Chemical Innovation and Regulation

University of Bologna

University of Barcelona

University of Algarve

Environmental risk of plastic materials

Environmental impact of polystyrene nanoplastics in crops

Report for the purpose of evaluation of the module E02 Environmental risk of plastic materials - taught by Professor Dr. Chiara Samorì

Carla Thaís Pereira Coelho

Bologna

2022

Summary

ABSTRACT

Polystyrene nanoplastics (PSNPs) are an emerging pollutant in the environment. This review covers some of the damage to crops recently studied, as the accumulation, translocation, phytotoxicity and oxidative stress, highlighting the danger of this pollutant.

1. INTRODUCTION

Plastic pollution has been an object of concern around the world due to the annual increase in the production, consume and waste of plastic (1) (2). Due to their remarkable multi-properties, durability and low cost, it has been used in many industrial fields, as packaging, engineering and construction, electronics, agricultural and many others, and in everyday life since the ‘50s (3) (4) (5). To date, over 370 million tons of plastic were produced in 2019, in 2015 approximately 5 billion tons of plastic ended in landfills or in natural environments, and it is estimated that by 2050, 12.000 tons of plastic will be accumulated in the natural environment (2) (4).

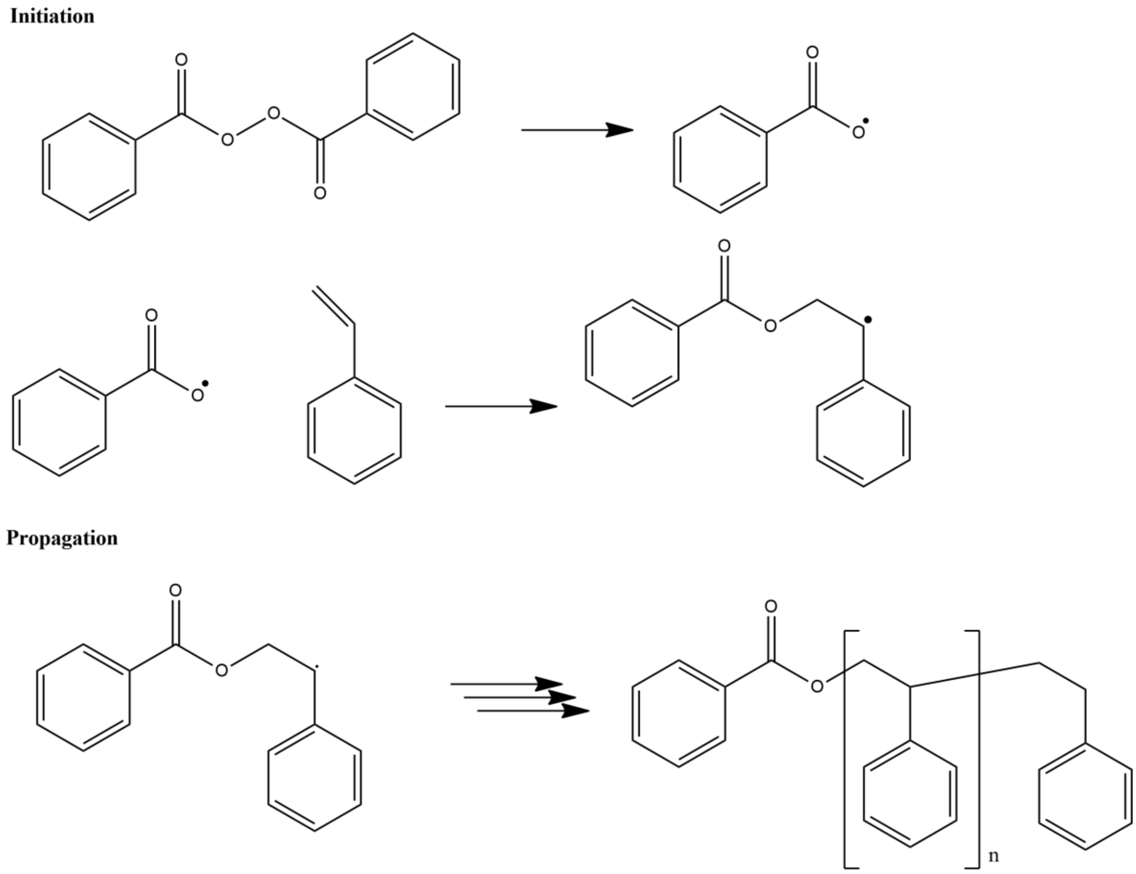
Plastics are synthetic polymers not degradable, which can persist and accumulate in the environment for a long period of time (6). Under the action of environmental factors, as oxidation, hydrolysis, ultraviolet degradation, wave motion, plastic can breakdown into small particles, ranging from micro (<5 mm) and nano (<100 nm) dimensions (2) (7) (8), being the nanoplastics (NPs) of specific concern (4). Nanoplastics can cause multiple adverse environmental impacts and more complex toxicity effects because of the capacity of penetrate biological surfaces, due its smaller size (6). These plastic materials can enter the environment from a wide range of sources (5), and recently studies report the presence of NPs in marine, freshwater and land-based ecosystems (2).

Surprisingly, plastic pollution in agroecosystems is worse than that in other terrestrial ecosystems because of the commonly adopted cultivation practices (7) (9). Once present on the soil, they are easy to be absorbed by plants and accumulated in its tissues, causing damage to it or it can entry the food chain and affect human health (7) (10). Despite all the possible problems that nanoparticles of plastics can cause in plants, animals and humans, the information on the effects of PSNPs is currently very scarce (7) (1). So the aim of this mini-review is to summarize recently papers regarding the effects of PSNPs in different crops.

2. POLYSTYRENE

Polystyrene (PS) is a common polymer widely used in plastic products present in daily life, such as packaging material, containers, bottles, and lids (1) (9). PS is synthetized from styrene by free radical chain mechanism, a scheme is presented in Fig.1 (11). It is an amorphous polymer with important properties for the industry, as high clarity, colorless, hard, but rather brittle (12). However, due improper disposal, it has become a source of pollution and polystyrene nanoplastics (PSNPs) has been detected in agricultural ecosystems, rivers, lakes, coastlines and sea (9) (1).

Figure 1: Polystyreno synthesis. Source: Terashima T. (2015), modified. (13)



Taking into account the already reported adverse effects of PS on aquatic organisms, in addition to the toxicity of various polymers to crops, such as polypropylene, polyethylene (PE), and polyvinylchloride (PVC), the toxicity of PSNPs has recently been extensively studied due to its possible threat to crops (1).

3. ACCUMULATION OF PSNPs AND TRANSLOCATION

Using the plant *Triticum aestivum* L., the author Lian et al., 2020, found that PSNPs can be absorbed by the root tips and subsequently transported through the xylem to the aerial parts of the plant. In addition, he observed that these particles also caused a hinder in the absorption and translocation of metallic nutrients by wheat (14). In 2021, the same author studied the absorption of PSNPs by the species *Lactuca sativa* L.. Using the techniques of Sem and Tem, he observed that this absorption occurred through the leaves stoma and the translocation downwards to plant roots (2).

In a recent study carried out by Spanò et al., 2022, results were similar to those found by Lian et al., in 2020, only this time with the species *Oryza sativa* L. She performed tests with two different concentrations of polystyrene nanoplastics, and using TEM and SEM observed the absorption by the roots and subsequent translocation of these particles to the aerial parts (4). Using the same plant, however, this time using a confocal laser scanning microscope, Liu et al., 2022, obtained the same conclusion regarding rice absorption pathways. Based on the results, he observed the aggregation of PSNPs in the vascular systems of roots, stems, and leaves, especially root stele, stem vascular bundles, and leaf veins, which indicates that translocation occurs mainly by apoplastic transport in the species *O. sativa* (15).

Another recent study was carried out by Wang et al., 2022, which studied the effect of the accumulation of PSNPs on the tolerance of *Hordeum vulgare* L. to low temperatures. The results show that nanoparticles accumulated in plant cells impair the thermal tolerance of barley, which can increase the disruption of crop responses to environmental stress (10).

These findings suggests the possibility of plastic pollution in agricultural products, which can enter the food chain and be amplified, representing a potential health risk to humans (2) (15).

4. PHYTOTOXICITY

Regarding the phytotoxicity of PSNPs, Giorgetti, et al., 2020 performed a cytological analysis of Allium cepa roots and contacted genotoxicity and cytotoxicity. From the lowest dose tested, a reduction in the mitotic index and induction of cytogenetic and micronucleus anomalies were observed in the root meristems of the analyzed onions (7).

Through transcriptomic analysis, Zhou et al., 2021, observed that PSNPs in *O. sativa*, have the ability to alter the gene expression associated with nutrient transport and root development, as was observed significant decrease of jasmonic acid in rice roots. Gene suppression was also reported in the *Arabidopsis thaliana* species, by Sun et al., 2020. In this study, the signal transduction pathways of plant hormones, such as alpha-linolenic acid metabolism and catoenoid biosynthesis, were significantly altered. Likewise, the gene expression patterns of wheat (*Triticum aestivum* L.) were also shaped by the presence of PSNPs, where carbon metabolism, amino acid biosynthesis, mitogen-activated protein kinase signaling pathway, hormone signal transduction plant, plant-pathogen interaction and some genes associated with transport and metal ions were altered (17).

The study carried out by Spanò et al., 2022, identified cytogenetic aberration caused by PSNPs in rice. This work observed that the particles affected the root cell ultrastructure, the germination process, seedling growth and root mitotic activity. In this case, only the highest concentration tested (1g/L) indicated 34.85% of decrease in the mitotic activity, where cytological anomalies leaded to polyploidy and aneuploidy and chromosome laggings. (4).

Using the *Allium cepa* species, Giri and Mukherjee, 2022, tested PSNPs with modified surfaces and also detected a variety of abnormalities. Using Evan's blue test, they proved the toxicity of PSNPs, where the amine nanoplastic showed the greatest damage to root cells, such as damage to proteins, lipids and DNA. Furthermore, it was observed that the damage is concentration dependent for all PSNPs tested (5).

5. OXIDATIVE STRESS

Exposure to PSMPs and PSNPs causes a disturbance in the production of reactive oxygen species (ROS), resulting in the unbalanced production of superoxide anion, hydrogen peroxide, hydroxyl radical, among other oxidative compounds. The antioxidant system of plants is essential to maintain normal physicochemical conditions, however, nanoparticles lead to an imbalance of homeostasis, damaging the balance between ROS and antioxidants produced by plants (5) (16).

In the study with lettuce leaves, Lian et al., 2021, detected oxidative stress caused by PSNPs by observing the increase in the rate of electrolyte leakage and the decrease in the total antioxidant capacity. Furthermore, ROS can damage the chloroplast structure and inhibit photosynthetic activity, thus decreasing the chlorophyll content in the plant (2).

Regarding the decrease in chlorophyll, another study showed that PSNPs decreased the levels of cucumber pigments, due to hydrogen peroxide excess produced by oxidative stress. Still concerning this effect, a study carried out in 2020 showed that the accumulation of ROS is dependent on the type of surface of the nanoparticle, where nanoparticles with positive charges (PS-NH_2) induced a greater accumulation of reactive oxygen species and further reduced the chlorophyll contents when compared to negatively charged particles (PS-SO_3H) (17).

Regarding the increase in the activities of antioxidant enzymes caused by the absortion of PSNPs, the same was observed in the specie Allium cepa. The Catalase and GPX enzymes showed a significant increase caused by the oxidative stress, which also caused damage to the cell membrane (5). A study performed with barley (*Hordeum vulgare* L.) showed that exposure to PSMPs induced an increase in hydrogen peroxide and superoxide anion in the roots. In addition, changes in the activities of the antioxidant enzymes of barley leaves were observed, due to the increase of ROS in their metabolism (16).

Wang et al., 2022, used a different strategy to test nanoparticle-induced oxidative damage. In this study he studied the level of ROS and the main activities of antioxidant enzymes in chloroplasts and mitochondria, which are responsible for photosynthesis and respiration, respectively, and are the main sources for the production of these reactive species. The results showed a significant increase in superoxide anion in mitochondria, in addition to a decrease in the activity of antioxidant enzymes. He concluded that PSNPs aggravated ROS production and the lack of control of these compounds by antioxidant enzymes in barley mitochondria, whereas chloroplasts had only a decrease in oxygen scavenging efficiency (10).

Thus, the increase in the production of reactive oxygen species (ROS) induced by polystyrene nanoparticles has been reported in several species, causing several anomalies and disturbances in the reported species.

6. CONCLUSIONS

In conclusion, the study and investigation of the effects of nanoparticles of plastics caused by soil pollution are it's an up-and-coming area, with many new studies in the last 5 years. Given that the world population is continuously growing, the accumulation and pollution by different plastics must also increase over the years (3).

The studies gathered in this review clearly showed that polystyrene nanoparticles (PSNPs) can be absorbed, translocated and cause several harmful effects to crops, such as oxidative stress and phytotoxicity. In this sense, these particles may raise a potential risk of disturbing the responses of crops to environmental stress. Thus, research into the effects of these compounds is necessary to ensure environmental and human health.

REFERENCES

1. **Dong, Y., Song, Z., Liu, Y., & Gao, M.** Polystyrene particles combined with di-butyl phthalate cause significant decrease in photosynthesis and red lettuce quality. *Environmental Pollution.* 278, 2021, Vol. 116871, https://doi.org/10.1016/j.envpol.2021.116871.

2. **Lian, J., Liu, W., Meng, L., Wu, J., Chao, L., Zeb, A., & Sun, Y.** Foliar-applied polystyrene nanoplastics (PSNPs) reduce the growth and nutritional quality of lettuce (Lactuca sativa L.). *Environmental Pollution.* 280, 2021, Vol. 116978, https://doi.org/10.1016/j.envpol.2021.116978.

3. **Zhang, H., Liang, J., Luo, Y., Tang, N., Li, X., Zhu, Z., & Guo, J.** Comparative effects of polystyrene nanoplastics with different surface charge on seedling establishment of Chinese cabbage (Brassica rapa L.). *Chemosphere.* 292, 2022, Vol. 133403, https://doi.org/10.1016/j.chemosphere.2021.133403.

4. **Spanò, C., Muccifora, S., Ruffini Castiglione, M., Bellani, L., Bottega, S., & Giorgetti, L.** Polystyrene nanoplastics affect seed germination, cell biology and physiology of rice seedlings in-short term treatments: Evidence of their internalization and translocation. *Plant Physiology and Biochemistry.* 172(January), 2022, Vols. 158–166, https://doi.org/10.1016/j.plaphy.2022.01.012.

5. **Giri, S., & Mukherjee, A.** Eco-corona reduces the phytotoxic effects of polystyrene nanoplastics in Allium cepa: emphasizing the role of ROS. *Environmental and Experimental Botany.* 198(January), 2022, Vol. 104850, https://doi.org/10.1016/j.envexpbot.2022.104850.

6. **Yin, L., Wen, X., Huang, D., Du, C., Deng, R., Zhou, Z., Tao, J., Li, R., Zhou, W., Wang, Z., & Chen, H.** Interactions between microplastics/nanoplastics and vascular plants. *Environmental Pollution.* 290(May), 2021, Vol. 117999, https://doi.org/10.1016/j.envpol.2021.117999.

7. **Giorgetti, L., Spanò, C., Muccifora, S., Bottega, S., Barbieri, F., Bellani, L., & Ruffini Castiglione, M.** Exploring the interaction between polystyrene nanoplastics and Allium cepa during germination: Internalization in root cells, induction of toxicity and oxidative stress. *Plant Physiology and Biochemistry.* 149(December 2019), 2020, Vols. 170–177, https://doi.org/10.1016/j.plaphy.2020.02.014.

8. **Zhang, Y., Yang, X., Luo, Z. xu, Lai, J. long, Li, C., & Luo, X. gang.** Effects of polystyrene nanoplastics (PSNPs) on the physiology and molecular metabolism of corn (Zea

mays L.) seedlings. *Science of the Total Environment.* 806, 2022, Vol. 150895, https://doi.org/10.1016/j.scitotenv.2021.150895.

9. **Gong, W., Zhang, W., Jiang, M., Li, S., Liang, G., Bu, Q., Xu, L., Zhu, H., & Lu, A.** Species-dependent response of food crops to polystyrene nanoplastics and microplastics. *Science of the Total Environment.* 796, 2021, https://doi.org/10.1016/j.scitotenv.2021.148750.

10. **Wang, Z., Li, S., Jian, S., Ye, F., Wang, T., Gong, L., & Li, X.** Low temperature tolerance is impaired by polystyrene nanoplastics accumulated in cells of barley (Hordeum vulgare L.) plants. *Journal of Hazardous Materials.* 426(August 2021), 2022, Vol. 127826, https://doi.org/10.1016/j.jhazmat.2021.127826.

11. **US Environmental Protection Agency.** Organic Chemical Process Industry, Section 6.6.3. Polystyrene. *1991.* 91, AP 42 Compliation of Air Pollutant Emission Factors.

12. **Niaounakis, M.** Polymers Used in Flexible Packaging. *Recycling of Flexible Plastic Packaging.* s.l. : William Andrew Publishing, 2020.

13. **Kobayashi S., Müllen K.** Polystyrene. [book auth.] Terashima T. *Encyclopedia of Polymeric Nanomaterials.* Berlin, Heidelberg : Springer, 2015.

14. **Lian, J., Wu, J., Xiong, H., Zeb, A., Yang, T., Su, X., Su, L., & Liu, W.** Impact of polystyrene nanoplastics (PSNPs) on seed germination and seedling growth of wheat (Triticum aestivum L.). *Journal of Hazardous Materials.* 385(38), 2020, Vol. 121620, https://doi.org/10.1016/j.jhazmat.2019.121620.

15. **Liu, Y., Guo, R., Zhang, S., Sun, Y., & Wang, F.** Uptake and translocation of nano/microplastics by rice seedlings: Evidence from a hydroponic experiment. *Journal of Hazardous Materials.* 421(July 2021), 2022, Vol. 126700, https://doi.org/10.1016/j.jhazmat.2021.126700.

16. **Li, S., Wang, T., Guo, J., Dong, Y., Wang, Z., Gong, L., & Li, X.** Polystyrene microplastics disturb the redox homeostasis, carbohydrate metabolism and phytohormone regulatory network in barley. *Journal of Hazardous Materials.* 415(February), 2021, Vol. 125614, https://doi.org/10.1016/j.jhazmat.2021.125614.

17. **Lian, J., Liu, W., Sun, Y., Men, S., Wu, J., Zeb, A., Yang, T., Ma, L. Q., & Zhou, Q.** Nanotoxicological effects and transcriptome mechanisms of wheat (Triticum aestivum L.) under stress of polystyrene nanoplastics. *Journal of Hazardous Materials.* 423(PB), 2022, Vol. 127241, https://doi.org/10.1016/j.jhazmat.2021.127241.