Proceedings of ICEGEE 2026 Symposium: Sustainable Environment and Ecology: Supporting a Sustainable Environment for Birds
DOI: 10.54254/2753-8818/2026.BH32602

Ecological Impact of PVC Microplastics on Microbial Communities in Wet Waste Treatment Systems

Xinyan Xu
School of Environmental and Chemical Engineering, Shanghai University, Shanghai, China
2480118727@shu.edu.cn

Abstract. The ecological impact of PVC microplastics on the microbial community in the wet waste treatment system mainly comes from three joint effects: particle persistence, microbial colonization of particle surfaces, and the continuous release of chemicals such as additives under high humidity, strong microbial activity and fluctuating physicochemical conditions. Compared with the relatively inert polyolefins, PVC contains chlorine-containing main chains and often contains plasticizers and stabilizers, so it is more likely to trigger physicochemical stress caused by particle surface interaction and additive release at the same time. This review focuses on the occurrence, transport, and fate of PVC in the process of pretreatment, aerobic composting and anaerobic digestion, focusing on surface aging, preferential microbial colonization, and the differences between attached communities and bulk-phase microbial communities. Studies have shown that the impact of PVC microplastics on wet waste treatment systems is not a single exposure effect, but the result of surface aging, interface colonization, additive release and co-pollutant coupling. These processes ultimately alter microbial community structure, functional organization, and overall treatment performance, particularly by disrupting key metabolic pathways involved in methane production. In general, PVC is more likely to be enriched in the solid phase and persists throughout the treatment process; its additive leaching is obviously time-dependent and strongly affected by environmental conditions. This suggests that microbial communities are more likely to experience chronic stress than transient disturbance. Future research should focus on how PVC properties and additive release interact under real operating conditions, and further clarify the mechanisms by which they affect microbial community structure, function, and treatment performance.

Keywords: PVC, microplastics, wet waste treatment, additive leaching, microbial communities

1. Introduction

The widespread use of plastic products has caused microplastics to accumulate in the environment and further exacerbated ecological problems [1]. At present, microplastics have been widely present in a variety of environmental media and have shown potential ecological toxicity [2,3]. As a heterogeneous particle, microplastics have obvious differences in polymer type, particle size and morphology. They also adsorb organic pollutants and metals, thus affecting the distribution of pollutants and their potential biological effectiveness [2,4]. Generally, microplastics can be divided into two categories: one is primary microplastics with a particle size of less than 5 mm, and the other is secondary microplastics formed by weathering and crushing of larger plastic objects [5]. Among common polymers, polyvinyl chloride (PVC) deserves particular attention because its chlorine-containing main chain and additive-rich composition make it more complex and uncertain in environmental transformation, chemical release and ecological risk assessment [2,6].

Wet waste treatment is a key link in urban solid waste management, and it is also an important process for microplastics to enter, decompose and redistribute [7]. Wet waste has a high water content and is rich in degradable organic matter. At present, it is mainly treated by aerobic composting and anaerobic digestion, both of which rely on core microbial communities [8,9] . Microplastics derived from PVC can enter the wet waste system with contaminated food waste. Their sources mainly include packaging bags, disposable plastic products, packaging residues, and synthetic fibers released during treatment and cleaning [10-12]. After entering the processing system, these microplastics may gradually accumulate along the process of material and energy transformation and remain in prolonged contact with core microbial communities. On the one hand, they can serve as substrates for microbial attachment and biofilm formation. On the other hand, PVC containing additives may also cause physicochemical stress through the release of additives, thus changing the habitat, community structure and treatment performance of microbial functional units [13,14]. Studies have shown that such effects can be further manifested as changes in compost maturity, fluctuations in methane-related performance, and changes in some risk characterization indicators [15,16].

In the wet waste treatment system, PVC is particularly worthy of attention, because its particles can act as carriers of microbial attachment and biofilm formation. At the same time, the additives may continue to be released during the treatment process, which has a long-term impact on the surrounding microenvironment [17]. Under high humidity and acidic conditions, the additives in PVC are more likely to seep out, and some chlorine-containing components may also be gradually released, thus interfering with key processes such as organic matter degradation, humification and methane production [4]. However, the direct evidence from the wet waste treatment unit is still limited, and the relationship between PVC release behavior and microbial community response and its main driving factors still need to be further systematically evaluated.

Therefore, this review addresses four interrelated issues: first, how PVC microplastics enter wet waste treatment systems and migrate, accumulate, and persist during composting and anaerobic digestion; second, how the physicochemical properties of PVC, together with high moisture and acidic conditions, influence additive migration and leaching; third, how PVC microplastics affect microbial attachment, biofilm formation, differentiation between particle-attached and bulk-phase communities, and key processes such as organic matter transformation and methane production; and fourth, how PVC interacts with antibiotics, metals, and other coexisting pollutants to generate combined stress and thereby affect process performance and ecological risk.

2. Sources and environmental behavior of microplastics in wet waste treatment systems

2.1. Primary sources of PVC microplastics

Due to the high content of organic matter in wet waste and the complex composition of the matrix, the presence of microplastics in wet waste is attracting increasing attention [18]. The microplastics that enter the wet waste are mostly secondary debris formed by the crushing of large plastic products, among which the sources related to packaging dominate [19,20]. In addition to the main packaging materials, label film, composite packaging, shrink film and other composite layer materials will also produce a large number of microplastics and are more likely to break during collection and processing [20,21]. Recycling cannot completely avoid this problem, because the sorting and reprocessing process itself will also produce debris residues, which may then re-enter the urban garbage stream [21]. Among them, labels and films containing PVC are particularly difficult to separate completely, so they are more likely to stay in the wet waste collection link in the form of fine debris and enter the follow-up processing unit [22].

2.2. Physicochemical characteristics of PVC microplastics

Microplastics in wet waste treatment systems come from a variety of polymers, and their distribution between the water phase and the solid phase is mainly affected by the physicochemical properties of the polymer, as shown in Table 1 [18]. PVC is a halogenated polymer with a chlorine content of about 57%, so it has a high density and is easier to settle in wet media such as leachate, slurry and digestate [23]. Therefore, PVC is more likely to accumulate in the bottom sludge, digested sludge and compost residue, thus enhancing its durability in the treatment system and increasing the likelihood of its occurrence in treatment products [23].

The risk brought by PVC is not only particle retention. Because PVC products usually contain plasticizers and stabilizers that are non-covalently bound to polymers, these additives may gradually migrate and leach out during use, disposal and treatment [17]. Under the conditions of high humidity and changing pH and temperature, PVC will not only be retained in the solid phase, but also may continue to release chemicals to the surrounding environment [18]. The long-term leaching of phthalate plasticizers has been confirmed, and this process is significantly affected by environmental factors [24,25]. In the process of anaerobic digestion, the additives released by PVC microplastics may also inhibit the methane production process, indicating that it not only affects the function of microorganisms, but also interferes with the process performance [26]. Based on the above evidence, PVC should be regarded as a priority type of microplastic in the wet waste treatment system, because it has both the risk of particle accumulation and additive release [27].

Table 1. Physicochemical properties and environmental fate of common microplastics in wet waste treatment systems

Polymer	Density ($g\cdot cm^{-3}$)	Main chemical feature	Buoyancy / fate in wet systems	Dominant environmental behavior	Key refs
PE	0.91–0.96	Hydrocarbon polymer (–C–C–)	Tends to float or suspend	Physically persistent; strong sorption of hydrophobic organic compounds	[2,4,28,29]
PP	~0.90	Hydrocarbon polymer	Floating / suspended	Like PE; relatively inert chemically	[2,28]
PS	1.04–1.06	Aromatic polymer	Partial settling	Brittle; prone to fragmentation; biofilm formation	[2,30]
PET	1.30–1.40	Ester-containing polymer	Settling	Chemically stable; limited additive release	[2,31]
PVC	1.30–1.45	Chlorinated polymer (C–Cl)	Rapid settling and accumulation	Dual physical–chemical behavior; additive leaching	[23,24,27]

3. Physicochemical properties and additive release behavior of PVC microplastics

3.1. Chemical structure and environmental stability of PVC

The persistence and ecological impact of PVC microplastics in wet waste treatment systems are mainly related to their stable chemical skeleton and additive-rich composition, as shown in Table 2 [17]. Commercial PVC is usually not a single material, but a composite system composed of resins, plasticizers and stabilizers. Since these additives are mostly introduced through physical mixing rather than fixed in the form of covalent bonds, they are easier to migrate under suitable conditions [17]. The wet waste treatment process provides a favorable environment for this process. Adequate water, pH changes and temperature fluctuations caused by organic acid formation will promote the diffusion and leaching of additives, so that the microbial community is continuously exposed to low-concentration chemicals [18].

In the wet waste treatment system, the migration potential of PVC additives will be further enhanced under specific environmental conditions. High moisture, pH fluctuations and temperature changes together promote the release of additives. High moisture provides the necessary medium for leaching, which can act as a solvent and promote the diffusion of additives within the polymer. The organic acid produced in the early stage of treatment will reduce the pH of the system, which may not only promote the hydrolysis of ester plasticizers, but also accelerate the aging of the PVC surface, which is conducive to the further release of additives. At the same time, the thermal action of the high-temperature stage of compost will improve the mobility of additive molecules and the activity of the polymer chain segment, thus accelerating the leaching process.

Table 2. Typical additives in PVC microplastics, release-promoting conditions, and potential ecological targets

Additive category	Representative chemicals	Key conditions promoting release in wet waste treatment systems	Potential ecological targets and effects	Key references
Plasticizers	Phthalate esters (PAEs, e.g., DEHP, DMP)	High moisture content; acidic conditions caused by organic acid accumulation; elevated temperature during composting; penetration of dissolved organic matter (DOM)	Inhibition of methanogenic archaea and hydrolytic–acidogenic bacteria; disturbance of anaerobic digestion stability	[24,25,27,31,32]
Thermal stabilizers	Metal-based stabilizers containing Pb and Cd (traditional formulations)	Surface aging and crack formation; enhanced solid–liquid contact; long-term immersion	Chronic toxicity to microbial metabolism; potential heavy metal exposure	[17,23,33]
Other additives	Bisphenols (e.g., BPA)	High moisture content; pH fluctuation; mechanical disturbance	Suppression of methane production; alteration of microbial metabolic pathways	[26,32]

3.2. Migration and accumulation behavior of PVC microplastics in wet waste treatment systems

In the collection and pretreatment stage, PVC mainly enters wet waste in the form of debris or film, and its sources mainly include plastic bags, packaging residues and cable plastics. Due to its high density, PVC is more likely to be retained in the solid phase of wet waste, thus reducing its removal efficiency in the sorting and dehydration process and promoting its accumulation in subsequent biological treatment units [23,24,33]. In addition, PVC residues have also been detected many times in compost products, indicating that these particles may enter the farmland or soil environment with the compost and become a secondary input source [12,15].

In the process of anaerobic digestion, PVC tends to persist and accumulate in the sludge phase. Because it is difficult to degrade rapidly in anaerobic environment, PVC can be retained in the digested sludge for a long time [13]. In addition, PVC particles are also easy to bind to organic matter and microorganisms and are wrapped in flocculents and particles, which will further prolong their residence time in the reactor [14]. Therefore, compared with feed sludge, PVC in digested sludge usually has a higher detection frequency and content [13,18].

The retention of PVC in the solid phase often occurs at the same time as the leaching of additives. Research shows that PVC microplastics can continuously release phthalate plasticizers for a long time, and the leaching strength is obviously affected by environmental conditions [24,25]. In a wet waste treatment system with high humidity and changing physical and chemical conditions, this means that PVC particles may continue to release additives to the liquid phase even if they remain in the solid phase [17]. Anaerobic digestion experiments further show that these leachable additives are related to the decline in methane production, indicating that the release of additives may interfere with the methane production process and reduce the process performance of the system [26].

4. The impact of PVC microplastics on microbial communities during wet waste treatment

4.1. Effects of PVC microplastics on microbial community structure and core functional microbial communities

Microbial communities dominate organic matter conversion and methane generation during composting and anaerobic digestion, so the interference of PVC microplastics may further affect the process performance and the structure of related functional communities. Compared with relatively inert polyolefin microplastics, PVC is more likely to cause physicochemical stress, because its formula often contains migrable additives, which can be gradually released during processing [24].

As shown in Figure 1, the methane production in the anaerobic digestion system usually decreases with the increase of the PVC microplastic load. This phenomenon is usually associated with chemicals released by PVC, which may interfere with hydrolysis, acid production and methane production processes [26]. As operation proceeds, PVC particles and their leachates may continue to influence microbial interactions and functional differentiation, and promote the gradual reorganization of the community structure, indicating that its impact is closer to cumulative changes than transient disturbances [13].

PVC additives provide a continuous source of chemical exposure, which helps to explain the response of microbial communities. Long-term studies show that PVC microplastics can continuously release phthalate plasticizers, indicating that they can be a stable source of soluble pollutants for a long time [24,27]. In the process of wet waste treatment, the high humidity environment and the changing pH and temperature will prolong the exposure time of low-dose additives, which may gradually inhibit the key functional group and change the community structure [17]. At the same time, the leaching strength is also affected by system factors such as hydrodynamic conditions and matrix composition, so he effects of PVC may therefore vary substantially across treatment conditions [25].

The study of single additives also supports this mechanism. Even in the absence of microplastic particles, some plastic additives can interfere with anaerobic digestion and microbial metabolism [32]. This shows that the impact of PVC microplastics is not only related to the particles themselves, but also to the continuous leaching of additives. Therefore, PVC microplastics can reasonably be regarded as a combined physical–chemical stressor [17].

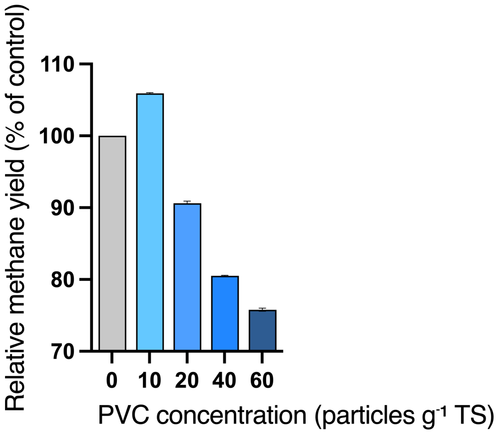

Figure 1. Dose-dependent effects of polyvinyl chloride (PVC) microplastics on methane production during anaerobic digestion. Methane yield is expressed as the percentage relative to the control without microplastics. Low PVC loading (10 particles g^{-1} TS) slightly promoted methane production, whereas higher concentrations (≥20 particles g^{-1} TS) caused a progressive inhibition. Error bars represent standard deviations as reported in the source study [26]

4.2. Microbial-associated behavioral characteristics of PVC microplastics in wet waste treatment systems

PVC microplastics can persist as solid-phase particles in wet waste treatment systems for extended periods and continue to interact with the microbial community. Because it exists in the form of particles and is not dispersed in the system in a dissolved state, it will change the attachment opportunities and spatial organization of microorganisms in the reactor [17,24].

Many studies have shown that microplastic surfaces often serve as preferential colonization interfaces for microorganisms, and its attached communities are different from those in the surrounding matrix [34]. Compared with free-living or floc-associated communities, such surface-attached communities are usually more selective, with differences in taxonomic composition and functional gene profiles [14]. For PVC, metagenomic evidence further shows that some functional groups and local metabolic characteristics can be enriched within particle-associated microenvironments and may deviate from the overall level of the system [35].

In addition to taxonomic changes, the impact of PVC microplastics on microorganisms is also reflected in the spatial redistribution of microbial functions. Anaerobic digestion research shows that resistance-related genes and other functional markers will be redistributed in different microenvironments. This distribution feature is closely related to the microbial community attached to the surface of microplastics, indicating that such particles can change the microbial microenvironment in the reactor [36]. At the same time, the PVC surface can also adsorb coexisting pollutants such as antibiotics, metals and hydrophobic organic matter, further strengthening the local interaction between particles and the microbial activity interface [4,37].

When the processed product enters the receiving environment, such particle-related effects may continue. Soil research shows that microplastic input can change the composition and functional characteristics of microbial communities, and further affect biogeochemical processes such as carbon and nitrogen cycling [15]. At the same time, the biofilm formed on the surface of microplastics provides a structured interface that can change the spatial relationship between local microorganisms. In some sludge systems, this change has been found to be related to changes in resistance-related signals and potential host distribution patterns [36].

5. PVC microplastics-induced composite stress effects and their ecological risk implications

5.1. Interactions between coexisting pollutants and microorganisms

In wet waste treatment systems, PVC microplastics usually coexist with antibiotics, metals and organic pollutants, so microbial communities are usually subjected to multiple stressors rather than a single effect. The presence of microplastics will change the contact interface and exposure level between pollutants and microorganisms during anaerobic digestion, which may further enhance the ecological impact and process risks under common pollution conditions [38]. The effects caused by different types of microplastics cannot be attributed only to adsorption, because their surface properties, aging state and environment will all affect the results. Therefore, understanding type differences and environmental dependence is the key to explaining the differences in different research conclusions [39]. On this basis, resistance-related indicators can be used as supplementary signals to reflect changes in microbial risks, as shown in Figure 2.

For PVC, its composite effect can be understood mainly from two aspects. On the one hand, PVC can enrich pollutants in the solid-phase microenvironment and increase the chance of microbial contact with these pollutants; on the other hand, the continuous release of additives in PVC will bring additional chemical stress, thus further amplifying the impact of exogenous pollutants [40]. Comparative studies show that there are clear differences in the effects of PVC and PS in the process of anaerobic digestion, indicating that polymer properties can significantly alter the fate and bioavailability of pollutants, and further affect the strength of composite stress [40]. Aging will further improve the polarity and active site of the surface of microplastics, enhance its ability to bind to pollutants, and may also increase local exposure through the biofilm interface [40]. At the same time, the active components produced during the aging process, such as free radicals, may also change the surface reactivity and interface process, thus affecting the accumulation and release of pollutants, which provides a possible mechanism for aging microplastics to often show stronger effects [41].

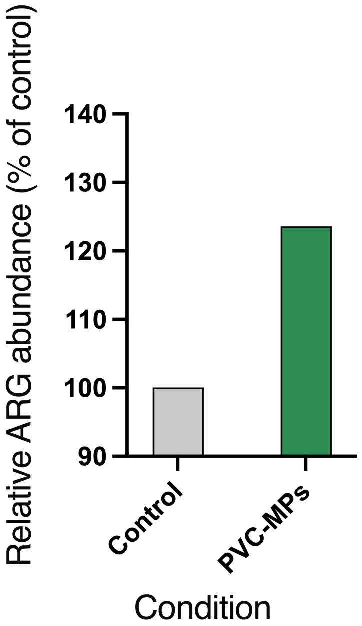

Figure 2. Increase in antibiotic resistance gene (ARG) abundance induced by PVC microplastics. ARG abundance is expressed as the percentage relative to the microplastic-free control (100%). Literature data indicate that exposure to PVC microplastics leads to an elevated ARG level (+23.6%), highlighting the potential role of PVC as a carrier and amplifier of antibiotic resistance risk in waste treatment systems [35]

5.2. Ecological risk implications of PVC microplastics via microbial process disturbances

In the biological treatment of wet waste, the combined stress induced by PVC is mainly manifested as the disturbance of microbial function. Anaerobic digestion research shows that PVC microplastics can reduce methane production by leaching toxic additives, which indicates that the release of additives will interfere with the methane production process and further affect system performance [42]. Process indicators such as greenhouse gas emissions and nitrogen loss may also change with microplastic exposure, which is consistent with microbial metabolic disturbance [43]. In addition, compost pretreatment may also change the surface properties of PVC and enhance its subsequent interaction with microorganisms, thus strengthening the connection between the interface process and biological response [44].

These changes at the process level are consistent with the release behavior of PVC additives. Additives will migrate during use and disposal, and in systems with high humidity and changing physical and chemical conditions, this migration will further lead to continuous chemical input and cumulative exposure [17]. Studies have shown that phthalate plasticizers can leach from PVC microplastics for a long time, and the leaching strength is significantly affected by environmental conditions [24,25] . Therefore, plasticizer leaching is a factor that cannot be ignored when assessing environmental risks [27]. Treated products, especially compost, may also bring microplastics and their related chemicals into the agricultural environment, further expanding the exposure range from the treatment system to the downstream environment [45]. Studies from composting and organic solid waste systems also show that the dynamic changes of microplastics in the composting process and their release risks should be included in the assessment framework [46]. In general, the ecological risks in the wet waste system come not only from the disturbance of the process itself, but also from the continuous release of PVC additives, and the discharge of treated products further provides a practical way for downstream environmental exposure.

6. Conclusions

PVC microplastics can exert multifaceted ecological effects in wet waste treatment systems, because particle retention, additive release and surface colonization often occur simultaneously. Studies from composting and anaerobic digestion show that these couplings can change the structure of the microbial community, reshape community functional structure, and interfere with key processes such as organic matter conversion and methane production. Compared with relatively inert polyolefins, PVC is more likely to impose combined stress, because its chlorine-containing main chain and additive-rich composition are more likely to bring continuous chemical input and particle-related effects. The formation of PVC surface biofilm will also provide a structured attachment interface, thus affecting community succession and local interaction. Future research should shift from fragmented observation to systematic evidence with time resolution and comparability, linking additive leaching, interfacial biofilm processes, community reorganization and functional changes, so as to improve the ability to explain the causal mechanism of PVC-microbial interaction.

References

[1] J. Li, H. Liu, J. Paul Chen, Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection, Water Research 137 (2018) 362–374.
[2] A.L. Andrady, The plastic in microplastics: A review, Marine Pollution Bulletin 119(1) (2017) 12–22.
[3] S.L. Wright, F.J. Kelly, Plastic and Human Health: A Micro Issue?, Environmental Science & Technology 51(12) (2017) 6634–6647.
[4] X. Guo, J. Wang, The chemical behaviors of microplastics in marine environment: A review, Marine Pollution Bulletin 142 (2019) 1–14.
[5] M. Cole, P. Lindeque, C. Halsband, T.S. Galloway, Microplastics as contaminants in the marine environment: a review, Mar Pollut Bull 62(12) (2011) 2588–97.
[6] R. Geyer, J.R. Jambeck, K.L. Law, Production, use, and fate of all plastics ever made, Science Advances 3(7) (2017) e1700782.
[7] D. Zhang, T.S. Keat, R.M. Gersberg, A comparison of municipal solid waste management in Berlin and Singapore, Waste Manag 30(5) (2010) 921–33.
[8] A. Genetu, Composting Technology for Municipal Solid Waste Management and Production of Organic Fertilizer, Advance in Environmental Waste Management & Recycling 7 (2024) 1–13.
[9] Y. Li, S.Y. Park, J. Zhu, Solid-state anaerobic digestion for methane production from organic waste, Renewable and Sustainable Energy Reviews 15(1) (2011) 821–826.
[10] M.A. Browne, P. Crump, S.J. Niven, E. Teuten, A. Tonkin, T. Galloway, R. Thompson, Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks, Environmental Science & Technology 45(21) (2011) 9175–9179.
[11] F. De Falco, E. Pace, M. Cocca, M. Avella, The contribution of washing processes of synthetic clothes to microplastic pollution, Scientific Reports 9 (2019) 6633.
[12] F. Corradini, P. Meza, R. Eguiluz, F. Casado, E. Huerta-Lwanga, V. Geissen, Evidence of microplastic accumulation in agricultural soils from sewage sludge disposal, Science of the Total Environment 671 (2019) 411–420.
[13] M. Alimohammadi, G.N. Demirer, Microplastics in anaerobic digestion: occurrence, impact, and mitigation strategies, Journal of Environmental Health Science and Engineering 22(2) (2024) 397–411.
[14] X. Wu, J. Pan, M. Li, Y. Li, M. Bartlam, Y. Wang, Selective enrichment of bacterial pathogens by microplastic biofilm, Water Research 165 (2019) 114979.
[15] L. Han, L. Chen, Y. Feng, Y. Kuzyakov, Q. Chen, S. Zhang, L. Chao, Y. Cai, C. Ma, K. Sun, M.C. Rillig, Microplastics alter soil structure and microbial community composition, Environment International 185 (2024) 108508.
[16] M. Xu, P. Gao, Y. Gao, S.-j. Xiong, H.-q. Chen, X.-x. Shen, Impacts of microplastic type on the fate of antibiotic resistance genes and horizontal gene transfer mechanism during anaerobic digestion, Journal of Environmental

Management 360 (2024) 121090.
[17] J.N. Hahladakis, C.A. Velis, R. Weber, E. Iacovidou, P. Purnell, An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling, Journal of Hazardous Materials 344 (2018) 179–199.
[18] S. Lievens, T. Slegers, M.A. Mees, W. Thielemans, G. Poma, A. Covaci, M. Van Der Borght, A simple, rapid and accurate method for the sample preparation and quantification of meso- and microplastics in food and food waste streams, Environmental Pollution 307 (2022) 119511.
[19] J. Song, C. Wang, G. Li, Defining Primary and Secondary Microplastics: A Connotation Analysis, ACS ES&T Water 4(6) (2024) 2330–2332.
[20] E.B. Jadhav, M.S. Sankhla, R.A. Bhat, D.S. Bhagat, Microplastics from food packaging: An overview of human consumption, health threats, and alternative solutions, Environmental Nanotechnology, Monitoring & Management 16 (2021) 100608.
[21] Y. Guo, X. Xia, J. Ruan, Y. Wang, J. Zhang, G.A. LeBlanc, L. An, Ignored microplastic sources from plastic bottle recycling, Science of the Total Environment 838 (2022) 156038.
[22] L. Gong, O. Martinez, P. Mesquita, K. Kurtz, Y. Xu, Y. Lin, A microfluidic approach for label-free identification of small-sized microplastics in seawater, Scientific Reports 13(1) (2023) 11011.
[23] G. Akovali, 2 - Plastic materials: polyvinyl chloride (PVC), in: F. Pacheco-Torgal, S. Jalali, A. Fucic (Eds.), Toxicity of Building Materials, Woodhead Publishing2012, pp. 23–53.
[24] C. Henkel, T. Hüffer, T. Hofmann, Polyvinyl Chloride Microplastics Leach Phthalates into the Aquatic Environment over Decades, Environmental Science & Technology 56(20) (2022) 14507–14516.
[25] C. Henkel, J. Lamprecht, T. Hüffer, T. Hofmann, Environmental factors strongly influence the leaching of di(2-ethylhexyl) phthalate from polyvinyl chloride microplastics, Water Research 242 (2023) 120235.
[26] W. Wei, Q.-S. Huang, J. Sun, J.-Y. Wang, S.-L. Wu, B.-J. Ni, Polyvinyl Chloride Microplastics Affect Methane Production from the Anaerobic Digestion of Waste Activated Sludge through Leaching Toxic Bisphenol-A, Environmental Science & Technology 53(5) (2019) 2509–2517.
[27] A.M. Gulizia, B. Philippa, J. Zacharuk, C.A. Motti, G. Vamvounis, Plasticiser leaching from polyvinyl chloride microplastics and the implications for environmental risk assessment, Marine Pollution Bulletin 195 (2023) 115392.
[28] H.A. Maddah, Polypropylene as a promising plastic: A review, Am J Polym Sci 6(1) (2016) 1–11.
[29] T. Hüffer, F. Metzelder, G. Sigmund, S. Slawek, T.C. Schmidt, T. Hofmann, Polyethylene microplastics influence the transport of organic contaminants in soil, Science of the Total Environment 657 (2019) 242–247.
[30] W. Zhao, T. Hu, H. Ma, S. He, Q. Zhao, J. Jiang, L. Wei, Deciphering the role of polystyrene microplastics in waste activated sludge anaerobic digestion: Changes of organics transformation, microbial community and metabolic pathway, Science of the Total Environment 901 (2023) 166551.
[31] H.S. Auta, O.P. Abioye, S.A. Aransiola, J.D. Bala, V.I. Chukwuemeka, A. Hassan, A. Aziz, S.H. Fauziah, Enhanced microbial degradation of PET and PS microplastics under natural conditions in mangrove environment, Journal of Environmental Management 304 (2022) 114273.
[32] X. Tang, M. Zhou, G. Zeng, C. Fan, The effects of dimethyl phthalate on sludge anaerobic digestion unveiling the potential contribution of plastic chemical additive to spread of antibiotic resistance genes, Chemical Engineering Journal 435 (2022) 134734.
[33] Y. Zhong, Q. Ding, Z. Huang, X. Xiao, X. Han, Y. Su, D. Wang, J. You, Influence of ultraviolet-aging and adsorbed pollutants on toxicological effects of polyvinyl chloride microplastics to zebrafish, Environmental Pollution 316 (2023) 120617.
[34] E.R. Zettler, T.J. Mincer, L.A. Amaral-Zettler, Life in the "plastisphere": microbial communities on plastic marine debris, Environ Sci Technol 47(13) (2013) 7137–46.
[35] T. Luo, X. Dai, Z. Chen, L. Wu, W. Wei, Q. Xu, B.J. Ni, Different microplastics distinctively enriched the antibiotic resistance genes in anaerobic sludge digestion through shifting specific hosts and promoting horizontal gene flow, Water Research 228(Pt A) (2023) 119356.
[36] T. Luo, X. Dai, W. Wei, Q. Xu, B.-J. Ni, Microplastics Enhance the Prevalence of Antibiotic Resistance Genes in Anaerobic Sludge Digestion by Enriching Antibiotic-Resistant Bacteria in Surface Biofilm and Facilitating the Vertical and Horizontal Gene Transfer, Environmental Science & Technology 57(39) (2023) 14611–14621.
[37] M. Jin, X. Yu, Z. Yao, P. Tao, G. Li, X. Yu, J.-L. Zhao, J. Peng, How biofilms affect the uptake and fate of hydrophobic organic compounds (HOCs) in microplastic: Insights from an In situ study of Xiangshan Bay, China, Water Research 184 (2020) 116118.
[38] Z. Li, D. Yuan, Metagenomic Analysis Reveals the Effects of Microplastics on Antibiotic Resistance Genes in Sludge Anaerobic Digestion, Toxics 12(12) (2024) 920.

[39] T. Zhu, S. Li, C. Tao, W. Chen, M. Chen, Z. Zong, Y. Wang, Y. Li, B. Yan, Understanding the mechanism of microplastic-associated antibiotic resistance genes in aquatic ecosystems: Insights from metagenomic analyses and machine learning, Water Research 268 (2025) 122570.

[40] C. Hongjin, S. ur Rahman, A. Rehman, A.A. Khan, M. Khalid, Microplastics and antibiotic resistance genes as rising threats: Their interaction represents an urgent environmental concern, Current Research in Microbial Sciences 9 (2025) 100447.

[41] K. Zhai, K. Yin, Y. Lin, S. Chen, Y. Bi, R. Xing, C. Ren, Z. Chen, Z. Yu, Z. Chen, S. Zhou, Free Radicals on Aging Microplastics Regulated the Prevalence of Antibiotic Resistance Genes in the Aquatic Environment: New Insight into the Effect of Microplastics on the Spreading of Biofilm Resistomes, Environmental Science & Technology 59(23) (2025) 11735–11744.

[42] Y. Sun, X. Ren, E.R. Rene, Z. Wang, L. Zhou, Z. Zhang, Q. Wang, The degradation performance of different microplastics and their effect on microbial community during composting process, Bioresource Technology 332 (2021) 125133.

[43] Y. Sun, X. Ren, J. Pan, Z. Zhang, T.-H. Tsui, L. Luo, Q. Wang, Effect of microplastics on greenhouse gas and ammonia emissions during aerobic composting, Science of the Total Environment 737 (2020) 139856.

[44] Č. Novotný, J. Fojtík, M. Mucha, K. Malachová, Biodeterioration of Compost-Pretreated Polyvinyl Chloride Films by Microorganisms Isolated From Weathered Plastics, Front Bioeng Biotechnol 10 (2022) 832413.

[45] M. Vithanage, S. Ramanayaka, S. Hasinthara, A. Navaratne, Compost as a carrier for microplastics and plastic-bound toxic metals into agroecosystems, Current Opinion in Environmental Science & Health 24 (2021) 100297.

[46] X. Tang, X. Yuan, W. Lu, X. Wen, Y. Wu, T. Chen, Microplastics in livestock manure and compost: environmental distribution, degradation behavior, and their impact on antibiotic resistance gene dissemination, Chemical Engineering Journal 513 (2025) 162881.