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Removal Methods of Plastic Waste and Interactions of Micro- and Nano-Plastics with Plants

Amra Bratovcic

ABSTRACT

The presence of plastic waste in large quantities in the environment is a major problem and therefore a challenge for many researchers to examine the most effective methods of their disposal. In this paper, the source of microplastic and its hazardous effect on human health and interactions of plastics with plants were studied. Due to the specific physical-chemical features of micro- and nano-plastics, they are ideal candidates for the adsorption of organic pollutants, pathogens and heavy metals. The uptake and accumulation of nanoplastics by plants, adsorption studies, and bioaccumulation are shown here. In addition, recent research on the interaction of polystyrene micro- and nanoplastics with plants has been discussed. Many studies have shown that the most affected part of the plant was the roots, followed by leaves, shoots, and then the stem. Nanoplastics are found to be more harmful than microplastics due to permeation through the biological membranes of plants, while microplastics adhere to leaves.

Keywords: Interactions, Nanoplastic, Microplastic, Plants, Polystyrene.

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A. Bratovcic*
University of Tuzla, Faculty of Technology, Department of Physical Chemistry and Electrochemistry, Bosnia and Herzegovina
(e-mail: amra.bratovcic@untz.ba)

****Corresponding Author***

I. INTRODUCTION

In the last 30 years, plastic has been one of the indispensable raw materials around the world [1]. During the pandemic caused by the Coronavirus, we witnessed a very large use of protective masks, gloves, packaging for food delivery and all made of very complex plastics. The problem is that these are hardly degradable plastic materials that require at least 450 years and that leave harmful consequences for human health and disrupt the ecosystem as a whole [2]. Recent research findings indicated that, microplastic contents in European river water range between 0.03 and 187,000 No m^3 [3]. Microplastics, different in chemical composition, size and shape, are produced by the decomposition of larger plastic pieces. One of the ways of microplastics input into the human body is explained by their presence in rivers and seas. Organisms that live underwater (fish, crabs, algae), also ingest microplastics with the food, and when they are consumed by humans, they end up in the human body, which causes serious health problems. In this paper, the recent findings in remediation methods have been discussed with emphasis on adsorption and phytoremediation. Moreover, the interactions between plastic–plant has been included. Fig. 1 shows the analysis of the number of publications per year, whereas the topic of plastics has had an exponential trend since 2009. It is possible to see that the number of publications increasing by the year, and the publication number using the keywords of "microplastics" is significantly higher than for the "nanoplastics".

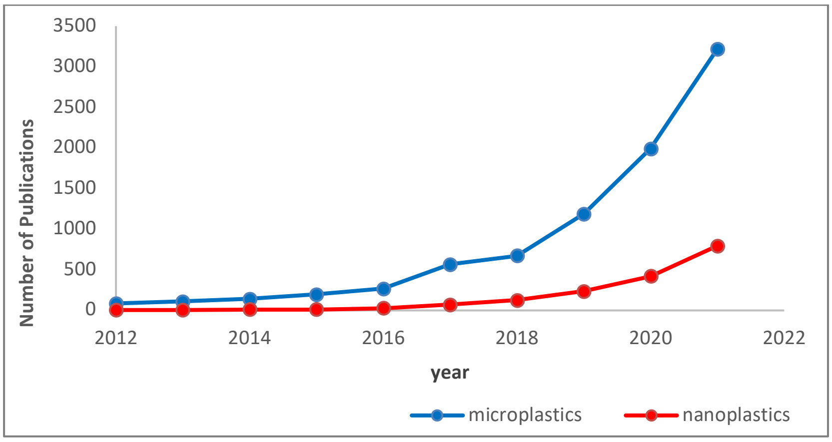

Fig. 1. Literature on microplastics and nanoplastics in ScienceDirect.

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A. Source of Microplastic and Its Hazardous Effect on Human Health

Soil is one of the most important natural resources and represents the base for the production of organic matter. The soil is a multiphase system and consists of a solid, liquid and gaseous phase. The most optimal ratio of soil phases for most plants is 45% mineral matter, 5% organic matter, 25% water and 25% air. Soil is food for plants. Within the soil there are also microorganisms that contribute to the creation of humus. Soil microflora consists of bacteria, nematodes, earthworms, actinomycetes and algae. However, soil is considered a greater reservoir of microplastics than water due to the formation of stable aggregates between soil and plastic [4]-[6].

Microplastics (MPs) can enter the environment through precipitation from the atmosphere, washing off the remains of car tires from the road, disposal of waste sludge, and flooding of wastewater. Due to its stability and persistence, after reaching the soil, microplastic remains for a long time and interacts with surrounding organisms, affecting biological diversity [7]. Furthermore, plants adopt microplastic waste in the form of highly complex and toxic organic compounds such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and organochlorine pesticides, and plasticizers, which pose a danger to human health [8]. Another way microplastics reach people is through absorption through the skin and mucous membranes through the daily use of personal hygiene products and protective masks and gloves [9]. Once introduced into the human body, microplastics can cause oxidative stress due to the creation of reactive oxygen species, which causes neurotoxicity and neurodegenerative diseases, chronic inflammation and cytotoxicity [10]. Microplastic affects the change in cell metabolism, and leads to the disruption of the intestinal microflora, which can ultimately cause cancer [11]. Due to its chemical composition, microplastic acts as a modulator of the endocrine system and thus affects the altered work of hormones. On top of that, microplastics can cause infections and tissue damage as they have proven to be a suitable habitat for bacterial growth [12].

Soil microplastics exist in various shapes (fibers, films, fragments, particles, and foams), and chemical compositions (polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC), polypropylene (PP), polyamide (PA) and polyethylene terephthalate (PET) which is an excess amount destroy the soil-plant system [13]. Wastewater treatment plants (WWTPs) are also significant sources of plastic contamination in terrestrial and agricultural systems [14]. In WWTPs, nanoplastics tend to infiltrate the biofilm. Microplastics (>100 nm and <5 mm) and nanoplastics (<100 nm) are highly hydrophobic polymer particles. Microplastics and nanoplastics (NPs) can act as a vector in spreading other toxic pollutants in the environment causing soil toxicity [15].

When it comes to ways of solving the problem of plastic waste in wastewater, treatment plants are preferred over physical-chemical and biological remediation due to economic feasibility [16].

II. Remediation Methods for Micro and Nano-Plastic Removal

Physical, chemical, photochemical and biogeochemical mechanisms are used to remove plastic waste from the environment because their complex chemical composition makes biodegradation difficult [17].

Fig. 2 represents a schematic review of methods used for plastic waste remediation. Methods and technologies used for remediation of plastic waste via chemical and bio-nanotechnologies are coagulation, biodegradation, membrane bioreactors and phytoremediation. Physical and chemical methods include sedimentation, filtration (membrane technology), advanced oxidation processes (AOPs) such as Fenton-like reactions, photocatalysis, and photoreforming.

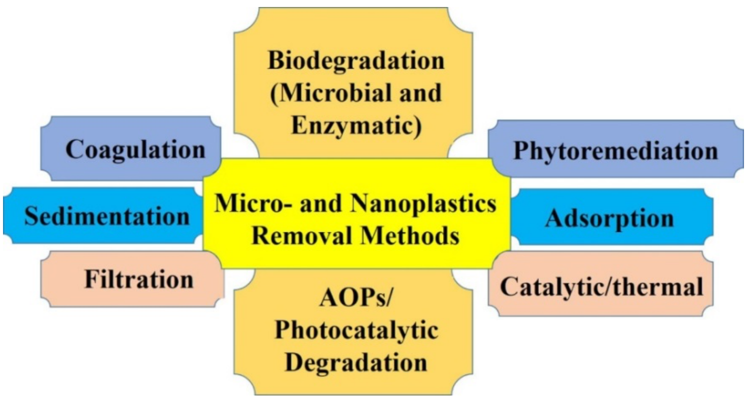

Fig. 2. Methods used for plastic waste remediation.

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The photocatalytic degradation of microplastics has attracted significant attention in the last five years [18]. The photocatalytic degradation by metal oxide has also been studied [19]. The transformation of plastic waste into value-added hydrocarbons (fuels) can be achieved by thermocatalytic processes [20]. The application of technologies based on AOPs and photocatalysis certainly represents one of the promising strategies for solving the problem caused by plastic waste.

Phytoremediation is an environmentally friendly technology that uses plants for the degradation, assimilation, metabolism, or detoxification of various environmental pollutants. It is used to remove pollutants from soil, water, and air. Depending on the type and amount of pollutants, the location of contamination and the type of plant, there are several methods of soil remediation using plants such as phytostabilization, phytofiltration/rhizofiltration, phytovolatization, phytoextraction, phytotransformation and phytostimulation. The mechanism of phytoremediation consists in the uptake of contaminants from the soil through the roots of the plant and accumulation in the above-ground biomass of the plant. The success of this technique depends on the yield of dry matter of the plant, the transfer coefficient from the soil to the plant and the choice of appropriate plant species [21].

Lian *et al.* [22] studied the uptake and accumulation of one hundred nm sized polystyrene nanoplastics (PSNPs) by wheat (*Triticum aestivum* L.). They reveal that PSNPs was able to shape the gene expression patterns of wheat in a tissue-specific manner. The mechanism of microbial remediation of plastic is based on the creation of a biofilm, which has a biological effect on gene transfer but also affects the climate, biogeochemical cycling and carbon sequestration.

A. Adsorption Studies

Abbasi *et al.* [23] studied the adsorption of five different concentrations of three heavy metal solutions (Pb, Cd, and Zn) onto 1g of polyethylene terephthalate (PET) particles. The results of adsorption-desorption experiments have shown that PET particles can act as a vector in transferring heavy metals to the rhizosphere zone.

Ganie *et al.* [24] used sugarcane bagasse-derived biochar for the removal of nanoplastics (NPs) from aqueous environment. Results of their study has shown that sugarcane bagasse-derived biochar (BC-750) prepared at 750 °C showed >99% of nanoplastics (NPs) removal, while BC-550 and BC-350 showed <39% and <24%, respectively. This result may be attributed to higher surface are and higher pore numbers as well as decreased carbonyl functional groups. Further sorption experiments have shown that BC-750 was able to adsorb 44.9 mg of $NPsg^{-1}$.

III. Interactions of Plastics with Plants

Microplastics can change soil physical structure, chemical nutrients, microbial and enzymatic activities by increasing the presence of MPs in the soil and consequently affect the plant performance. Moreover, due to the specific properties of MPs such as high specific surface area and hydrophobicity they attract and adsorb different organic contaminants and pathogens as well as heavy metals. They also contain a wide array of harmful additives (fillers, flame retardants, antioxidants, plasticizers and colorants) [25],[26].

According to a study by Zhang *et al.* [27], the most affected part of the plant was the roots, followed by leaves, shoots, and then the stem. Nanoplastics are found to be more harmful than microplastics. Nanoplastics can permeate through the biological membranes of plants, while microplastics adhere to leaves. Nanoplastics block pathways for nutrient and water uptake which is manifested by a decrease in root and plant growth. Micro- and nano-plastics can be transported through the entire plant from root to leaf and it can absorb other contaminants that were detrimental for plants' health [28],[29].

Rillig *et al.* [30] studied the mechanisms of action of MPs on plant growth and development. One of the predicted mechanisms states that MPs from soil or water enter the rhizosphere zone (several mm of soil surrounding the plant root where complex biological and ecological processes take place). In the rhizosphere, plants with different nutritional genotypes secrete different exudates that play an important role in activating nutrients in the soil and improving the plant's ability to mobilize nutrients. With the help of exudates, the plant affects the pH and structure of the soil, increases the cation exchange capacity in the soil (CEC), and biological and sorption properties. However, plant root exudates change under the influence of contamination and can increase up to a thousand times compared to normal values.

Wang *et al.* [31] in 2006 found a strong influence of aluminum contamination in the soil on the variability of wheat root exudates.

While taking food from the soil, plants can simultaneously introduce microplastics and become bioaccumulators of plastic waste [32]. If microplastics are introduced into the plant, physiological changes may occur in the plant, which manifests itself through a reduction in plant growth [33]. These changes occur due to the formation of reactive oxygen compounds (ROS) that disrupt biochemical processes, more precisely lead to altered enzyme action and oxidation of lipid membranes, and suppression of photosynthesis [34],[35]. Although plants possess antioxidant enzymes to fight against oxidative stress [36], micro- and nano-plastic particles can still continue to move and accumulate in the plant [37].

For example, Li *et al.* [38] found in their research that the presence of polystyrene microparticles up to 2 micrometers in size near the roots of wheat and lettuce can be adopted and further transported from underground to aboveground parts of the plant and accumulated [39]. For this reason, there is a great need for further understanding of the transport and mechanism of interaction between microplastics and soil, or microplastics and plants [40].

A. Interaction of Polystyrene Micro and Nano Plastics with Plants

Recently, few research studies investigated the interaction of polystyrene nanoplastics with plants.

The study of Lian *et al.* [41] found phytotoxicity of polystyrene nanoplastics (PSNPs) in the interaction with plants. Foliar exposure of 0.1 and 1 mgL^{-1} of PSNPs on soil-grown lettuces (*Lactuca sativa L.*) resulted in reducing leaf area and micronutrients and essential amino acids (nutritional quality) of lettuce. The plant pigment content (chlorophyll a, b and carotenoid) was considerably reduced at 1 mg/L PSNPs. However, the key indicators that oxidative stress has happened in lettuce leaves were increase in electrolyte leakage rate and the decrease in total antioxidant capacity.

Research carried out by Giorgetti *et al.* [42] shows that the nano polystyrene (50 nm size, at concentrations of 0.01, 0.1 and 1 $g\ L^{-1}$) have no effect on the percentage of seed germination of *Allium cepa* seeds after germination for 72 h, while root growth was inhibited by 0.1 and 1 $g\ L^{-1}$ nano PS. Cytological analysis of the root meristems indicated cytotoxicity and genotoxicity starting from the lowest dose.

Jiang *et al.* [33] investigated ecotoxicity and genotoxicity of 0.1 μm and 5 μm polystyrene microplastics (PS-MPs) on higher plant *Vicia faba*. They reveal that smaller particles are more toxic, and its concentration of 100 mg/L significantly reduces the growth. Furthermore, the biomass and catalase enzymes activity of *V. faba* roots decreased under 5 μm PS-MPs whereas superoxide dismutase and peroxidase enzymes activity significantly increased.

In a study conducted by Li *et al.* [43], it was found that 50 mgL^{-1} concentration of polystyrene with a particle size of 0.3 μm significantly affects the reduction of cucumber biomass because it disrupts the photosynthetic process, sugar metabolism and the antioxidant power of the leaves. It is assumed that benzene is responsible for this metabolic disorder.

IV. Conclusion

According to the number of published scientific papers, intensive research in the field of micro- and nano-plastics has been evident in the last five years. However, up to date, more research has been done on microplastics than on nanoplastics, but research indicated that nanoplastics are more toxic than microplastics due to their dimensions. In this context, more research should be focused on nanoplastics as well as a better understanding of their impact on soil, water, and plants, as well as the mechanisms of interaction and their toxicity to plants and humans.

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