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REVIEW ARTICLE

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Vermicomposting as a potential strategy for microplastic reduction in organic waste: mini review

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Abstract
Microplastics have emerged as one of the most concerning pollutants increasingly detected in organic waste streams, including household waste, agricultural residues, and fecal sludge. The presence of microplastics in recycled waste products, such as compost, introduces a new threat to soil quality and food safety. One promising biological approach for mitigating microplastic contamination is vermicomposting a process that involves the decomposition of organic waste facilitated by earthworms. This review aims to evaluate the potential of vermicomposting in reducing microplastic contamination, as well as its effects on earthworm health and the quality of the resulting compost. The methodology involved an extensive literature review of articles published in Scopus-indexedjournals between 2020 and 2025. The review findings indicate that earthworm activity can contribute to the physical fragmentation of microplastics, stimulate microbial degradation within the gut, and potentially alter the chemical structures of specific polymers, such as polypropylene (PP) and high-density polyethylene (HDPE). However, the presence of microplastics also exerts negative effects, including the induction of oxidative stress, reduced earthworm biomass, decreased survival rates, and alterations in compost quality, particularly the carbon-to-nitrogen (C/N) ratio. These findings suggest that although vermicomposting is not yet fully capable of completely degrading microplastics, it holds potential as an early-stage technology for managing organic waste contaminated with microplastics. Further research is required to gain a deeper understanding of the underlying biological mechanisms and to develop more efficient and safe integrated vermicomposting systems for sustainable agricultural practices.

KEYWORDS
Earthworm, Microplastic, Vermicomposting, Vermicompost

1. INTRODUCTION

The reduction of microplastics through natural processes represents a crucial strategic step in addressing the escalating environmental pollution crisis (Amesho et al., 2023). Microplastics, which originate from the degradation of larger plastic materials as well as everyday consumer products, have been found to contaminate soil (Ekalaturrahmah et al., 2025; Garfansa et al., 2024b), water bodies (Garfansa et al., 2024b; Garfansa et al., 2024c; Setyobudi et al., 2024b; Setyobudi et al., 2024c), and even the human food chain (Garfansa et al., 2024a; Iswahyudi et al., 2024a; Iswahyudi et al., 2025c; Iswahyudi et al., 2024c; Mamun et al., 2023; Putri et al., 2023; Setyobudi et al., 2024a). The utilization of natural processes, such as microbial biodegradation, enzymatic breakdown, and biological interventions through organisms like earthworms, offers an environmentally friendly and sustainable alternative (Iswahyudi et al., 2025a; Iswahyudi et al., 2025b). Unlike chemical or thermal degradation methods, which often require high energy input and may generate toxic by-products. natural processes do not produce harmful residues. Additionally, biological degradation can occur under relatively mild environmental conditions, making it feasible for application in agricultural fields, residential areas, and integrated waste management systems (Mor & Ravindra, 2023). By leveraging the inherent strength of ecosystems, natural processes can also promote soil microbial balance and contribute to overall soil quality improvement. This approach aligns with the principles of the circular economy and organic agriculture, which are increasingly gaining global attention. In the long term, adopting natural methods for microplastic reduction holds the potential to minimize pollutant accumulation in food sources and groundwater systems.

The vermicomposting technique offers several advantages over other methods for reducing microplastics in organic waste streams. One of its primary benefits is its environmentally friendly nature, as this process utilizes living organisms specifically earthworms that operate naturally without the need for chemical additives or high energy input, as required in pyrolysis or thermal combustion processes (Ahmed et al., 2019; Hernandez et al., 2021). Earthworms not only facilitate the degradation of organic matter but also physically fragment microplastics within their digestive systems, thereby increasing the potential for further microbial degradation (Cherian et al., 2025; Meng et al., 2023). Additionally, the earthworm gut serves as a microhabitat for diverse microbial communities capable of producing enzymes that may modify or reduce the structural complexity of plastic polymers (Khaldoon et al., 2022b). Unlike chemical or thermal treatments that often generate harmful gaseous emissions, vermicomposting enhances soil structure and improves the quality of the resulting compost (Chatterjee et al., 2020). This technique is also cost-effective, scalable from household-level to industrial agricultural applications and does not require sophisticated equipment. The compost produced through vermicomposting possesses high agronomic value and can serve as an organic fertilizer, supporting sustainable agricultural practices (Ducasse et al., 2022). Moreover, vermicomposting significantly reduces overall waste volume while simultaneously treating microplastic contaminants within a single, integrated process (Seetasang & Iwai, 2025). Given these advantages, vermicomposting is considered one of the most promising eco-based technologies for managing organic waste contaminated with microplastics. However, despite its promising potential, there is still limited comprehensive understanding regarding the effectiveness, mechanisms, and limitations of vermicomposting in reducing microplastic contamination. Therefore, a systematic review is urgently needed to evaluate and consolidate the existing scientific evidence on this topic.

The purpose of this review is to comprehensively explore the potential of vermicomposting techniques in reducing microplastic contamination in organic waste, as well as to assess their impacts on earthworm health and compost quality. The novelty of this review lies in its focus on the mechanisms of microplastic fragmentation and the early-stage biodegradation potential driven by the biological activity of earthworms and their gut-associated microorganisms. Additionally, this review integrates findings from various recent studies published between 2020 and 2025, which, although still limited in number, indicate a rapidly growing research interest in this field. The significance of this review is to provide a scientific foundation for the development of ecology-based technologies with practical applications in both agricultural and household waste management systems as sustainable solutions to the escalating microplastic pollution crisis. By emphasizing both the advantages and challenges associated with vermicomposting, this review is expected to stimulate further advanced research and to inform the formulation of environmental policies that promote the safe, efficient, and eco-friendly management of organic waste contaminated with microplastics.

The purpose of this review is to comprehensively explore the potential of vermicomposting techniques in reducing microplastic contamination in organic waste, as well as to assess their impacts on earthworm health and compost quality

2. RESEACRH METHODOLOGY

This review was compiled based on a extensive literature review method on various scientific publications that discuss the role of vermicomposting in the reduction of microplastics in organic waste. Data collection was conducted by searching articles from the international scientific database Scopus, which was selected because it is one of the largest and most reputable databases for high-quality, peer-reviewed scientific literature. The keywords used in the search included "microplastics", "vermicomposting", "earthworms", "organic waste", "biodegradation of microplastics", and "plastic pollution mitigation". The keywords were combined using Boolean operators AND and OR to ensure a comprehensive search. The exact search string used was ("microplastics" AND "vermicomposting") AND ("earthworms" OR "organic waste" OR "biodegradation of microplastics" OR "plastic pollution mitigation").The articles selected for this review were published between 2020 and 2025, as research focusing on microplastic reduction through vermicomposting has significantly emerged and expanded during this period. In addition to primary articles in the form of experimental research results, review articles, environmental organization reports, and relevant policy documents are also reviewed. Each publication is analyzed quantitatively and qualitatively to identify key findings, methodological approaches, and remaining research gaps. The data collected are then categorized into several main themes, namely: the characteristics of microplastics in organic waste, the basic principles of vermicomposting, the potential mechanisms of microplastic reduction, as well as the challenges and prospects for the future development of this technique.

3. RESULT AND FINDING

3.1 Microplastics in organic waste

Table 1 presents a summary of findings from various studies regarding the presence of microplastics in different types of solid organic waste. This table includes quantitative data, specifically the abundance of microplastics per unit mass, as well as the types of polymers identified in each waste category. The general pattern of the compiled data demonstrates that microplastics are widely distributed across multiple forms of organic waste, including domestic solid waste, food waste, fecal sludge, and grocery store waste. The reported abundance of microplastics varies significantly, ranging from the lowest concentration of 5 items/g

(Edo et al., 2022) to the highest concentration of 220,000 items/kg (Zhou et al., 2023) in solid organic waste.

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The most frequently detected polymers include polypropylene (PP), polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). Some studies reported the predominance of specific polymer types; for example, Rashti et al. (2023) observed that microplastics in biosolid sludge were dominated by PET (41.6%) and PE (23.6%), while Edo et al. (2022) found that 94% of microplastics consisted of PE, PS, polyester, PP, PVC, and acrylic. The highest abundance of microplastics was recorded by Zhou et al. (2023) in solid organic waste, while the lowest was reported by Edo et al. (2022). Additionally, PP and PE consistently appeared as the most frequently reported polymers, suggesting the dominance of single-use plastics within organic waste streams. Overall, the table illustrates that microplastics have contaminated almost all types of organic waste, whether derived from domestic, industrial, or agricultural sources, with notable variations in concentration and polymer type depending on the waste origin and study location. These findings highlight the urgent need to develop effective mitigation strategies, such as vermicomposting, to reduce microplastic contamination in agricultural and environmental systems.

Table 1. Microplastic in organic waste.

No.	Material	Findings	References
1	Municipal solid organic waste	Abundance 17407 ± 1739 items/kg and polymer type PET 5%, PP 14-50%, HDPE 21-27%, PS 17-27%, LDPE 17-27%	(Sholokhova et al., 2022)
2	Municipal solid organic waste	Amount 5–20 items/g and polymer type 94% of polyethylene, polystyrene, polyester, polypropylene, polyvinyl chloride, and acrylic polymers	(Edo et al., 2022)
3	Solid organic waste	Abundance 220 ×103 items/kg and polymer type PP and PE	(Zhou et al., 2023)
4	Food waste, livestock manure, and sludge	Abundance 2000-25000 items/kg and polymer type PP, PE and PET	(Tan et al., 2022)
5	Sewage sludge biosolids	Abundance 1000–3100 items/kg and polymer type polyethylene 23.6% and polyethylene terephthalate (41.6%).	(Rashti et al., 2023)
6	Rural domestic waste	Abundance 2400 ± 358 items/kg and polymer type polyester, polypropylene (PP) and polyethylene (PE)	(Gui et al., 2021)
7	Municipal, industrial, grocery store biowaste	Abundance 944 ± 586 items/g and polymer type polyethylene terephthalate	(Risku et al., 2025)
8	Municipal solid waste	Abundance 49.000 ± 7.000 & 62.000 ± 6.000 items/kg and polymer type polyethylene and polypropylene	(Okori et al., 2025)
9	Food waste	Abundance 12.3 items/g and polymer type PP, PET, and PE	(Mohammadi et al., 2023)
10	Municipal solid organic waste	Amount 160 items/200g and polymer type polyethylene terephthalate	(Iswahyudi et al., 2024d)
11	Biowaste	Abundance 12.3 items/g and polymer type PP, PET, PVC, PS, and PE	(Steiner et al., 2023)

3.2 Vermicomposting procces inorganic material

Figure 1 illustrates the detoxification mechanisms of heavy metals and metalloids within both the extracellular (ES) and intracellular (IS) systems of earthworms. When solid organic material contaminated with heavy metals enters the earthworm's digestive system, inorganic compounds undergo an initial digestive process in the extracellular system. The resulting products, comprising heavy metal fragments (MES) and soft metals or metalloids (mES), are subsequently transported across cell membranes by specific membrane proteins that are specialized for the transport of heavy metals, soft metals, and metalloids (Ratnasari et al., 2023).

When solid organic material contaminated with heavy metals enters the earthworm's digestive system, inorganic compounds undergo an initial digestive process in the extracellular system

Upon entering the intracellular system, two distinct detoxification pathways are activated depending on the type of contaminant. For heavy metals such as copper (Cu), nickel (Ni), and zinc (Zn), earthworms synthesize metallothionein (Me), a cysteine-rich, metal-binding protein. Metallothionein binds to heavy metal fragments (MES) through a chelation process, forming the MeMES complex. In contrast, for soft metals and metalloids such as cadmium (Cd) and arsenic (As), glutathione (GSH) a tripeptide composed of glutamine, glycine, and cysteine stimulates the production of phytochelatins (PC). Phytochelatins then bind to mES, forming the PCmES chelation complex (Ratnasari et al., 2021). Both the MeMES and PCmES complexes play critical roles in neutralizing toxic metals, which subsequently accumulate in the intestinal tissues and chloragogen cells of the earthworm (Hussain et al., 2021). This detoxification pathway is an essential component of the earthworm's biological defense system against toxic metal exposure and holds significant potential for application in bioremediation technologies, including vermicomposting. The adaptive capacity of membrane transport proteins, along with the presence of bioactive molecules such as metallothionein and phytochelatins, highlights the vital role of earthworms as effective agents in reducing heavy metal pollution in the environment.

This detoxification pathway is an essential component of the earthworm's biological defense system against toxic metal exposure and holds significant potential for application in bioremediation technologies, including vermicomposting

Figure 1 provides a detailed description of the detoxification mechanisms employed by earthworms, particularly Eisenia fetida, to neutralize heavy metals and metalloids through two primary pathways: the production of metallothionein (Me) for heavy metals and the synthesis of phytochelatins (PC) for soft metals and metalloids. In this process, metals undergo initial digestion within the extracellular system (ES), are subsequently transported across cellular membranes via specialized membrane proteins into the intracellular system (IS), and are eventually bound by metal-binding proteins to form complexes such as MeMES and PCmES. These complexes serve to neutralize the toxic effects of metals on worm cells and body tissues. When associated with microplastics, although microplastics differ structurally and chemically from heavy metals, similar biological interactions can occur within the earthworm's body. Microplastics ingested alongside organic matter during the vermicomposting process also undergo physical fragmentation within the digestive tract, particularly in the extracellular system, such as the intestinal lumen. Here, microplastics experience abrasion, mechanical breakdown, and interactions with digestive enzymes and symbiotic microorganisms.

Microplastics ingested alongside organic matter during the vermicomposting process also undergo physical fragmentation within the digestive tract, particularly in the extracellular system, such as the intestinal lumen

Although microplastics do not form chelation complexes like metals, the resulting smaller fragments may be absorbed into the intestinal tissues and distributed throughout the earthworm's body, where they can interact with membrane proteins or lipid bilayers through physical and chemical adsorption. Additionally, microplastics may bind to xenobiotic-binding proteins that, in some cases, function analogously to phytochelatins and metallothioneins, although they are not specific to metals. Some studies have indicated that earthworms can secrete bioactive enzymes and compounds capable of modifying microplastic surfaces, thereby enhancing their susceptibility to microbial degradation within the digestive tract (Ragoobur et al., 2022). Therefore, the metal detoxification mechanisms observed in earthworms can serve as an analogous framework for understanding how these organisms process other foreign microparticles, including microplastics. Although microplastics do not undergo chemical chelation like metals, they may be managed within the earthworm body through processes such as adsorption, absorption, physical fragmentation, encapsulation in fecal pellets, or even transfer to chloragogen tissues as part of a biological adaptation to non-metallic contaminants (Iswahyudi et al., 2024b). Integrating the understanding of both metal detoxification and microplastic processing in earthworms is crucial for advancing vermicomposting as an effective microplastic mitigation strategy in agricultural environments.

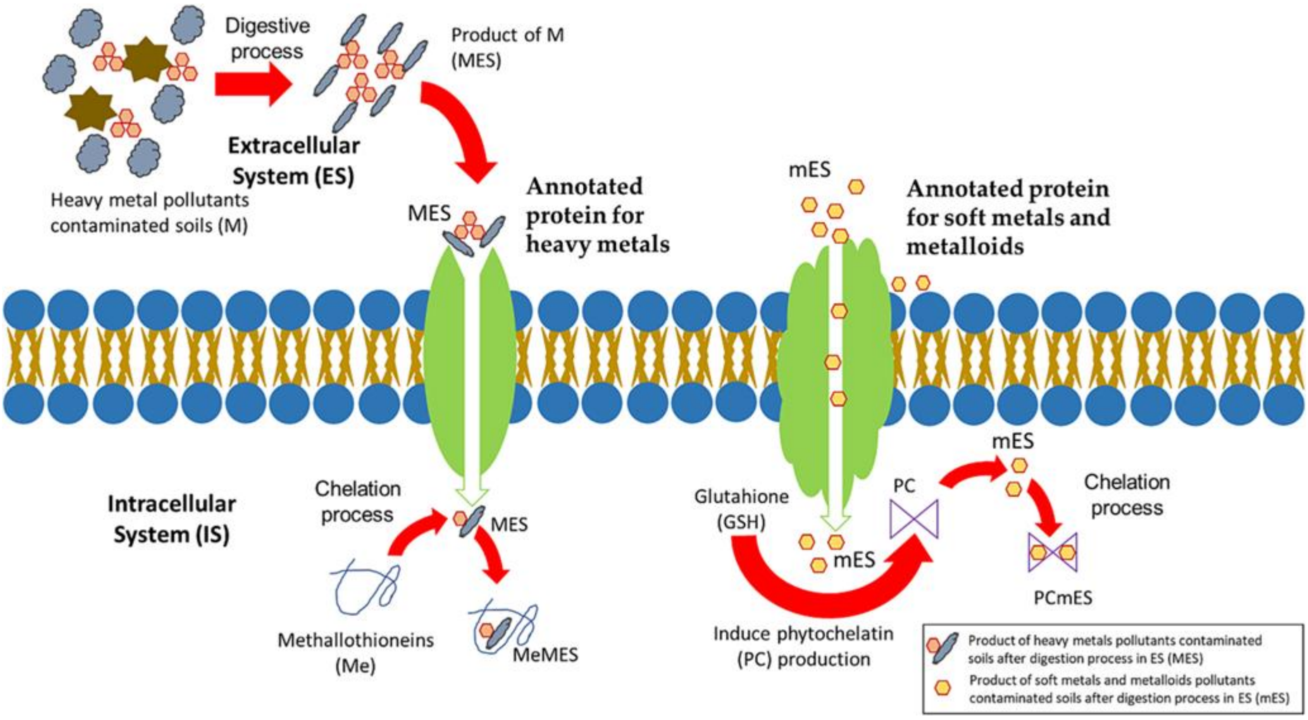

Figure 1. Schematic diagram showing the decomposition of inorganic materials in the extracellular and intracellular systems during the vermicomposting process mechanism (Ratnasari et al., 2023).

3.3 The potential of vermicomposting in microplastic reduction

The trend in the number of research publications related to microplastics in the vermicomposting process from 2020 to 2025 is presented in Figure 2. In 2020, two publications were recorded; however, this number decreased to only one publication in 2021. A notable surge occurred in 2022, with a total of six publications, indicating a growing interest among researchers in this area. This trend slightly declined in 2023 with five publications but increased again to six publications in 2024. Interestingly, in 2025, a significant decrease was observed, with only one publication recorded as of mid-year, which is likely due to the incomplete data for the current publication cycle. Overall, the graph illustrates a significant increase in research interest over the past five years, highlighting the rising urgency and global concern for developing biological solutions to microplastic pollution. The increase in the number of studies also suggests that this topic is gaining recognition as a promising interdisciplinary research field, particularly in relation to organic waste management and sustainable environmental practices.

Interestingly, in 2025, a significant decrease was observed, with only one publication recorded as of mid-year, which is likely due to the incomplete data for the current publication cycle

Table 2 provides a summary of the research findings related to the influence of microplastics in the vermicomposting process. This table compiles nine studies that evaluate the impact of microplastics on earthworm physiology, composting performance, and the potential for microplastic reduction or biodegradation during vermicomposting. In general, the data reveal two key aspects: (1) the negative effects of microplastics on earthworm health and productivity, and (2) the potential role of earthworms in facilitating the degradation of microplastics, although this capacity remains limited.

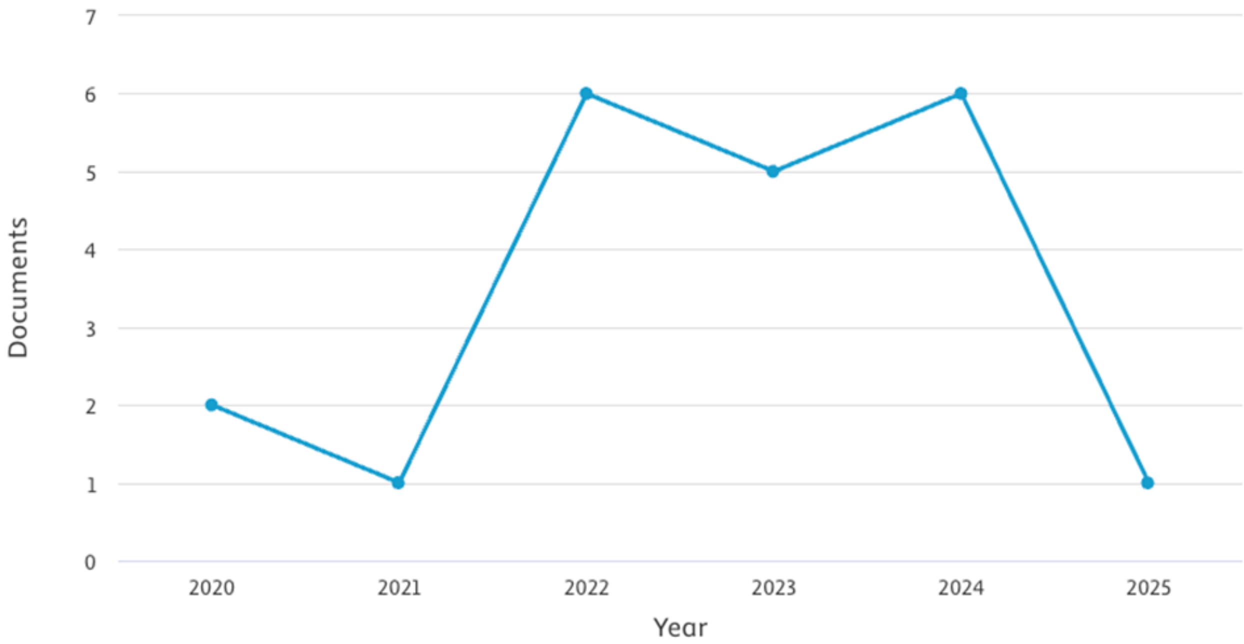

Figure 2. Microplastic research trends using vermicomposting by Scopus database.

Table 2. Effect of microplastics in vermicomposting process.

No.	Research Object	Findings	References
1	Earthworms to enhance decaying of biodegradable plastics	Earthworms can increase the biodegradation rate of biodegradable polymers by creating optimal habitats for gut microbial proliferation	(Hernandez et al., 2020)
2	Effect of microplastics in sludge	High addition of microplastics results in oxidative stress and neurotoxicity in earthworms	(Zhong et al., 2021)
3	Impact of microplastics on Eudrilus eugenia worms	Polylactic acid (PLA) microplastics cannot be degraded in the short term, but have the potential to degrade in the long term	(Khaldoon et al., 2022a)
4	Impact of vermicompostic on municipal sludge waste	Gizzard milling and biodegradation can lead to an increase in microplastics in municipal sludge waste vermicompost	(Cui et al., 2022)
5	Reduction of microplastics in sewage sludge by vermicomposting	There was a reduction in the absorbance band for microplastic alkane groups by 11% for PP and 34% for HDPE, indicating the possibility of biodegradation	(Ragoobur et al., 2022)
6	Impact of microplastics on Eisenia fetida worms	Oxidative stress occurs in E. fetida worms but does not depend on the size or plastic processed	(Marco et al., 2023)
7	Impact of microplastics on vermicompost	Microplastics have a significant impact on the C/N content ratio in vermicompost	(Iswahyudi et al., 2024b)
8	Impact of microplastics on earthworm	Microplastics reduce the weight of earthworms, but there is no impact on hatching and lowers the C/N ratio content	(Bhat et al., 2024)
9	Impact of microplastics on vermicomposting	Microplastics significantly reduced earthworm survival rates by 10.51% and 14.52%, respectively	(Iswahyudi et al., 2025d)

Several key studies have reported that microplastics can induce oxidative stress and neurotoxicity in earthworms (Marco et al., 2023; Zhong et al., 2021), reduce the carbon-to-nitrogen (C/N) ratio in vermicompost (Bhat et al., 2024; Iswahyudi et al., 2024b), and significantly decrease earthworm survival rates (Iswahyudi et al., 2025d). Additionally, reductions in earthworm body weight have also been observed, although this effect does not appear to impact egg hatching rates (Bhat et al., 2024). These findings suggest that the presence of microplastics in vermicomposting substrates may disrupt the biological balance of the composting system.

Nevertheless, some studies have also highlighted the potential positive contributions of earthworms in facilitating microplastic biodegradation. For example, Hernandez et al. (2020) reported that earthworms can create optimal conditions for the proliferation of gut-associated microbial communities that are involved in the degradation of biodegradable polymers. Ragoobur et al. (2022) further observed a reduction in the absorption bands of microplastic alkane groups by 11% for polypropylene (PP) and 34% for high-density polyethylene (HDPE), indicating the potential for microplastic biodegradation during the vermicomposting process. Additionally, Cui et al. (2022) suggested that mechanical grinding within the earthworm gizzard, combined with microbial biodegradation, may increase the apparent abundance of microplastic particles in vermicompost, likely due to the fragmentation of larger particles into smaller microplastic fragments. Thus, although microplastics have been demonstrated to exert negative effects on earthworm physiology and compost quality, several studies also suggest that the biological activity of earthworms and their associated microbial communities may support microplastic fragmentation and possibly initiate early stages of biodegradation. This potential provides valuable opportunities to develop vermicomposting as an integrated microplastic mitigation strategy in environmental management, although careful monitoring and management are essential to prevent unintended ecological consequences.

4. PROSPECTS AND RECOMMENDATIONS

Vermicomposting holds significant promise as a biological approach for reducing microplastic contamination in organic waste, particularly within the framework of sustainable agriculture. This process leverages the physiological and biological activities of earthworms to decompose organic matter while simultaneously promoting the fragmentation and physical modification of microplastics. Several studies have demonstrated that earthworms, such as Eisenia fetida, can create microenvironments that support the proliferation of plastic-degrading microorganisms, while also contributing directly to the mechanical breakdown of microplastic particles within their digestive systems. Moreover, changes in microplastic characteristics observed after passage through the earthworm gut suggest that vermicomposting may serve as a critical initial step in the subsequent biodegradation of microplastics.

However, several challenges must be addressed to enable the effective implementation of this technique. The toxicological impacts of microplastics on earthworm health, the reduction of the carbon-to-nitrogen (C/N) ratio in compost, and the decline in earthworm survival rates are among the critical issues requiring careful consideration. Additionally, the absence of standardized methods for assessing microplastic reduction in vermicomposting systems presents a significant barrier to accurately comparing the effectiveness across studies. Based on these findings, several recommendations can be proposed: (1) further research is necessary to elucidate the molecular and microbiological mechanisms involved in the digestion and transformation of microplastics by earthworms; (2) the development of more microplastic-tolerant earthworm strains and compost-associated microbial communities; (3) the implementation of integrated vermicomposting systems combined with supporting technologies such as bioaugmentation or thermal/physical pretreatment; and (4) the establishment of standardized microplastic analysis protocols in compost to ensure the safety of vermicompost application in agricultural settings. With more targeted research efforts and innovative technological advancements, vermicomposting has substantial potential to become an integral part of long-term ecological solutions aimed at mitigating the impact of microplastics on agricultural environments and food systems.

5. CONCLUSION

Vermicomposting represents a promising biological approach for mitigating microplastic contamination in organic waste. This process not only facilitates the decomposition of organic matter but also promotes the fragmentation and physicochemical transformation of microplastics through the physiological activity of earthworms and the symbiotic microorganisms residing within their digestive systems. Several studies have reported a reduction in both the number and size of microplastics during the vermicomposting process, along with preliminary indications of biodegradation for specific types of plastics such as polypropylene (PP) and high-density polyethylene (HDPE). However, the presence of microplastics has also been shown to exert adverse effects on earthworm physiology, including oxidative stress, body weight loss, and decreased survival rates, as well as negatively impacting the quality of the compost produced. Therefore, despite its considerable potential, the implementation of vermicomposting as a microplastic reduction strategy requires a cautious, scientifically grounded approach that accounts for environmental factors, microplastic characteristics, and system operational conditions. Further in-depth and comprehensive research is essential to optimize this technique as an environmentally sustainable solution for organic waste management and to position vermicomposting as part of a broader global strategy to address microplastic pollution in agricultural ecosystems.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Muzna Ardin Abdul Gafur: Writing – original draft, Conceptualization. Puneet Kumar Gupta: Conceptualization, Supervision, Methodology. Iswahyudi Iswahyudi: Writing – review & editing, Supervision. Roy Hendroko Setyobudi: Data curation.

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ETHICS APPROVAL

No ethical approval was needed for this study.

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CONFLICT OF INTEREST

The author declares no conflicts of interest.

DATA AVAILABILITY STATEMENT

The review did not report any data.

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