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Impact of Polyethylene Microplastic, Electrical Conductivity and *E. coli* of Composts on Seed Germination

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Abstract

This study evaluated the influence of polyethylene (PE) microplastic, electrical conductivity (EC), and the presence of *E.coli* in different composts on the seed germination of mung bean seeds. Four types of composts were examined: T1 and T2, originating from dining food waste and kitchen waste, respectively; T3, a vermicompost produced by earthworms; and T4, a chemical organic fertiliser derived from human hair. The composts were prepared and diluted with deionised water, and PE microplastic particles were added at various concentrations. Mung bean seeds were soaked in these solutions for 8 hours, then placed on tissue paper in closed containers and kept moist by spraying with the solutions every 2 days. Germination tests were conducted over five days, and the germination index (GI), relative seed germination (RSG), and relative radicle growth (RRG) were calculated. EC and pH of the solutions were measured, and *E.coli* presence was assessed using the US EPA method 1603. PE microplastics at concentrations below 0.8% w/w stimulated seed germination, with the highest GI observed at these levels, suggesting low concentrations may not be as harmful as previously thought. High EC levels significantly inhibited seed germination, with the chemical organic fertiliser (T4) exhibiting the highest EC values and severe phytotoxicity even at high dilutions, highlighting the need to manage salt content in composts. Only the food waste compost (T1) contained *E. coli*, likely due to post-contamination, but *E.coli* did not significantly inhibit germination after dilution and filtration, indicating proper treatment can mitigate microbiological risks. The combined effects of microplastics and EC on germination were complex, underscoring the need for balanced management of both factors. These findings provide insights into the interactions between microplastics, EC, and *E.coli* in composts, informing better compost management practices and contributing to sustainable agricultural productivity.

Keywords : food waste compost; germination test; microplastics; mung bean seed; phytotoxicity

Introduction

Regarding the post-modernization era, approximately 190 million tonnes of plastic packaging was produced in Asia. Only 26% of plastic packaging was recycled, but the rest was entered either in landfills or the environment [1, 2]. Plastic wastes undergo fragmentation into particles of different sizes; microplastic (from 1 µm to < 5 mm) and nanoplastic (< 0.1 µm) [1]. Microplastics can remain in the soil for hundreds of years [3] and also have been contaminated in agro-ecosystem [4]. The accumulation of microplastics in soil has indeed reached significant levels, with studies indicating that the average accumulation in agricultural soils during long-term repeated application of compost could be up to 3.30 million particles per hectare per year [5]. This high concentration of microplastics can induce toxic effects on plants by disrupting physiological processes such as ionic homeostasis, redox regulation, and photosynthesis [6]. Additionally, microplastics can be taken up and translocated within plant tissues, potentially entering the food chain and posing risks to human health [6, 7]. Microplastics can reduce plant growth and development by altering the physiological processes, involving ionic homeostasis, redox regulation, and photosynthesis [8, 9]. During the young seedlings, microplastics can be adsorbed onto root hairs, thus retarding root growth [10].

Oxo-degradable plastic waste can be possibly entered into composting processes. The mechanical processes in composting, including crushing, granulation, drying, cooling, and sieving [11], and the biological processes, which are high temperature and microbial activities, can contribute to the fragmentation of microplastics [12]. Seed germination is highly sensitive to stress conditions [13]. Microplastics can clog the pores in the seed capsule, reducing water uptake and the imbibition process, which in turn lowers the germination rate. This blockage prevents seeds from absorbing the necessary water for germination, leading to delayed or inhibited seed growth [10, 14]. The presence of plasticisers in microplastic can induce cytotoxicity during seed germination [15]. The inhibition depends on the dose, particle size, plant species and exposure time-dependent [16]. The leachates of oxo-degradable microplastic can reduce the sorghum seed germination, and garden cress [17, 18]. Seed germination of wheat can be promoted under high concentrations of microplastic due to agglomeration and charge on microplastic particles [19, 20]. In addition, electrical conductivity (EC) and pH can interrupt the germination as they were associated with ionic strength. Oxo-degradable plastic particles mainly contain polyethylene (PE), which can affect root growth and weight [7, 8, 21]. The elliptical-shaped PE microplastic less inhibits the seed root growth and soil bacterial communities than the sharp-edged ones [22]. The mung bean is sensitive to PE microplastics with particle sizes of 57-229 µm at concentrations between 0.1-1% w/w, and the toxicity can be examined by germination index and relative root elongation [23,24]. Studies have shown that these microplastics can significantly affect the germination and growth of mung bean seeds. For instance, Lee et al. (2022) [22] found that PE microplastics within this size range and concentration can inhibit root growth and reduce the germination index of mung bean seeds. Additionally, Dey et al. (2011) [23] demonstrated that the presence of PE microplastics can alter root elongation and overall seedling development. These findings confirm that the toxicity of PE microplastics to mung bean seeds can be effectively measured using germination index and relative root elongation.

Pathogenic *Escherichia coli* (*E.coli*) is an enterohemorrhagic bacteria, which are associated with catastrophic outbreaks of food poisoning. The outbreak of Shiga toxin-producing *E.coli* (STEC) O104:H4 in 2011 occurred primarily in Germany. It resulted in approximately 4000 cases of infection and 53 registered deaths. The outbreak was associated with the consumption of raw fenugreek sprouts and affected multiple countries, including other parts of Europe and North America [cited in 24]. In 1996, an outbreak of *E.coli* O157:H7 in Sakai City, Osaka Prefecture, Japan, affected more than 6,000 primary school children who consumed radish sprouts contaminated with the bacteria. The consequences were severe, with many children developing symptoms such as

diarrhea, abdominal pain, and vomiting. A significant number of cases progressed to hemolytic uremic syndrome (HUS), a serious condition that can lead to kidney failure. The outbreak resulted in several deaths and long-term health complications for some of the affected children [25]. To ensure microbiological safety, the National Advisory Committee on Microbiological Criteria for Foods (NACMCF) recommends that treatments should reduce the pathogen population present in seeds by 100,000 times (a 5-log reduction) [26]. This research examined the seed germination and phytotoxicity of the mung bean seeds in microplastic-contaminated solutions and four composts. Additionally, statistical analysis was conducted using a two-tailed Student's t-test with a 90% confidence interval to define the correlations among factors influencing germination. A correlation matrix method was employed to identify the relationships between the variables (EC, PE concentrations, and *E.coli*) and their impact on germination.

Materials and Methods

Organic fertiliser preparation

Four fertiliser samples were introduced in this research. Two organic composts were collected from Bangkachao Farm, Samut Prakan Province, Thailand. The compost originated from food waste collected from the catering services of hotels. The hotels sorted the waste into two categories: dining room waste and kitchen waste. The kitchen waste mainly contained non-edible parts of vegetables and fruits, while the dining food waste was a mixture of cooked food. Both types of organic waste were mixed with effective microorganisms (EM) powder No.1 from the Land Development Department, which is rich in bacteria, fungi, and actinomyces. These species are non-pathogenic and can enhance the biodegradation rate of organic matter. The EM was activated according to the instructions and incubated until mature. The composts from the dining waste and the kitchen waste were labeled T1 and T2, respectively. The dining and kitchen wastes were mixed with coconut coir to absorb the residual moisture in the wastes. The composting materials were prepared with an approximate ratio (by weight) of waste: EM: coconut coir at 10:1:10 (% w/w). The mixtures were separately filled into a waste composter connected to a motor that rotated horizontally at low speed. The composting materials were mixed using stainless-steel paddles for 24 hours under aerobic conditions.

The other compost was obtained from earthworms, known as vermicompost. Due to the food waste reduction policy, the amount of dining food waste can sometimes be very low. The kitchen waste was supplied as food for earthworms, and composting took one month. This vermicompost is labeled as T3. Another sample was a chemical organic fertiliser, which served high-protein plant cultivation. The fertiliser was derived from human hair waste that was chemically extracted. This sample was labeled T4. The samples were collected quarterly and then diluted at different ratios by adding deionised (DI) water. The specific electrical conductivity (EC) of the solutions was measured after soaking for 24 hours.

Microplastic particles

Microplastic particle was supplied by Aldrich Co. Ltd., and it was a polyethylene (PE), ultra-high molecular weight, with surface-modified powder employed as a control set. The PE particle size was an average of 125 μm, which can be possibly sensitive to the germination of a microgreen plant, typically a bean sprout.

Test of phytotoxicity

To examine the effect of microplastic particles on the seed germination, mung bean was selected as the assigned size of PE particles can affect germination. Premium-grade seeds of mung bean (*Vigna radiata*) were obtained from the local market. The preliminary test was conducted, with an average germination rate greater than 95%. One hundred mung bean seeds were kept in solutions for 8 hours at room temperature and then placed onto the tissue paper, kept in closed containers, and wrapped to prevent light. A 5 mL of solution was sprayed on the tissues every 2 days, to maintain the moisture. The numbers of germinated seeds were counted,

and the lengths of roots were measured on the 5 days of incubation. Due to the non-form of the root, the thread was applied to measure the root length. Refer to the International Rules for Seed Testing Association, a seed was completely germinated when the radicle attained a length of 1 mm and the plumule had just unfolded. The tests were repeated five times. The germination viability and germination rate were examined to identify the toxicity of microplastics on the microgreen plants by Czabator (1976) calculation formula [27], as follows.

$$RSG = \left(\frac{N_t}{N_c} \right) \times 100\% \quad (1)$$

$$RRG = \left(\frac{L_t}{L_c} \right) \times 100\% \quad (2)$$

$$GI = RSG \times RRG \times 100\% \quad (3)$$

where RSG is the relative seed germination, RRG is the relative radicle growth and GI is the germination index. N_t is the number of germinated seeds in aqueous extract, N_c is the number of germinated seeds in deionized water (control), L_t is the radicle length of germinated seeds in aqueous extracts, and L_c is the radicle length germinated seeds in deionized water (control).

The microplastic particles and EC may be either stressors or stimulators for seed germination. The effect of these factors on root development is examined as follows [28].

$$TI = (RL/RL_c) \times 100 \quad (5)$$

where TI is the tolerance index calculated after 5 days of germination, RL is root length (cm) and RL_c is root length (cm) in the control, C.

The fertiliser solutions were examined to determine the specific electrical conductivity (EC) and pH, which are further calculated for the ionic strength (I) from equation.

$$EC = 6.67 \times 10^4 \times I^{0.991} \quad (6)$$

where EC is a specific electrical conductivity (mS/cm) and I is an ionic strength (mol/L).

The correlation matrix method involves calculating the Pearson correlation coefficient for pairs of variables to determine the strength and direction of their linear relationship. The formula for the Pearson correlation coefficient (r) between two variables (X) and (Y) is:

$$r_{XY} = \frac{\sum \left(X_i - \overline{X} \right) \left(Y_i - \overline{Y} \right)}{\sqrt{\sum \left(X_i - \overline{X} \right)^2 \sum \left(Y_i - \overline{Y} \right)^2}} \quad (7)$$

where, Xi and Yi are the individual sample points. $\overline{X}$ and $\overline{Y}$ are the means of the variables X and Y, respectively. $\sum$ denotes the summation over all sample points.

The correlation matrix is a table showing the correlation coefficients between many variables. Each cell in the table shows the correlation between two variables. The diagonal of the matrix is always 1, as each variable is perfectly correlated with itself. This study has three variables (X-PE concentration), (Y-EC), and (Z-*E.coli*), the correlation matrix (R) is:

$$R = \begin{pmatrix} 1 & r_{XY} & r_{XZ} \\ r_{YX} & 1 & r_{YZ} \\ r_{ZX} & r_{ZY} & 1 \end{pmatrix} \quad (8)$$

where, r_{XY} is the correlation coefficient between X and Y. r_{XZ} is the correlation coefficient between X and Z. r_{YZ} is the correlation coefficient between Y and Z.

Investigation of *E.coli* culture

The US EPA method 1603 (Modified mTEC) was used to investigate *E. coli* culture which is possibly present with enteric pathogens. The method provides a direct count of *E. coli* in sample water by developing colonies of *E. coli* which grow on the surface of the membrane filter. After filtration put the membrane on the modified mTEC agar, then incubate the agar at 35°C±0.5°C for 2 ± 0.5 hours to resuscitate injured or stressed bacteria after that, incubate at 44.5°C ± 0.2°C for 22 ± 2 hours. After incubation, the *E. coli* colonies appeared in red or magenta colonies. Statistical

analysis was done by the confidential interval of 90%, two-tailed student t-test, was applied to statistically analyse data.

Results and Discussion

Fertiliser characteristics

Table 1 presents the characteristics of the fertiliser samples. All fertiliser solutions increased the EC ionic strength. The pH of all organic composting materials ranged from slightly acidic to neutral, while the chemical organic fertiliser was relatively acidic. The C:N ratio of the T2 fertiliser exceeded the maximum of 20:1, suggesting that non-edible vegetables and fruits may contain low nitrogen levels. The macronutrient content of the T4 fertiliser was relatively high, likely due to the protein in the human hair extract. The T1 fertiliser had a slightly high sodium content, attributed to the seasoning remaining in the cooked food waste.

Effect of microplastics on germination

The control test was conducted using deionised (DI) water, which has low electrical conductivity (EC) and neutral pH, providing a baseline for the germination index of mung bean seeds. When microplastic particles were added, they did not change the EC or pH of the solution, implying low solubility of microplastic particles. This is supported by studies indicating that microplastics generally do not dissolve in water and thus do not significantly alter its EC or pH [29]. The solution containing microplastic particles may still influence the germination of mung bean seeds. Figure 1 illustrates the statistical analysis of root length in bean sprouts. The upper limit of root length increases when the PE concentration does not exceed 8,000 mg/L. However, the lower limit of root length in all treatments is lower than the control. The mean root length shows that higher PE concentrations result in shorter roots. At 10,000 mg/L, PE prohibits root elongation. A concentration of 8,000 mg/L of PE is the maximum level that may act as either a stressor or stimulator for root elongation.

Correlation between EC and pH on the dissolubility of PE Microplastics and Fertiliser

The key parameters, electrical conductivity (EC) and pH, are critical in understanding the dissolubility of polyethylene (PE) microplastics and fertilisers. EC of fertiliser solutions at varying concentrations is transformed into ionic strength (I). Higher concentrations of PE in deionised water do not significantly affect ionic strength or pH due to PE's low solubility [30]. Conversely, higher concentrations of fertiliser solutions result in increased ionic strength, as demonstrated in Table 2. This indicates that ionic strength is a reflection of fertiliser solubility, with higher concentrations leading to elevated ionic strength [31].

Table 1 Characteristics of fertilisers

Parameter	Fertiliser Samples				Standard*
	T1	T2	T3	T4	
pH (1:2)	7.45	6.44	6.64	6.40	5.5-8.52/5.5-10
Electrical Conductivity (dS/m)	9.37	5.18	2.54	83.1	<10/<15
Organic Carbon (%)	37.4	45.4	25.4	8.5	-
Organic Matter (%)	64.3	78.1	43.7	25.5	>20/>20
Total Nitrogen (%)	2.49	1.20	1.85	14.8	>1.0/>1.0
C:N ratio	15:1	38:1	14:1	0.6:1	<20:1/<20.1
Total Phosphorus (%P_2O_5)	0.78	0.62	1.69	4.2	>0.5/>2.5
Total Potassium (%K_2O)	4.14	1.84	1.22	4.9	>0.5/>1.0
Macronutrient Content (%)	7.41	3.66	4.76	23.9	>2%/> 9 % < 20%
Total Sodium (%)	1.00	0.63	0.13	0.301	<1/<1
Total Calcium (%)	32,387	23,730	19,759	12,000	-
Cation Exchange Capacity (cmol/kg)	98.0	46.7	61.0	19.7	-

Note: *Organic fertiliser standards of the Land Development Department: Compost (Grade 2)/High quality organic fertiliser.

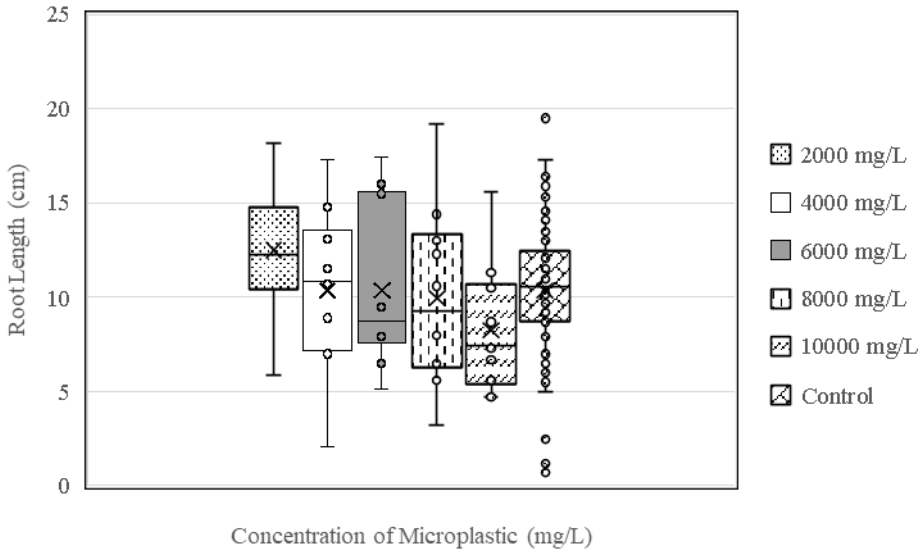

Figure 1 Box plot for root length of germinated seeds at different PE concentrations spiked into DI water

Table 2 Characteristics of microplastic, compost and fertiliser solutions

Material	Dilution by weight (mg Material: mL DI water)	EC (mS/cm)	I (mol/L)	pH
DI water (C1)	-	0.0006	0.00001	6.98
DI water with microplastic (C2)	2:1000 (0.2% *w/v*)	0.0008	0.00001	6.92
	4:1000 (0.4% *w/v*)	0.0011	0.00001	6.94
	6:1000 (0.6% *w/v*)	0.0015	0.00002	6.89
	8:1000 (0.8% *w/v*)	0.0016	0.00002	6.92
	10:1000 (1.0% *w/v*)	0.0018	0.00002	6.96
Food waste compost (T1) [Salinity 2.9 ppt*]	1:1	7.45	0.10949	7.18
	1:10	6.12	0.08979	6.95
	1:20	2.53	0.03682	6.74
Kitchen waste compost (T2) [Salinity 1.9 ppt]	1:1	6.67	0.09793	7.13
	1:10	4.12	0.06023	6.97
	1:20	1.80	0.02614	6.74
Vermicompost (T3) [Salinity 2.1 ppt]	1:1	8.60	0.12656	7.29
	1:10	2.90	0.04226	7.18
	1:20	1.42	0.02056	6.97
Chemical organic fertiliser (T4) [Salinity 2.3 ppt]	1:1	43.30	0.64663	8.76
	1:20	31.60	0.47056	8.47
	1:100	9.37	0.13800	8.04

Note: * ppt refers to parts per thousand

Influence of Electrical Conductivity (EC) and pH *on E.coli*

The presence of *E.coli* in compost was examined, as shown in Table 3. Due to the heterogeneity of composts T1 and T2, the samples were randomly selected. The numbers of *E.coli* in composts varied significantly. Only food waste compost (T1) contained *E. coli*, suggesting post-contamination or unhygienic conditions during food preparation. The kitchen waste compost (T2) was free from *E.coli*, likely because the inedible vegetables and fruits in the compost do not support *E.coli* growth. Similarly, vermicompost (T3) was free from *E.coli* since earthworms do not harbor *E.coli* in their digestive systems. The chemical organic fertiliser (T4) also had no *E.coli*, possibly due to the chemical processes involved, which can eliminate *E.coli*. This indicates that biodigestion in the composting process may not effectively eliminate *E.coli*. For food safety, organic compost may require further thermal treatment to reduce *E.coli* levels. Reducing *E. coli* contamination on seeds is crucial for public health protection [30, 31].

The EC and pH of fertiliser have less influence on *E.coli* in fertiliser compared to the dilution effect. However, EC and pH can affect the growth of *E.coli*. Studies have shown that *E.coli* can be eliminated at high pH levels, typically above 9.0, and at high EC levels, which disrupt the bacterial cell membrane [32, 33]. Heat treatment during the fermentation of T1 and T2 may also reduce *E. coli* levels.

Toxicity test of *E. coli* on germination

The presence of *E. coli* in composting may not clearly indicate germination inhibition. The compost was diluted with deionised water and then filtered, significantly reducing the amount of *E. coli*, which likely has no effect on the roots of germinated seedlings. The correlation between *E. coli* in T1 fertiliser and germination rate is undefined. Studies have shown that *E. coli* contamination does not adversely affect seed germination. For instance, research indicates that *E. coli* does not inhibit the germination of seeds, as the bacteria do not produce toxins that affect plant growth [32, 34, 35]. Therefore, the presence of *E. coli* in compost is unlikely to be toxic to seed germination.

Toxicity test of microplastic on germination

The details of Relative Seed Germination (RSG), Relative Root Growth (RRG), and Germination Index (GI) are displayed in Table 4. The data indicated that after 5 days, the final germination percentage (FGP) was obtained. A GI higher than 80% was classified as free of phytotoxicity. Adding microplastic particles, all the treatments in C2 had 100% FGP, implying that microplastic particles can stimulate the germination of mung bean seeds. The RRG and GI were highest when the microplastic concentration was lower than 8000 mg/L or 0.8% w/w. This suggests that microplastic particles can clog the root hair, reducing water absorbability [23]. The results revealed that microplastics within a lower concentration range of 0.2-0.8% can stimulate root length. None of these treatments showed phytotoxicity. The seedlings might respond to polyethylene microplastic particles similarly to amino acids, potentially altering their metabolites [36]. Further investigations are needed to fully understand plant-microplastic interactions, particularly in the long term. The radicle length of a 0.4% w/w microplastic solution seemed to follow a normal distribution. The germinated seeds exhibited uniform RSG and RRG, indicating that microplastics might stimulate root development by enhancing water absorption ability. Studies have shown that microplastics at certain concentrations can indeed stimulate root elongation. For instance, Liu et al. (2021) [37] found that polyethylene microplastics reduced shoot weight and height at high concentrations but stimulated root elongation at lower concentrations. Additionally, research on *Pisum sativum* sprouts indicated that microplastics at doses of 100 mg/L and 500 mg/L resulted in significant root length increases [38]. The uniformity in RSG and RRG suggests that the microplastic particles may enhance the water absorption ability of the roots. This enhancement could be due to the microplastics' ability to improve soil aeration and water retention, which are crucial for robust root growth. Studies have shown that microplastics can alter soil properties, such as increasing porosity and water-holding capacity, which in turn can facilitate better water uptake by plant roots [39, 40]. Additionally, microplastics can interact with root exudates, potentially enhancing nutrient availability and uptake [40].

Table 3 Numbers of *E. coli* in fertilisers

Fertiliser	Number of colonies on plates											
Dilution	Food waste compost (T1)			Kitchen waste compost (T2)			Vermicompost (T3)			Chemical organic fertiliser (T4)		
	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
10^{-2}	NC	NC	NC	0	NC	0	0	0	0	0	0	0
10^{-3}	NC	NC	NC	0	0	0	0	0	0	0	0	0
10^{-4}	33	0	0	0	0	0	0	0	0	0	0	0
10^{-5}	9	5	0	0	0	0	0	0	0	0	0	0
10^{-6}	2	1	2	0	0	0	0	0	0	0	0	0
10^{-7}	0	0	0	0	0	0	0	0	0	0	0	0
10^{-8}	0	0	0	0	0	0	0	0	0	0	0	0

Note: NC is non-countable when the number of single colony greater than 300 cells.

Table 4 Enhancing and inhibiting of EC and pH of fertiliser solutions upon seed germination

Treatment	Dilution by weight (mg Material: mL DI water)	PE conc. (%)	Root length (cm)			N	FGP (%)	RSG (%)	RRG (%)	GI (%)
			Min	Max	Avg.					
C1	-	-	0.7	24.0	12.0	473*	95	100	100	100
C2	-	0.2	5.9	14.7	14.7	50	100	106	122	129
	-	0.4	2.1	17.3	12.7	50	100	106	106	112
	-	0.6	5.1	17.4	12.7	50	100	106	105	111
	-	0.8	3.2	19.2	12.1	50	100	106	100	106
	-	1.0	4.7	15.6	9.8	50	100	106	82	86
T1	1:20	0.4	1.5	30.6	14.0	48	96	101	116	118
	1:20	0.6	0.9	31.5	17.3	48	96	101	144	146
T2	1:20	0.4	1.5	18.5	9.4	50	100	106	78	82
	1:20	0.6	0.8	15.0	8.0	48	96	101	66	67
T3	1:20	0.4	0.8	29.6	14.0	47	94	99	116	115
	1:20	0.6	0.8	28.0	17.3	49	98	104	144	149
T4	1:100	0.4	0.5	3.8	2.4	50	100	106	20	21
	1:100	0.6	0.5	5.3	3.3	44	88	93	28	26

Note: * Tests were conducted with 500 seeds.

Toxicity test of ionic strength on germination

By comparing data from Tables 2 and 4, it was found that the germination index (GI) of dining food waste compost (T1) was higher than that of kitchen waste compost (T2). Both types of waste underwent the same composting process. Dining food waste, which was cooked and served to clients, contained salt and other seasonings. This waste was used as raw material for composting, and the microbes might not have been able to reduce the salt content. Electrical conductivity (EC) can indicate the level of salts in fertiliser solutions [28]. All treatments showed little change in the pH of the fertiliser solution, indicating strong phytotoxicity of salinity and EC to mung bean sprouts. T1 compost required a dilution of at least 1:20, while T2 compost required at least 1:10 to enhance germination. The GI was lower than 50% at dilutions of 1:10 and 1:1 for T1 and T2 composts, respectively, indicating phytotoxicity at threshold limit concentrations.

Kitchen waste was fed to earthworms to produce vermicompost (T3). The vermicompost had slightly higher salinity and EC than T2 due to the digestion process of earthworms. The GI of T3 was slightly lower than T2, but diluting the fertiliser with deionised water at least 1:10

enhanced germination. The threshold limit concentration of T3 was the same as T2, but the GI was lower than 25%, indicating strong phytotoxicity. The chemical organic fertiliser (T4) had relatively high salinity and EC, reaching phytotoxic levels. T4 inhibited germination even at a high dilution of 1:100, presenting a GI lower than 25%, which was severely phytotoxic.

Microplastics at a concentration of 0.4% w/w resulted in the highest tolerance index. Fertilisers T1, T2, and T3 with a dilution of 1:20 had the highest tolerance index, but mung bean seeds could not tolerate T4 fertiliser at any dilution. High ionic strength in fertiliser solutions can inhibit seed germination due to osmotic stress and ion toxicity. Properly balanced ionic environments are essential for nutrient availability and microbial activity, which support germination and seedling growth. Excessive ionic strength disrupts water absorption and nutrient uptake, negatively impacting plant development [41, 42, 43].

Since Electrical Conductivity (EC) and *E.coli* have no correlation, the correlation metric cannot be determined. However, EC and ionic strength (I) are correlated. Beyond this the EC may refer the constituents in fertiliser. Organic composts might contain both essential micronutrients, such as Cu, Mg, Zn and Ni, and non-essential metalloids, such as Cd, Hg, Pb and As, all these elements can elevate the EC and I. Whenever both essential and non-essential micronutrients are in proper concentration, they can play a beneficial role in seed germination and root development [29]. The correlation between EC and TI can classify the germination into 3 categories, involving stimulation, strong inhibition, and severe inhibition, as presented in Figure 2.

Toxicity test of microplastic concentration and EC on germination

As ionic strength is a key factor in germination, the fertiliser solutions were diluted to 1:20 for T1, T2, and T3, and 1:100 for T4. These dilutions achieved the highest germination rates. Microplastic particles were mixed with fertiliser solutions at concentrations of 4 and 6 g/L to determine their inhibiting or enhancing effects on germination, as shown in Table 3. The microplastic particles and EC in food waste compost (T1) and vermicompost (T3) enhanced germination. When the concentration of microplastic particles increased, the roots and culms appeared slimmer and longer than the control. The adventitious roots and elongation of hypocotyls were stimulated, as shown in Figure 3, indicating changes in growth hormones, particularly auxins [44, 45]. Conversely, the microplastic particles and EC in kitchen waste compost (T2) and chemical organic fertiliser (T4) inhibited germination. Observations showed that the root radicles developed slowly, and the seeds absorbed little water. The microplastic particles and EC may reduce gibberellic acid, affecting the elongation growth of bean hypocotyls.

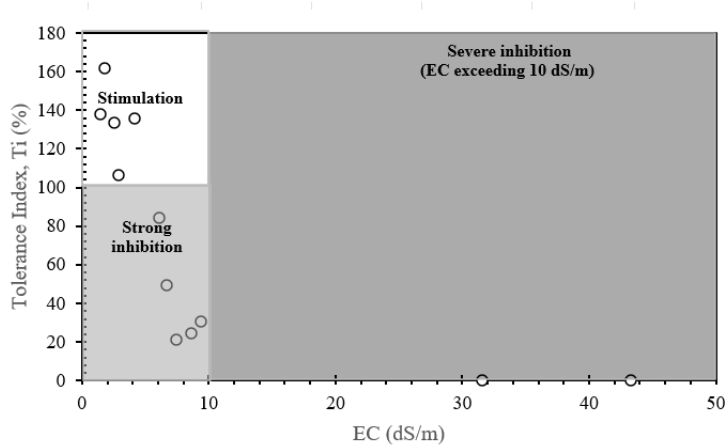

Figure 2 Classification of EC effect on germination of bean sprout

Figure 3 illustrates the physical appearance of germinating mung bean seeds under different treatments. The physical appearance of germinating seeds under different treatments shows variations in root and shoot development. Higher concentrations of microplastics in T1 and T3 resulted in slimmer and longer roots and culms compared to the control, indicating enhanced water absorption and growth hormone activity, particularly auxins. Conversely, T2 and T4 treatments showed inhibited germination, with slower root radicle development and reduced water absorption, likely due to decreased gibberellic acid levels, which are crucial for elongation growth of bean hypocotyls. Table 5 presents the plant hormones of sprouts. Polyethylene (PE) microplastics at concentrations of 0.4% and 0.6% can stimulate the production of gibberellins (GA3). T1 and T3 fertilisers can relatively stimulate GA3 hormones, as they have slightly higher electrical conductivity (EC) than T2 fertiliser. This condition may induce stress in sprouts. However, T4, with its high EC, can inhibit the synthesis of GA3.

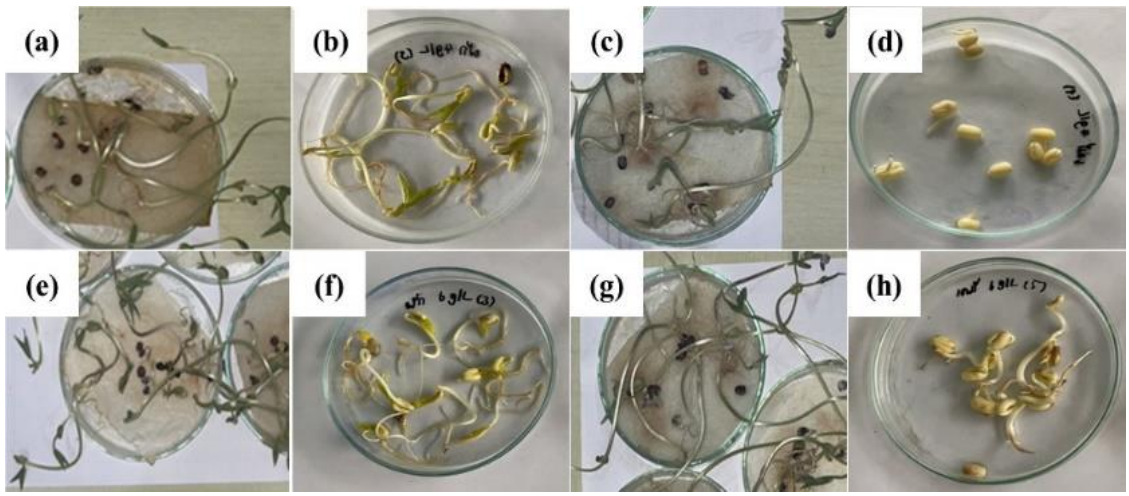

Figure 3 Physical appearance of bean sprout at 0.4% (a-d) and 0.6% (e-h) of PE particle in fertiliser solutions of T1 (a, e), T2 (b, f), T3 (c, g) and T4 (d, h) treatments

Table 5 Plant hormones of mung bean sprout

Solution	Dilution (Fertiliser: DI)	Microplastic (%)	Hormone concentration (mg/g wet weight)			
			GA3	IAA	IBA	NAA
C1	-	-	32.1	ND	ND	ND
C2	-	0.4	96.6	ND	ND	ND
	-	0.6	84.6	ND	ND	ND
T1	1:20	0.4	12.1	ND	ND	ND
T2	1:20	0.4	5.4	ND	ND	ND
T3	1:20	0.4	18.3	ND	ND	ND
T4	1:100	0.4	10.8	ND	ND	ND

Note: ND refers to non-detectable.

Conclusions

The study found that microplastic particles, particularly polyethylene (PE), can stimulate mung bean seed germination at concentrations below 0.8% w/w, challenging the perception that all microplastics are harmful to plant growth. High electrical conductivity (EC) levels in composts significantly inhibit seed germination, highlighting the need to manage salt content for beneficial plant growth. The presence of *E. coli* in food waste compost (T1) underscores the importance of hygienic conditions during compost preparation, with findings suggesting that proper treatment can mitigate microbiological risks. The combined effects of microplastics and EC on seed germination are complex; while microplastics can enhance germination in some composts, high EC levels can negate these benefits. Practical guidelines for optimising compost use include managing salt content in food waste composts (T1 and T2) and carefully diluting chemical organic fertilisers (T4) to avoid phytotoxicity. The findings support sustainable agricultural practices by highlighting the potential benefits and risks of using composts contaminated with microplastics and high EC, informing strategies to mitigate negative impacts and enhance positive effects on plant growth. The research also emphasises the importance of addressing microbiological safety in composting processes to protect public health.

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References

[1] Azeem, I., Adeel, M., Ahmad, M.A., Shakoor, N., Zain, M., Yousef, N., Yinghai, Z., Azeem, K., Zhou, P., White, J.C., Ming, X. and Rui, Y. 2022. Microplastic and Nanoplastic Interactions with Plant Species: Trends, Meta-analysis, and Perspectives. Environmental Science & Technology Letters. 9(6): 482-492.

[2] Huang, Y., Liu, Q., Jia, W., Yan, C. and Wang, J. 2020. Agricultural Plastic Mulching as a Source of Microplastics in the Terrestrial Environment. Environmental Pollution. 260: 114096.

[3] Duan, J., Bolan, N., Li, Y., Ding, S., Atugoda, T., Vithanage, M., Sarkar, B., Tsang, D.C.W. and Kirkham, M.B. 2021. Weathering of Microplastics and Interaction with Other Coexisting Constituents in Terrestrial and Aquatic Environments. Water Research. 196: 117011.

[4] Mao, X., Xu, Y., Cheng, Z., Yang, Y., Guan, Z., Jiang, L. and Tang, K. 2022. The Impact of Microplastic Pollution on Ecological Environment: A Review. Frontiers in Bioscience (Landmark Ed.). 27(2): 46.

[5] Yang, S.S., Ding, M.Q., He, L., Zhang, C.H., Li, Q.X., Xing, D.F., Cao, G.I., Zhao, L., Ding, J., Ren, N.Q. and Wu, W.M. 2021. Biodegradation of Polypropylene by Yellow Mealworms (*Tenebrio molitor*) and Superworms (*Zophobas atratus*) via Gut-microbe-dependent Depolymerization. Science of The Total Environment. 756: 144087.

[6] Corradini, F., Meza, P., Eguiluz, R., Casado, F., Huerta-Lwanga, E. and Geissen, V. 2019. Evidence of Microplastic Accumulation in Agricultural Soils from Sewage Sludge Disposal. Science of The Total Environment. 671: 411-420.

[7] Guo, M., Zhao, F., Tian, L., Ni, K., Lu, Y. and Borah, P. 2022. Effects of Polystyrene Microplastics on the Seed Germination of Herbaceous Ornamental Plants. Science of The Total Environment. 809: 151100.

[8] Li, X., Ullah, S., Chen, N., Tong, X., Yang, N., Liu, J., Guo, X., and Tang, Z. 2023. Phytotoxic Assessment of Dandelion Exposed to Microplastics Using Membership Function Value and Integrated Biological Response Index. Environmental Pollution. 333: 121933.

[9] Maity, S., Guchhait, R., Sarkar, M.B. and Pramanick, K. 2022. Occurrence and Distribution of Micro/Nanoplastics in Soils and Their Phytotoxic Effects: A Review. Plant, Cell & Environment. 45 (4): 1011-1028.

[10] Bosker, T., Bouwman, L.J., Brun, N. R., Behrens, P. and Vijver, M.G. 2019. Microplastics Accumulate on Pores in Seed Capsule and Delay Germination and Root Growth of the Terrestrial Vascular Plant *Lepidium sativum*. Chemosphere. 226: 774-781.

[11] Braun, M., Mail, M., Heyse, R. and Amelung, W. 2021. Plastic in compost: Prevalence and Potential Input into Agricultural and Horticultural Soils. Science of The Total Environment. 760: 143335.

[12] Accinelli, C., Abbas, H.K., Bruno, V., Khambhati, V.H., Little, N.S., Bellaloui, N., et al. 2022. Field Studies on the Deterioration of Microplastic Films from Ultra-thin Compostable Bags in Soil. Journal of Environmental Management. 305: 114407.

[13] Wang, J., Li, J., Liu, W., Zeb, A., Wang, Q., Zheng, Z., Shi, R., Lian, Y. and Liu, L. 2023. Three Typical Microplastics Affect the Germination and Growth of Amaranth (*Amaranthus mangostanus L.*) Seedlings. Plant Physiology and Biochemistry. 194: 589-599.

[14] Balestri, E., Menicagli, V., Ligorini, V., Fulignati, S., Galletti, A.M.R. and Lardicci, C. 2019. Phytotoxicity assessment of conventional and biodegradable plastic bags using seed germination test. Ecological Indicators 102, 569–580.

[15] Bao, Y., Pan, C., Li, D., Guo, A. and Dai, F. 2022. Stress response to oxytetracycline and microplastic-polyethylene in wheat (*Triticum aestivum L.*) during seed germination and seedling growth stages. Sci. Total Environ. 806: 150553.

[16] Sahasa, R.G.K., Dhevagi, P., Poornima, R., Ramya, A., Moorthy, P.S., Alagirisamy, B., Alagirisamy, B., Karthikeyan, S. 2023. Effect of Polyethylene Microplastics on Seed Germination of Blackgram (*Vigna mungo L.*) and Tomato (*Solanum lycopersicum L.*). Environmental Advances. 11: 100349.

[17] Schiavo, S., Oliviero, M., Chiavarini, S. and Manzo, S. 2020. Adverse Effects of Oxodegradable Plastic Leachates in Freshwater Environment. Environmental Science and Pollution Research. 27: 8586-8595.

[18] Pflugmacher, S., Sulek, A., Mader, H., Heo, J., Noh, J. H., Penttinen, O.P., Kim, Y., Kim., S. and Esterhuizen, M. 2020. The Influence of New and Artificial Aged Microplastic and Leachates on the Germination of *Lepidium sativum L.* Plants (Basel). 9(3): 339.

[19] Lian, Y., Liu, W., Shi, R., Zeb, A., Wang, Q., Li, J., Zheng, Z. and Tang, J. 2022. Effects of Polyethylene and Polylactic Acid Microplastics on Plant Growth and Bacterial Community in the Soil. Journal of Hazardous Materials. 435: 129057.

[20] Ge, J., Li, H., Liu, P., Zhang, Z., Ouyang, Z. and Guo, X. 2021. Review of the Toxic Effect of Microplastics on Terrestrial and Aquatic Plants. Science of the Total Environment. 791: 148333.

[21] Shi, R., Liu, W., Lian, Y., Wang, Q., Zeb, A. and Tang, J. 2022. Phytotoxicity of Polystyrene, Polyethylene and Polypropylene Microplastics on Tomato (*Lycopersicon esculentum L.*). Journal of Environmental Management. 317: 115441.

[22] Lian, J., Shen, M. and Liu, W. 2019. Effects of Microplastics on Wheat Seed Germination and Seedling Growth. Journal of Agro-Environment Science. 38(4): 737-745.

[23] Lee, T.Y., Kim, L., Kim, D., An, S. and An, Y.J. 2022. Microplastics from Shoe Sole Fragments Cause Oxidative Stress in a Plant (*Vigna radiata*) and Impair Soil Environment. Journal of Hazardous Materials. 429: 128306.

[24] Dey, A., Bagchi, B., Das, S., Basu, R. and Nandy, P. 2011. A Study on the Phytotoxicity of Nano Mullite and Metal-Amended Nano Mullite on Mung Bean Plants. Journal of Environmental Monitoring. 13: 1709.

[25] Uphoff, H., Hedrich, B., Strotmann, I, Arvand, M., Bettge-Weller, G. and Hauri, A. 2014. A Prolonged Investigation of an STEC-0104 Cluster in Hesse Germany, 2011 and Implications for Outbreak Management. Journal of Public Health. 22(1): 41-48.

[26] Watanebe, Y., Ozassa, K., Mermin, J.H., Griffin, P.M., Masuda, K., Imashuku, S. and Sawada, T. 1999. Factory Outbreak of *Escherichia coli* O157:H7 Infection in Japan. Emerging Infectious Diseases. 5(3): 424-428.

[27] NACMCF. 1999. Microbiological Safety Evaluations and Recommendations on Sprouted Seeds. International Journal of Food Microbiology. 52: 123-153.

[28] Parera, V., Parera, C.A. and Feresin, G.E. 2023. Germination and Early Seedling Growth of High Andean Native

Plants under Heavy Metal Stress. Diversity. 15(7): 824.
[29] Li, Y., Chen, P., Tang, Y., Yang, Y., Zhou, C., Bu, J., and Zhong, S. 2024. Microplastics in Water: A Review of Characterization and Removal Methods. Sustainability. 16(10): 4033.
[30] Seidensticker, S., Grathwohl, P., Lamprecht, J., and Zarfl, C. 2018. A Combined Experimental and Modeling Study to Evaluate pH-dependent Sorption of Polar and Non-polar Compounds to Polyethylene and Polystyrene Microplastics. Environmental Sciences Europe. 30(1): 30.
[31] Atlas Scientific. 2024. Understanding the Relationship between pH and Electrical Conductivity. https://atlas-scientific.com/blog/relationship-between-ph-and-conductivity/.
[32] Parhad, N. M., and N. U. Rao. 1984. Effect of pH on Survival of *Escherichia coli*. Journal of Water Pollution Control Federation. 56(9): 980-986.
[33] Environmental Protection Agency (EPA). 2021. *E. coli* (*Escherichia coli*). https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_e.-coli.pdf.
[34] El Kayal, W., Darwiche, L., Farhat, Y.A. Hdeib, M., AlJardaly, R., Shbaro, M. and Iskandar, C.F. 2024. Agricultural Mitigation Strategies to Reduce the Impact of Romaine Lettuce Contamination. Plants. 13(17): 2460.
[35] Robbens, J., Dardenne, F., Devriese, L., De Coen, W. and Blust, R. 2010. *Escherichia coli* as a Bioreporter in Ecotoxicology. Applied Microbiology and Biotechnology. 88: 1007-1025.
[36] Bouaicha, O., Tiziani, R., Maver, M., Lucini, L., Miras-Moreno, B., Zhang, L., Trevisan, M., Cesco, S., Borruso, L. and Mimmo, T. 2022. Plant Species-Specific Impact of Polyethylene Microspheres on Seedling Growth and the Metabolome. Science of The Total Environment. 840: 156678.
[37] Liu, L., Zhang, Y., Fu, W., Liu, X., Wang, Q., Tanveer, M. and Huang, L. 2021. Microplastic Stress in Plants: Effects on Plant Growth and Their Remediations. Frontiers in Plant Science. 14: 1226484.
[38] Zhang Y., Fu, W., Liu, X., Wang, Q., Tanveer, M. and Huang, L. 2023. The Impact of Microplastic Concentration and Particle Size on the Growth of *Pisum sativum* Sprouts. Agronomy. 14(5): 923.
[39] Panda, S. and Behera, R. 2024. Microplastic Accumulation in Agricultural Soils - Impacts on Crop Microbiomes and Soil Health. Journal of Agriculture and Livestock Farming. 1(4): 1-4.
[40] Jiang, M., Zhao, W., Liang, Q., Cai, M., Fan, X., Jiang, Y., Li, T., Wang, Y., Peng, C. and Liu, J. 2024. Advances in Physiological and Ecological Effects of Microplastic on Crop. Journal of Soil Science and Plant Nutrition. 24: 1741-1760.
[41] Dodd, G.L. and Donovan, L.A. 1999. Water Potential and Ionic Effects on Germination and Seedling Growth of Two Cold Desert Shrubs. American Journal of Botany. 86(8): 1146-1153.
[42] Ludwiczak, A., Osiak, M., Cárdenas-Pérez, S., Lubińska-Mielińska, S. and Piernik, A. 2021. Osmotic Stress or Ionic Composition: Which Affects the Early Growth of Crop Species More? Agronomy. 11(3): 435.
[43] Bartakova, I., Kummerova, M., Mandl, M. and Pospisil, M. 2001. Phytotoxicity of Iron in Relation to Its Solubility Conditions and the Effect of Ionic Strength. Plant and Soil. 235: 45-51.
[44] Li, X., Ullah, S., Chen, N., Tong, X., Yang, N., Liu, J., Guo, X. and Tang, Z. 2023. Phytotoxic Assessment of Dandelion Exposed to Microplastics Using Membership Function Value and Integrated Biological Response Index. Environmental Pollution. 333: 121933.
[45] Kollárová, K., Henselová, M. and Lišková, D. 2005. Effect of Auxin and Plant Oligosaccharides on Root Formation and Elongation Growth of Mung Bean Hypocotyls. Plant Growth Regulation. 46: 1-9.