Received: 4 September 2023 | Revised: 2 January 2024 | Accepted: 8 January 2024

DOI: 10.1002/tqem.22184

RESEARCH ARTICLE

WILEY

Determination and quantification of microplastics in compost

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Funding information
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Abstract

Although microplastics (MPs) in solid organic waste have been intensively studied, the presence of MPs in organic fertilizer and their potential as new emerging pollution to environment because of their use in agriculture has not been explained completely. Therefore, the identification and quantification of MPs in commercially available compost is important. This study aimed to estimate the quantity of MPs in commercial composts. The characteristics of MPs (shape, color, size, and type of polymers) were identified. This study found that MPs in commercial compost samples were found, reaching up to 160 particles/200 g of compost with various colors (blue, black, red, yellow, and white). The identified MPs had various sizes (0.1–1 mm) and shapes (81.8% fragment, 16.2% fiber, and 2% filament). The findings of this study are very important and significant to inform community and policymakers regarding the presence of MPs in commercial compost, hence, their intensive use in agriculture must be controlled and careful.

KEYWORDS
compost, environmental pollution, microplastics, organic fertilizers

1 | INTRODUCTION

Microplastics (MPs) are tiny plastic particles less than 5 mm (0.2 in.) in diameter (Sathish et al., 2022). MPs are one of the main contributors to environmental pollution (Bao et al., 2022). Due to their very small size, MPs can easily be carried by water and wind (Aini et al., 2022); thus, they can massively spread in environments such as wetlands, lakes, seas, and soil (Deng et al., 2023; Nirmala et al., 2023). The emergence of MPs has received considerable critical attention (Alimi et al., 2022). In farming soils, the presence of MPs is associated with the use of organic fertilizers (Zhang, Li, et al., 2022). MPs were found in conventional agricultural land (Piehl et al., 2018), resulting from the application of compost made from organic trash, livestock manure, and biosolids (Hernández-Arenas et al., 2021). Annual use of compost reaching up to 4.07 million tons in agriculture and horticulture in Germany is estimated to contribute 817 tons of MPs (Blanke, 2020).

Previous studies reported that MPs were detected in many compost products, including municipal biowaste compost (Prosenc et al., 2021), solid organic waste and organic compost (Zhou et al., 2023), and rural domestic waste (RDW) compost (Gui et al., 2021). Moreover, total amount of MPs in the composting field located in northeastern Spain was 10—30 particles/g at five sampling sites (Edo et al., 2022). In addition, 6433 ± 751 particles/kg MPs of green compost were found in the organic wastes of Kaunas and Alytus regional waste management centers in Lithuania (Sholokhova et al., 2022). Another research indicated that the long-term implementation of compost on maize fields in China contaminated 3.63 × 109 to 4.99 × 109 particles/ha (Zhang, Wang, et al., 2022), whereas maize is usually used as a food source for human consumption. These studies show that MPs strongly negatively affect the agricultural environment. Thus, MPs in agricultural and compost environments become interesting and important to inspect.

The properties of MPs in organic fertilizers are mostly influenced by their feedstocks (Rynk et al., 2022; Tang, 2023). The production of fertilizers, which mostly involves aerobic composting and anaerobic digesting, significantly impacts the enrichment of MPs (Zhang, Li, et al., 2022). In several aerobic decomposition studies, the addition of plastics resulted in fragmentation, which was linked to a substantial increase in particle number (Andrady et al., 2022; Chamas et al., 2020; Dimassi et al., 2022; Liao & Chen, 2021). Furthermore, MPs can generate strong free radical reactions in the highly oxidizing environment of aerobic decomposition (Xing et al., 2022). Hydrolysis is added during anaerobic fermenting, resulting in the brittleness and fragmentation of plastics; however, the resultant plastic fragments do not completely vanish (Hale et al., 2022). The presence of MPs in the compost has the potential to cause soil contamination (Vithanage et al., 2021). Previously, MPs were reported in compost from various countries, such as southeastern Mexico and southern China (Pironti et al., 2021). It was revealed that it is possible that MPs can be consumed by humans at the same time as the consumption of agricultural products (Zhou et al., 2023). MPs can infiltrate the human body via inhalation and consumption of food and beverages. Consuming food contaminated with MPs can cause various immune system-related issues, including immunosuppression, immune activation, and aberrant inflammatory responses. In addition, it can cause stress, reproductive toxicity, and developmental problems (Wu et al., 2022). Consequently, additional research is required to investigate the potential effects of MPs on the environment and human health through more rigorous clinical investigations.

Enhancing soil fertility may be achieved using organic fertilizers, as opposed to chemical fertilizers, due to their higher organic carbon, nitrogen, and phosphorus content. Organic fertilizers are generally composed of animal dung or bacterial wastes, which are abundant in organic materials and plant nutrients, hence contributing to improved soil quality (Schwinghammer et al., 2020). However, these feedstocks frequently contain MPs (Rynk et al., 2022) and MPs experience a sequence of conditioning, breakdown, and processing steps that typically concentrate and enrich them in the final products. But threshold values for plastics are frequently absent, particularly for MPs concentrations in organic fertilizer (Braun et al., 2021).

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Insufficient data is describing the composition and distribution of MPs in organic fertilizers, limiting our understanding of the contributions of these fertilizers to soil pollution. In addition, the use of these fertilizers varies significantly across provinces based on their unique environmental and economic conditions. There is an imperative need for additional research to characterize the MPs in organic fertilizers and control MPs contamination on farmlands. Thus, this study aimed to estimate the abundance of MPs in compost. The findings of this study are crucial to inform community and policy makers regarding the presence of MPs in commercial compost. Therefore, intensive use of compost containing MPs in agriculture must be minimized.

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2 | MATERIALS AND METHODS

2.1 | Materials

The compost used in this study was purchased from a local agricultural store (Stand Flamboyan, Pamekasan City, East Java province, Indonesia), and the compost brand was Kompos Organik. Chemical, 30% hydrogen peroxide (H_2O_2) (UN2014), was purchased from Kimia Farma company (Pamekasan City, East Java province, Indonesia). Classification of compost with multiple raw materials with a complex composition (a mixture of manure and agricultural waste) often contains additional ingredients.

Stainless with a mesh size of 5 mm is used to first filter compost samples by removing leaves, roots, and other larger debris to facilitate the extraction of MPs. Filter stainless, 300 mesh for second stage filtration used to be carried out after the sample is centrifuged for the identification stage. Distilled water is used to rinse the sample after it has been placed in a strong acid solution. This research also uses glass equipment, including glass beakers, measuring flasks, pipettes, glass bottles, vials bottles, glass stirrers, Petri dishes, and mortar. It also uses aluminum foil for containers in drying ovens and covers for glassware. Some label paper is also needed for sample indication. A strong acid solution, H_2O_2, breaks down and releases organic matter from the MPs samples (Aini et al., 2023; Putri et al., 2023).

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leaves, roots, and other larger debris to facilitate the extraction of MPs. A strong acid solution, H_2O_2, breaks down and releases organic matter from the MPs samples

similar to those of organic-rich soil and livestock manure

2.2 | Sampling method

The instrument used to collect the 50 g sample compost was a glass beaker with a diameter of 9 cm, and then first filtered using a stainless with a mesh size of 5 mm and second filtered using a stainless with a mesh of 300. Four multiple raw materials (same brand) used in this study were taken, namely sample 1 (C1), sample 2 (C2), sample 3 (C3), and sample 4 (C4). This brand of compost was chosen because it is often used by farmers, which is very crucial since MPs have the potential to contaminate the soil and be absorbed by roots. Another selection criterion is the availability of compost which can be easily purchased. The remained materials on the filter were mixed with 30% H_2O_2 solution and dried at room temperature for 1 h. The solution of H_2O_2 was used to degrade any organic residue so that targeted MPs could be freely from organic residue before observing by using a microscope. The method applied for MPs extraction from the compost sample was an adjustment of the method for extracting MPs from organic-rich environmental matrices (Zhang, Li, et al., 2022). The physicochemical properties of the organic fertilizers were similar to those of organic-rich soil and livestock manure, so the dried and sieved organic fertilizer samples were subjected to sequential flow separation and density flotation extraction for the identification of MPs (Corradini et al., 2021).

The method applied for MPs extraction from the compost sample was an adjustment of the method for extracting MPs from organic-rich environmental matrices. The physicochemical properties of the organic fertilizers were

2.3 | MPs identification

Rinse water from a stainless filter, 300 mesh is lowered into a Petri dish, for MPs identification. The microscope with 40× magnification used in this study was Trinocular Digital Ways Dw-tc-y Black Edition, Kaisi Rotation LED Lamp K-D056 for microscope, and 51-megapixel microscope camera connected to Samsung Smart TV 32. Under the microscope, the sample was counted while its shape, size, and color were carefully observed. Following, the MPs samples were analyzed using fourier transform infrared spectroscopy (FTIR) Thermo Scientific Nicolet iS10 to characterize a type of polymer. The selection of the FTIR was made due to its simplicity as a method for identifying the type of polymer by examination of its vibrational spectrum, which exhibits distinctive characteristics for each polymer type (Xu et al., 2019).

3 | RESULTS AND DISCUSSION

3.1 | Number of MPs

The presence of MPs and their characteristics observed in this study is presented in Exhibit 1. The total number of MPs found was 160 particles while in compost. It is noted that the MPs in C1, C2, C3, and C4 the MPs found were 58 particles/50 g, 48 particles /50 g, 41 particles/50 g, and 13 particles/50 g, respectively. Surprisingly, the number of MPs in the C1 compost was found to be the highest compared to the others. It is important to first understand the raw materials for composting to determine MP contamination in the compost.

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The findings of this study support previous works that also observed the presence of MPs in compost produced by using different materials, which are municipal biowaste compost (Prosenc et al., 2021), municipal organic waste, and garden and greenhouse waste (van Schothorst et al., 2021). The average contaminations of MPs in compost were

EXHIBIT 1 The presence of microplastics (MPs) in compost.

Sample	Shape	Number of MPs	Color	Size (mm)
C1	Fragment (52)	58	Blue, black, red, white, and yellow	0.1–1
	Fiber (6)			
C2	Fragment (31)	48	Black, red, and white	0.1–1
	Fiber (14)			
	Filament (3)			
C3	Fragment (35)	41	Black, red, yellow	0.1–1
	Fiber (6)			
C4	Fragment (13)	13	Red, yellow	0.06–0.6

EXHIBIT 2 Comparison of the characteristics of microplastics (MPs) in compost in Indonesia and other countries.

Sampling	Number/ weight	Size (mm)	Shape	Polymer	Reference
Compost, Indonesia	13–58/50 g	0.1–1	Fragment, fiber, and filament	Polyethylene terephthalate (PET)	Present study
Compost, Spain	5–20/g	<5	Fragment and fiber	Polyethylene, polystyrene, polyester, polypropylene, and polyvinyl chloride	(Edo et al., 2022)
Compost, China	2400 ± 358/kg	0.05–5	Fiber, film	Polyester, polypropylene, and polyethylene	(Gui et al., 2021)
Compost, China	2–34/50 g	–	Fiber and fragment	Polypropylene and polyethylene	(Wu et al., 2021)
Compost, China	1500–6615/kg	0.5–1	Fragment, fiber, film	Polypropylene, polyethylene, and polyethylene terephthalate	(Zhang et al., 2023)

2800 ± 616 particles kg^{-1} and 1253 ± 561 particles kg^{-1} of compost for municipal organic waste and from garden and greenhouse waste, respectively. An alternative study also reported that MPs were identified in chicken manure , sludge , and domestic waste composts with the number of particles of 14,720 ± 2468, 8600 ± 1428, and 11,640 ± 3565 particles kg^{-1}, respectively (Zhang, Wang et al., 2022).

3.2 | Size of MPs

Sizes of MPs particles found in this study are shown in Exhibit 1. The current study found that identified MPs in compost have various sizes ranging from 0.06 to 1 mm. At C1, C2, and C3 MPs sizes measure around 0.1–1 mm, meanwhile, at C4, the sizes are 0.06–0.6 mm. It is witnessed that the bigger MPs are found at C1, C2, and C3, compared to C4. It is noted that smaller MPs have higher toxicity because they can easily be absorbed by the roots, impacting the inhibited nutrient uptake, reducing biomass, and contaminating fruit (Roy et al., 2022).

Exhibit 2 presents a comparison with other prior efforts. The size of MPs observed in the previous investigation conducted on compost exhibited a range covering from 0.1 to 5 mm. For instance, in the study conducted in Spain (Edo et al., 2022), MP sizes are not larger than 5 mm, while in China, the sizes are 0.05 to 5 mm (Gui et al., 2021), and 0.5–1 mm (Zhang et al., 2023). The latest findings on MPs contamination originating from compost and its subsequent use in soil brought attention to the possible consequences of micropollutant transfer from compost (Le et al., 2023). Specifically, MPs accumulation in soils has been shown to have an impact on three key markers of soil health, namely, soil microbiological, chemical, and physical characteristics (Chia et al., 2022; Zhang, Wang et al., 2022). Therefore, the high-risk MPs sizes for the plant, especially for the root, photosynthetic pigments, and biomass are below 3 μm.

3.3 | Shape of MPs

The identification of MPs shapes obtained from compost is provided in Exhibit 3. Generally, there are three shapes of MPs, fragment, fiber, and filament. In compost, 81.8% of fragments, 16.2% of fiber, and 2% of filament were found. Similarly, several previous studies have reported that fragments and fibers are the predominant MPs morphologies in agricultural soil, thereby introducing this form of MPs into arable soil (Liu et al., 2018) and indicating that organic fertilizers contributed to the contamination of farmland soils with MPs (Yu, Song et al., 2021).

Previous work reported that the fiber shape of MPs was observed in municipal solid waste compost (Edo et al., 2022) and RDW compost

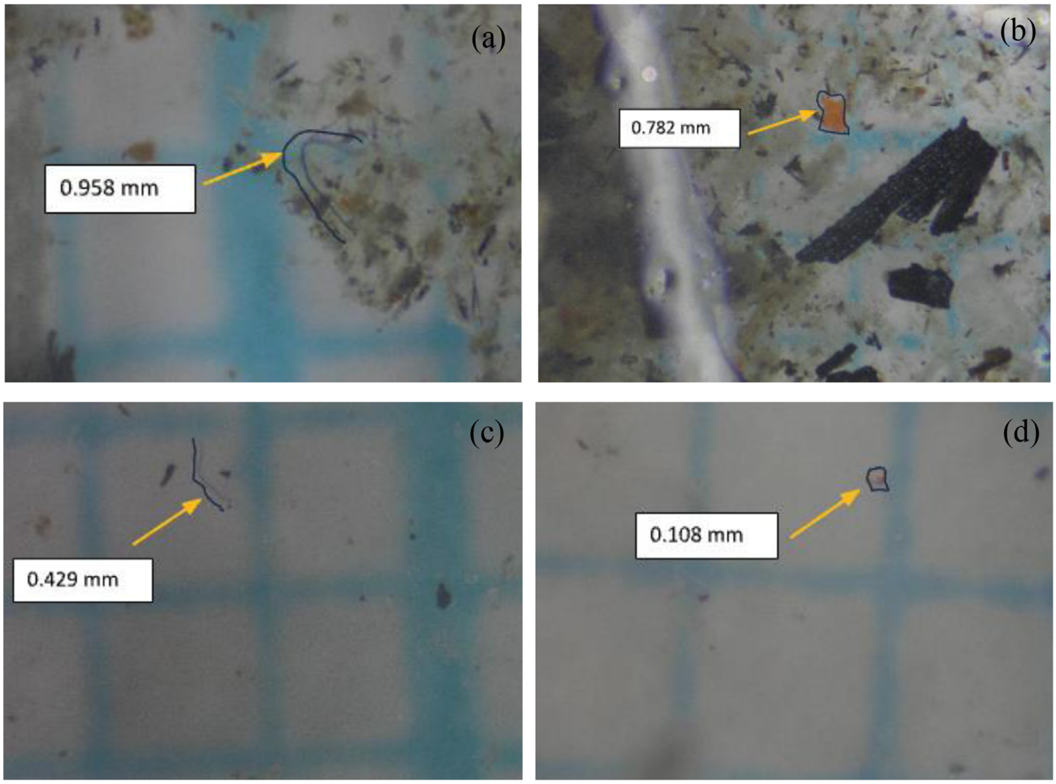

EXHIBIT 3 Microplastics (MPs) shapes of (a) fiber and blue, (b) fragment and yellow, (c) fiber and black, and (d) filament and white-red. [Color figure can be viewed at wileyonlinelibrary.com]

(Gui et al., 2021). The fragment shape of MPs particles was also found in livestock and poultry manure compost (Wu et al., 2021). It indicated that fiber and fragment shapes are easy to find in compost. Mostly, in composting, fragment shape was generated by the breakdown of larger pieces of MPs. Plastic fragmentation from larger size to smaller size, MPs, can occur in aerobic and anaerobic composting processes and other processes depending on environmental conditions (Zafiu et al., 2023). However, most of the MPs in organic fertilizers consisted of finer particles. Plastics are extremely difficult to degrade, and the production cycle of organic fertilizers (40 days) is frequently inadequate. Thus, MPs fragmentation during the production of organic fertilizer may be as significant as projected, and 0.1–1 mm plastic dominated the samples.

MPs in compost had various shapes due to the different sources of plastic waste that contributed to compost production. The shape of MPs in compost was influenced by the mechanical crushing, anaerobic, and aerobic processes involved in composting (Premarathna et al., 2023). The dominant shapes of MPs in compost samples were found to be fragments, fibers, and films (Sholokhova et al., 2022). These shapes were likely derived from plastic bags, packaging materials, and other plastic waste that entered the composting process (Vithanage et al., 2021). The presence of different shapes of MPs in compost highlighted the diverse types of plastic waste that were being processed and the potential for these MPs to contaminate the soil when the compost was used as a fertilizer (Schwinghammer et al., 2020).

3.4 | Color of MPs

Red was the most dominant color of the MPs found in compost, that is, 30, 29, and 8 particles, respectively, in C2, C3, and C4. In C1, the most dominant is yellow with 38 particles detected while in C3 is yellow with 16 MPs particles second dominant. The color of MPs found in the previous study was white and blue (Yu, Zhang et al., 2021). In China, Yang, Kang et al. (2022) witnessed MPs in transparent and white. Meanwhile, white, blue, and red were the colors of MPs found in Indonesia (Aini et al., 2023; Putri et al., 2023). Also in Brazil, the colors of MPs were transparent, red, and blue (Dantas Filho et al., 2023).

Color may also represent the presence of MPs in compost. Considering that plastics can degrade under environments with rich organic matter presented in Exhibit 3, MPs were categorized into five primary hues: red, yellow, blue, black, and white. These color categories were generally compatible with those reported by a wide number of research (Bertoldi et al., 2021; Grbić et al., 2020). Considering that plastics readily age in high organic matter conditions (Xiao et al., 2021). Yu, Zhang et al. (2021) also reported white MPs were the most prevalent in samples of fertilized soil, followed by blue MPs. The color of MPs may indicate their origin and the presence of contaminants, their colors can transform because of degradation and residence time in the terrestrial (Campanale et al., 2023). For example, white MPs are abundant in agriculture and orchards, which frequently require organic fertilizers (Chai et al., 2020). Furthermore, the color of MPs is closely related

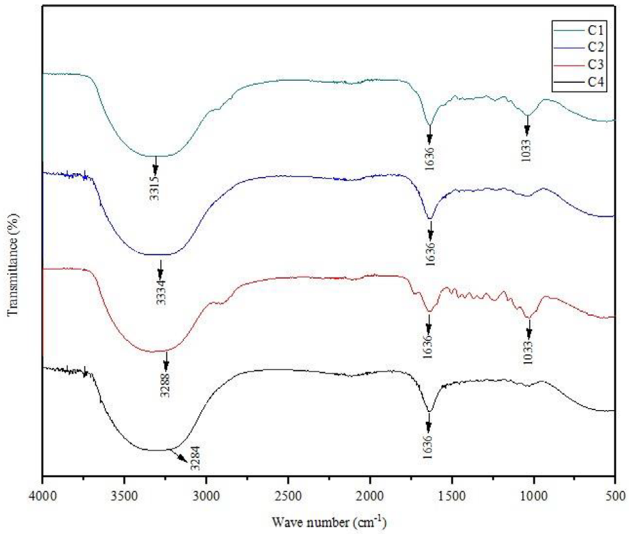

EXHIBIT 4 Fourier transform infrared spectroscopy (FTIR) spectra for microplastics (MPs) detected in C1, C2, C3, and C4 (identified as polyethylene terephthalate for all). [Color figure can be viewed at wileyonlinelibrary.com]

to the contaminants on their surface. For example, black MPs are frequently associated with higher quantities of organic contaminants (Crawford & Quinn, 2017) than other MPs colors. Clear MPs had significant effects on the environment. It posed a threat to the ecological balance, water environment, food sustainability, and safety, ultimately impacting human health (Oleksiuk et al., 2023).
Materials such as anthraquinone, which could be produced quickly, had color intensity, and were transparent, were used to create yellow. Anthraquinones were frequently used in polymers including polypropylene (PP), polystyrene (PS), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polymethyl methacrylate/acrylic, polycarbonate, polybutylene terephthalate, and polyethylene terephthalate (PET). In addition to yellow MPs, red MPs were found. Anthraquinone, which had medium to high color intensity and transparency, was the most common red pigment. This pigment was typically incorporated into PS, PP, LDPE, and HDPE polymers. Triphenylmethane, azo, anthraquinone, perylene, and indigoid were interesting and widely used categories of dyes, which were also the main focus of the study by (Fleischmann et al., 2015) because these compounds had a broad range of applications.

3.5 | Polymer type

The chemical components and arrangement of macromolecules determine the physical characteristics of polymeric materials. Numerous spectroscopic techniques are currently available to examine these properties, and FTIR-spectroscopy is one of the most popular techniques due to its versatility in determining composition; consequently, the polymer type can be determined by comparing the FTIR spectra of the polymer to the library data. Exhibit 4 shows the FTIR spectra of all compost-analyzed MPs.

It is interesting to note that the FTIR spectra for MPs from compost at local agriculture stores (see Exhibits 4 and 5) have similar characteristics. For samples C1, C2, C3, and C4 (see Exhibit 4), a peak in wavenumber 3316 cm^{-1}, 1636 cm^{-1}, and 1033 cm^{-1}; 3336 cm^{-1}, 1636 cm^{-1}, and 1031 cm^{-1}; 3288 cm^{-1}, 1636 cm^{-1}, and 1033 cm^{-1}; and 3284 cm^{-1}, 2119 cm^{-1}, and 1031 cm^{-1} are related OH group (hydroxyl), stretching of C = O of carboxylic acid group, terephthalate group ($OOCC_6H_4$-COO), methylene group, and vibrations of the ester C-O bond, respectively, and they are the typical characteristics of PET (Kankanige & Babel, 2020; Mei et al., 2022; Pereira et al., 2017; Putri et al., 2023).

Exhibit 4 demonstrates the polymer composition of MPs in the compost from a local agricultural store. This study found that there is one type of polymer, namely PET. PET is the most often used polymeric polyester. PET polymers are extensively used in the manufacture of textiles, clothes, and wool (Islam et al., 2020). It was hypothesized that the PET in the compost came from village household garbage (Gui et al., 2021). PET is a clear polymer with excellent mechanical qualities and dimensional stability under varied loads (Wang et al., 2018). Moreover, PET offers excellent gas barrier qualities and chemical resistance. PET is a material with good physical qualities and recycling capability (Asensio et al., 2020). It accounts for about 18% of all polymers manufactured globally. More than 60% of its output is for synthetic fibers and bottles, which accounts for around 30% of the worldwide demand for PET (Padhan et al., 2013).

3.6 | Possible impacts of MPs on compost for human health

Generally, MPs entered the human body concluded three main routes, namely—ingestion (via food and water), inhalation (indoor and outdoor air), skin contact (via personal care products, dust, and textiles), and dermal contact (Blackburn & Green, 2022; Prata et al., 2020). Human contact with MPs could cause physical and chemical toxic effects. The type of particle and individual susceptibility might have influenced the adverse effects. Their physical effects might have had varying impacts, including increased inflammatory response, oxidative stress, cellular damage, and size-related toxicity (Prata & Dias-Pereira, 2023). Therefore, this section was organized based on the health effects caused by MPs in compost.

The acceptance of MPs in plants has been detected and plastic particles are especially absorbed on root hairs (Azeem et al., 2021). Furthermore, MPs can observe on terrestrial plant surfaces, be absorbed, and transported by plants, and accumulate in the edible parts of plants, leading to the possibility of enhancement and transmission through the food chain and threatening human health (Li et al., 2020; Wang et al., 2022). However, the fundamental mechanism remains unclear. To calculate the impact of MP on humans, measurements were made of particles that might have entered the body through agricultural food according to the scenario described by Nor et al. (2021). This model probabilistically simulated MPs concentrations in the gut, body tissue, and feces, allowing validation against empirical data. From the findings of Aydın et al. (2023) in detecting MP in most consumed fruits

EXHIBIT 5 Comparison of the Fourier transform infrared spectroscopy (FTIR) data in compost and other studies.

Sampling	Wave number (cm^{-1})			Polymer	Reference
Compost, Indonesia	3.315 3.288	1.636 1.636	1.033 1.033	Polyethylene terephthalate (PET)	Present study
PET Composites, Brazil	3.323	1.713	1.089	PET	(Pereira et al., 2017)
Salt, Indonesia	3.352 3.336	2.915 2.915	1.692 1.643	PET	(Putri et al., 2023)
Bottled water, Thailand	2.982	2.906	1.285	PET	(Kankanige & Babel, 2020)
Tea filter bags, China	2.885	2.852	1.295	PET	(Mei et al., 2022)

and vegetables from Turkey, total 210 particles (2.9 ± 1.6 particle g^{-1}) MPs found in eight fruits and vegetables samples. If the main route of exposure to humans was through food consumption, then the estimated intake was 39,000—52,000 plastic particles/person/year (Mercogliano et al., 2020). Meanwhile, the average intake level of MPs (1—5000 μm) was 553–883 particles/capita/day (Nor et al., 2021). While definitive evidence linking MPs consumption to human health was lacking, studies suggested that MPs could have provoked immune and stress responses, induced reproductive and developmental toxicity, and increased the risk of chronic inflammation and neoplasia (Yang, Man et al., 2022). Further research was needed to fully understand the potential implications of MPs in compost on human health.

4 | CONCLUSION

The objective of this was to estimate the number and characteristics of MPs in compost. The results indicated that the total number of MPs was 160 particles/200 g in compost. This study found that MPs were identified in compost with the colors of red (43.75%), yellow (38.13%), black (8.75%), white (8.75%), and blue (0.62%). The size MPs ranged from 0.06 to 1 mm and the shape of MPs was dominated by fragments (81.87 %), fiber (15.36%), and filament (1.88%). FTIR analysis clarified that the types of polymers were PET. In general, this study has successfully identified the presence of MPs, and findings of this study are significant particularly to improve community awareness about MPs present in compost. Future research must be performed to develop a simple MPs removal in compost.

ACKNOWLEDGMENTS

The authors are grateful for all the resources provided by the Universitas Islam Madura to support this study. Collaboration from Universitas Muhammadiyah Malang is highly appreciated.

CONFLICT OF INTEREST STATEMENT

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.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Iswahyudi, I., Widodo, W., Warkoyo, W., Sutanto, A., Garfansa, M. P., & Septia, E. D. (2024). Determination and quantification of microplastics in compost. *Environmental Quality Management*, 1–10. https://doi.org/10.1002/tqem.22184