

Effect of Polyethylene Microplastics on Coriander Plant Growth and Root morphology

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Abstract

Microplastics are tiny pieces of plastics that are less than 5 millimeters in length. Microplastics influence the soil properties and plant growth and development. Hence, the study was conducted to analyze how microplastics affect plant growth and root morphological traits of coriander at different concentrations of polyethylene microplastics (PE-MPs) (0, 0.25, 0.50, 0.75 and 1% w/w). From the study, a reduction in seed germination and delay in the shoot emergence was observed in the coriander seeds exposed to 1.00% PE-MPs. Root length declined by 7% at 1.00% PE-MPs exposure; whereas shoot length was not significantly affected. The study also observed that with increasing concentration of PE-MPs, the amount of photosynthetic pigments in the coriander leaves also increased. At 1.00% PE-MPs the chlorophyll a, chlorophyll b, total chlorophyll and carotenoids content increased by 8%, 19%, 12% and 7% respectively.

The occurrence of PE-MPs in the soil had no significant impact on average root width, while significant increase was observed in network depth, and maximum number of roots of all the treatments exposed to PE-MPs when compared with control, but there were no significant variations among the treatments themselves irrespective of the concentrations of microplastics. Moreover, the highest increase of 126% in the median no of roots was observed at the 1.00% PE-MPs concentration in comparison with the control. In contrast to other parameters, the network volume, network length, network width and network width to depth ratio of coriander roots decreased with the presence of PE-MPs in the soil irrespective of their concentration. From the current study, it is observed that the PE-MPs in soil affects number of days taken for shoot emergence, increase the levels of photosynthetic pigments and alter the root morphology of the coriander plant.

1. Introduction

Plastic utilisation has become a common occurrence in nearly every part of the day to day life. The amount of plastic waste generation around the world has increased from 202 million tonnes in 2021 to approximately 227 million tonnes in 2026. Due to rapid growth of population and product consumption, the quantity of plastic waste getting mismanaged has also increased, as evidenced from the rise of mismanaged plastic from about 69 million tonnes in 2021 to 72 million tonnes in 2026. This highlights the fact that plastic waste management capacity of the countries is not growing fast enough to offset the increasing generation [1]. In India, the plastic industry continues to grow significantly since 1950s after the introduction of Polystyrene production. The country is one of the major contributors to global plastics production, with over 20,000 processing units [2]. India also faces challenges with plastic waste management. In 2023, the country's plastic waste per capita was 7.6 kg per year, and about 10.829 million tonnes of plastic waste generated. Out of this waste, the share of mismanaged plastic waste was almost 7.43 million tonnes, i.e. nearly 70% of the plastic waste was mismanaged [3].

The mismanaged plastic waste leads to release of primary microplastics or production secondary microplastics, which are plastic particles whose dimensions is less than 5 millimetres, into the

environment. Moreover, India is projected to be one of the top contributors to microplastic pollution globally. Specifically, India is predicted to release around 391,879 tonnes of microplastics into water bodies, making it the second-largest polluter after China. This significant volume of microplastics comes from various sources, including tyre abrasion, textile fibres, and improper waste disposal [4]. Plastics in the form of foam, films, pipes, and other kinds of materials are now widely used in the horticultural and agricultural sectors. These materials are used in buildings and infrastructure, for the transportation of fertiliser, for the control of weeds, pests, and diseases, and for crop preservation and storage [5, 6]. Potential sources of microplastics in agricultural lands includes greenhouse covers, plastic mulch films [7], solarisation films, plastic seed coatings, wastewater irrigation [8,9], landfills [10], and composts [11]. Recent studies have highlighted that microplastics contamination in agricultural soils can alter physicochemical and biological properties of soil and thereby affect plant growth and development [12].

In recent years, in order to understand how microplastics influence plant growth, various studies have been conducted on major crops like *Oryza sativa* L. [13–15], *Zea mays* L. [16, 17], *Triticum aestivum* [18–20], *Daucus carota* [21], *Allium cepa* L. [22, 23] and *Lycopersicon esculentum* L. [24]. Microplastics have shown either positive or negative or neutral effect on most of the crops which have been studied till date [25, 26]. However, a special focus on the impacts of microplastics on green leafy vegetables is necessary as several of them like, spinach and leek (*Allium ampeloprasum* L.), can be grown as perennial or annual crops with several harvests throughout this time, in contrast to other crops.

Generally, green leafy vegetables have a high capacity for water absorption and typically favour warm, humid conditions. This implies that microplastics will almost certainly be assimilated by the roots or interact with plant roots if they occur in their growing environment [27]. Among leafy vegetables, since coriander (*Coriandrum sativum*) is frequently cultivated in areas where the use of agricultural plastics such as mulch films, greenhouse covers, and plastic irrigation pipes are extensive, it is extremely susceptible to microplastic contamination [28]. Coriander is vulnerable to absorbing and moving microplastics (MPs) and nanoplastics (NPs) from polluted soils into its upper tissue since it is a short-duration horticulture crop with a high transpiration rate. This bioaccumulation directly threatens the human food chain since the entire aboveground plant i.e., leaves and stems is harvested for food [29]. This crop is highly sensitive to abiotic stresses, and hence it is likely to be impacted by the presence of microplastics in the soil [30]. This particular study was conducted to understand the impact of polyethylene microplastics (PE-MPs) on coriander plant growth.

2. Materials and Methods

2.1. Collection of plant seeds and microplastics

The polyethylene microplastics (PE-MPs) used in this study was purchased in the powder form from Arunachal Polymer Industries, Coimbatore, Tamil Nadu, India. The average diameter of microplastics were 60 to 100 µm. The seeds of Coriander (*Coriandrum sativum*) variety Annamalai 30 were obtained from Rasi Agro Service, Athimugam, Tamil Nadu.

2.2. Experimental details

The experimental soil (Sandy clay loam) was collected from a farm of Adhiyamaan College of Agriculture and Research (12.743294°N 77.98592°E). The soils were shade dried and sieved through 2 mm and then initial physical and chemical properties were analysed per the standard procedures (Table 1).

Table 1
Characteristics of the soil utilized for the Experiment

Soil Parameter	Results of Analysis
Soil Texture	Sandy Clay Loam
Bulk density (g/cc)	1.46 ± 0.010
Porosity (%)	41.32 ± 0.603
pH	6.82 ± 0.009
EC (dS m ⁻¹)	0.38 ± 0.007
Total Organic Carbon (%)	0.41 ± 0.006
Soil Available Nitrogen (kg ha ⁻¹)	198 ± 0.270
Soil Available Phosphorus (kg ha ⁻¹)	55 ± 0.180
Soil Available Potassium (kg ha ⁻¹)	90 ± 0.220
Soil Available Calcium (meq/100g)	15 ± 0.270
Soil Available Magnesium (meq/100g)	7.6 ± 0.025

A pot experiment was conducted at Horticulture Shade net, Adhiyamaan College of Agriculture and research, Hosur. The concentrations of PE-MPs fixed for the experiments are as follows: T₁ (0%), T₂ (0.25%), T₃ (0.50%), T₄ (0.75%) and T₅ (1.00%) of dry soil weight (w/w). The sieved soil was spiked with PE-MPs in accordance with the fixed treatments. Four replications for each treatment were fixed.

The potted soil was watered to maintain 50% moisture and incubated for stabilization for 10 days. Then, the coriander seeds were sown at the rate of 25 seeds per pot at a depth of 2 cm. All the recommended crop management practices were followed as per the TNAU crop production guide. The changes in the plant growth were determined at vegetative stage of coriander at 25 days of age. The morphology of the roots was observed using GiaRoots software after the roots were thoroughly washed free of dirt and debris. All the root images were captured from the exactly same position at a constant distance in order to maintain the aspect ratio [31]. Images were collected using Canon EOS R100 camera.

2.3. Statistical analysis

The experiment was conducted in a completely randomized design (CRD) with five treatments and four replications. The test results were calculated, the data was represented as Mean $\pm$ SD format and in the graphical format using Microsoft Excel 2016. The significance of the parameters was tested using one-way ANOVA test followed by Tukey's HSD as post hoc test to find the source of variation among the treatments. A Pearson correlation matrix was prepared for Gia Roots parameters using Microsoft Excel.

3. Results and Discussion

3.1. Effect on Germination and Plant growth

The results of effect of PE-MPs on coriander germination and plant growth is represented in the Table 2. The presence of PE-MPs had a significant influence on germination rate at 1.00% PE-MPs and there was no significant variation among other treatments when compared with the control. The germination of coriander seeds decreased by 4 and 6% in the treatments exposed to 0.75% and 1.00% PE-MPs. However, the effect became apparent at the highest concentration used in the study i.e. 1.00 PE-MPs and rest of the concentrations had shown no effect on germination rate of the coriander seeds (Fig. 1). Similar results were observed by other researchers in their previous studies with cress (*Lepidium sativum* L.) [32], and tomato (*Solanum lycopersicum* L.) [33] on exposure to PE-MPs. Similarly, in the present study, the number of days taken for shoot emergence was also significantly delayed by two to three days at 0.75% and 1.00% PE-MPs respectively, while the lower concentrations had no impact.

Table 2. Effect of PE-MPs on germination, plant growth and photosynthetic pigments

Treatment Parameter	Control (0% PE- MPs)	0.25% PE- MPs	0.50% PE- MPs	0.75% PE- MPs	1.00% PE- MPs
Germination Rate (%)	98 ± 2.31 ^a	97 ± 2.00 ^{ab}	95 ± 2.00 ^{ab}	94 ± 2.31 ^{ab}	92 ± 3.27 ^b
Shoot emergence (No. of days)	6.75 ± 0.50 ^a	6.75 ± 0.50 ^a	7.75 ± 0.50 ^a	9.25 ± 0.96 ^b	9.75 ± 0.50 ^b
Root Length (cm)	9.2 ± 0.67 ^a	9.2 ± 0.56 ^a	8.7 ± 0.95 ^a	8.6 ± 0.66 ^a	8.5 ± 0.91 ^a
Shoot Length (cm)	12.9 ± 0.90 ^a	13.1 ± 0.68 ^a	12.5 ± 0.73 ^a	12.4 ± 0.92 ^a	12.6 ± 0.57 ^a
Chlorophyll a (mg/g)	3.38 ± 0.11 ^a	3.51 ± 0.05 ^{abc}	3.55 ± 0.05 ^b	3.65 ± 0.06 ^c	3.65 ± 0.09 ^{bc}
Chlorophyll b (mg/g)	1.51 ± 0.02 ^a	1.91 ± 0.03 ^{ab}	1.64 ± 0.04 ^b	1.73 ± 0.04 ^c	1.81 ± 0.04 ^c
Total Chlorophyll (mg/g)	4.89 ± 0.05 ^a	5.09 ± 0.11 ^{ab}	5.19 ± 0.09 ^b	5.37 ± 0.07 ^c	5.47 ± 0.13 ^c
Carotenoids (mg/g)	1.37 ± 0.04 ^{ac}	1.39 ± 0.02 ^{ac}	1.40 ± 0.02 ^{ab}	1.42 ± 0.02 ^{cd}	1.46 ± 0.04 ^d

Exposure to various concentrations of PE-MPs had no significant influence on root length and shoot length of the coriander plant at the vegetative stage. Compared to control, a 7% and 2% reduction was observed in root and shoot length respectively in the treatments exposed to 1.00% PE-MPs (Fig. 1). Similar results were reported in crops like cress (*Lepidium sativum*) [32] and maize (*Zea mays* L.) [34, 35]. The reason for reduction in germination rate at higher concentration of PE-MPs and delay in shoot emergence could be due to the blocking of seed pores by microplastics in soil thereby affecting water imbibition process [32, 36].

In other studies, it was observed that generally PE-MPs stick to the surface of the seed coat and restrict water uptake and negatively affect the redox homeostasis within the seeds [36]. These types of disruption in seed germination may also be associated with the reduction in root and shoot length in the plants like rice [37], mung bean [38], wheat [39] and tomato [40, 41]. However, in coriander the root and shoot length were not significantly affected by the presence of PE-MPs regardless of the concentration. The contradictions in responses observed here might be due to variations in the seed structure and root architecture of the coriander seed and also variations in the physicochemical properties of microplastics. This emphasizes the fact that the effect of microplastics on plant growth varies with plant species and also the characteristics of the microplastics present in the soil [36, 41].

3.2. Effect on Photosynthetic pigments

In plants, the light energy utilized for photosynthesis is harvested by photosynthetic pigments present in the membranes of chloroplasts called chlorophyll a, chlorophyll b and carotenoids [42]. Several of the previous studies which investigated the effects of microplastics on plant growth, metabolism and physiology had found that the microplastics reduced photosynthetic pigments in the plant [43 – 47]. However, a study had also reported that microplastics like polystyrene (PS) had elevated chlorophyll content in wheat [48].

The results of effect of PE-MPs on coriander germination and plant growth is represented in the Table 2. In contrast to PE-MPs exhibiting no significant impact on growth attributes of the coriander plant, photosynthetic pigments were significantly affected by the presence of microplastics irrespective of the concentrations. The chlorophyll a content in coriander leaves was increased by a 4% and 5% at 0.25% and 0.50% PE-MPs respectively, while at both 0.75% and 1.00% PE-MPs, an 8% increase was observed (Fig. 2). Similarly, a 14 and 19% increase in chlorophyll b content of the coriander leaves was observed in the treatments exposed to 0.75 and 1.00% PE-MPs respectively.

Overall, the total chlorophyll content in the leaves was observed to increase by 4, 6, 10 and 12% at 0.25, 0.50, 0.75 and 1.00% PE-MPs. Moreover, the carotenoid content in the coriander leaves also increased by 3 and 7% at 0.75 and 1.00% PE-MPs concentrations compared to the control and at the lower concentrations, i.e., up to 0.50% PE-MPs, no significant changes were observed (Fig. 2). Similarly, the results of this study also indicate that increase in the concentration of polyethylene microplastics (PE-MPs) increase the amount of chlorophyll a, chlorophyll b, and as a consequence total chlorophyll content in coriander leaves. Interestingly, carotenoids content also increased with concentration of PE-MPs.

3.3. Root morphological traits

The morphological traits of roots from all the treatments were imaged at vegetative stage of coriander and analysed through GiARoots software. GiA Roots is a software which generates root architecture parameter values in a semi-automated fashion [49]. The initial results yielded 20 parameters, out of which 8 parameters average root width, network depth, maximum number of roots, median number of roots, network volume, network length, network width, network width to depth ratio were selected to study the effect of polyethylene microplastics on root morphology of coriander.

The lateral roots and associated fine roots development in root system are essential to plants for water and nutrient uptake. Two of the GiA Roots parameters, maximum number of roots and median number of roots are related to lateral and fine roots growth and development in the plants [49]. The occurrence of PE-MPs in the soil had no significant impact on average root width, while significant increase was observed in network depth, and maximum number of roots of all the treatments exposed to PE-MPs when compared with control, but there were no significant variations among the treatments themselves irrespective of the concentrations of microplastics. Average root width in vegetative stage is observed to be increased by 0.91% in treatments with 1% PE-MPs compared to control. Network depth and maximum

no. of roots in coriander showed an increase of 33% and 123% from control respectively, but no variation among treatments.

The median number of roots in the treatments did not significantly differ from among the treatments with 0.25, 0.50 and 0.75% PE-MPs, however, they differed significantly from both the control and the treatment with 1.00% PE-MPs. Moreover, the highest increase of 126% in the median no of roots was observed at the 1.00% PE-MPs concentration in comparison with the control. In contrast to other parameters, the network volume, network length, network width and network width to depth ratio of coriander roots decreased with the presence of PE-MPs in the soil irrespective of their concentration.

The Pearson Correlation analysis was performed to evaluate the relationships among average root width, network depth, maximum number of roots, median number of roots, network volume, network length, network width, and network width-to-depth ratio. The correlation analysis revealed varying degrees of association among the measured root parameters (Fig. 3). The average root width showed negligible positive correlation with network depth ($r = 0.022$) and maximum number of roots ($r = 0.036$); whereas with median number of roots ($r = -0.095$), network width ($r = -0.026$) and network width to depth ratio ($r = -0.022$), it showed negligible negative correlation. However, a weak negative correlation and strong negative correlation were observed with network volume ($r = -0.246$) and network length ($r = -0.621$). This indicates that lower network volume was exhibited by the treatments with greater average root width.

The network depth showed strong positive correlations with maximum number of roots ($r = 0.99$) and median number of roots ($r = 0.99$), while also showing strong negative correlation with network volume ($r = -0.89$), network length ($r = -0.72$), network width ($r = -0.99$) and network width to depth ratio ($r = -1$). This suggests that in treatments with greater network depth also has greater root numbers. Similarly, the network volume exhibited strong positive correlation with network length ($r = 0.91$), network width ($r = 0.89$), network width to depth ratio ($r = 0.89$), whereas it exhibited strong negative correlation with network depth ($r = -0.89$), maximum number of roots ($r = -0.89$) and median number of roots ($r = -0.81$). This indicates that an increase in the network volume was observed in the treatments with increased number of root network length and width. Overall, it can be concluded that root architecture and root morphology of coriander in the treatments exposed to PE-MPs varied from control.

4. Conclusion

The present work used an economic crop as the experimental object to study the impact of PE-MPs on root morphology and plant growth parameters. Our findings further establish the understanding on how microplastics when present in soil at higher concentrations could influence the crop growth and soil properties. Based on the results observed, it was seen that the significant impact was recorded in the experimental units at the 1% PE-MPs. Therefore, it was observed that the PE-MPs in soil affects number of days taken for shoot emergence, increase the levels of photosynthetic pigments and alter the root morphology of the coriander plant. Moreover, the research studies conducted until now focused on how

different types and sizes of microplastics could influence plant growth parameters, metabolic and physiological parameters. There is still a need for studies which focus particularly on the effect microplastics could have on root morphology and root architecture, since the root system is essentially in contact with microplastics in the soil for more duration than any other plant part. This present study was conducted to bridge this gap.

Declarations

Ethics approval

No ethical approval was needed for this study. The plant material (seeds) used in this experiment was obtained from a commercial source and cultivated under controlled experimental conditions. The collection, handling and use of the plant material complied with all relevant local and national guidelines and regulations. No protected, endangered or wild-collected plant materials was used in this study. No licenses or permissions were applicable for the plant material used.

Consent for Publish

Not Applicable in the manuscript

Consent to participate

Not applicable

Availability of data and materials

Data and other materials will be made available on reasonable request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' contributions

R. Sudarvizhi: Data Curation – Writing original draft, Prepared Rough Manuscript; N. Gayathri - Data Curation – Writing original draft; R. Gnana Keerthi Sahasa: Conceptualization – Methodology – Visualization – Writing – review & editing - Supervision; A. Agatha Angeleena: Data Curation – Writing original draft; V. Aranganayaki: Data Curation – Writing original draft; M. Myvizhi: Data Curation – Writing original draft; C.M. Tamil Priya: Data Curation – Writing original draft.

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Figures

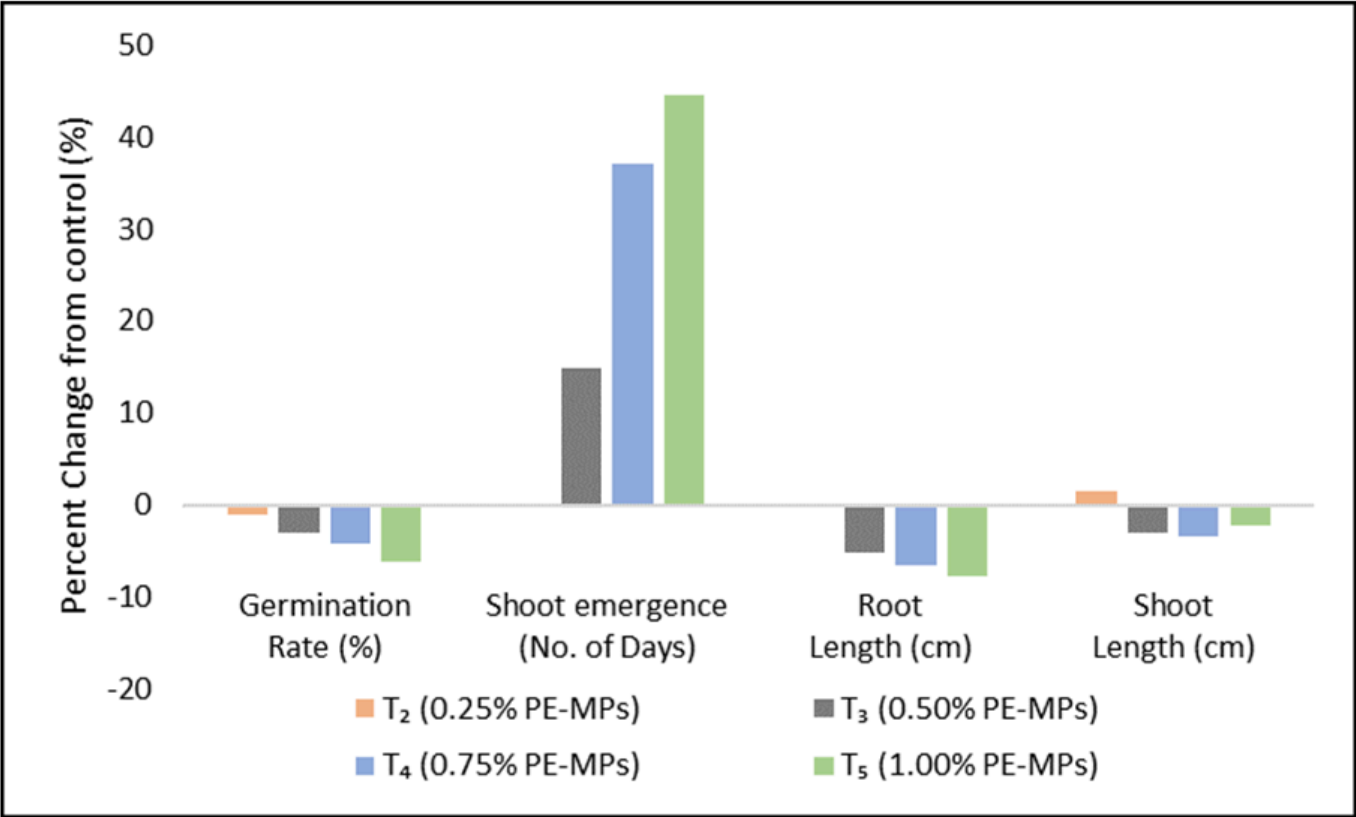


Figure 1

Effect of PE-MPs on Germination and plant growth of Coriander (*Coriandrum sativum*L.)

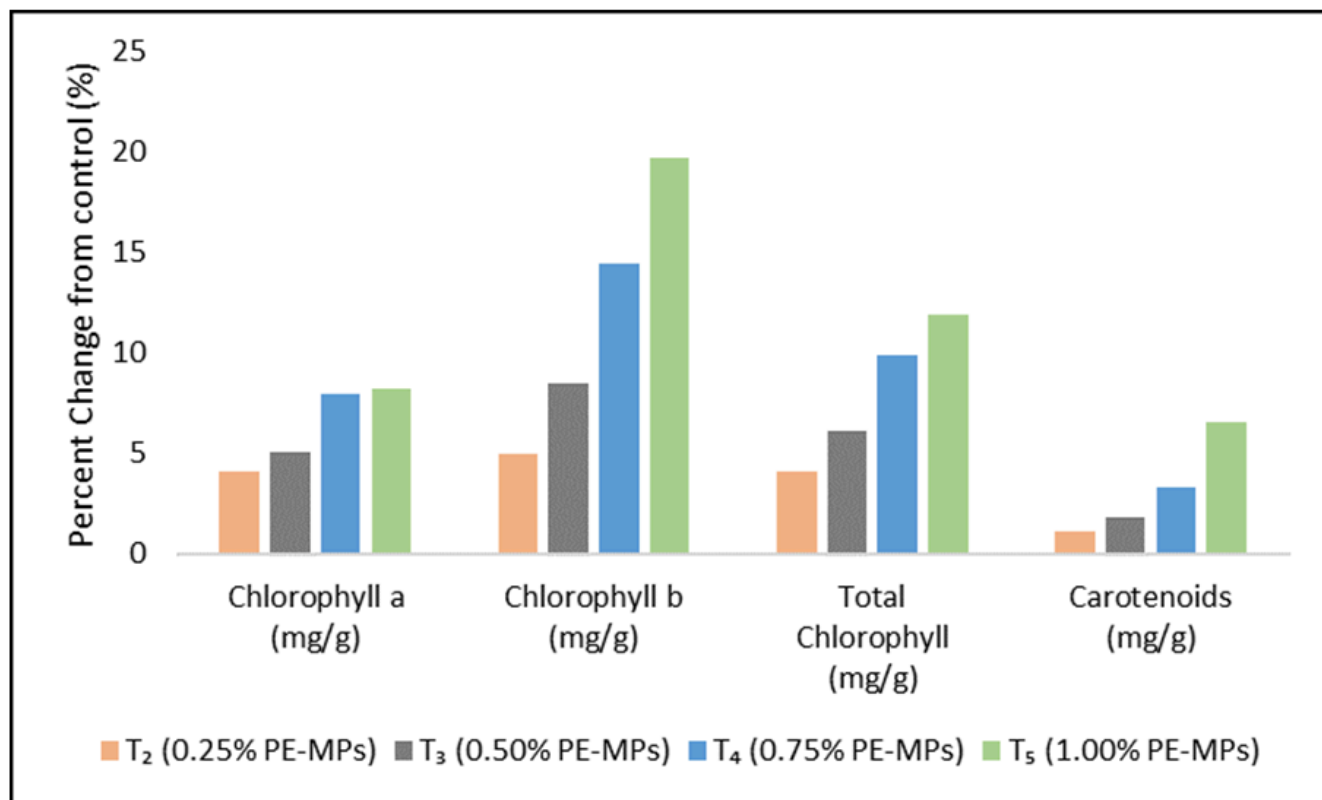


Figure 2

Effect of PE-MPs on Photosynthetic pigments of Coriander (*Coriandrum sativum* L.)

	ARW	ND	MNR	MDR	NV	NL	NW	NWDR
ARW	1							
ND	0.02192	1						
MNR	0.0357	0.99982	1					
MDR	-0.0951	0.98692	0.98611	1				
NV	-0.2462	-0.889	-0.887	-0.8136	1			
NL	-0.6211	-0.7184	-0.7227	-0.6025	0.90889	1		
NW	-0.0261	-1	-0.9999	-0.9868	0.88804	0.71943	1	
NWDR	-0.0221	-1	-0.9998	-0.9869	0.88882	0.71833	0.99998	1

Figure 3

The Pearson Correlation Matrix indicating the relationships among average root width (ARW), network depth (ND), maximum number of roots (MNR), median number of roots (MDR), network volume (NV),

network length (NL), network width (NW), and network width-to-depth ratio (NWDR) of Coriander (*Coriandrum sativum*L.)