

Insects in the Decomposition of Plastic Waste

^{*}Sandeep Patidar¹, Dr. Hemant Swami² and Sumedha Sharma³

¹Ph.D. Research Scholar, Department of Entomology, Rajasthan College of Agriculture, MPUAT, Rajasthan, India

²Assistant Professor, Department of Entomology, Rajasthan College of Agriculture, MPUAT, Rajasthan, India

³M.Sc. Research Scholar, Department of Entomology, B.A. College of Agriculture, AAU Anand, Gujarat, India

^{*}Corresponding Author's email: patidarsandeep839@gmail.com

Plastics are typically constructed from long chain polymeric molecules and are synthetic or semi-synthetic organic compounds with a high molecular mass. Over time, there have been significant advancements in the stability and durability of polymers, leading to their association with materials that exhibit resistance to various environmental influences. Several widely utilized plastics, have been found to be detrimental to ecosystems due to their capacity to generate problems including long-term persistence in the environment, hence presenting a persistent hazard to various forms of life, particularly those inhabiting aquatic and terrestrial ecosystem (Ali *et al.*, 2021). It also has an impact on the soil community's biomass and ecological balance. When plastic is burned, it emits greenhouse gases that are harmful to human health. Polymers in the oceans contribute to global warming by inhibits plankton growth, resulting in higher temperatures (Ali *et al.*, 2021). A number of plastic-based wastes are hydrophobic, which enhances their capacity to aggregate with other types of pollutants such as PAHs, organic pollutants, and polychlorinated biphenyls. Furthermore, the presence of plastic garbage in the soil changes the composition and function of the microbiome by fragmented plastic debris leaches into the soil, increasing toxin levels (Lear *et al.*, 2021). When birds swallow plastic textiles, it leads to neurological problems, infertility, and immune system abnormalities (Alimba and Faggio, 2019). The universal awareness has been attracted by the discovery of microplastics in a number of areas of the human body, including the blood, lungs and placenta. The assignment of toxicity to these substances is due to their detrimental attributes and their ability to spread over different ecosystems.

The decomposition of plastics by insects can be categorised into five distinct stages:

- Firstly, the plastics are mechanically chewed by the mouthparts of the insects and subsequently enter their intestinal tract.
- Secondly, the gut of the insects facilitates the adherence of microbes, which then proceed to erode the plastic material.
- Thirdly, through the action of enzymes, the plastic undergoes depolymerization, resulting in the formation of oligomer fragments. This depolymerization process can occur through either oxidation or hydrolysis. These oligomer fragments are further degraded into smaller molecules.
- Fourthly, the insect's body absorbs these small molecules, utilising them as sources of energy.
- Finally, the insect excretes the final products from its body (Yang *et al.*, 2023)

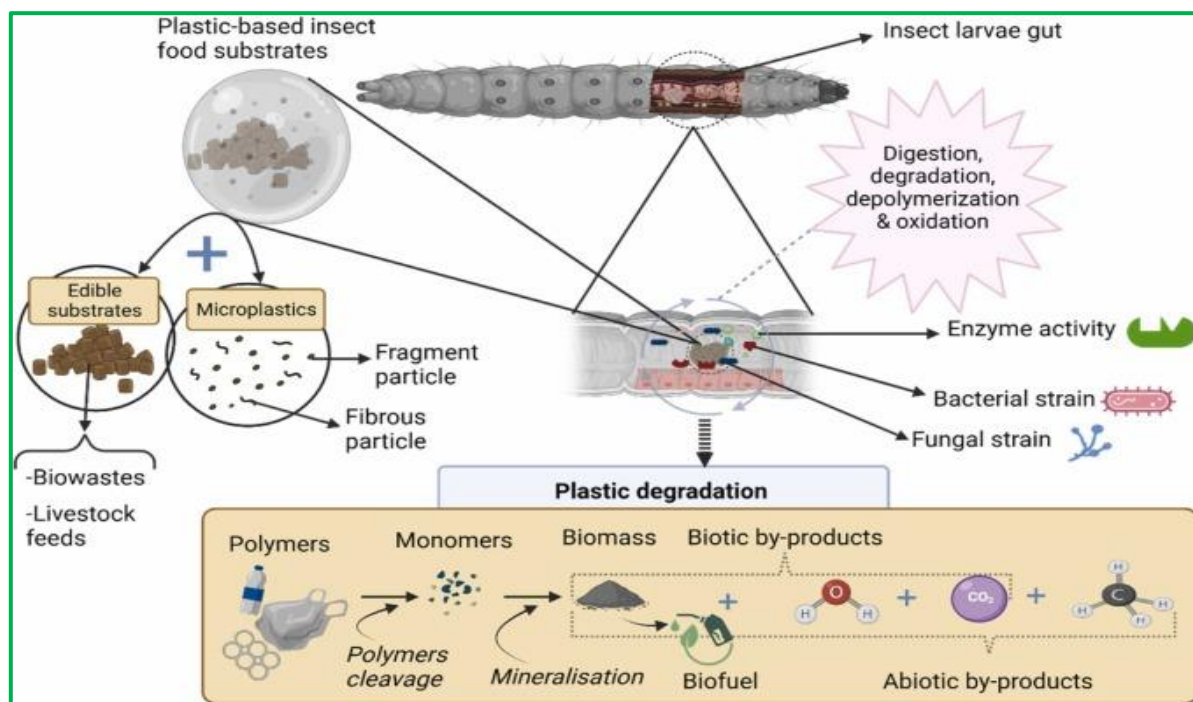


Fig. 01: Degradation of plastic by insects through microbial activity.

Insects Identified as Plastics Eating Insects

Order Lepidoptera

It is an order of insects that includes butterflies and moths. In this order, Pyralidae family, some species are identified as plastic feeding insects are Indian meal moth (*Plodia interpunctella*), the lesser wax moth (*Achroia grisella*), the greater wax moth (*Galleria mellonella*) and Rice meal worm (*Corcyra cephalonica*).

i. Waxworm: *G. mellonella* larval stage can chew and consume PE films because they can feed on and digest beeswax (Khyade, 2018; Yang *et al.*, 2014). Since beeswax and PE have structural similarities, *G. mellonella* biochemical machinery for beeswax metabolism may be used for PE metabolism. Under in situ and *in-vitro* conditions, the function of *G. mellonella* enzymes and intestinal microbiota in PE degradation is still unknown. It's important to find out how *G. mellonella* enzymes and microbiota contribute to PE degradation (Kong *et al.*, 2019). *G. mellonella* larvae have a remarkable capacity to use pre-existing metabolic mechanisms to get energy from PE as a sole source of food (LeMoine *et al.*, 2020).



ii. Lesser Wax Worm: *A. grisella* can eat silo bags, which are made up of three layers of polyethylene and one anti-UV layer (Chalup *et al.*, 2018). Lesser waxworms feeding PE, WC, or PE-WC completed all stages of the life cycle. New carbonyl and alcoholic groups appear in the frass of lesser waxworm-fed PE samples, as well as a rise in unsaturated hydrocarbon, indicate the development of biodegraded intermediates (Kundungal *et al.*, 2019).



iii. Indian Meal Moth: *P. interpunctella* larvae can cause damage to polyethylene (PE) packing films by chewing and consuming them. *P. Interpunctella* contains gut bacteria that degrade the synthetic polymers (Mereghetti *et al.*, 2017). *Enterobacter asburiae* YT1 and *Bacillus* sp. YP1 was isolated from the guts of *P. interpunctella* larvae in another study (Yang *et al.*, 2014). After 28 days of incubation, they reduced the hydrophobicity of the PE film and caused surface disruption. *E. tabaci* strain and *B. subtilis* subsp. Spizizenii strain was isolated from the midgut larvae, and they have a role in degradation (Mahmoud *et al.*, 2020).



iv. Rice Meal Worm: *C. cephalonica* larvae can degrade low-density polyethylene. It has been reported that, any gut microbes that may be responsible for degrading LDPE. It can be interpreted that enzyme for the decomposition of LDPE may be produced by the gut tract of these larvae (Kesti and Thimmappa, 2019).



Order Coleoptera

It is an order of insects that includes beetles and weevils. In this order, Tenebrionidae family, there are some species which are identified as plastic feeding insects are Meal worm (*Tenebrio molitor*), Super worm (*Zophobas atratus*), Confused flour beetle (*Tribolium confusum*), *Uloma* spp, and Red flour beetle (*Tribolium castaneum*).

i. Mealworm: *T. molitor*, is capable of depolymerizing and biodegrading polystyrene, polyethylene (Ghatge et al., 2020; Peng et al., 2020), polypropylene (Yang et al., 2021) and polyvinyl Chloride (PVC) (Peng et al., 2020). Mealworms were found to be capable of eating and quickly degrading up to 50 % of ingested PS in just 24 hours, according to changes in chemical composition, molecular weight, isotopic trace following tracks through the intestinal tract (Yang et al., 2015a).



ii. Super Worm: *Z. atratus* larvae consume polystyrene, polyethylene and polyphenylene sulfide (PPS) foams (Lee et al., 2020). The biodegradation of ingested Styrofoam was supported by microbial symbionts in the gut (Yang et al., 2015b; Yang et al., 2021), of plastic eating mealworms, more bacteria have been isolated, and their PS-degrading ability is still being evaluated.



iii. Red Flour Beetle

Extruded polystyrene foam (EPS) was chewed and eaten by *T. castaneum* larvae (Fabreag and Familara, 2019). The gut microbiota of *T. castaneum* larvae fed plastic or bran revealed that *Acinetobacter* sp. was closely linked (Wang et al., 2020). PS biodegradation can be mediated by a newly isolated *Acinetobacter* sp. AnTc-1 from a *T. castaneum* larva, and beetles (*R. dominica*, *T. variable*, and *T. mauretanicus*, with others in the Order Coleoptera) can eat, chew and penetrate a variety of plastic packing materials.



iv. Confused Flour Beetle: Polyethylene foam, Polystyrene, and ethylene-vinyl acetate are degradable by *T. confusum*. During the study, an increase in the mass weight of the larvae was reported, indicating that plastic materials are not an effective source of energy for larvae other than survival. Larvae feeding PS, PE, and EVA lost 26.2, 31.4, and 45.8 % of their weight, respectively (Abdulhay, 2020). *P. davidis* larvae can eat PS, and in 14 days, feed 34.27 ± 4.04 mg of Styrofoam (PS foam) per larva, surviving solely on Styrofoam.



v. Uloma spp. : Larvae feeding WC and PS completed all phases of the life cycle (larvae, pupae, beetles, egg) and PS degradation was favourable in the second generation. The study of egested frass using FTIR and HNMR revealed signs of depolymerization and oxidation, indicating that PS is effectively biodegraded in the gut tract (Kundungal et al., 2021).



Advantages of Using Insects in the Decomposition of Plastic and Organic Waste

- 1. Eco-friendly Waste Management** – Insects offer a natural, biodegradable solution to waste decomposition, reducing reliance on landfills and incineration.
- 2. Efficient Bioconversion** – Insects rapidly break down organic waste, converting it into valuable byproducts like protein-rich biomass, compost, and biofertilizers.

3. **Reduction of Greenhouse Gas Emissions** – Unlike traditional waste management methods, insect-based decomposition produces lower methane and CO₂ emissions, helping to combat climate change.
4. **Plastic Degradation Potential** – Certain insects, such as waxworms (*Galleria mellonella*) and mealworms (*Tenebrio molitor*), can digest plastics like polyethylene and polystyrene, offering a biodegradation pathway for plastic waste.
5. **Resource Recovery and Circular Economy** – The insect biomass produced (e.g., black soldier fly larvae) can be used as animal feed, biofuels, and fertilizers, creating a sustainable waste-to-resource model.
6. **Low-Cost and Scalable Technology** – Insect farming requires minimal infrastructure compared to conventional waste treatment facilities, making it a cost-effective and scalable solution.
7. **Soil and Agricultural Benefits** – Insect frass (waste) is rich in nutrients and beneficial microbes, enhancing soil fertility and promoting sustainable agriculture.

Challenges

1. **Limited Efficiency in Plastic Decomposition** – While some insects can degrade plastic, the process is slow and incomplete, requiring further optimization through microbial symbiosis and genetic engineering.
2. **Pathogen and Disease Risks** – Insect waste processing may attract pathogens, parasites, or harmful bacteria, posing risks to human and animal health if not properly managed.
3. **Regulatory and Safety Concerns** – Many countries lack clear regulations on using insects for waste decomposition, particularly regarding food safety and environmental impact.
4. **Scalability Issues for Plastic Biodegradation** – Unlike organic waste management, plastic degradation by insects is still in experimental stages and not yet commercially viable on a large scale.
5. **Ethical and Public Acceptance Issues** – The use of insects for waste decomposition, particularly in food systems, may face cultural and ethical resistance in some societies.
6. **Environmental Risks from Invasive Species** – The introduction of non-native insects for waste decomposition may disrupt local ecosystems if not carefully controlled.
7. **Optimal Conditions Requirement** – Insects need specific temperature, humidity, and diet conditions for efficient waste degradation, which may limit their use in certain environments.

Conclusion

Using insects for plastic waste decomposition presents a promising, sustainable, and circular approach to waste management. However, addressing challenges related to efficiency, safety, scalability, and regulation is crucial for its widespread implementation. With further research and technological advancements, insect-based waste management could become a key solution for a cleaner and more sustainable future.

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