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Effect of varying weight of mealworms (*Tenebrio molitor* L.) on styrofoam degradation

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Abstract

Background: Waste management involves systematic and sustainable practices, including recycling daily solid waste. Globally, styrofoam , a common type of plastic waste, is widely used in packaging and food services. In 2022, its production capacity was 15.44 million metric tons, projected to rise by 2026, posing significant environmental challenges due to its non-biodegradable nature and contribution to pollution. Regarding this issue, mealworms *(Tenebrio molitor* L.) show the potential to degrade styrofoam , converting it into CO_2, fecal matter, and minimal biomass.

Methods: This study investigated styrofoam degradation by mealworms and its impact on their growth and nutrient content, focusing on degradation efficiency based on mealworm weight. Using a pre- and post-test design without a control group, mealworms were tested at weights of 100, 200, and 300 g. The study measured styrofoam weight reduction and mealworm weight increase, as well as heavy metal content in residues and mealworms.

Results: The results show significant differences in degradation rates: 2.72% for 100 g, 54.25% for 200 g, and 70.37% for 300 g treatments, with the highest reduction in the 300 g treatment, proving significant relationship between mealworm weight and styrofoam degradation. Heavy metal analysis indicates mealworms excrete most heavy metals through residues, efficiently converting styrofoam into biomass, CO_2, and excrement.

Conclusion: These findings highlight mealworms' potential as a sustainable plastic waste management solution. Future research should focus on protein content analysis in mealworms before and after styrofoam consumption to understand nutritional its impacts. This study contributes to the discourse on innovative plastic waste management strategies.

Keywords: Solid waste, Styrofoam, *Tenebrio*, Larva, Biomass

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Introduction

Waste management involves systematic, comprehensive, and sustainable activities in reducing and handling waste, including the recycling of solid waste produced daily by human activities or natural processes into useful products. Specific waste requires specialized management due to its properties, concentration, or volume. Waste producers include any individual or natural process generating waste. Effective waste management encompasses the systematic reduction, handling, and utilization of waste (1,2).

Generally, there are various types of plastic waste such as plastic bags, bottles, straws, styrofoam , balloons, diapers, etc. Plastic waste can cause pollution in soil, water, and air. In soil, plastic can obstruct water absorption and sunlight, thereby, reducing soil fertility and increasing the risk of flooding (3). In oceans, plastic waste can be exposed to ultraviolet rays from the sun, causing photodegradation that breaks down the plastic into small particles known as microplastics (4,5). Air pollution from plastic occurs primarily through the emission of toxic chemicals during plastic production and incineration, as well as through the release of airborne microplastics, which can affect respiratory health and contribute to environmental contamination (6).

Globally, the packaging and food services rely heavily on the usage of styrofoam . In 2022, the global production capacity of polystyrene (PS), the material from which styrofoam is made, reached approximately 15.44 million metric tons and is expected to increase slightly by 2026 (7). This extensive use poses significant environmental challenges because styrofoam is non-biodegradable and persists in nature, contributing to pollution and ecological harm (8).

In 2018, the demand for plastic materials in Indonesia reached up to 7.6 million tons. Polypropylene (PP) and polyethylene (PE) are the most common types of plastic found in the environment (9). Based on the data from the Ministry of Environment and Forestry in 2016, the volume of waste in Indonesia in 2015 was 64.5 million tons, projected to increase to 65.8 million tons in 2017. Plastic waste accounted for 14% of this total. Styrofoam, or PS, is one of the most commonly used types of plastic waste, primarily for food packaging and cushioning material for fragile goods delivery. Styrofoam does not degrade naturally and takes thousands of years to decompose (10).

The life cycle of Mealworms (*Tenebrio molitor* L.) encompasses several stages: eggs, larvae, pupae, and adult beetles, with varying lengths at each stage (11). Research on the length of *T. molitor* L. larvae exposed to various types of plastic indicated that larvae exposed to High-Density Polyethylene (HDPE) had the highest average length (1.83 cm), in comparison, those exposed to Low-Density Polyethylene (LDPE) had the lowest (1.41 cm). Body weight measurements showed consistent average weights (0.07 grams). The highest degradation rates belonged to Tenebrio molitor L. in the control group (0.075), followed by PP (0.011) and LDPE (0.009). 9).

Adding styrofoam to the *T. molitor* L. diet impacts several factors: how much their body weight increases, how much feed they consume, and how efficiently they convert feed into body mass. When *T. molitor* L. were given a diet consisting of 75% of their basic feed needs, they gained the most body weight. Specifically, they gained 0.82 g for every 100 *T. molitor* L. per day, which is equivalent to 0.0082 grams per *T. molitor* L. per day. Additionally, their feed consumption rate was 3.25 (12).

The discovery of Mealworms' (*T. molitor* L.) ability to degrade styrofoam has gained significant attention in recent years. This capability presents a potential solution for addressing the persistent nature of styrofoam . Generally, the current methods for styrofoam degradation are considered ineffective, whereas *T. molitor* L. has shown efficacy in consuming and degrading styrofoam . It is estimated that 47.7% of the carbon molecules in styrofoam consumed by *T. molitor* L. are converted into carbon dioxide (CO_2), 49.2% are excreted as fecal matter, and about 0.5% is converted into biomass. This research underscores the effectiveness of degradation by *T. molitor* L. larvae (13).

This study aimed to investigate the impact of styrofoam consumption on the nutrient content and growth of mealworms while examining the differences in the weight of mealworms (*T. molitor* L.) in degrading styrofoam , using various mealworm weights of 100, 200, and 300 g.

Materials and Methods

This study employed an experimental research design, specifically a pre- and post-test design without a control group. The research aimed to investigate the differences in the weight of mealworms in degrading styrofoam. Three weights (100, 200, and 300 g) were selected to represent a range of mealworm population sizes to observe how different quantities of mealworms affect styrofoam degradation. These specific weights were chosen to provide a comparative analysis across small, moderate, and large groups of mealworms, allowing for a clearer understanding of how the weight and number of mealworms influence the rate of styrofoam degradation and mealworm growth. Using these varied weight categories, the study could more effectively examine the relationship between mealworm biomass and styrofoam breakdown efficiency.

In this study, the mealworms were exclusively fed with styrofoam throughout the experimental period and were not provided with other food sources. This approach was intended to isolate the effects of styrofoam consumption on the degradation process and mealworm growth, eliminating any confounding variables from additional food sources.

Regarding the parameters affecting mealworm activity and growth, the experiment was conducted under controlled laboratory conditions to ensure consistency. The temperature, humidity, and light exposure were kept stable throughout the study, the range of ambient temperature was 35.9-37.5 °C, meanwhile, the range of ambient humidity was 60-65, and the average of light exposure as 106 lux. Mealworm activity and growth are influenced by these environmental factors, and the controlled conditions were maintained to minimize their variability.

In addition to measuring the weights of styrofoam and mealworms, this study also assessed the heavy metal content in the mealworms and the residues produced by them. The research was conducted on a laboratory scale at the Vector and Pest Laboratory, Department of Environmental Health, Bandung Health Polytechnic (14).

In this study, the population comprised mealworms (*T. molitor* L.), while a sample was representative of the population studied. The sample in this study consisted of a specific number of mealworms (*T. molitor* L.) taken from the population (15). The eggs of *T. molitor* were obtained from a farm and cultivated in the laboratory to become larvae. The *T. molitor* larvae used in this study were two weeks old and in a growth phase, making them highly active. The sample size for this study was determined using the formula: $t (r-1) \geq 15$, resulting in six repetitions for each treatment group. Therefore, a total of 3.6 kg of mealworms (*T. molitor* L.) were required for the experiment (16).

The average number of mealworms used in each treatment varied, 121 mealworms in treatment 1, 231 mealworms in treatment 2, and 321 mealworms in treatment 3. The size of the styrofoam pieces was standardized for all treatment groups to maintain consistency in surface area exposure, with 5 cm height, 15 cm diameter, and 7.5 cm radius. The ratio of styrofoam to mealworm weight is 1:24. The mealworms were fed styrofoam continuously during the study period without additional supplementation of other food sources. The feeding process was passive, as the styrofoam remained in the reactors throughout the experiment.

The mealworms were kept in a controlled laboratory environment, where the range of ambient temperature was 35.9-37.5 ℃, meanwhile, the range of ambient humidity was 60-65, the average of light exposure was 106 lux, and the parameters exposure was maintained consistently. In this study, parameters such as time, temperature, and light were controlled to ensure a consistent environment for the mealworms (*T. molitor* L.) across all treatment groups. However, these factors were not the primary focus of the experiment and were not systematically varied, as the objective was to investigate the effect of different mealworm weights on styrofoam degradation. Previous research has established that such environmental factors can influence mealworm metabolism and feeding rates, but for this study, they were held constant to isolate the impact of mealworm weight on degradation efficiency. Future studies may consider exploring the interaction between environmental conditions and mealworm feeding behavior to provide a more comprehensive understanding of the degradation process under varying conditions.

The mealworms were monitored daily to ensure their survival, and no additional nutrients or food sources were provided to the mealworms. No mortality was recorded, and the conditions were optimized to support their growth based solely on the styrofoam consumption.

In this study, a control group was not included as the primary objective was to assess the impact of varying mealworm weights on styrofoam degradation. The experiment specifically focused on quantifying the degradation efficiency and weight changes in mealworms exposed solely to styrofoam , building on prior research that has already established normal growth patterns in mealworms fed on organic matter. The experimental conditions were standardized to minimize the influence of external variables such as age, diseases, and environmental factors, with all mealworms being of the same age and housed in a controlled laboratory environment. Given these consistent conditions, it is reasonable to attribute the observed weight changes and degradation outcomes primarily to styrofoam consumption rather than external influences. This approach allowed for a more focused investigation of the relationship between mealworm weight and styrofoam degradation efficiency.

The equipment and materials prepared for this research include mealworms (*T. molitor* L.), styrofoam, an analytical balance, an oven, and a mealworm reactor. In this study, mealworm (*T. molitor* L.) digestion followed a standardized method for processing insect biomass, which involved oven-drying and grinding the mealworms into fine powder. The drying process was carried out at 40-50°C for four hours, after which the mealworms were pulverized to ensure uniformity in particle size before further analysis. This method is consistent with the procedures used in previous research on mealworm digestion for various studies, where similar techniques were applied to analyze biomass, heavy metal accumulation, and degradation efficiency in plastic-consuming insects (17,18). Such controlled methods allow for accurate determination of mealworm weight gain and nutrient analysis post-treatment. The examination of heavy metals in the residue and the mealworms' bodies will be conducted using atomic absorption spectrophotometry (AAS).

In this study, the concentration of heavy metals (lead [Pb], mercury [Hg], cadmium [Cd], and arsenic [As]) in mealworm residues and the mealworms' bodies was measured using AAS. The AAS device used had a limit of detection (LOD) for each metal, the LOD of Pb is 0.0215 ppm, 0.0040 ppm for Hg, 0.0035 ppm for Cd, and 0.0050 ppm for As. These values ensure the sensitivity and accuracy of the metal measurements throughout the experiment.

The examination of heavy metals was conducted to study *T. molitor* L. Some studies have found that certain types of insect larvae can digest plastic waste containing heavy metals (19). These larvae possess the ability to degrade PS plastic, such as styrofoam, through their digestive mechanisms in collaboration with bacteria in their digestive systems. The styrofoam consumed by *T. molitor* L. passes into their digestive tract, where this process occurs (20).

The heavy metal content in styrofoam will be digested by *T. molitor* L., producing enzymes and bacteria that work together to degrade the styrofoam. Enzymes produced by *T. molitor* L., such as lipase, break down the chemical bonds in the styrofoam structure into simpler organic compounds (20). Therefore, it is necessary to measure the amount of heavy metals, such as Pb, Cd, Hg, and arsenic, that can be digested by the larvae and expelled through residual waste or excrement as a byproduct of styrofoam degradation. *T. molitor* L., also known as mealworms or Hong Kong worms, have been shown to biologically break down PE plastic and styrofoam (a type of PS plastic) (20,21).

Meanwhile, the presence of aromatic hydrocarbon styrene in the excrement and body of the mealworms was not specifically checked or measured in this study. The primary focus was on evaluating the overall degradation efficiency of styrofoam by mealworms, with particular attention to weight changes and heavy metal content in both the excrement and mealworms. While previous research has indicated that mealworms can metabolize styrofoam , converting it into CO_2, biomass, and fecal matter, the detailed breakdown and measurement of specific chemical components such as styrene were beyond the scope of this investigation. Future studies could explore the presence and fate of styrene and other by-products in more detail.

The examination of heavy metals in the residue and the mealworms' bodies is also analyzed for further consideration of utilization possibilities based on the heavy metal content for reference of further research.

The research procedure is as follows:

1. Mealworms (*T. molitor* L.) were collected from their natural habitat and held in the laboratory for three days without being fed; any deceased individuals were replaced with new ones (22).
2. Styrofoam was weighed using an analytical balance, and each piece was labeled accordingly (22).
3. Mealworms were weighed in batches of 100, 200, and 300 g using the analytical balance (22).
4. The styrofoam was placed into reactors containing mealworms for each treatment group (18).
5. The weight of the styrofoam and mealworms was measured daily using the analytical balance (8,22).
6. The residue from the styrofoam degradation by the mealworms was analyzed in the laboratory for heavy metals, including Hg, Pb, Cd, and As (2).
7. After the treatment, the mealworms were dried in an oven at a temperature between 40-50 °C for four hours. Once dried, they were ground into a fine powder using a mortar and pestle. The powder was then sifted to ensure it was uniform before being analyzed in the laboratory (2).

The data collected from the pre-treatment and post-treatment phases of the study were analyzed using computer software such as Microsoft Excel and SPSS (23). The results of statistical analysis showed that the data were normally distributed, and ANOVA analysis indicated a significant relationship between mealworm weight and styrofoam degradation ($P < 0.05$) (24,25).

Results

The following results show the degradation of styrofoam by mealworms (*T. molitor* L.) under three different treatments: Treatment 1, Treatment 2, and Treatment 3. Measurements of styrofoam weight were taken from Day 1 to Day 14 for each treatment, to determine the initial and final weights of the styrofoam .

Based on Figure 1, in Treatment 1, the degradation weight of styrofoam by mealworms (*T. molitor* L.) ranged from 2.61% to 2.86%, with an average reduction of 2.72%. In Treatment 2, the degradation weight ranged from 51.1% to 58.25%, with an average reduction of 54.25%. In Treatment 3, the degradation weight ranged from 68.17% to 73.54%, with an average reduction of 70.37%.

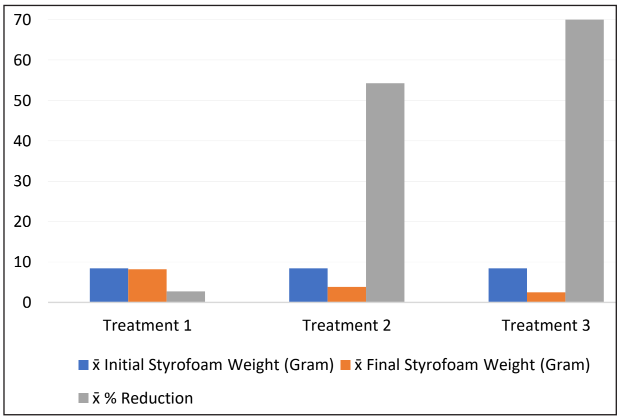

Figure 1. Styrofoam degradation by mealworms (*Tenebrio molitor* L.)

The weight measurements of mealworms (*T. molitor* L.) over 14 days before and after styrofoam degradation are as follows:

Based on Figure 2, in Treatment 1, the weight increase of mealworms (*T. molitor* L.) ranged from 1.15% to 1.39%, with an average increase of 1.39%. In Treatment 2, the weight increase ranged from 2.32% to 2.99%, with an average increase of 2.50%. In Treatment 3, the weight increase ranged from 3.10% to 4.77%, with an average increase of 3.69%.

The residue measurements produced by mealworms (*T. molitor* L.) after degrading styrofoam are as follows:

Based on Table 1, in Treatment 1, the residue weight ranged from 0.01% to 0.03%, with an average residue production of 0.02%. In Treatment 2, the residue weight ranged from 0.05% to 0.07%, with an average residue production of 0.06%. In Treatment 3, the residue weight ranged from 0.09% to 0.21%, with an average residue production of 0.12%.

Based on Figure 3, the average heavy metal content in the residue produced by mealworms *(T. molitor* L.*)* is as follows: Pb: 0.135 mg/L, Hg: 0 mg/L, Cd: 0 ppm, and As: 0 ppm.

Based on Figure 4, the average heavy metal content in the mealworms (*T. molitor* L.) is as follows: Pb: 0.25 mg/L, Hg: 0 mg/L, Cd: 0.31 ppm, and As: 0 ppm.

Based on Table 2, the normality test indicates that the data were normally distributed, as the P-value for each treatment exceeded 5% (α). Therefore, it can be concluded that the data are normally distributed, and subsequent analysis will be conducted using ANOVA.

Based on Table 2, the normality test indicates that the data were normally distributed, as the P value exceeded 5% for all the results.

Based on Table 3, the ANOVA test results show a P value (0.00) < 5% (α), indicating that Ha is rejected and H0 is accepted, thereby concluding that there is a significant relationship between mealworms and the degradation of styrofoam .

Some documentation taken during the research are

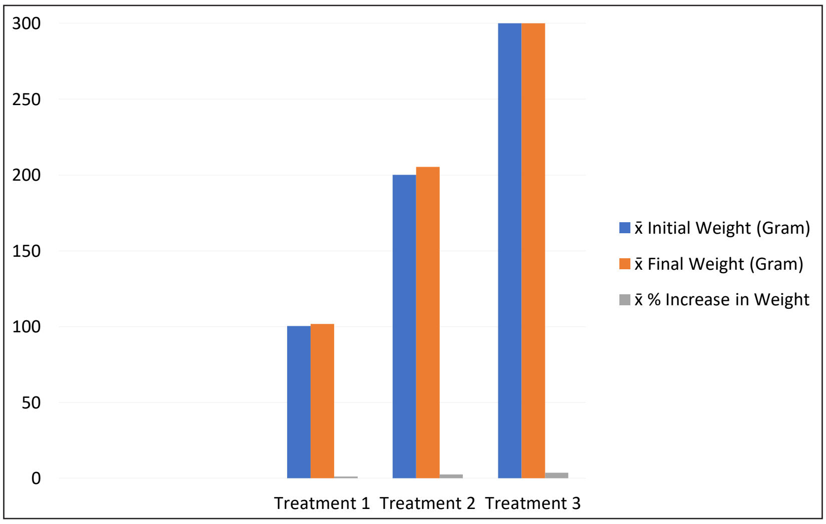

Figure 2. Mealworm weight (*Tenebrio molitor L.*) before and after treatment

Table 1. Residue produced by mealworms (*T. molitor* L.)

No.	Treatment	Residue produced (g)
1	1st Replication of Treatment 1	0.0292
2	2nd Replication of Treatment 1	0.0295
3	3rd Replication of Treatment 1	0.0167
4	4th Replication of Treatment 1	0.0091
5	5th Replication of Treatment 1	0.0129
6	6th Replication of Treatment 1	0.0174
7	1st Replication of Treatment 2	0.0578
8	2nd Replication of Treatment 2	0.0519
9	3rd Replication of Treatment 2	0.0618
10	4th Replication of Treatment 2	0.0669
11	5th Replication of Treatment 2	0.0698
12	6th Replication of Treatment 2	0.0534
13	1st Replication of Treatment 3	0.0906
14	2nd Replication of Treatment 3	0.0956
15	3rd Replication of Treatment 3	0.1201
16	4th Replication of Treatment 3	0.2119
17	5th Replication of Treatment 3	0.1019
18	6th Replication of Treatment 3	0.1129

shown in Figure 5.

Discussion

The average reduction in styrofoam weight was 2.72% for Treatment 1, 54.25% for Treatment 2, and 70.37% for Treatment 3. The significant reduction observed in Treatment 3 is correlated with the life cycle of mealworms (*T. molitor* L.), which undergo complete metamorphosis (*holometabola*). This life cycle of mealworms consists of the egg, larval, pupal, and adult stages. In the study, metamorphosis did not occur exclusively in the 300 g group; all mealworms, regardless of weight, follow the same life cycle of complete metamorphosis (*holometabola*), progressing from larvae to pupae and eventually into adult beetles. However, the mealworms in the 300 g treatment group exhibited faster growth and development due to their larger size, increased food intake, and energy reserves, accelerating their progression towards metamorphosis (18). Significant differences were observed between the weight categories in terms of age, ability to digest food, and growth rates. The 300 g mealworms were older and consumed more food compared to the 100 g and 200 g groups, leading to more efficient styrofoam degradation (2,18). This higher efficiency in digestion can be attributed to the presence of specific gut bacteria such as *Bacillus* sp. and *Enterobacter asburiae*, which assist in breaking down styrofoam into simpler compounds (2). The 300 g worms also showed the greatest increase in body weight (3.69%), while the 100 g group had the lowest one (1.39%), correlating with the worms' energy needs for molting and their advanced developmental stage (2,18). These distinctions highlight the importance of worm size and age in their ability to degrade plastic efficiently, which should be reflected in the materials and methods section to provide a clearer understanding of the experimental setup.

The eggs of *T. molitor* L. are oval-shaped, with a width of approximately 3.5 mm and a length of approximately 1 mm. These eggs are white and difficult to distinguish from the substrate. The larvae hatch after 7 days, entering the larval phase, where they are commonly referred to as mealworms and are widely utilized by the community, especially for poultry feed. During this active phase, the mealworms' movement and eating behaviors are more noticeable and intense. The larval stage includes 10 instar stages. The pupal stage is a quiet phase in which the larvae transform into adults. During this time, the larvae do not move or eat; instead, they undergo significant changes to develop into adult beetles. During this phase, the body size slightly decreases compared to the larval stage, and the pupae are yellowish-white, with a width of

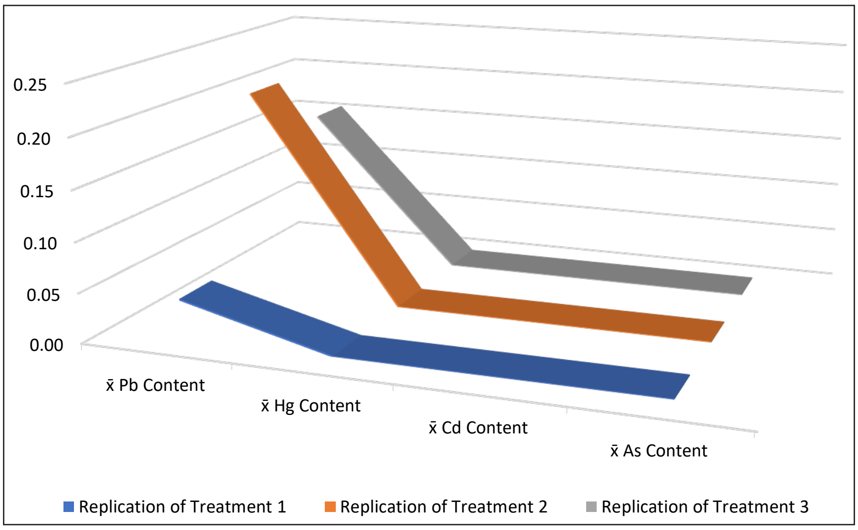

Figure 3. Heavy Metal Analysis in The Residue Produced by Mealworms (*Tenebrio molitor* L.)

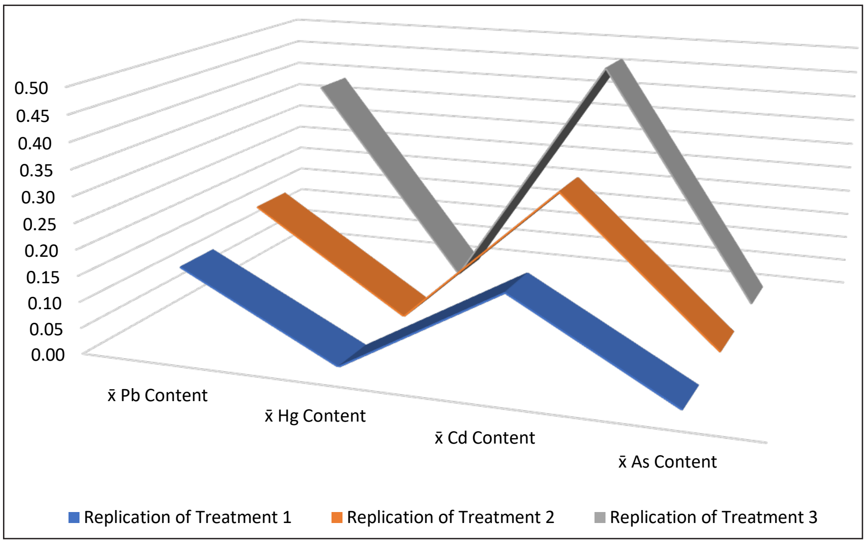

Figure 4. Heavy Metal Analysis in Mealworms (*Tenebrio molitor* L.)

approximately 5 mm and a length of up to 15 mm. The adult stage is divided into two phases: young and mature beetles. Initially, the young beetles have short wings and a soft, wrinkled body that hardens (sclerotization) and darkens over time (26).

The decrease in styrofoam weight observed in Treatment 1 is partly due to the loss of 40 mealworms that died between Day 1 and Day 14. Additionally, the mealworms tended to congregate at a single point rather than spreading out, resulting in minimal degradation of styrofoam . In contrast, no mortality was observed in Treatment 2 and Treatment 3. The larval stage requires significant protein intake to meet the energy demands for growth and a transition through various life stages. Older larvae consume more feed than younger instars, particularly as they approach the pupal stage, which demands higher nutrition levels (12).

External factors such as ambient temperature and humidity, as well as the increased consumption capacity with larval age, play crucial roles. Studies have shown that higher temperatures can increase metabolic rates, leading to greater styrofoam degradation (18). The controlled laboratory conditions in this study may have contributed to optimal degradation rates, but variations in these environmental conditions could result in different outcomes in more natural settings. The study by Iza et al demonstrated that mealworms could degrade styrofoam into CO_2 and other organic materials (18). Similar findings were observed in this study, particularly with the 300-g mealworm group showing the highest degradation rate of 70.37%. This result is consistent with the results of other research that suggests larger, more mature mealworms consume more plastic due to their increased metabolic needs (18). These comparisons and environmental considerations provide a broader context for understanding the effectiveness of mealworms in

Table 2. Results of the data normality test

No.	Treatment	*P* value
1	Initial styrofoam Weight of Treatment 1	0.457
2	Initial styrofoam Weight of Treatment 2	0.052
3	Initial styrofoam Weight of Treatment 3	0.871
4	Final styrofoam Weight of Treatment 1	0.523
5	Final styrofoam Weight of Treatment 2	0.807
6	Final styrofoam Weight of Treatment 3	0.740

Table 3. Result of ANOVA Test

No.	Treatment	*P* value
1	Initial styrofoam weight – final styrofoam weight	0.000

Figure 5. Styrofoam degradation by *Tenebrio molitor* L.

plastic degradation, highlighting their potential as a sustainable solution for managing styrofoam . In this study, environmental factors such as temperature, humidity, and oxygen levels were controlled to maintain consistent laboratory conditions. However, these factors were not the primary focus of the analysis, as the research aimed specifically to evaluate styrofoam degradation based on variations in mealworm weight. While controlled conditions helped standardize the experiment, the primary objective was to assess how different mealworm weights (100, 200, and 300 g) affected the degradation process.

The average weight increase of *T. molitor* L. after the first treatment was 1.39%. Under the second treatment, the average weight increase was 2.50%. For the third treatment, the average weight increase reached 3.69%. The larvae's ability to degrade styrofoam is significantly influenced by physical, mechanical, biochemical, and microbial activities.

The results of statistical analysis showed that the data were normally distributed, and ANOVA analysis indicated a significant relationship between *T. molitor* L. weight and styrofoam degradation ($P < 0.05$).

The physical or mechanical degradation of styrofoam is supported by the strong jaw structure of *T. molitor* L., which can tear apart styrofoam and various other types of plastic (20,21). Biochemical degradation of styrofoam is driven by chemical processes involving enzymes in the mealworms' digestive system. Particularly noteworthy is the role of microorganisms within this system, researchers have identified beneficial bacteria living in the larvae's gut, with each *T. molitor L.* larva containing about 500 000 to 600 000 bacteria. These include species like *Bacillus* sp., *Enterobacter asburiae*, and *Exiguobacterium* sp. strain YT2 (17).

As the body weight of mealworms increases, their feed consumption also increases. Furthermore, mealworms molt, or shed their skin, every 7-8 days. This process of molting requires more food, leading to even higher feed intake. The average weight and length growth of *T. molitor* L. larvae are linked to their development through different instar stages and the corresponding rise in their feed consumption (17).

The larvae of *T. molitor* L., commonly known as mealworms or Hong Kong caterpillars, have demonstrated the capability to biologically degrade PE and styrofoam (a type of PS). These larvae can consume styrofoam as their sole food source, with no significant difference in survival rates between larvae fed on styrofoam and those fed on bran (2).

The heavy metals-Hg, Pb, Cd, and As-were selected for analysis due to their known environmental toxicity and potential association with synthetic materials like styrofoam (19). These metals are commonly found in industrial by-products, and their presence in styrofoam or contamination from the environment could pose significant health and ecological risks. By analyzing these metals in both the mealworms and their residues, the study aimed to ensure that the styrofoam degradation process did not result in harmful metal accumulation or environmental release, ensuring the safety and sustainability of using mealworms for plastic waste management.

The average levels of heavy metals found in the residue left behind by *T. molitor* L. larvae are Pb at 0.135 mg/L, Hg at 0 mg/L, Cd at 0 ppm, and As at 0 ppm. For the larvae themselves, the average levels are Pb at 0.25 mg/L, Hg at 0 mg/L, Cd at 0.31 ppm, and As at 0 ppm. This analysis shows that after the larvae degrade styrofoam , they excrete most of the heavy metals through their residue. Specifically, Pb and Cd are efficiently converted into larval biomass, carbon dioxide (CO_2), and larval excrement within less than 24 hours.

The media used for the activity of the worms was styrofoam , chosen specifically due to its role in environmental pollution and its difficult degradation through natural processes. styrofoam was selected for its non-biodegradable nature, providing an ideal substance to test the degradation capabilities of mealworms (*T. molitor* L.) (22). The use of styrofoam was aimed at evaluating how well these mealworms could contribute to plastic waste management by converting styrofoam into biomass, CO_2, and other by-products (22). The selection was supported by previous findings that *T. molitor* L. can efficiently degrade styrofoam through both mechanical and biochemical processes involving gut bacteria.

The digestive system of *T. molitor* L. larvae forms a biofilm layer and creates small holes on the surface of styrofoam , aiding in its degradation. Additionally, bacteria in the larvae's digestive system can break down 7.4% of styrofoam in liquid media over 60 days. This indicates that insect larvae, such as *Galleria mellonella* and *T. molitor*, along with the bacteria in their digestive systems, have the potential for addressing plastic waste, particularly in degrading resistant plastics like PE and styrofoam. However, more research is needed to understand how these larvae and their bacteria can be used on a larger and more sustainable scale for plastic waste management (2). The significant degradation rates observed in this study (2.72% for 100 g, 54.25% for 200 g, and 70.37% for 300 g) are consistent with the findings of Iza et al, who reported that *T. molitor* could degrade PS effectively, converting 47.7% of the carbon in styrofoam into CO_2 and excreting 49.2% as fecal matter (18). Similarly, Putra and Marufah observed degradation rates of PE and PS using mealworms, where higher mealworm weights correlated with more efficient degradation (9). The significant reduction in styrofoam mass in the 300 g group aligns with these findings, reinforcing that mealworm size and weight directly impact their degradation efficiency.

In comparison to chemical methods of plastic degradation, such as photodegradation and incineration, which require substantial energy and time, biological methods using mealworms present a more sustainable and efficient alternative. Previous studies have suggested that the bacteria in the gut of *T. molitor*, particularly species like *E. asburiae* and *Bacillus* sp., play a crucial role in breaking down plastic compounds (2,17). These results further validate this, showing higher degradation rates as mealworm biomass increases, possibly due to the larger digestive capacity and more active microbial colonies in larger worms.

Future research should continue exploring the synergistic role of microbial activity in the degradation process, especially identifying key enzymes that could be harnessed for industrial applications. This study adds to the growing body of evidence supporting the use of mealworms as a viable solution for plastic waste management, particularly styrofoam , which is notoriously resistant to traditional degradation methods.

Conclusion

The most significant findings from this study showed that styrofoam weight reduction was 2.72% in Treatment 1, 54.25% in Treatment 2, and 70.37% in Treatment 3, with the greatest reduction observed in the 300-gram treatment. The mealworms' average weight increased by 1.39% in Treatment 1, 2.50% in Treatment 2, and 3.69% in Treatment 3. Heavy metal content analysis revealed that Pb in the residue was 0.135 mg/L, while in the larvae it was 0.25 mg/L. Hg and As were not detected, and Cd levels were 0.31 ppm in the larvae and 0 ppm in the residue.

This study highlights the potential of *T. molitor* larvae as an innovative solution for styrofoam degradation, contributing to sustainable waste management strategies. By demonstrating a clear relationship between mealworm biomass and styrofoam degradation, the findings emphasize the viability of using biological organisms to address the challenge of non-biodegradable plastics. The ability of mealworms to convert styrofoam into biomass and excrete heavy metals suggests a promising alternative to traditional waste processing methods.

The insights gained from this research lay the groundwork for further exploration into optimizing the conditions for large-scale mealworm-based waste management systems. Future studies should focus on the nutritional impacts on the larvae post-degradation and the scalability of this approach. This biological method, coupled with further technological advancements, could significantly reduce plastic pollution and contribute to global environmental sustainability efforts.

Future studies should also focus on two critical areas: (a) scaling this biological degradation process for practical applications in waste management, and (b) exploring the biochemical pathways that enable mealworms to degrade plastic, particularly the role of gut bacteria. Identifying the specific enzymes and microbial interactions responsible for breaking down plastic compounds could pave the way for optimizing this method for industrial use. Furthermore, understanding how mealworm protein content changes before and after styrofoam consumption could provide insights into the nutritional and ecological implications of using mealworms in large-scale plastic degradation.

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Competing interests

None.

Ethical issues

Does not require any ethical issue.

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