



Unveiling the Effects of Polypropylene Microplastics (PP-MPs) on Growth Attributes and Antioxidant Defense System in Wheat (*Triticum aestivum* L.)

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Abstract Microplastics (MPs), as emerging pollutants in soil ecosystems, are increasingly alarming and present severe environmental threats to crop plants. Despite the elevated pollution of MPs in terrestrial ecosystems, the impact of polypropylene microplastics (PP-MPs) on plant growth and physiology has not been clearly elucidated. Therefore, this study aimed to reveal the effects of different levels of polypropylene microplastics (0.05%, 0.1%, 0.5%, and 1% PP-MPs) on wheat, one of the world's foremost crops. While 0.05% PP microplastic did not affect plant growth, 0.1%, 0.5%, and 1% PP microplastic pollution resulted in inhibition of shoot and root growth attributes. Stunted plant growth was accompanied by oxidative stress, as indicated by increased malondialdehyde (MDA) and hydrogen peroxide (H₂O₂) content in this study. Higher levels of PP-MPs (0.5% and 1% PP) notably reduced photosynthetic pigment contents (chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid) and total protein amount. Furthermore, exposure to higher concentrations of PP-MPs induced

an increase in proline content, superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and ascorbate peroxidase (APX) activities to reduce the harmful effects of oxidative stress. The overall pattern of this study demonstrated that 0.05% PP-MPs had no adverse effect on wheat, but higher PP-MP contamination led to detrimental effects. These findings encourage addressing issues associated with microplastic pollution in crop plants and ultimately highlight the importance of plastic waste management for sustainable agriculture in soils.

Keywords Antioxidant · Ecophysiological parameters · Microplastic · Polypropylene · Soil pollution · Wheat

1 Introduction

Today's world, known as the plastic age, is encountering a serious threat to both biodiversity and ecosystem functioning, with annual plastic production exceeding 300 million tons (Boots et al., 2019; Zhang et al., 2022a). It is thought that more than 30% of plastic waste is found in soil ecosystems and that microplastics are the most environmentally dangerous. Microplastics (MPs) are formed from the natural fragmentation of larger plastic parts into particles smaller than 5 mm in size. Despite the fact that the majority of MPs' pollution in aquatic ecosystems is of terrestrial origin, the potential effect of MPs on soil

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ecosystems is widely unexplored (Bhatt et al., 2021; Zang et al., 2020). Moreover, it is considered that terrestrial environments can be 4 to 23 times more polluted with MPs than aquatic environments (Horton et al., 2017).

Soil is a main reservoir of microplastics (Boots et al., 2019), as it can store larger amounts of microplastics, and these microplastics can remain in soil for hundreds of years (Azeem et al., 2021). The existence of MPs in soil is attributed to various pathways, such as agricultural plastic mulching, sludge fertilization, irrigation with wastewater, atmospheric deposition, and more (Bläsing & Amelung, 2018; Lo Porto et al., 2024). The most abundant polymer types in soil ecosystems are microplastics, such as polypropylene (PP), polyethylene (PE), polystyrene (PS). The effects of MPs on plants, principal members of the soil ecosystem, have received great attention in recent years. MPs have direct toxic effects on plant growth, development, and biochemical processes. These effects comprise reduced seed germination, inhibition of root and shoot growth, disturbance of photosynthesis, oxidative damage, and impairment of antioxidant defense system (Kumar et al., 2020; Zhang et al., 2022b). MPs can block the pores in seed coats or plant roots through absorption, which hinders seed germination and the penetration of nutrients and water into the plant (De Silva et al., 2021). Larger-scale MPs that cannot be taken up by plants can accumulate around plant roots and mechanically damage them, thereby inhibiting root activity and growth. However, by entering plant roots, smaller-scale MPs can be transported to different organs through the transpiration flow. In particular, they can accumulate in cell wall pores to block water and nutrients while being transported in leaf veins, thereby causing oxidative damage and disrupting photosynthesis (Zhang et al., 2022a). Besides that, they can also cause direct toxicity by releasing pollutants and additives absorbed onto their surface. In addition to direct toxicity, MPs also indirectly affect plant growth by altering soil structure and affecting microbial communities in the soil. They can increase soil drought by promoting soil cracking, which inhibits plant growth. By modifying the soil microbiome or adsorption, they can also reduce nutrient availability for plants (Jia et al., 2023). Nevertheless, not all effects of microplastics on plants are negative, and sometimes they have no significant effect or produce stimulating effects on plants, similar

to fertilization with nutrients such as nitrogen, which some of them contain (Li et al., 2022).

Along with polyethylene, polypropylene is the most common plastic reported in agricultural soils (Koutnik et al., 2021). Polypropylene microplastics (PP-MPs), which are currently used in plastics such as bottles and packaging, are highly contaminating soil ecosystems (Shorobi et al., 2023). Although agricultural soils are contaminated with MPs, studies regarding the effects of MPs on plants are both limited and uncertain. Moreover, exploring the effects of PP-MPs in wheat, one of the world's leading crops, is critical for food security. Hence, we conducted a pot experiment to examine the effect of soil contamination with various concentrations of polypropylene microplastics on wheat. We hypothesized that PP pollution has a negative impact on the growth parameters and antioxidant enzyme capacity of wheat seedlings.

2 Materials and Methods

Polypropylene (PP) microplastic in granular form, with a size of less than 5 mm, was purchased from Smart Kimya Trade and Consulting Limited Company, Türkiye.

2.1 Plant Material and Growth Attributes

In the current study, wheat (*Triticum aestivum* L.) was used as the experimental material. Wheat seeds were soaked in sodium hypochlorite solution (10%, 10 min) and rinsed 3 times with distilled water before sowing. Then, PP microplastics were mixed with soil, and wheat seeds were sown in each pot. The levels of PP-MPs were selected based on environmentally relevant concentrations. The treatments were set as follows: control (C, no PP-MP), 0.05% (w/w) PP, 0.1% (w/w) PP, 0.5% (w/w) PP, and 1% (w/w) PP. The experiment was carried out in a growth chamber (DigiTech) under controlled conditions (16/8 light/dark regime), and plants were irrigated with distilled water every two days. After two months, the wheat plants were harvested. On the harvest day, root-shoot lengths (cm) and root-shoot fresh and dry weights (g) were measured.

2.2 Evaluation of Relative Water Content

Relative water content (RWC) of leaf samples was assayed according to the method of Smart and Bingham (1974). The fresh leaves were separated into leaf discs, and fresh weights were measured. Afterwards, the leaf discs were soaked in distilled water for 6 h, and turgid weights were determined. Subsequently, the leaf discs were placed in an oven (70 °C) for recording dry weights.

2.3 Measurement of Photosynthetic Pigment Contents

Chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid contents were measured according to the methods outlined by Arnon (1949), and Lichtenthaler and Buschmann (2001). Fresh leaf samples (0.05 g) were homogeneously mixed with 80% (v/v) acetone (15 mL). Then, OD (optical density) values were recorded on a spectrophotometer (AgileSpec) at wavelengths of 470, 645, and 663 nm.

2.4 Determination of Lipid Peroxidation and Hydrogen Peroxide Content

Malondialdehyde (MDA) content, a pivotal indicator of lipid peroxidation, was determined by thiobarbituric acid (TBA) reaction using the method of Sairam and Saxena (2000). Leaf tissue (0.25 g) was homogeneously mixed with 0.1% (w/v) trichloroacetic acid (TCA) (5 mL). Following a 5-min centrifugation process of mixture at 10,000 g, the supernatant (500 µL) was reacted with 0.5% (w/v) TBA dissolved in 20% (w/v) TCA (2 mL). The mixture was heated (95 °C, 30 min) and centrifuged (10 min at 10,000 g) after cooling in an ice bath. Using a spectrophotometer, the absorbance of the supernatant was read at wavelengths of 532 nm and 600 nm.

Hydrogen peroxide (H₂O₂) content was quantified using the method previously described by Velikova et al. (2000). Leaf tissue (0.5 g) was homogeneously mixed with 0.1% (w/v) TCA (5 mL) in an ice bath. The homogenate was centrifuged (15 min at 12,000 g), and the supernatant (0.5 mL) was reacted with 10 mM potassium phosphate buffer (0.5 mL) and 1 M potassium iodide (KI) (1 mL). A spectrophotometer was used to measure the absorbance of the supernatant at a wavelength of 390 nm.

2.5 Assessment of Protein Amount and Proline Content

To quantify the protein amount in samples, leaf tissue (0.1 g) was homogeneously mixed with extraction buffer (2 mL) consisting of 1% PVP, 50 mM phosphate buffer, and 1 mM EDTA. The homogenate was centrifuged (20 min at 20,000 g) to collect the supernatant, and the antioxidant enzyme activity assays were performed using the supernatant. Protein amount in leaf tissues was detected using the method of Bradford (1976) and bovine serum albumin (BSA) standard.

The proline content was measured according to the method reported by Bates et al. (1973). Leaf tissue (0.5 g) was homogeneously mixed with 3% (w/v) sulfosalicylic acid (10 mL), and the homogenate was centrifuged (15 min at 10,000 g). The supernatant (2 mL) was then incubated with acid ninhydrin (2 mL) and glacial acetic acid (2 mL) in a water bath (100 °C, 1 h), followed by rapid cooling in an ice bath to terminate the reaction. Toluene (4 mL) was used to extract the reaction mixture, and the absorbance value was obtained at 520 nm in a spectrophotometer.

2.6 Antioxidant Enzyme Assays

Superoxide dismutase (SOD) activity was monitored by measuring the inhibition of nitroblue tetrazolium (NBT) photoreduction at 560 nm using the procedure suggested by Beauchamp and Fridovich (1971). Peroxidase (POD) activity was assessed by guaiacol oxidation at 470 nm, as outlined by Zhao et al. (2016). Catalase (CAT) activity was determined by tracing the decomposition of H₂O₂ at 240 nm, as described by Li and Yi (2012). Ascorbate peroxidase (APX) activity was estimated by measuring the decrease in reaction rate at 290 nm using the method previously reported by Nakano and Asada (1981).

2.7 Statistical Analysis

Each stage of the experiment was performed with three independent replicates. Data were expressed as mean ± standard deviation and analyzed by using GraphPad Prism 9. Statistical analyses were performed with analysis of variance (ANOVA) followed by Tukey's multiple comparisons test. Differences between groups were considered statistically

significant when $P < 0.05$ and statistically significant values were indicated by different letters.

3 Results and Discussion

3.1 Effect of PP-MPs on Wheat Growth Attributes and Relative Water Content

MPs affect the ecological functioning of terrestrial agroecosystems (Okeke et al., 2022). MP-induced restrictions of plant growth and development are among the most destructive effects (Zhou et al., 2021). Colzi et al. (2022) reported that PP-MPs reduced shoot–root fresh and dry weights of *Cucurbita pepo* L. in a concentration-dependent manner. Lian et al. (2024) also indicated the inhibitory effect of PP-MPs on lettuce growth. On the other hand, Shorobi et al. (2023) stated that PP-MPs positively affected the elongation of tomato and cherry tomato seedlings. Hence, whether the effect of MPs on plants will be detrimental or not may depend on the plant species, microplastic type, concentration, size and exposure time. As often mentioned in the literature, our results exhibited that different levels of PP-MPs remarkably impaired the wheat growth (Table 1). In the

present study, PP-MPs inhibited plant growth and led to dramatic declines in shoot, and especially root growth and development. The wheat shoot and root lengths reduced significantly with increasing concentrations of PP-MPs, except for the 0.05% PP level. The lowest (0.05%) PP level did not cause significant changes in all shoot and root growth attributes of wheat plants. In comparison to the control group, plants treated with 1% PP-MPs showed the most significant reductions in shoot and root lengths. Besides the plant lengths, 0.1%, 0.5%, and 1% PP-MP treatments decreased the fresh and dry weights of the shoot, which were significantly lower than those in the control. Similarly, significant declines were observed in root fresh and dry weights. As an exception, no change was observed in root dry weight in the 0.1% PP-MP treatment compared to the control. Overall, higher PP-MP treatments (0.5% and 1%) negatively affected both shoot and root growth of wheat and caused more pronounced reductions, as shown in Table 1. This may be related to the accumulation of MPs around the root, forming a blockage that prevents water and nutrient uptake, thus hindering plant growth and development (Ullah et al., 2021). Given the fact that wheat is the most important cultivated plant used as food in the world, the development of shoot and root is fundamental for wheat cultivation. Furthermore, knowledge of the impact of MPs on shoot and root structures emphasizes the importance of understanding the potential serious damage and threats to the agriculture-based economy (Colzi et al., 2022).

The Relative Water Content (RWC) serves as a valuable indicator of the physiological water status in plant tissues. As illustrated in Fig. 1, when seedlings were exposed to lower PP concentrations (0.05% and 0.1%), RWC in wheat leaves remained unchanged relative to the control. However, RWC in the wheat leaves was markedly reduced under 0.5% and 1% PP-MPs treatments. Our results are consistent with some previous studies, which indicated that different type of MPs reduced RWC in the leaves of maize (Liu et al., 2025) and broccoli seedlings (Yar et al., 2025).

3.2 Effect of PP-MPs on the Content of Photosynthetic Pigments

Photosynthesis is a crucial process for plant growth and development (Zhang et al., 2022b). MPs, as an emerging stressor, negatively impact the photosynthetic activity of plants by reducing the content of

Table 1 Effect of PP-MPs on shoot and root parameters of wheat plants

	Shoot Length (cm)	Shoot FW (g)	Shoot DW (g)
Control	49.43 ± 0.25a	2.58 ± 0.28a	0.37 ± 0.023a
0.05% PP	47.90 ± 0.14ab	2.71 ± 0.14a	0.46 ± 0.033a
0.1% PP	45.63 ± 0.88b	1.76 ± 0.07b	0.27 ± 0.014b
0.5% PP	38.88 ± 1.24c	1.55 ± 0.03b	0.23 ± 0.006b
1% PP	36.63 ± 0.18c	1.44 ± 0.04b	0.20 ± 0.024b
	Root Length (cm)	Root FW (g)	Root DW (g)
Control	26.88 ± 0.18a	0.68 ± 0.033a	0.070 ± 0.003a
0.05% PP	25.63 ± 0.88ab	0.65 ± 0.032a	0.068 ± 0.003a
0.1% PP	24.48 ± 0.04b	0.56 ± 0.002b	0.070 ± 0.003a
0.5% PP	16.13 ± 0.53c	0.32 ± 0.005c	0.046 ± 0.005b
1% PP	12.53 ± 0.04d	0.19 ± 0.007d	0.030 ± 0.003c

FW: Fresh Weight, DW: Dry Weight. Values are mean ($n=3$) ± SD. Different letters in the same column are significantly different at $p < 0.05$ among the treatments according to Tukey's multiple comparisons test

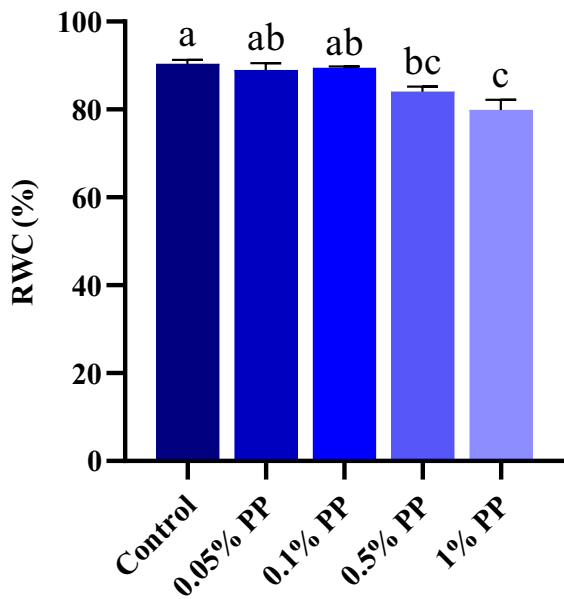


Fig. 1 Effect of PP-MPs on the relative water content (RWC) in the leaves of wheat plants. Values are mean ($n=3$) $\pm$ SD. Different letters on the bars represent significant differences ($p < 0.05$) among treatment means according to Tukey's multiple comparisons test

photosynthetic pigments (Chang et al., 2024). We found that exposure to PP-MPs led to a reduction in the content of photosynthetic pigments compared to the control, as shown in Fig. 2a-d. As with the shoot and root growth findings, photosynthetic pigment content followed a similar pattern. Consequently, the lowest (0.05%) PP level did not cause a significant alteration in chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid contents. The exposure to higher PP-MPs (0.5% and 1%) elicited a remarkable decline in chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid content of wheat leaves. Previous studies have achieved similar results, showing that MPs reduced photosynthetic pigment contents in lettuce (Gao et al., 2019), maize (Wang et al., 2020), and rice (Iswahyudi et al., 2024). MPs can inhibit photoelectron flow during photosynthesis and cause oxidative stress by increasing the content of reactive oxygen species (ROS), such as hydrogen peroxide (Ren et al., 2022). In our study, the photosynthetic pigment content and photosynthetic capacity of wheat plants showed a severe decline, probably due to oxidative stress mediated by PP-MPs.

3.3 Effect of PP-MPs on Oxidative Stress Markers

As with various abiotic stress factors, MPs can trigger the overproduction of ROS (Jia et al., 2023). Subsequently, the overproduced ROS interact with biomolecules, such as lipids and proteins in the cell wall, cell membrane, and chloroplast membranes of plants, disrupting their structure (Dumanović et al., 2021). Therefore, elucidation of MP-induced oxidative damage is essential for a better understanding of the effects of MPs on plant growth (Chang et al., 2024). The toxic effect of MP-induced oxidative stress can be determined by measuring H_2O_2 (a dangerous type of ROS) and MDA (a hazardous product of ROS) (Tsikas, 2017). With respect to the control, no significant change occurred in the MDA content of wheat leaves after exposure to 0.05% PP-MP. However, the addition of 0.1%, 0.5%, and 1% PP-MPs induced lipid peroxidation and led to the higher MDA levels. The MDA content reached a maximum value at 1% PP-MP concentration (Fig. 3a). Likewise, no significant difference was recorded in plants treated with 0.05% and 0.1% PP-MPs in terms of H_2O_2 content, whereas H_2O_2 content markedly increased with increasing PP levels in the 0.5% and 1% PP treatments (Fig. 3b). Our data clearly demonstrated that higher levels of PP-MP pollution induce oxidative damage in wheat, as evidenced by a striking increase in MDA and H_2O_2 content. In agreement with our findings, a previous research reported that exposure to polystyrene and polytetrafluoroethylene microplastic particles caused an increase in $O_2^{\bullet-}$ and H_2O_2 content and induced lipid peroxidation in the roots and leaves of rice seedlings (Dong et al., 2020). Another study also revealed that polyethylene microplastics increased MDA and H_2O_2 content in wheat and maize (Geng et al., 2024).

3.4 Effect of PP-MPs on Protein Amount and Proline Content

MP-induced oxidative stress can affect protein metabolism in plants, including the synthesis of proteins and free amino acids (Chen et al., 2023). Wheat plants exposed to 0.05% and 0.1% PP-MPs had higher protein amounts than the control. Under 0.5% and 1% PP-MP stress, the protein amount in the leaves exhibited a gradual decline. Furthermore, the decline in plants treated with higher PP-MPs (0.5% and 1%) was

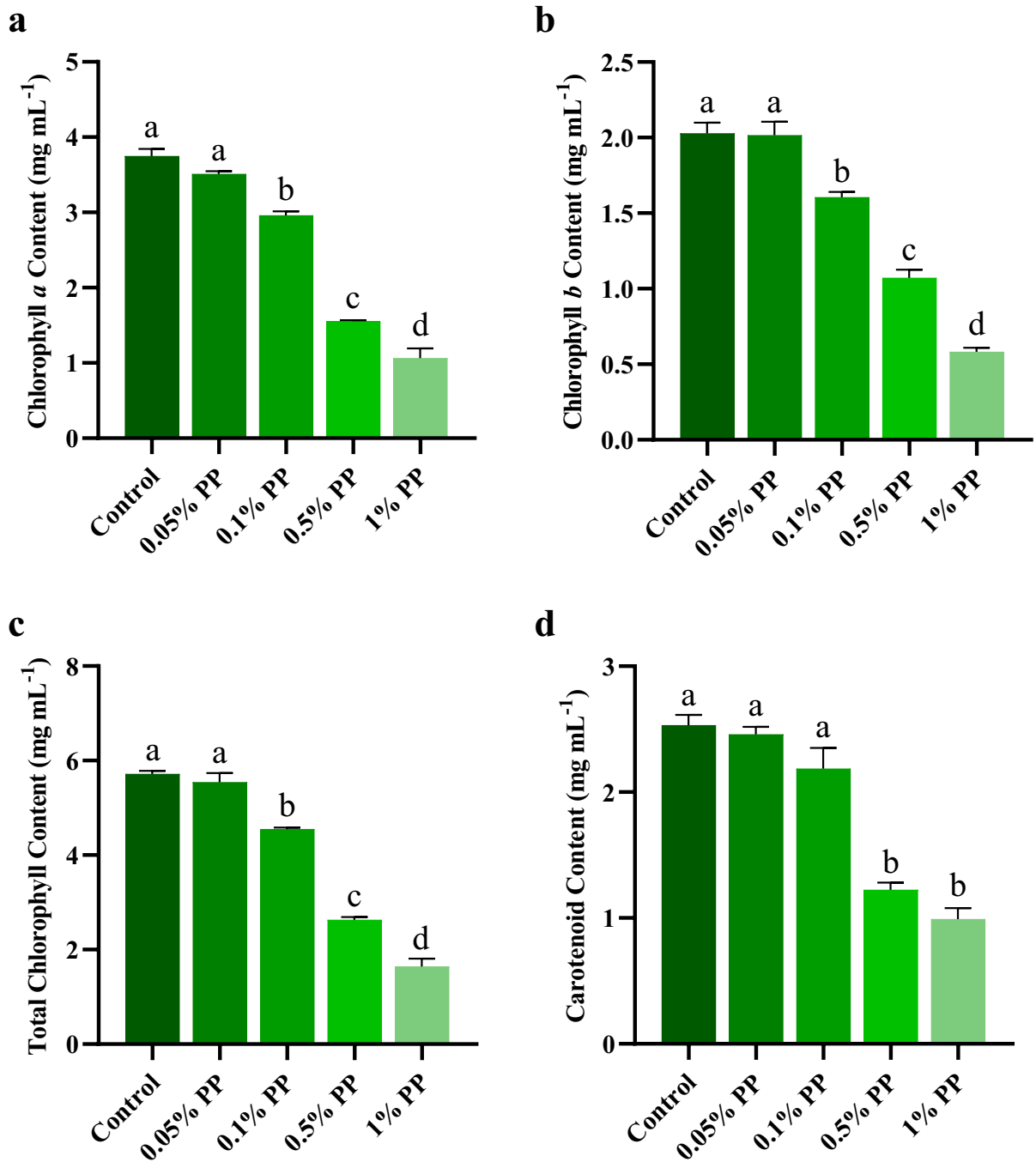


Fig. 2 Effect of PP-MPs on the photosynthetic pigments, including chlorophyll *a* **a**, chlorophyll *b* **b**, total chlorophyll **c**, and carotenoids **d**. Values are mean ($n=3$) $\pm$ SD. Different

letters on the bars represent significant differences ($p < 0.05$) among treatment means according to Tukey's multiple comparisons test

more pronounced than the increase in plants treated with lower PP-MPs (0.05% and 0.1%) (Fig. 4a). The decrease in total protein amount at higher PP-MP

levels may be associated with ROS-induced protein damage. Protein oxidation by ROS may result in enzyme inhibition and increased susceptibility of

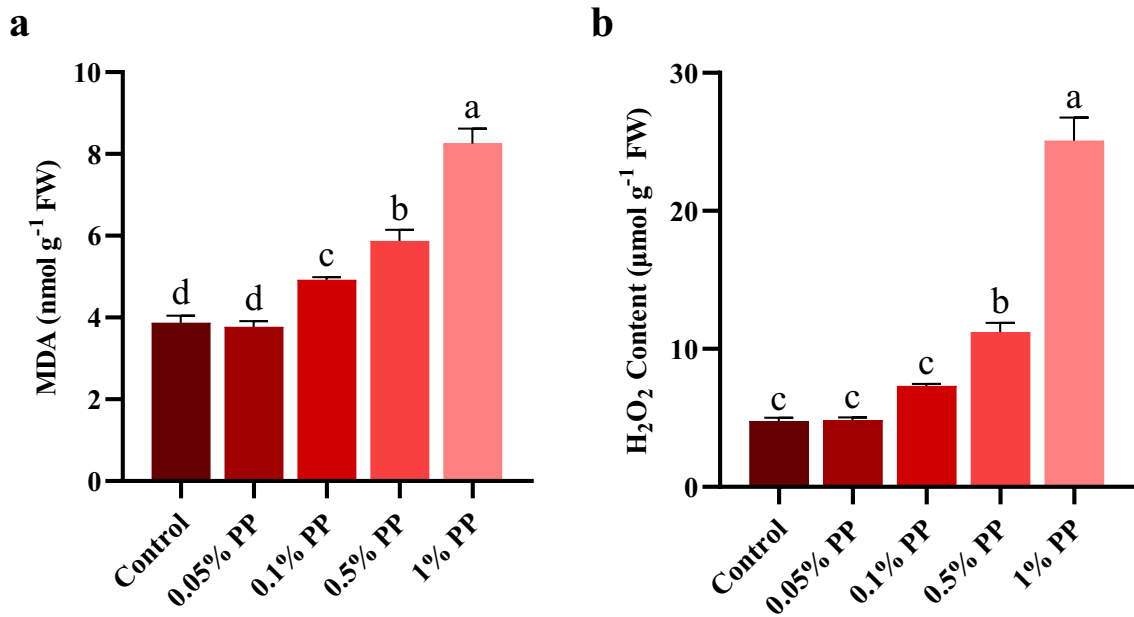


Fig. 3 Effect of PP-MPs on the oxidative stress indicators; MDA **a**, and H₂O₂ content **b**. Values are mean ($n=3$) $\pm$ SD. Different letters on the bars represent significant differences ($p < 0.05$) among treatment means according to Tukey's multiple comparisons test

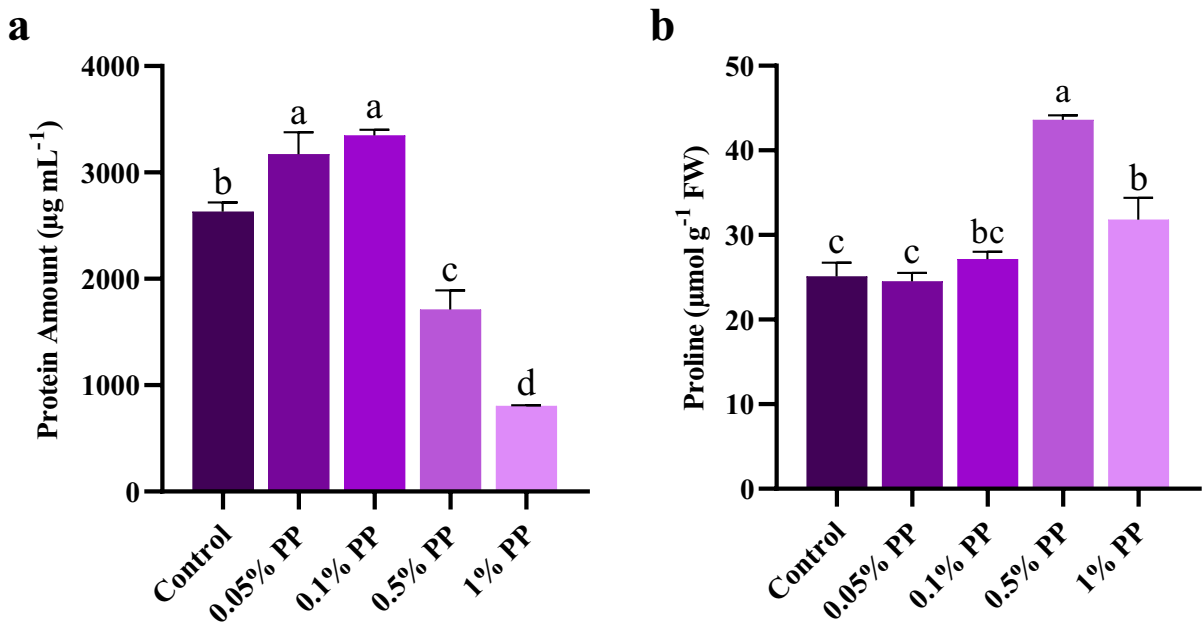


Fig. 4 Effect of PP-MPs on the protein amount **a** and proline content **b**. Values are mean ($n=3$) $\pm$ SD. Different letters on the bars represent significant differences ($p < 0.05$) among treatment means according to Tukey's multiple comparisons test

proteins to proteolysis (Sharma et al., 2012). In line with the present results, Shi et al. (2022) documented that PS, PE, and PP-MPs reduced protein amount in

tomato seedlings with increasing concentration. Yu et al. (2022) also stated that 1.5% and 5% small-sized PP-MPs reduced the protein amount in pak choi.

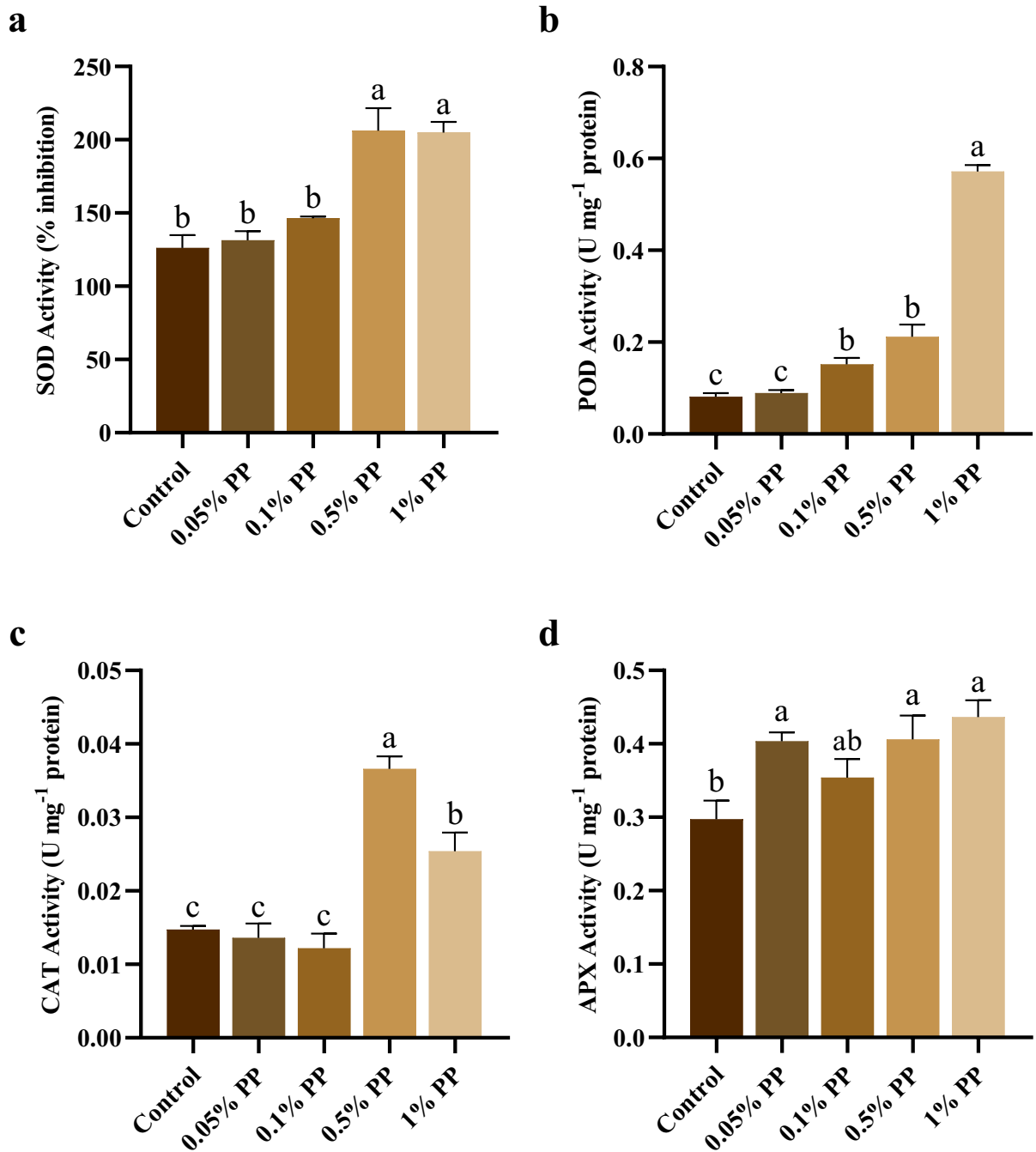


Fig. 5 Effect of PP-MPs on the antioxidant enzyme activities; SOD **a**, POD **b**, CAT **c**, and APX **d**. Values are mean ($n=3$) $\pm$ SD. Different letters on the bars represent significant

differences ($p < 0.05$) among treatment means according to Tukey's multiple comparisons test

Proline, a key amino acid involved in protein structure and function, is often overproduced by most plants under stress conditions to help maintain

metabolic activity (Ghosh et al., 2022). Although known as an osmoprotectant during stress, it also plays a vital role in scavenging ROS and stabilizing

proteins and enzymes (Zulfikar & Ashraf, 2023). Compared to the control, there was no significant alteration in the proline content of 0.05% and 0.1% PP-MPs treated plants, but 0.5% and 1% PP-MPs treated plants had a remarkable increase in proline content. The maximum value of proline content was noted at 0.5% PP-MP concentration (Fig. 4b). The high proline content in 0.5% and 1% PP-MP concentrations may be attributed to the osmoregulatory role of proline, which accumulates under challenging environmental conditions (Hayat et al., 2012; Sevgi & Leblebici, 2025). Polyvinyl chloride (PVC) microplastic also did not alter proline content at low levels but increased it at higher levels in cucumber (Zhuang et al., 2023). Similarly, PE-MPs increased the proline content of black gram at the vegetative, flowering and harvest stages in parallel with the increase in concentration (Sahasa et al., 2023).

3.5 Effect of PP-MPs on Antioxidant Enzyme Activities

Plant metabolism maintains a dynamic balance between the formation and elimination of ROS under normal conditions (Huchzermeyer et al., 2022). When plants are exposed to stress, they initiate a defense mechanism composed of antioxidant enzymes to combat oxidative damage caused by a disturbed balance of ROS (Nadarajah, 2020). The first line of defense against oxidative stress in plants is superoxide dismutase (SOD), a metalloenzyme that converts $O_2^{\bullet-}$ into H_2O_2 and O_2 (Gill et al., 2015). Subsequently, other enzymes, such as peroxidase (POD), catalase (CAT), and ascorbate peroxidase (APX) detoxify H_2O_2 in plant tissues. To highlight the common features of these enzymes, they are the most effective elements of the antioxidant defense system that scavenge H_2O_2 (Sharma et al., 2022). Xiao et al. (2023) reported that exposure to PP-MPs caused oxidative damage in cucumber and increased SOD, POD, CAT, and APX activities to protect against this damage. Irshad et al. (2024) also noted that polylactic acid microplastics increased SOD, POD, CAT, and APX activities in rice as the concentration increased. In addition, Ma et al. (2022) documented that SOD, POD, and CAT activities were enhanced in rice to tolerate the adverse effects of PS and PVC-MPs. Consistently, in this study, higher (0.5% and 1%) PP-MP stresses resulted in a marked rise in the

activities of SOD, POD, CAT, and APX. The activities of SOD, POD, CAT, and APX in plants exposed to 0.5% PP-MP concentration increased 1.6, 2.6, 2.5, and 1.4-fold, respectively, compared to the control. In a similar manner, exposure to the highest concentration of PP-MP (1%) increased the activities of these enzymes in wheat plants by 1.6, 7, 1.7, and 1.5-fold, respectively. Conspicuously, the highest values of 0.5% and 1% PP-MP pollution were recorded in POD activity, with a 2.6- and 7-fold increase, respectively. However, the activities of antioxidant enzymes generally did not change under lower (0.05% and 0.1%) PP-MP stress conditions in wheat. As an exception, 0.05% PP-MP exposure increased APX activity 1.4-fold, while 0.1% PP-MP exposure increased POD activity 1.9-fold, relative to the control (Fig. 5a-d). Taken together, our results showed that the activity of antioxidant enzymes increased at higher levels of PP-MPs, suggesting that antioxidant enzymes are overproduced to scavenge ROS and reduce the detrimental effects of PP-MPs.

4 Conclusion

Wheat crop is one of the world's main staple food sources, and the study of MP pollution in wheat is vital to ensure food security and nutrient supply for humans and animals. This study clearly shows that higher levels of PP-MP pollution adversely affect wheat growth and development. In addition to growth inhibition, PP-induced toxicity caused oxidative stress, reduced photosynthetic pigment contents, and elevated antioxidant enzyme activities in wheat. Therefore, the current study provides critical information for assessing the risks of MPs contamination in agricultural soils and for taking future mitigative actions in these soils. Altogether, our findings serve as a reminder that minimizing the overuse of both PP and other plastics while promoting sustainable plastic waste management practices is inevitable for environmental safety. As this research is a pot experiment and focuses only on plant-microplastic interactions, new investigations on soil physicochemical properties, soil microbiome dynamics, and field trials are needed to better elucidate the underlying mechanisms of PP-MPs' effects on plant growth and development. Moreover, further studies to determine the possible transfer of MPs into the food chain and the risks this

transfer poses to food quality and human health are encouraged.

Author Contributions Kübra Sevgi: Writing – original draft, Writing – review and editing, Data curation, Formal analysis, Methodology, Investigation, Visualization, Conceptualization. Büşra Sevgi: Writing – original draft, Writing – review and editing, Data curation, Formal analysis, Methodology, Investigation, Visualization, Conceptualization. Sema Leblebici: Supervision, Writing – review and editing, Methodology, Conceptualization.

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Data Availability All data generated or analyzed during this study are included in this article.

Declarations

Ethics Approval Not applicable.

Consent for Publication All authors have read and agreed to the published version of the manuscript.

Competing Interest The authors declare that they have no competing interest.

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