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Insect Biodegradation of Plastic: A Review

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Review Article

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ABSTRACT

Plastic poses a persistent threat to various ecosystems and organisms due to its prolonged environmental existence. Traditional methods of managing plastic waste, such as landfill disposal and chemical treatments, have proven environmentally harmful. Despite the recognition of insects as potential agents for plastic degradation, the practical application of this concept remains limited. While the exact mechanisms of insect-mediated plastic breakdown are not fully understood, utilizing insect larvae for this purpose offers advantages such as cost-effectiveness and minimal secondary pollution. This review aims to comprehensively analyze recent research on plastic degradation by insects and microorganisms, shedding light on the processes involved and exploring the potential applications, challenges, and future directions in plastic biodegradation.

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1. INTRODUCTION

Plastics made from synthetic material are highly valued materials in most of the modern countries. This is because plastics have amazing qualities that change with time, like being inexpensive, stable, and resilient because of their polymeric properties, which make them an essential part of every facet of our daily lives [1]. Plastics are among the materials that are used the most on earth due to their rapid growth in use. It is commonly utilized to package foods, cosmetics, chemicals, medications, and detergents. Industrial manufacturing of plastic began in the 1950s and has risen at an astonishing rate [2]. Many commonly used plastics are harmful to ecosystems because of their potential to cause issues, such as long-term persistence in the environment, which poses an ongoing threat to many different kinds of life, especially those that inhabit aquatic and terrestrial ecosystems [3]. Examples of these plastics include polyethylene (PE), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC). Contamination of plastic waste is now largely acknowledged as a serious environmental problem. Up to 6,300 million metric tonnes of plastic waste have been produced to date, according to a recent study [4]. Less than half of the waste produced plastic, though, was recycled or dumped in landfills. The production of plastics has increased dramatically during the past few decades, reaching 359 million tons in 2018 [5]. Approximately 140 million Mg (tonnes) of polyethylene (PE) are produced worldwide each year, making it the most frequently used synthetic polymer [6]. The yearly production of plastic is 180 million Mg (tonnes), and both supply and demand are rising. Global plastic pollution is increasing in tandem with rising plastic consumption. Up to 26 billion tonnes of plastic waste are expected to be produced by 2050, of this, more than half will end up in landfills where they will eventually infiltrate ecospheres such as wetlands and oceans, seriously contaminating the ecosystem [7,8,9]. This also affects biodiversity and soil biomass [10]. It emits greenhouse gasses into the atmosphere that are dangerous to human health [11]. Water bodies containing plastics contribute to global warming by obstructing plankton growth, which raises temperatures. Because of their hydrophobic nature, plastics can mix more easily with other contaminants, such as organic pollutants and polychlorinated biphenyls [10]. Furthermore, as broken-up plastic garbage seeps into the soil and raises toxin levels, it affects the composition and activity of the microbiome in the soil ecosystem [12]. Birds that eat plastic fabrics develop immune system problems, infertility, and brain issues [13]. Global awareness has increased as microplastics have been found in several human bodily organs, including the blood [14], lungs [15], and placenta [16]. These substances are categorized as toxic due to their detrimental characteristics and propensity to disperse throughout ecosystems.

In light of this conundrum, it is imperative to look for ecologically suitable substitutes for traditional disposal, like biodegradation [10]. The process of plastic biodegradation is an essential step in reducing the negative effects of plastic pollution. Nevertheless, little is currently known about the mechanisms and effectiveness of plastic biodegradation. The idea of invertebrates, such as insects, in the breakdown of plastics, is also discussed in the present, highlighting their crucial role in the future.

2. IMPACTS AND DISPOSAL METHODS OF PLASTIC WASTE

Plastic waste is being widely acknowledged as the second most significant environmental issue after climate change [17]. Plastic garbage takes up a lot of room in landfills, 10,000 tonnes of plastic were disposed of in just 0.067 hectares, releasing a large number of dangerous chemicals in the process [18]. These substances have the potential to seep into the soil, deteriorating its quality and tainting groundwater. Lower agricultural yields can result from buried polyethylene (PE) waste because it can damage soil fauna, disturb drainage patterns, and degrade soil quality. Additionally, the amount of plastic pollution entering the ocean is astounding, ranging from 0.48 to 1.27 million tonnes annually, and it doubles every ten years or so [19]. Food intended for human consumption is impacted by this plastic's contamination of marine ecosystems and the food chain [20]. Carcinogenic air pollutants such as dioxins, nitro-PAHs, and polycyclic aromatic hydrocarbons (PAHs) are released during the burning of plastic wastes like polystyrene (PS), PET, PE, and polyvinyl chloride (PVC) [21]. Important ecological species including salt marsh grasses, mussels, and corals may be impacted by harmful pollutants from plastic trash, particularly microplastic particles, that find their way into food chains [22,23]. Cells and other tissues may be harmed by the accumulation of these plastics and the substances they are associated with in the bodies of humans and marine animals [24].

3. DIFFERENT METHODS OF PLASTIC DEGRADATION

Because natural plastic breakdown occurs very slowly, plastic garbage builds up and becomes a serious environmental hazard. Plastic degradation is influenced by several variables, including age, weathering, polymer type, temperature, pH, and radiation [25]. Plastic treatment mostly comprises 77% reclamation, 13% incineration, and 10% mechanical and chemical recovery due to the absence of efficient degrading techniques. Reclamation poses serious dangers to human health and the environment since burning polyethylene trash releases harmful carcinogens like ketones and acrolein as well as greenhouse gasses like methane, which can contaminate soil and groundwater [26]. The main technique for recovering thermoplastic wastes has been mechanical recycling, however, the qualities of most recycled goods are adversely affected by multiple manufacturing cycles, which reduces their market appeal. On the other hand, chemical recycling can extract additional materials, such as monomers, from a variety of plastic wastes, nevertheless, the process's efficiency and cost will determine how successful the recycling is [27]. One potential way to get rid of plastic trash without creating more pollution is through the biodegradation of plastic by bacterial and fungal strains [28]. Nevertheless, there are drawbacks to this approach, such as long processing periods and the requirement for ideal circumstances for efficient biodegradation. The biodegradation of plastic trash by arthropods is one developing approach. It has been found that several worms consume plastic and can break it down into non-hazardous substances [29]. Thus far, it has been discovered that seven different forms of plastic are broken down by insects: extruded polystyrene, polyethylene, polystyrene, polyvinyl chloride, polypropylene, polyphenylene sulfide, and ethylene-vinyl acetate. Although the precise processes underlying the breakdown of plastic in insects are still being investigated, it is thought that gut bacteria and enzymes have a major impact.

3.1 Insect Species Capable of Degrading Plastic Materials

Through mechanisms like bioaccumulation, bioaugmentation, and biodegradation, microorganisms, algae, and insects can naturally attenuate microplastics [30]. For more than ten years, researchers have demonstrated the ability of different insect groups, especially lepidopterans and coleopterans, to invade and consume plastic materials [31]. Researchers discovered in the 1950s that some beetles and their larvae, belonging to families such as Tenebrionidae, Anobiidae, and Dermestidae, have an extraordinary capacity to degrade plastic wrapping [32]. *Tenebrio obscurus*, *Tenebrio molitor*, *Zophobas atratus*, and *Galleria mellonella* are the insect larvae that have been identified as plastic consumers and have been the subject of the most research. These insects are more effective at degrading plastic than other insect species. Significant quantities of microplastics have been discovered to be degraded by *Tenebrio* and *Galleria* larvae species, according to [30]. Polyethylene (PE), Polystyrene (PS), Polyvinyl chloride (PVC), Polypropylene (PP), and Low-Density Polyethylene (LDPE) are just a few of the plastics that these larvae are able to break down, progressively lowering their molecular weight and producing biomass [33,34].

Insect plastivores use natural microorganisms and enzymes from their digestive systems to carry out biological remediation [35]. Plastic undergoes three distinct processes of biodegradation: biodeterioration, biofragmentation, and assimilation, which together result in the total disintegration of the plastic. Before being eaten by insects, certain plastics undergo biodeterioration when they are exposed to environmental factors such as high temperatures, sunshine, and pH changes in water. On the other hand, the rate of degradation depends on the length of exposure as well as the strength of the external forces. For example, plastics will break down into microplastics more quickly in hotter climates than in colder climates [35, 36,37]. Microbes aid in the digestive process inside the insect's gut during the fragmentation stage. Enzymes such as lipase, proteinase k, and dehydrogenase are secreted by these microbes, especially different strains of bacteria. These enzymes can break down polymer chains into oligomers and monomers via hydrolytic cleavage and depolymerization [37]. Ultimately, during the assimilation step, bacteria and enzymes transform plastic monomers into biomass through oxidation and biomineralization, producing byproducts such as carbon dioxide, methane, and water. The biomass and its byproducts are then eliminated by the insect as waste. Even while the process of biodegradation by different insect larvae is typically slower than that of physical and chemical approaches, it is nevertheless an economical, feasible, and environmentally beneficial way to remediate plastic [10,30,38,39]. It's crucial to remember that not all insects can completely break down microplastics into innocuous biomass.

3.2 Factors Affecting the Degradation Process of Plastics

Abiotic and biotic variables often interact to affect plastic deterioration, with physicochemical processes taking place before biological degradation. The term "biotic factors" refers to the breakdown processes that are aided by enzymes or microorganisms such as bacteria, fungi, and algae, which are frequently found in insects. More plastic-degrading enzymes are secreted by fungi than by bacteria, which makes them more effective degraders of plastic in terms of enzyme activity [10]. In contrast to biotic factors like microbial and enzyme activity, studies have shown that abiotic factors such as soil composition, water content, weathering conditions, temperature variations, moisture levels, oxygen availability, and pH play a critical role in promoting higher rates of biodegradation and microbial growth [35,37].

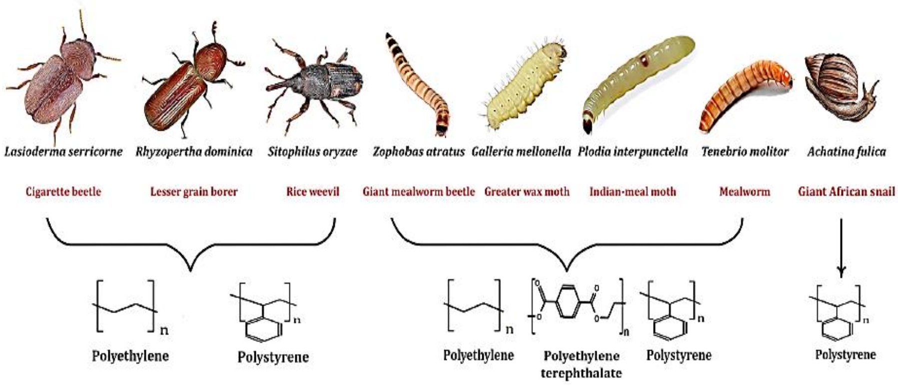

Fig. 1. Insect species capable of degrading plastic materials
Source: Sameh et al. [40]

Table 1. Plastic types degraded by Insects and their Symbiont microbes [41]

Plastic material	Insect Scientific name	Symbiont Microbes
Polyethylene	*G. mellonela*	*Enterobacter asburiae* YT1 *Bacillus* sp. YP1 *Enterobacter* sp. D1 *Aspergillus flavus*
	A. grisella	-
	P. interpunctella	*Bacillus* sp. YP1 and *Enterobacter asburiae* YT1
	C. cephalonica	-
	T. molitor	*Citrobacter* sp. and *Kosakonia* sp.
	Z. atratus	*Pseudomonas aeruginosa*
Polystyrene	*T. molitor*	*Exiguobacterium* sp. YT2, *Klebsiella, Pseudomonas* and *Serratia.*
	T. obscurus	-
	Z. atratus	*P. aeruginosa*
	T. castanium	*Acinetobacter* sp. AnTc-1
	Uloma spp	-
Polyphenylene sulphide	*Z. atratus*	*P. aeruginosa*
Ethylene-vinyl acetate	*T. confusum*	-
Polyvinyl chloride (PVC)	*T. molitor*	-

Numerous processes, such as photodegradation, hydrolysis, thermal oxidative degradation, and biodegradation, cause plastics to break down in the environment. Common plastics such as LDPE, PP, and high-density polyethylene degrade naturally under most conditions by photodegradation, which is mostly caused by UV-B radiation. This is followed by thermooxidation and, to a lesser degree, hydrolysis. Plastics break down into smaller pieces during degradation processes, which lowers the molecular weight (MW) of the polymer. Microorganisms may aid in the disintegration of these low-molecular-weight (low-MW) compounds [10,42,43]. Nevertheless, the quantity and variety of bacteria present determine how well-living things break down microplastics. As a result, soil or water moisture content might act as a stimulant for insect microorganisms, which can have an indirect effect on biodegradation, especially during hydrolytic cleavage processes [37]. Furthermore, [44] found that soil temperature had a major impact on how well soil-dwelling bacteria biodegrade materials.

There has been recent research on the biodegradation of plastics, notwithstanding the difficulties in evaluating and comparing the exposure of different types of plastics to diverse environmental variables [45,46,47]. The structural features of plastic materials such as their kind, size, form, molecular weight, chain length, strength, and physicochemical properties as well as their additives and biosurfactants have a big impact on how easily microbes may break down plastics. [10,31, 37,48] reported that the chemical makeup of the plastic, insect consumption rate, larval development rate, morphological alterations (number and efficacy of microbiota), and larval growth rate all had a significant impact on the biodegradation of plastics consumed by insects. The type of bacteria, dominant microbial strains, insect developmental stage, feeding substrate, and structural characteristics of the plastic all influence how well biotic biodegradation by microbes and enzymes from insect-fed plastics works [45]. Ahmed [48] further emphasized how important it is for natural enzymes produced by microbes specifically, bacterial and fungal species to play a part in the bioremediation of plastics.

3.3 Mechanism of Degradation of Plastic by Insect Larvae

The breakdown and degradation process by bacteria and enzymes in the insect's diet is greatly influenced by exposure to several abiotic variables such as heat, weathering, and UV radiation prior to the plastic being broken down by insects. For instance, worn plastic that is exposed to strong UV light and temperatures deteriorates more quickly than newly made plastic of the same kind. Furthermore, research by Urbanek [49,50] shows that when insects are exposed to various plastic kinds, the plastics experience substantial morphological changes and molecular weight reduction due to the development of cracks and holes. When it comes to breaking down different types of plastic, worms and moths are more efficient than other insects or microbes. Growing interest over the last ten years has been shown in insect larvae's capacity to break down plastics like PVC, PS, and PP. This implies that synthetic polymers could be broken down by the same enzymes that larvae employ to break down plant-derived and refractory polymers. It is unclear, therefore, if the larvae's ability to degrade lignocellulose also applies to other kinds of polymers, such as plastics. However, it has been shown that insects and their larvae can biodegrade some plastics, such as PS and PE [11]. Expanded polystyrene (EPS) can be chewed and consumed by *T. molitor* larvae, also referred to as mealworms, according to a recent study [51]. Their propensity to consume plastic, however, might be connected to the digestive activity of gut microorganisms that aid in digestion. Numerous insects' bodies, including their stomachs and cavities, have been found to contain symbiotic bacteria [52]. This suggests that microbes play a major role in the degradation of plastic chemicals in insects' digestive systems. The particular qualities of the plastics under evaluation, however, may have an impact on how easily larvae can bite through the material because harder plastics are more resistant.

On the other hand, although substantial degradation levels were still noted for EPS, a higher melt flow rate (MFR), which denotes longer polymer chains, would shield the material from being devoured by larvae [53]. Six short legs, two primitive hind prolegs, thirteen segments with yellow-brown rings at the joints, a dark spot on the head, and dark stripes at the end of the tail are all features of the larvae. *Z. atratus* larvae from Beijing, China were investigated by Elahi [54], who discovered that the larvae ate, depolymerized, and biodegraded PS. When a combination of antibiotics was used to suppress the gut microbiota, the depolymerization of EPS was markedly slowed [45].

Because of this degrading mechanism, plastics can be consumed and digested by insect larvae as their only food supply. As they move through the digestive tract, the polymers quickly break down into lower molecular weight chemicals and CO2 [55,56,57]. The chewing mechanism used by lepidopteran larvae involves two jaws; in adults, this mechanism atrophies. The chewing mouthparts are retained by the larvae [31]. Nonetheless, compared to other bacterial strains, some derived from insect guts show slower rates of breakdown. Even while metabolic and enzymatic processes break down plastic in insects, different insect microbial species—including separate bacterial strainssecrete different enzymes that are in charge of various microbial activities, like plastic biodegradation. The phylum Pseudomonadota is home to the majority of strains that break down plastic in insect stomachs, followed by Bacillota. Specifically, PE, PS, PVC, LDPE, and HDPE microplastics can all be broken down by these strains [58]. Protease enzymes are released by Bacillus siamensis and other Bacillota species to break down plastic. Laccase enzymes, on the other hand, are utilized by fungi such as Aspergillus niger and Aspergillus japonicus for their catalytic activity [48,58]. According to [59], microorganisms' metabolic and enzymatic activities are the main factors in the plastic biodegradation method in insects. These actions cause the plastics' molecular weight to decrease, which in turn causes major changes in the polymer structure.

3.4 Effect of Plastic on the Gut Microbiota of Insects

The growth and proliferation of gut microorganisms are directly impacted by the breakdown of microplastics by microbes. The particular kind of plastic and the type of insect involved play a major role in determining the changes seen in the bacteriome. Different microbial communities can break down plastic polymers in addition to individual bacteria, and these consortia frequently show higher biodegradation efficiency than single strains. Either actively participating in the degradation process or eliminating potentially hazardous degradation byproducts can lead to this efficiency. For example, in a nutrient-limited environment, a consortium consisting of five distinct strains of Bacillus and Pseudomonas exhibited synergistic development when PET was the only carbon source. The consortium also displayed cooperative behavior and cross-feeding capabilities. By participating in metabolic cross-feeding or generating metabolites that encourage co-metabolic destruction, certain members of microbial communities might indirectly accelerate biodegradation. Microbes aid in the abiotic degradation of polyolefins such as PE, PP, and PS, which are generally inert and resistant to microbial attack. Research on microorganisms has demonstrated that the gut microbiota of insects plays a major role in mediating the decomposition of plastic. Because of this, studies have mostly concentrated on examining the role played by the gut microbiota in the degradation process, based on the theory that larvae such as *G. mellonella* may eat, digest, and obtain energy from plastic. Nonetheless, research has demonstrated that, in comparison to the larvae's inherent enzymatic activities, the contribution of microorganisms to the PE degradation by G. mellonella larvae is negligible, as shown by the small differences in the species richness and diversity indices. Furthermore, a number of taxa that are frequently observed in other lepidopterans are also present and well-represented in *G. mellonella*, indicating that the role of microbes in the degradation of PE is restricted [32].

It is important to recognize that environmental elements like high temperatures and humidity can have a negative impact on the growth and effectiveness of insect microorganisms. Toxic materials including heavy metals and chlorine may accumulate as a result of this [60]. As [30] has shown, the addition of plastic to insect diets dramatically changes gut microbiota, especially the bacterial community. Because fewer hydrolytic and acidogenic bacteria are present, which are in charge of fermenting and hydrolyzing soluble organic monomers, this modification has a detrimental effect on bacterial populations. Furthermore, a significant decline in species from the phyla Firmicutes, Actinomycetes, and Bacteroidetes is observed when PVC is added to insect diets. On the other hand, it seems that the presence of microplastics in insect diets has a bigger impact on fungal communities than gut bacterial diversity [48]. Insects that consume plastics may damage the intestinal lining, impairing normal cellular activity and causing inadequate uptake of nutrients required for development and reproduction. Because of the interaction between molecular oxygen and microplastics, this may result in elevated rates of death in specific insect species as well as exposure to reactive oxygen species (ROS) [61]. Moreover, the buildup of microplastics in vertebrates can obstruct their digestive tracts, resulting in malnourishment and energy depletion, which may cause serious disease or even death [30].

4. CHALLENGES

In general, non-biodegradable polymers like polystyrene, polyethylene, polyvinyl chloride, and polypropylene have been shown to be consumed by the larvae of coleopteran species like *T. molitor*, *T. obscurus*, and *Z. atratus*, as well as lepidopteran species like *Plodia interpunctella* and *Achroia grisella* [62]. These larvae that eat plastic have been dubbed "plastivores" in a study by [63]. It has been proposed that the gut bacteria found in insect larvae aids in the digestion of plastic. During this process, the polymers are mechanically broken up by the larvae, and the resulting tiny pieces are then exposed to bacteria that are found in the insect's digestive system [64] states that sorting waste plastic is complicated by the existence of oxidized plastic fragments that can be broken down by bacteria and insect cells. An important obstacle facing plastic biodegradation research today is the lack of a standardized method for precisely evaluating and contrasting the plastic-degrading capacities of separate microorganisms and enzymes. Because there are many different ways to measure plastic biodegradation—such as weight loss, biofilm growth, and tensile strength reduction—there isn't a single standard for assessing it. Not only can distinct plastic compositions and structures affect the growth and development of insects, but they also cause differences in the rate of deterioration between different insect species.

Furthermore, despite the substantial amount of data that has been gathered thus far, the first bacterial species reported in P. interpunctella and T. molitor have not been regularly observed again [65,66]. Additionally, each dataset on gut microorganisms has revealed a wide range of bacterial genera or families [67,68]. The lack of consistency in research findings, even within the same insect species, is not surprising given that these insects' digestive systems are rather homogenous tubular structures lacking obvious adaptations for housing an organized microbiome. Lepidopteran larvae have extremely different bacterial communities in their intestines, and these communities appear to be shaped by the particular settings in which they reside [69]. Moreover, optimizing larval eating and plastic breakdown requires a balanced co-diet rich in important nutrients. Research has indicated that when larvae were fed polystyrene (PS) and either wheat bran or soy protein, the larvae would eat the PS after eating the protein. Under all feeding settings, the survival rates were higher than in the unfed controls. The survival rate values were comparable for mealworms fed PS alone and in combination with soy protein or wheat bran. But when compared to PS alone, the inclusion of soy protein or wheat bran greatly accelerated the rate of PS breakdown [70].

5. FUTURE PROSPECTS

The experimental method used to investigate the degradation of plastic by insects has been greatly affected by years of research in the field of microorganism biodegradation. Research on the gut microbiota has been a primary emphasis since the first data gathering. The importance of the larval gut microbiota in the breakdown of plastic has been questioned, though, with some speculating that the animal may already have an innate mechanism for this [33,71]. In a recent study, the ability of *G. mellonella* larvae to oxidize untreated polyethylene (PE) in a few of hours after contact was demonstrated. It has been demonstrated that waxworms break down polyethylene with their saliva. Small oxidized molecules are formed as byproducts of breakdown when saliva oxidizes the polymer in an aqueous solution at room temperature for a few hours. The investigation also discovered waxworm enzymes in the saliva of larvae that are members of the PEases family of phenol oxidase activities. The breakdown of the polymer into shorter molecules was confirmed by the detection of degradation products, such as tiny oxidized aliphatic chains, by gas chromatography-mass spectrometry analysis. Waxworm salivary protein GmSal underwent proteomic investigation, which revealed the presence of several hexamerin/prophenoloxidase family enzymes [72]. The first time that PE has been broken down by enzymes without the need for an abiotic pretreatment is demonstrated by this work, which provides insight into the molecular mechanisms underlying enzymatic oxidation and opens up new research directions. Finding new insect species with the ability to biodegrade plastic is a worthwhile line of inquiry. Although lepidopteran and coleopteran larvae have demonstrated potential in this area, other options should also be investigated. For example, the dipteran larva Hermetia illucens, the black soldier fly (BSF), is well-known for its voracious hunger and its capacity to bioconvert a variety of organic wastes [73]. While there is no evidence that H. illucens can eat plastic trash, new research indicates that it might be possible to use these larvae for the bioconversion of organic wastes contaminated with plastic. According to research, there was no discernible difference between the weight and survival rates of H. illucens larvae fed meat or vegetables containing 3-6% plastic packaging material and larvae fed plastic-free food [74]. Termites are another species of insects that may be able to degrade plastic because of their gut microbiome; they are typically found in soil habitats [75]. Although they don't normally eat plastics, termites have been found to break down several polymers. Normally, they eat biomass. The mechanical hardness and surface structure of plastics determine how resistant they are to termite assault; yet, because plastic and lignocellulosic biomass are similar, termite gut microorganisms can aid in the destruction of polymers. For example, Xylaria sp., a fungus isolated from termites that feed on wood, showed that it could break down polymer sheets and use them as a source of carbon. Furthermore, compared to individual yeast treatments, a consortium including low-density polyethylene and a tri-culture yeast consortia demonstrated considerable LDPE degradation, resulting in a 33.2% reduction in net LDPE mass. These yeasts generated a variety of enzymes that broke down LDPE, which resulted in the creation of several metabolites such fatty acids, ethanol, alkanes, and aldehydes. This study offers a novel method for biodegrading plastic waste by using termites that feed on wood and yeasts that break down LDPE.

6. CONCLUSION

Because it is inexpensive, portable, and simple to process, plastic is utilized extensively around the world. Nevertheless, there is currently no perfect way to manage wasted plastics, and incorrect plastic product disposal has resulted in serious contamination. Because plastics are essentially difficult to disintegrate, traditional approaches like landfilling and chemical treatment have demonstrated limitations and significant environmental implications. There are benefits to using insect larvae to break down plastics, such as minimal cost and no secondary contamination. These insects can also be important sources of nutrition for animals. Though there are currently few practical applications, recent study has investigated how some microbes and insect larvae break down plastics. Additionally More research is required to find new species of insects that can eat plastic, as well as to find out which kinds of plastic are preferred by various insects and how best to help insect larvae digest plastic. Feeding discarded plastics to insects could be a practical way to recycle them. In order to minimize any toxicological concerns or the buildup of hazardous materials, researchers must perform toxicological tests on insects that eat plastic.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ru J, Huo Y, Yang Y. Microbial degradation and valorization of plastic wastes. Front. Microbiol. 2020;11:507-487.
2. Alabi OA, Ologbonjaye KI, Awosolu O, Alalade OE. Public and environmental health effects of plastic wastes disposal: A review. J. Toxicol. Risk Assess. 2019; 5(021):1-3.
3. Arp HP, Kühnel D, Rummel C, MacLeod M, Potthoff A, Reichelt S, Rojo-Nieto E, Schmitt-Jansen M, Sonnenberg J, Toorman E, Jahnke A. Weathering plastics as a planetary boundary threat: Exposure, fate, and hazards. Environ. Sci. Technol. 2021; 55(11):7246-55.
4. Geyer R, Jambeck JR, Law KL. Production, use, and fate of all plastics ever made. Science Advances. 2017 Jul 19;3(7): e1700782.
5. Lebreton L, Andrady A. Future scenarios of global plastic waste generation and disposal. Palgrave Commun. 2019;5(1):1-1.
6. Sivan A. New perspectives in plastic biodegradation. Curr. Opin. Biotechnol. 2011;22(3):422-6.

7. Lönnstedt OM, Eklöv P. Retracted: Environmentally relevant concentrations of microplastic particles influence larval fish ecology. Science. 2016;352(6290):1213-6.
8. Siddiqui SA, Abd Manap AS, Kolobe SD, Monnye M, Yudhistira B, Fernando I. Insects for plastic biodegradation–A review. Process Safety and Environmental Protection; 2024 Apr 5.
9. Yang SS, Wu WM, Bertocchini F, Benbow ME, Devipriya SP, Cha HJ, Peng BY, Ding MQ, He L, Li MX, Cui CH. Radical innovation breakthroughs of biodegradation of plastics by insects: history, present and future perspectives. Frontiers of Environmental Science & Engineering. 2024 Jun;18(6):78.
10. Ali SS, Elsamahy T, Al-Tohamy R, Zhu D, Mahmoud YA, Koutra E, Metwally MA, Kornaros M, Sun J. Plastic wastes biodegradation: Mechanisms, challenges and future prospects. Sci. Total Environ. 2021;780:146-590.
11. Al-Tohamy R, Ali SS, Zhang M, Sameh M, Mahmoud YA, Waleed N, Okasha KM, Sun S, Sun J. Can wood-feeding termites solve the environmental bottleneck caused by plastics? A critical state-of-the-art review. J. Environ. Manage. 2023;326:116-606.
12. Lear G, Kingsbury JM, Franchini S, Gambarini V, Maday SD, Wallbank JA, Weaver L, Pantos O. Plastics and the microbiome: Impacts and solutions. Environmental Microbiome. 2021;1-9.
13. Alimba CG, Faggio C. Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile. Environ. Toxicol. Pharmacol. 2019;68:61-74.
14. Leslie HA, Van Velzen MJ, Brandsma SH, Vethaak AD, Garcia-Vallejo JJ, Lamoree MH. Discovery and quantification of plastic particle pollution in human blood. Environ. Int. 163;107199.
15. Amato-Lourenço LF, Carvalho-Oliveira R, Júnior GR, dos Santos Galvão L, Ando RA, Mauad T. Presence of airborne microplastics in human lung tissue. J. Hazard. Mater. 2021;416:126-124.
16. Ragusa A, Svelato A, Santacroce C, Catalano P, Notarstefano V, Carnevali O, Papa F, Rongioletti MC, Baiocco F, Draghi S, D'Amore E. Plasticenta: First evidence of microplastics in human placenta. Environ. Int. 2021;146:106-274.
17. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL. Plastic waste inputs from land into the ocean. Science. 2015;347(6223):768-71.
18. Lithner D, Larsson Å, Dave G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Sci. Total Environ. 2011;409(18):3309-24.
19. Crompton TR. Additive migration from plastics into food, A guide for analytical chemists. Elsevier. 2007;1:1-246.
20. Lusher A, Hollman P, Mendoza-Hill J. Microplastics in fisheries and aquaculture: Status of knowledge on their occurrence and implications for aquatic organisms and food safety. FAO; 2017.
21. Al-Salem SM, Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste Manag. 2009;29(10):2625-43.
22. Uhrin AV, Schellinger J. Marine debris impacts to a tidal fringing-marsh in North Carolina. Mar. Pollut. Bull. 2011;62(12): 260-510.
23. Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). Environ. Sci. Technol. 2008;42(13):5026-31.
24. Pauly JL, Stegmeier SJ, Allaart HA, Cheney RT, Zhang PJ, Mayer AG, Streck RJ. Inhaled cellulosic and plastic fibers found in human lung tissue. Cancer epidemiology, biomarkers & prevention: A publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology. 1998;7(5):419-28.
25. Akbay İK, Özdemir T. Monomer migration and degradation of polycarbonate via UV-C irradiation within aquatic and atmospheric environments. J. Macromol. Sci. Part A. 2016;53(6):340-5.
26. Briassoulis DJ. Mechanical behavior of biodegradable agricultural films under real field conditions. Polym. Degrad. Stab. 2006;91(6):1256-72.
27. Rahimi A, García JM. Chemical recycling of waste plastics for new materials production. Nat. Rev. Chem. 2017;1(6): 0046.
28. Lee HM, Kim HR, Jeon E, Yu HC, Lee S, Li J, Kim DH. Evaluation of the biodegradation efficiency of four various types of plastics by Pseudomonas aeruginosa isolated from the gut extract of

superworms. Microorganisms. 2020;8(9): 13-41.

29. Bombelli P, Howe CJ, Bertocchini F. Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella. Curr. Biol. 2017;27(8):293.
30. Goveas LC, Nayak S, Kumar PS, Rangasamy G, Vidya SM, Vinayagam R, Selvaraj R, Dai Viet NV. Microplastics occurrence, detection and removal with emphasis on insect larvae gut microbiota. Mar. Pollut. Bull. 2023;188:114-580.
31. Pivato AF, Miranda GM, Prichula J, Lima JE, Ligabue RA, Seixas A, Trentin DS. Hydrocarbon-based plastics: Progress and perspectives on consumption and biodegradation by insect larvae. Chemosphere. 2022;293:133-600.
32. Boschi A, Scieuzo C, Salvia R, Arias CF, Perez RP, Bertocchini F, Falabella P. Beyond microbial biodegradation: Plastic degradation by *Galleria mellonella*. J. Polym. Environ. 2023:1-20.
33. Yang SS, Ding MQ, He L, Zhang CH, Li QX, Xing DF, Cao GL, Zhao L, Ding J, Ren NQ, Wu WM. Biodegradation of polypropylene by yellow mealworms (*Tenebrio molitor*) and superworms (*Zophobas atratus*) via gut-microbe-dependent depolymerization. Sci. Total Environ. 2021;756:144087.
34. Wang J, Wang Y, Li X, Weng Y, Wang Y, Han X, Peng M, Zhou A, Zhao X. Different performances in polyethylene or polystyrene plastics long-term feeding and biodegradation by *Zophobas atratus* and *Tenebrio molitor* larvae, and core gut bacterial-and fungal-microbiome responses. J. Environ. Chem. Eng. 2022;10(6):108-957.
35. Yasin NM, Akkermans S, Van Impe JF. Enhancing the biodegradation of (bio) plastic through pretreatments: A critical review. Waste Manag. 2022;150:1-2.
36. Folino A, Karageorgiou A, Calabrò PS, Komilis D. Biodegradation of wasted bioplastics in natural and industrial environments: A review. Sustain. 2020; 12(15):6030.
37. Bahl S, Dolma J, Singh JJ, Sehgal S. Biodegradation of plastics: A state of the art review. Materials Today: Proceedings. 2021;39:31-4.
38. Seeley ME, Song B, Passie R, Hale RC. Microplastics affect sedimentary microbial communities and nitrogen cycling. Nat. Commun. 2020;11(1):2372.
39. Mughini-Gras L, van der Plaats RQ, van der Wielen PW, Bauerlein PS, de Roda Husman AM. Riverine microplastic and microbial community compositions: A field study in the Netherlands. Water Res. 2021; 192:116-852.
40. Sameh S Ali, Tamer Elsamahy, Rania Al-Tohamy, Daochen Zhu, Yehia A G Mahmoud, Eleni Koutra, Metwally A Metwally, Michael Kornaros, Jianzhong Sun. Plastic wastes biodegradation: Mechanisms, challenges and future prospects. Science of the Total Environment. 2021;780:146590.
41. Bilal H, Raza H, Bibi H, Bibi T. Plastic biodegradation through insects and their symbionts microbes: A review. Journal of Bioresource Management. 2021;8(4):7.
42. Andrady AL. Microplastics in the marine environment. Mar. Pollut. Bull. 2011; 62(8):1596-605.
43. Webb HK, Arnott J, Crawford RJ, Ivanova EP. Plastic degradation and its environmental implications with special reference to poly (ethylene terephthalate). Polym. 2012;5(1):1-8.
44. Pischedda A, Tosin M, Degli-Innocenti F. Biodegradation of plastics in soil: The effect of temperature. Polym. Degrad. Stab. 2019;170:109017.
45. Peng BY, Sun Y, Zhang X, Sun J, Xu Y, Xiao S, Chen J, Zhou X, Zhang Y. Unveiling the residual plastics and produced toxicity during biodegradation of polyethylene (PE), polystyrene (PS), and polyvinyl chloride (PVC) microplastics by mealworms (Larvae of *Tenebrio molitor*). J. Hazard. Mater. 2023;452:131-326.
46. Luo L, Wang Y, Guo H, Yang Y, Qi N, Zhao X, Gao S, Zhou A. Biodegradation of foam plastics by *Zophobas atratus* larvae (Coleoptera: Tenebrionidae) associated with changes of gut digestive enzymes activities and microbiome. Chemosphere. 2021;282:131-006.
47. Nabi I, Ahmad F, Zhang L. Application of titanium dioxide for the photocatalytic degradation of macro-and micro-plastics: A review. J. Environ. Chem. Eng. 2021;9(5): 105-964.
48. Ahmed T, Shahid M, Azeem F, Rasul I, Shah AA, Noman M, Hameed A, Manzoor N, Manzoor I, Muhammad S. Biodegradation of plastics: Current scenario and future prospects for environmental safety. Environ. Sci. Pollut. Res. Int. 2018;7287-98.

49. Du H, Xie Y, Wang J. Microplastic degradation methods and corresponding degradation mechanism: Research status and future perspectives. J. Hazard. Mater. 2021;418:126-377.
50. Akarsu C, Özdemir S, Ozay Y, Acer Ö, Dizge N. Investigation of two different size microplastic degradation ability of thermophilic bacteria using polyethylene polymers. Environ. Technol. 2023;44(24): 3710-20.
51. Yang Y, Chen J, Wu WM, Zhao J, Yang J. Complete genome sequence of *Bacillus* sp. YP1, a polyethylene-degrading bacterium from waxworm's gut. J. Biotech. 2015;200:77-8.
52. Hosokawa T, Kikuchi Y, Nikoh N, Shimada M, Fukatsu T. Strict host-symbiont cospeciation and reductive genome evolution in insect gut bacteria. PLoS Biol. 2006;4(10):337.
53. Urbanek AK, Rybak J, Wróbel M, Leluk K, Mirończuk AM. A comprehensive assessment of microbiome diversity in Tenebrio molitor fed with polystyrene waste. Environ. Pollut. 2020;262:114-281.
54. Yang Y, Wang J, Xia M. Biodegradation and mineralization of polystyrene by plastic-eating superworms *Zophobas atratus*. Sci. Total Environ. 2020;708:135-233.
55. Brandon AM, Gao SH, Tian R, Ning D, Yang SS, Zhou J, Wu WM, Criddle CS. Biodegradation of polyethylene and plastic mixtures in mealworms (larvae of *Tenebrio molitor*) and effects on the gut microbiome. Environ. Sci. Technol. 2018;52(11):6526-33.
56. Zhou D, Luo H, Zhang F, Wu J, Yang J, Wang H. Efficient photocatalytic degradation of the persistent PET fiber-based microplastics over Pt nanoparticles decorated N-doped TiO2 nanoflowers. Adv. Fiber Mater. 2022;4(5):1094-107.
57. Yang SS, Wu WM. Biodegradation of plastics in *Tenebrio* genus (mealworms). Microplastics in Terrestrial Environments: Emerging Contaminants and Major Challenges. 2020:385-422.
58. Elahi A, Bukhari DA, Shamim S, Rehman A. Plastics degradation by microbes: A sustainable approach. J. King Saud Univ. Sci. 2021;33(6):101-538.
59. Ghosh SK, Pal S, Ray S. Study of microbes having potentiality for biodegradation of plastics. Environ. Sci. Pollut. Res. 2013;20:4339-55.
60. Wei R, Breite D, Song C, Gräsing D, Ploss T, Hille P, Schwerdtfeger R, Matysik J, Schulze A, Zimmermann W. Biocatalytic degradation efficiency of postconsumer polyethylene terephthalate packaging determined by their polymer microstructures. Adv. Sci. 2019;6(14): 1900491.
61. Li JY, Yu Y, Craig NJ, He W, Su L. Interactions between microplastics and insects in terrestrial ecosystems-A systematic review and meta-analysis. J. Hazard. Mater. 2023;14:132-783.
62. Sanchez-Hernandez JC. A toxicological perspective of plastic biodegradation by insect larvae. Comparative Biochemistry and Physiology Part C: Oxicol. Appl. Pharmacol. 2021;248:109117.
63. Cassone BJ, Grove HC, Elebute O, Villanueva SM, LeMoine CM. Role of the intestinal microbiome in low-density polyethylene degradation by caterpillar larvae of the greater wax moth, *Galleria mellonella*. Proceedings of the Royal Society B. 2020 Mar 11;287(1922): 20200112.
64. Bertocchini F, Arias CF. Why have we not yet solved the challenge of plastic degradation by biological means? PLoS Biol. 2023;21(3):300-1979.
65. Yang J, Yang Y, Wu WM, Zhao J, Jiang L. Evidence of polyethylene biodegradation by bacterial strains from the guts of plastic-eating waxworms. Environ. Sci. Technol. 2014;48(23):13776-84.
66. Taghavi N, Udugama IA, Zhuang WQ, Baroutian S. Challenges in biodegradation of non-degradable thermoplastic waste: From environmental impact to operational readiness. Biotechnol. Adv. 2021;49: 107731.
67. Montazer Z, Habibi Najafi MB, Levin DB. Microbial degradation of low-density polyethylene and synthesis of polyhydroxyalkanoate polymers. Can. J. Microbiol. 2019;65(3):224-34.
68. Ren Liu RL, Men LiNa ML, Zhang ZhiWei ZZ, Guan FeiFei GF, Tian Jian TJ, Wang Bin WB, Wang JiHua WJ, Zhang YuHong ZY, Zhang Wei ZW. Biodegradation of polyethylene by Enterobacter sp. D1 from the guts of wax moth *Galleria mellonella*. Int. J. Environ. Res. Public Health. 2019; 16(11).
69. Engel P, Moran NA. The gut microbiota of insects–diversity in structure and function. FEMS Microbiol. Rev. 2013;37(5):699-735.

70. Yang SS, Wu WM. Biodegradation of plastics in *Tenebrio* genus (mealworms). Microplastics in Terrestrial Environments: Emerging Contaminants and Major Challenges. 2020:385-422.
71. Kong HG, Kim HH, Chung JH, Jun J, Lee S, Kim HM, Jeon S, Park SG, Bhak J, Ryu CM. The Galleria mellonella hologenome supports microbiota- independent metabolism of long-chain hydrocarbon beeswax. Cell Rep. 2019;26(9):2451-64.
72. Sanluis-Verdes A, Colomer-Vidal P, Rodriguez-Ventura F, Bello-Villarino M, Spínola-Amilibia M, Ruiz-Lopez E, Illanes-Vicioso R, Castroviejo P, Aiese Cigliano R, Montoya M, Falabella P. Wax worm saliva and the enzymes therein are the key to polyethylene degradation by *Galleria mellonella*. Nat. Commun. 2022;13(1):1-1.
73. Gold M, Tomberlin JK, Diener S, Zurbrügg C, Mathys A. Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Manag. 2018;82, 302-318.
74. Van der Fels-Klerx HJ, Meijer N, Nijkamp MM, Schmitt E, Van Loon JJ. Chemical food safety of using former foodstuffs for rearing black soldier fly larvae (*Hermetia illucens*) for feed and food use. J. Insects Food Feed. 2020;6(5):475-88.
75. Kumar A, Kalleshwaraswamy CM, Sharma R, Sharma P, Poonia A. Biodegradation of plastic using termites and their gut microbiota: A mini review. In IOP Conference Series: Environ. Earth Sci. IOP Publishing. 2022 Aug 1;1057(1): 012016).

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