of PEMPs. The quantity of Parabacteroides was decreased, but the abundance of *Staphylococcus* increased (Li *et al*., 2020).

Unsurprisingly, human consumption of MPs occurs through the food chain. In the maritime environment, fish are particularly vulnerable to MPs. As a result, MPs bioaccumulation in fish has paved the way to MPs accumulation in the human body. In Malaysia, MPs were discovered in the gills and guts of commercially produced fish. Worryingly, the majority of the MPs were contaminated with heavy metals such as chromium (Jaafar *et al*., 2021). This study adds to the growing body of evidence that MPs along with heavy metals may be ingested by humans. Moreover, the presence of microplastics has been detected in edible fruits and vegetables including carrots, potatoes, broccoli, lettuce, apples, and pears (Conti *et al*., 2020). This study further revealed the presence of MPs is more likely in fruits than in vegetables.

The gut microbiota populations have been changed by passing PET via a simulated human gastrointestinal route. This might be due to infections conveyed in the PET particles (Tamargo *et al*., 2022). MPs, for the most part, are not alone; they serve as a vector for a variety of other contaminants. Chromium and lead were desorbed from MPs surface and precipitated in the human gut in another *in vitro* study. Chromium was released early in the gastric phase, but did not begin to precipitate until the beginning of the duodenal phase, whereas lead was released slower and in less quantity than chromium, and did not precipitate until the beginning of the duodenal phase (Godoy *et al*., 2020). The interaction of MPs with biochemical components in humans has the potential to change macromolecule metabolism. An investigation by Tan *et al* (2020), revealed that PSMPs inhibit fat breakdown in the human gut. The high MP hydrophobicity resulted in the development of large lipid-MPs hetero aggregates, which lowered the bioavailability of lipid droplets; and PSMPs adsorbed lipase, which inhibited its activity by modifying the secondary structure and disrupting the necessary open conformation. The decrease in lipid digestion was mostly due to the first step of MP-lipid interaction.

MPs may be transmitted to fetus during pregnancy, which is concerning. MPs were found in the human placenta for the first time (Ragusa *et al*., 2021). A total of 12 MP pieces with spherical or irregular shapes (varying in size from 5 μm to 10 μm) were discovered during this examination. All of them were pigmented; three of them were identified as stained polypropylene, a thermoplastic polymer, while the remaining nine could only be identified by their pigments. They were all used in man-made coatings, paints, adhesives, plasters, finger paints, polymers, cosmetics, and personal care products. Alarmingly, MPs have been detected in human breast milk. Among them, 38 % were PE, 21 % were PVC and 17 % were PP. The extent of MPs transportation in the food chain is indicated by the presence of MPs in human breast milk. Literally, MPs are being fed in breast milk in addition to nutrition (Ragusa *et al*., 2022).

The contamination of MPs in the food chain and their bioaccumulation in humans and other organisms is thus no longer in question. It is undeniable that MPs are more likely to pose serious health effects in present and future life on Earth. Table 3. illustrates the effects of MPs in several terrestrial organisms.

5. CURRENT GLOBAL ACTIONS ON MITIGATION OF WHITE POLLUTION

Plastic pollution is also known as white pollution. A European plastics strategy has been established by the European Union (EU) in January 2018. According to the EU's policy for plastics in a circular economy, recycling of plastic packaging waste must match levels of other packaging materials. Accordingly, at least 75–85 percent of the plastic garbage produced in Europe must be recycled. Furthermore, the export of unsorted plastic garbage must gradually be phased out, and sorting and recycling capacity must expand fourfold since 2015. Further, the EU would implement efficient measures to prevent MPs from polluting the environment including reduction of single-use plastic waste, implementation of the directive on single-use plastics, and prohibition of placing single-use plastic products such as plastic plates, straws, and beverage stirrers in markets.

Table 2. Effects of Microplastics and Nanoplastics on plants physicochemical functions.

Study area	Plant species	Polymer size	Effects on plant physicochemical function	Reference
Accumulation of MPs on seed capsule and effect on seed germination	Cress (*Lepidium sativum)*	4800 nm, 500 nm, 50 nm Fluorescent MPs	Decreased germination rate, no impact on leaf growth and chlorophyll content.	(Bosker *et al*., 2019)
Effect of PSNP on plant metabolism and homostatistics	Barley	The non-fluorescent polystyrene 5.64 ± 0.07 µm, and fluorescently labelled polymethylmeta crylate (PMMA) 96.75 ± 0.58 nm	Decreased germination rate, no impact on leaf growth and Chlorophyll content. Increased the concentrations of Hydrogen peroxide and Oxygen in roots.	(Li *et al*., 2020)
Effects of Different types of PVC on plant physiology	Lettuce	PVCa with 100 nm to 18 µm, and PVC-b with 18 to 150 µm	PVC b enhanced carotenoid production PVC a inhibited carotenoid synthesis	(Li *et al*., 2020)
Uptake and *In vivo* Distribution of PSNP	Cucumber (*Cucumis sativus* L.)	PSNP 100, 300, 500, 700 nm	MPs distributed to leaves, flower ,fruits and increased root activity, MDA and proline content	(Li *et al*., 2021)
Effect of PSNPs on terrestrial plant	Cucumber (*Cucumis sativus* L.)	100, 300, 500, and 700 nm Polystyrene NPs	300nm PSNP decrease leave bio mass 100nm decrease chlorophyll b, soluble sugar, caretene, proline in leaf	(Li *et al*., 2020)
Impact of PSNPs on seed germination and seedling growth	Wheat	100 nm	Reduced shoot, root biomass ratio, altered leaf metabolic profile. No effect on seed germination	(Lian *et al*., 2020)
Toxic effect of MPs on terrestrial higher plant	Wheat (*Triticum aestivum* L.)	100 nm and 5 µm polystyrene MPs	Inhibited the elongation of roots and stems. Fluctuation in Photosynthetic pigments and soluble protein content.	(Liao *et al*., 2019)
Effect of aged plastics on plants	Cress *(Lepidium sativum)*	Aged MPs obtained from soil layer	New and short term aged plastics reduced germination, seedling growth, chlorophyll concentrations, and increased catalase activity.	(Pflugmacher *et al*., 2021)
Oxidative burst in plant	*Lepidium sativum*	Different sizes of polyethylene terephthalate	Changed biometric parameters and metabolic activities	(Pignattelli *et al.*, 2020)
Short-term physicoological and biometrical responses to PET made MPs	*Lepidium sativum*	0.125 mm plastics	Different sizes of PET are able to affect plant growth and physiological responses, with or without acid-rain	(Pignattelli *et al.*, 2021)

Polystyrene nano- and microplastic accumulation	Arabidopsis (*Arabidopsis thaliana*) and wheat (*Triticum aestivum*).	Fluorescently-labeled polystyrene at 40 nm and 1 µm	Micro and nano plastics accumulated in root tip in both species.	(Taylor *et al*., 2020)
Adverse effect MPs on physiology of plant and snail which fed with microplastic treated plant	Mung bean (*Vigna radiata*)	0.02 µm, yellow-green fluorescent MPs	Reduced root growth, decreased diet intake and growth rate of snail	(Chae *et al*., 2020)
Effect of micro and macro plastics on plant growth	Lime (*Citrus aurantium*)	5 mm low-density polyethylene, polypropylene and polystyrene	Negative effects on vegetative growth	(Verla *et al*., 2019)
Response of rice to polystyrene MPs	*Oryza sativa* L.	polystyreneMPs	Shoot biomass and metabolite level decreased.	(Wu *et al*., 2020)
Ecotoxicity of polystyrene MPs	*Utricularia vulgaris*	1, 2 and 5 µm polystyrene fluorescent MPs	Higher concentrations decreased crop growth rate, caused higher oxidative damage and eco toxicity.	(Yu *et al*., 2020)

Table 3. Effects of MPs in human and terrestrial organisms.

Organism	**Organ/ Tissue**	**Type and size of MPs /NPs**	**Effect on organism**	**Reference**
Nematodes	Intestinal tract	PSMP at 100 µg/L concentration	Increased ROS production, lipofuscin accumulation. Altered the expression of oxidative stress-related genes and intestinal development genes. Caused intestinal injury.	(Yu *et al*., 2020)
Rat	Gut	Phthalate esters of microplastics	Caused inflammation and metabolic disorders in gut by increasing intestinal permeability, enhancing inflammation and gene regulation. Ultimately induced oxidative stress.	(Deng *et al*., 2020)
Rat	C57BL/6 mice model.	polyethylene microp lastics	Enhanced the abundance of gut microbial species including Parabacteroides *Staphylococcus* and consequently induced inflammatory bowel disease, intestinal dysbacteriosis and inflammation.	(Li *et al*., 2020)
Human	Human gut (*In vitro*)	PET	Directly or indirectly affected gut microbiota abundance and related with gut dysbiosis.	(Tamargo *et al*., 2022)
Human	Huma gut (*In vitro*)	PS, PE, T, PE, PVC	Decreased gut lipid digestion	(Tan et al., 2020)
Human	*In vitro* human lung epithelial cells	PSNP	Induced oxidative stress and inflammatory responses, followed by cell death and lung disease.	(Ragusa *et al*., 2021)

Meanwhile, the United Nations Environment Assembly (UNEA) has decided to draft an international legally enforceable document to stop plastic pollution by 2024. This treaty includes the alternatives to the whole life cycle of plastics, as well as the creation of reusable and recyclable goods and materials, and the enhancement of international collaboration for scientific and technological cooperation among member states (IPEN).

6. CONCLUSION

Ecosystems on land and in the sea now include plastic as a vital component. Plastics that cannot be seen with the human eye, such as micro and nanoplastics, are created as a result of weathering. It is now quite difficult for life on Earth to avoid the fate and negative effects of these small pieces of plastic. Plastics will cause an irreversible process once they are introduced to the environment. Plastics' interactions with the soil and other living organisms in the agroecosystem are still unclear. The main sources of plastic for arable land, according to recent research, include organic compost of low quality, sludge, plastic mulches, and landfill leachates. Recent studies have found strong evidence that lead, cadmium, and other heavy metals may be transported by soil microplastics. The adsorption of these heavy metals on the surface of microplastics is influenced by environmental factors such as pH, ion compositions, the presence of organic components, and heavy metal composition. Therefore, future research on heavy metals in agricultural fields should take the existence of microplastics into account. According to recent studies, MPs have evolved into a novel carrier for antibiotic resistance genes and a new surface for microbial habitation. By enabling horizontal gene transfer to harmful bacteria, this situation poses a serious risk. According to the studies cited above, MPs and NPs accumulate in plant roots and translocate to the stem, leaves, flowers, and fruits. Also, those are present in fruits and vegetables available at the market. Thus MPs themselves may directly pose a risk to food safety and food security. Additionally, the investigations revealed that accumulating MPs can change a plant's metabolism, which has a detrimental effect on its physicochemical activities. As a result, there was decreased seed germination, reduced chlorophyll in the leaves, and reduced root and shoot elongation. These physicochemical alterations may cause a sharp reduction in crop productivity, which will ultimately have an impact on food sustainability. Seasonal crops have been the real focus of MPs in recent investigations. Despite this, the greatest impact seems to be on perennial crops since they are exposed to MPs for a long period. Therefore, studies are needed on the accumulation of MPs in harvestable plant tissues in both annual and perennial including tea leaves, and coconut also need to be included in future studies. There is no doubt that the introduction of plastics to arable land will begin the process of incorporating these microscopic components into the food chain. Studies strongly show MPs and NPs accumulate in humans and soil biota through inhalation and ingestion. Also, NPs can enter the digestive tract and change metabolism, particularly fat digestion in humans. Further, regular inhalation of MPs and NPs has shown acceleration in oxidative stress, inflammation in the lungs, and alteration of physiological fluid in model animals. Thus, deep investigations are needed into the contamination of MPs and NPs in the food chain. Also, measurements are needed of air quality concerning MP concentration. EU and several countries are now concerned about white pollution mitigation. Banning single-use plastics, enhancing the production of biodegradable plastics and, labeling of biodegradable plastics are some of the mitigation measures that have been taken. However, this alarming situation is not yet thoroughly understood by several developing countries. There is a high chance of plastic pollution if biodegradable plastics are labeled. Because people might think that biodegradable plastics get degraded naturally and enhance the habit of plastic littering. Thus, clear awareness should be created among the public on plastic management. Plastic pollution cannot be mitigated if the consumer habit of plastics continues. Not only a person, not a nation rather, globally centralized policies and frameworks monitoring systems are required to mitigate plastic pollution to save lives on earth.

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