***Review Article***

# Mitigation of Soil Pollution by Biodegradation of Plastic Materials through Activity of Mealworms


## ABSTRACT

Over the last few years, the concept of Circular Economy (CE) has received a lot of attention due to its potential contribution to the Sustainable Development Goals (SDGs), especially by reconciling economic growth with the protection of the environment through its grow-make-use restore approach. The use of insects in circular production systems has been a good example of this concept as insects can transform a wide range of organic waste and by-products into nutritious feedstuffs, which then go back into the production cycle. This paper explores the potential of mealworms (*Tenebrio molitor*) in circular production systems by reviewing their use and applicability in several industries such as pharmaceuticals, agriculture, food, etc. Despite the high versatility of this insect and its potential as a substitute source of nutrients and other valuable components, there are still many legislative and behavioral challenges that hinder its adoption and acceptance.Most petroleum-based plastics are resistant to biodegradation in the environment. Observation of damage, penetration, and ingestion of plastics by insects and their larvae lead to research on biodegradation of plastics by insects.The rapid biodegradation of PS and PE is likely a result of synergistic effects of intestinal microbial activities and host digestive system, and further research is needed to understand the mechanisms. The main objective of this review is to analyse the potential of insects from the perspective of circular economy, focusing our attention on mealworm larvae. This study will also contributed the mitigation of climate change through reduction in soil pollution.



**Keywords:** Plastic, Mealworms, Soil pollution, Biodegradation, Soil Health




## INTRODUCTION

Most petroleum-based plastics are resistant to biodegradation in the environment. Observation of damage, penetration, and ingestion of plastics by insects and their larvae lead to research on biodegradation of plastics by insects. The larvae of darkling beetles (Coleoptera: Tenebrionidae), especially *Tenebrio molitor* and *Tenebrio obscurus* larvae, showed the capacity of rapid gut microbe-dependent degradation of polystyrene (PS). *T. molitor* larvae also degrade low-density polyethylene (LDPE). The biodegradation was evaluated on the basis of plastic mass balance, modification of ingested polymers, formation of biodegraded intermediates, as well as $^{13}C$ isotopic tracer tests. Ingested PS or LDPE polymer can be depolymerized by up 60–70% within 12–24 h after 1- or 2-week adaption. Ingested PS or PE supports the larvae with energy for life activities but not growth. Co-feeding normal diet (e.g., bran) enhances PS and PE consumption rate significantly. Gut microbial communities shifted after the larvae were fed with PS or PE. A few plastic-degrading gut bacterial strains have been isolated from gut of *T. molitor*, but they grow on plastics slowly. The rapid biodegradation of PS and PE is likely a result of synergistic effects of intestinal microbial activities and host digestive system, and further research is needed to understand the mechanisms (Yang et al., 2015), (Brandon et al., 2021).

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Since 1950s, synthetic plastic products derived from petroleum have been widely used in our daily lives from electronic products, water supply and drainage pipelines, coating and wiring, to packaging and containers. In 2013, global plastic production was 299 million tons, which is a nearly 200 fold increase over the annual production of 1.5 million tons in 1950 [1]. The annual produced plastic production has been and will continue increasing in the foreseeable future [2].

According to USEPA [3], plastics wastes (PSW), which are a rapidly growing segment of municipal solid waste (MSW), are found in all major MSW categories, such as the containers and packaging category (e.g. bags, sacks, and wraps, other packaging, PET bottles, jars and HDPE natural bottles, and other containers). Compared with plastics wastes (390,000 tons) generated in 1960, the quantity of plastics wastes generation has increased relatively steadily to 31.8 million tons in 2011 [3]. With regard to percentage of MSW generation, plastics wastes generation was increased from less than 1% in 1960 to 12.7% in 2011. A recent study indicates that up to 6,300 million metric tons of plastic waste have been generated to date [4]. However, among the generated plastic wastes, less than half of it was confined to landfills or recycled. Of the remaining plastic wastes, a large proportion litters continents, oceans, and every corner of our world to make the world a “Plastic World” [5]. In our daily life, the most widely used plastics are thermoplastics, the most common of which are: polyethylene (PE) 29.6%, polypropylene (PP) 18.9%, polyvinyl chloride (PVC) 10.4%, polyurethane (PUR) 7.4%, polystyrene (PS) 7.1%, and polyethylene terephthalate (PET) 6.9% [2] (Figure 1). These plastic materials are also major sources of micro plastic pollution in ocean [2]. Of particular concern is that, several of these plastic materials, especially PS, PVC, PUR as well as polycarbonate [6]-[8], making up approximately 26% of the plastics production, are the most hazardous to environment and human health [5]. There is a growing scientific consensus demonstrating that plastic wastes are a major environmental concern of increasing global significance:

Soil contamination by plastic wastes causes severe environmental pollution, and could lead to the decline of crop production. The plastics wastes in landfill occupy a great area of land (Landfill disposal of 10,000 tons plastic wastes occupy 0.067 hm2 land), and also inevitably release large amounts of chemicals including oligomers, catalyst remnants, polymerization solvents, and a wide range of plastic additives [7]. These hazardous chemicals could leech from the plastic wastes and impact the soil quality [9], as well as neighboring groundwater. λ Water contamination by plastic wastes has been a major concern because they harms large ocean animals, deteriorate fishing industry, and damage aquatic environment. A recent report indicates that approximately 0.48-1.27 million tons of plastic waste enters ocean annually and the introduction of plastic into the ocean is increasing at an astonishing rate, with an estimated doubling time of 10 years [10], [11]. Studies have shown that the plastics wastes occupied 60-80% of all marine debris are widespread in the marine environment, at the sea surface, on shorelines and on the seabed [12]. Abiotic degradation, by wind, rain and sun, could cause harmful materials and chemicals to leech from plastic wastes, causing a secondary pollution problem within surface water, groundwater, and marine water bodies. λ Air pollution is another serious environmental concern. Referring to the disposal and management of solid wastes, PSW is co-incinerated with MSW. The combustion of PSW could result in the emission of air pollutants such as volatile organic compounds (VOCs), heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzofurans (PCDFs), dioxins, NOx, SOx, etc. if off gases are not managed properly. At worst, some carcinogenic substances such as PAHs, nitro-PAHs, dioxins, etc., could be released as airborne pollutants during the incineration of plastic wastes containing PVC, PET, PS and PE [13]. λ Plastic pollution has the potential to poison animals and pose a serious threat to human health. According to a hazard-ranking model based on the United Nations' Globally Harmonized System of Classification and Labeling of Chemicals, the chemical ingredients of more than 50% of plastics are hazardous [7]. These harmful chemicals leeched from the plastic wastes or in the form of small or micro plastic debris are more likely to infiltrate food webs [14], and potentially impact ecologically important species including mussels, salt-marsh grasses and corals [14], [15]. Humans and mussels that ingested the chemicals from plastics and small or micro plastic debris could accumulate in the body, and harm the cells and other tissues [14], [16].

**Plastic wastes control and management strategies**

Except for the risks and hazards to the human health and the environment safety, the improper management and disposal of plastic wastes impact the aesthetic of the environment, badly affect the beauty of urban and remote environments. The generation of plastic wastes can be mainly classified into two categories.

1: Preconsumer or industrial plastic wastes

2: postconsumer plastic wastes

Preconsumer or industrial plastic wastes referred to the discarded plastics, which are produced during the plastic production and product fabrication processes. These kinds of plastic wastes can be directly recycled and re-used by the processing and manufacturing departments.Sustainable plastic wastes management solutions should apply methods or technologies that meet the requirements for efficient recycling of resources without generation of harmful substances (toxic and hazardous by-products or end-products) to humans or the environment. As we described elsewhere [2], the overall strategy for controlling plastics pollution should primarily focus on source reduction, increased use of biodegradable materials, improved reuse, recycle and recovery of plastic via improved separation efficiency from waste streams, and subsequently the development of costeffective clean-up and bioremediation technologies.

**Biodegradation of polystyrene wastes**

Industrial production of PS began around 1930 [17]. Today, PS products are widely used in our daily lives. The application of PS products includes use of expanded PS (EPS), trade name Styrofoam, in building insulation and packing, extruded PS (XPS) in containers (coffee cups and food trays), and high density PS materials as liquid containers. Most PS are used as foam products. With the rapid development of economy and society, the demand for PS materials and products has been continually increasing. By 2013, annual global production of PS was around 21 million tons, accounting for about 7.1% of the total global plastic production [18]

Biodegradation of PS Wastes by PS-Eating Mealworms Yellow mealworms are the larvae of Tenebrio molitor Linnaeus which is a holometabolic insect, passing through the stages of egg, larva, pupa, and beetle. They are pest insects for storage and also are commercial animal feed available in pet markets and stores. Mealworms eating Styrofoam and isolation of bacteria from mealworms' gut were reported by several middle and high school students for science fairs via public media (newspapers and internet) in 2000s. However, these early studies did not get academic attention as they did not result in peer-reviewed publications or archiving of isolates. Mealworms have chewing and eating behavior for Styrofoam and other plastic foam. The confirmation results of the biodegradation and mineralization of PS in the larval gut of the Tenebrio molitor Linnaeus were published by Yang et al. (2015) [39]. The mealworms were purchased from a pet market in Beijing, China. After fed with Styrofoam (5.8 g) as the sole diet for 30 days, the mealworms (500 in an incubator) consumed 31.0±1.7% of Styrofoam. A test for the determination of the survival rate (SR) over a 1 month period showed that the difference between of the SR of Styrofoam-feeding mealworms and the SR of conventional diet (bran)-feeding mealworms was not significant (average 85%). Similar results have been observed using different batch of mealworms from Harbin, China and Compton, California, the USA. The SR was approximate 81.3 ± 2.5% and 86.7 ± 3.3% for the Styrofoam-feeding mealworms from Harbin and California, respectively when Styrofoam was fed as a sole diet over one month. For one incubator containing 120 mealworms and Styrofoam was consumed by 29.9 ± 3.84% and

23.6 ±0.1% over one month period, respectively. The consumption of Styrofoam and high SG indicated that Styrofoam-feeding could be digested and utilized as energy source to maintain their life activity.

**Future research and perspectives of microbial degradation of plastics**

Mealworms degraded ingested PS in their gut up to 40-50% within the relatively short 12-15 hrs gut retention time. Further studies with antibiotics have suggested that the PS biodegradation is likely gut microbe-dependent. To date, however, no microorganisms isolated, including strain YT2 isolated from the mealworm gut, can degrade PS at the same rate as the mealworms. More research is needed to understand the mechanisms of the PS biodegradation in mealworm gut and interactions between the mealworm host and gut microbes. The mealworms' ability to biodegrade PS may expand to other plastic materials such as PE, PP, PET, and PUR and will be tested. The ubiquity of PS biodegradation by mealworms around world in relation to their gut microbiota should be investigated in order to further understand the mechanisms and select highly efficient mealworm strains and microorganisms. Future microbiological work can focuses on isolation and characterization of more PS-degrading single cultures and define high efficiency mixed cultures (if present) from various PS-degrading mealworms.

**CONCLUSION**

Insect production is expected to dramatically grow in the next few years due to the increasing need of finding alternative sources of protein. Given the « zero waste » context and the need to contribute to the circular economy, it is necessary to capitalize on all components of the insects, including their frass. Tis study indicates that frass has a great potential to be used as a partial or a complete substitute of mineral NPK fertilizer. Indeed, due to its rapid mineralization and its high content in readily-available nutrient, frass has similar effectiveness to supply N, P and K and sustain biomass production than NPK fertilizer. In addition, compared to mineral fertilizer, water soluble P concentration is up to five times lower in the presence of frass, which prevents P from loss and sorption onto soil constituents. Most importantly, the presence of frass may increase microbial metabolic activity and diversity, suggesting a better soil functioning, especially when frass is combined with mineral fertilizer. As this was a greenhouse study, further in situ researches are required because temporal mineralization in controlled conditions may be different from mineralization in field due to e.g. differences of moisture, temperature and soil and crop biodiversity, thereby affecting possibly the temporal release of nutrient for plants.

Nonetheless, our findings suggest that the forecasted growing amount of frass generated in the near future might constitute a sustainable resource for managing NPK nutrition in cropping system and a promising alternative to conventional fertilizer.

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