Exploring the life cycle of Tenebrio molitor on a polystyrene diet: The potential for mealworms to reduce the impact of plastics in the environment

This study investigated whether Tenebrio molitor (mealworms) could survive and reproduce on a polystyrene (PS) diet. Two colonies were maintained—one fed oats (control) and the other shredded PS—with both receiving potato slices for hydration. Over 80 days, PS-fed larvae sustained higher and more stable biomass, successfully pupated, matured, and produced viable second-generation larvae. Statistical analysis confirmed a significant biomass difference favoring the PS diet. Although PS-fed larvae pupated earlier, the oat-fed colony showed greater adult emergence and reproductive success overall. These findings demonstrate that T. molitor can metabolize PS, suggesting potential for biological plastic waste management, though long-term viability on a PS diet remains uncertain.

literature Review

Polystyrene (PS), a petroleum-based plastic first commercially produced in 1930, is widely used in packaging, insulation, and construction, with global production reaching ~33 million tonnes annually—about 7% of total plastic production (Farrelly & Shaw, 2017). Its popularity comes from being low-cost, lightweight, and versatile. However, environmental and health concerns are significant: in 1986 the US EPA identified PS manufacturing as the fifth-largest source of hazardous waste (Mwanza & Mbohwa, 2017), and styrene, its precursor, was classified as a possible carcinogen in 2014 (National Research Council, 2014). Despite this, PS itself is not categorized as hazardous. Scholars drawing on new materialisms argue that PS's risks vary by environment, challenging its simple classification as "household waste."

Due to resistance to biodegradation, PS waste accumulates in terrestrial and marine ecosystems, becoming a major pollution issue (Jambeck et al., 2015). Early microbial degradation studies (Guillet et al., 1974; Kaplan et al., 1979; Mor & Sivan, 2008) showed very slow rates. Recently, insect larvae such as mealworms (Tenebrio molitor) have been found to ingest and degrade PS foam with the help of gut microbes (Yang et al., 2015a,b). This discovery expanded research to other species, including superworms (Zophobas atratus), waxworms (Galleria mellonella), and black soldier fly larvae (Hermetia illucens), which also demonstrate plastic consumption abilities (Bombelli et al., 2017; Burgos et al., 2024). Marine invertebrates like sea cucumbers and polychaete worms physically fragment plastics, aiding microbial colonization (Wright, Thompson, & Galloway, 2012).

A notable study by Brandon et al. (2019) showed that T. molitor can metabolize PS containing the toxic flame retardant HBCD, converting about half into CO_2 and excreting the rest as degraded fragments. They expelled ~90% of HBCD within 24 hours and nearly all within 48 hours, without accumulation in their bodies, and remained healthy. Even shrimp that ate these mealworms showed no adverse effects, suggesting potential for safe bioconversion of contaminated plastics into protein-rich animal feed.

The degradation process is linked to gut enzymes and microbial symbionts. Evidence shows similarities between PS and lignocellulosic degradation pathways (Mamtimin et al., 2023; Kuan et al., 2022). Specific bacterial strains, such as Enterobacter hormaechei LG3, isolated from T. molitor guts, can oxidize and depolymerize PS under anaerobic conditions by forming biofilms on the plastic surface (Li et al., 2023).

However, long-term studies reveal limitations. Zhong et al. (2022) found that T. molitor fed only on PS (EPS, HIPS, or LDPE) showed reduced growth, survival, and colony biomass compared to standard diets, indicating poor nutrition and potential toxicity over time. Multi-colony experiments confirmed that PS diets alone cannot sustain healthy mealworm populations.

Scientific Research Question

To what extent can *T.molitor* maintain their biomass and complete their life cycle successfully on a diet predominantly based on polystyrene?

Scientific Hypothesis

Ho - Tenebrio molitor on a diet predominantly consisting of polystyrene will be unable to maintain their body mass and therefore not successfully develop into the pupa and adult stage of their life cycle.

Ha - Tenebrio molitor on a diet predominantly consisting of polystyrene will be able to maintain their body mass and successfully develop into the pupa and adult stage of their life cycle.

Methodology

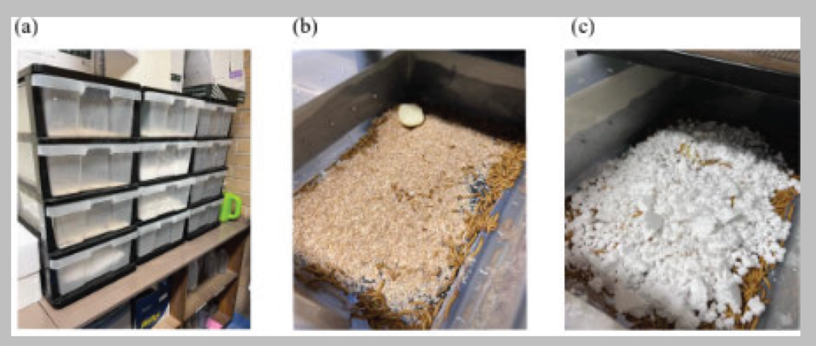

Figure 1. Colony setup of (a) 3 sets of drawers for two colonies and spares for adults and second generation mealworms & trials (b) oat diet setup and (c) PS diet draw setup.

Two colonies of approximately 2500 *Tenebrio molitor* larvae were established—one fed ground oats (control) and the other shredded polystyrene (PS), both supplemented with potato slices for moisture and nutrients. Each colony was housed in ventilated plastic drawers containing 3–4 cm of their respective diets. Four additional colonies were created to separate pupae and adult beetles as larvae progressed through their life cycle. Adult colonies were monitored for the emergence of new larvae, indicating successful reproduction.

Results and Analysis

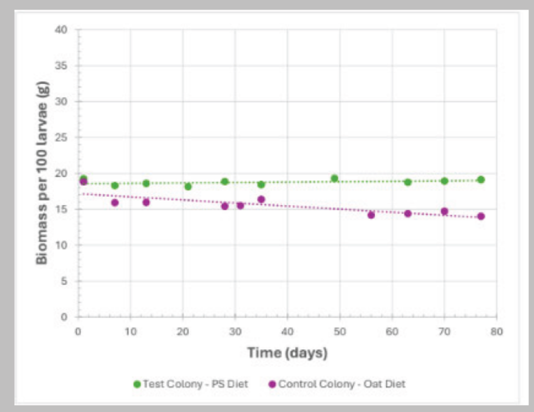

Figure 2. Observed changes in biomass per 100 larvae over 80 days

Over an 80-day observation period, larvae fed a polystyrene (PS) diet maintained significantly higher and more stable biomass than those on an oat diet. The PS-fed colony showed minimal fluctuation in biomass per 100 mealworms (M = 18.77g, SD = ±0.40g), while the oat-fed control group had lower average biomass (M = 15.53g, SD = ±1.41g) with greater variability and a slight decline over time, suggesting possible nutritional stress. A two-tailed t-test confirmed this difference was statistically significant ($t(10) = 6.99$, $p = 3.77 \times 10^{-5}$), indicating that diet had a clear impact on average biomass

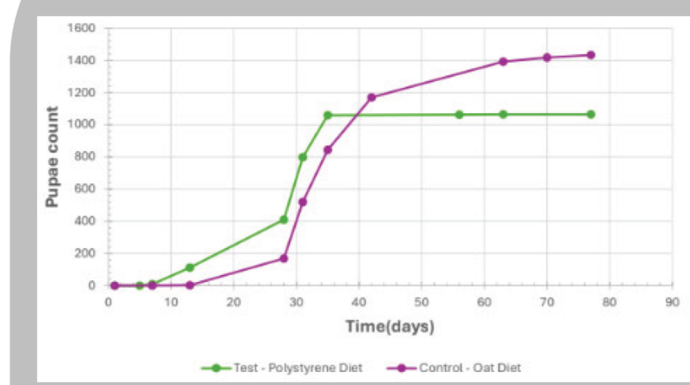

Figure 3. Observed cumulative pupae count over 80 days

Figure 3 shows the cumulative pupae counts over 80 days for larvae on two different diets. Pupation began between days 20–30 for both groups, but larvae on the PS diet transitioned earlier, plateauing just above 1,000 pupae by day 35. In contrast, the oat-fed colony continued pupating until after day 60, peaking above 1,400. This aligns with Morgan (2022), who found faster pupation on a PS diet. The lower pupae peak in the PS group suggests reduced nutritional support for full development, yet the significant number of pupae indicates the PS diet still supports basic physiological functions. These results suggest potential for adapting mealworm colonies to polymer-heavy diets, though further study is needed to assess long-term effects across generations.

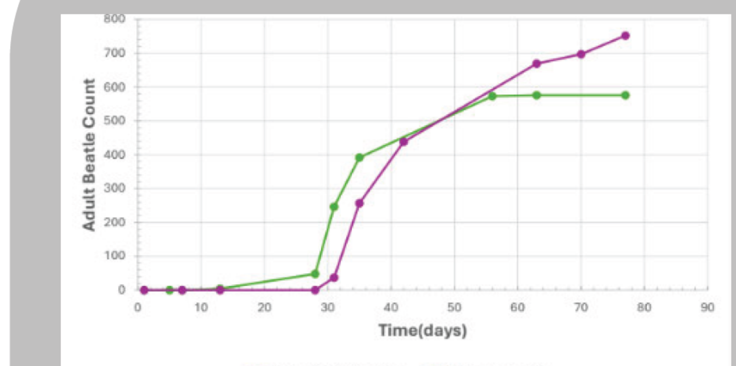

Figure 4. Observed cumulative adult beetle counts over 80 days

Figure 4 shows the cumulative number of adult beetles maturing from pupae over 80 days under two diets. The oat-fed control group showed a steady increase in adult beetles from day 28, reaching over 750 by day 80. The PS-fed test group transitioned earlier and in greater numbers initially but plateaued at around 580 adult beetles. This supports the idea that the PS diet provides fewer nutritional resources compared to oats. However, the ability of the PS-fed colony to produce a substantial number of adults suggests mealworm colonies can potentially be adapted to sustain development and adult emergence on a polymer-based diet.

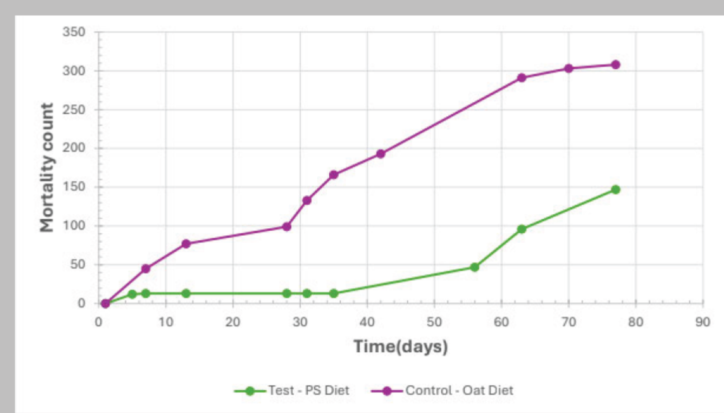

Figure 5. Observed cumulative mortality counts over 80 days.

Figure 5 shows cumulative mortality of mealworms over 80 days under both diets. The control colony (oat diet) had consistently higher mortality, exceeding 300 deaths by the end, while the PS-fed colony maintained a lower mortality trajectory. This suggests that factors such as stress, crowding, microbial growth, or competition may have contributed to higher deaths in the oat group, despite its nutritional value. Although counterintuitive given PS's limitations, the results indicate survival is shaped by more than macronutrient content. Further research is needed to clarify the long-term effects of unconventional diets on mortality.

Figure 6. Left to right progression of changes to potato pieces added to larvae colonies over four weeks showing dehydration and partial consumption.

The progression of potato pieces in both control (oat diet) and test (PS diet) colonies showed dehydration and clear signs of larvae consumption. The shrinkage and surface erosion indicate mealworms extracted both moisture and nutrients, meaning potatoes served a dual role: reducing dehydration and providing nutrients that supported biomass retention. This was particularly important in the PS diet group, where the main substrate lacked nutritional value. The visible consumption supports the hypothesis that mealworms adaptively use available organic matter to enhance survival and growth under unconventional diets.

Figure 7. Photographic evidence of PS consumption from Test colony. Left to right progression of boring in large PS pieces and progressive fragmentation to smaller pieces mixed with frass.

Figure 7 shows clear evidence of polystyrene (PS) consumption, with intact pieces progressively breaking down into fragmented particles mixed with frass. Boring marks and fragmentation indicate active mechanical breakdown by mealworms, aided by mandibular action and digestion. The small amount of uneaten PS in the final frass suggests both physical division and mineralisation of PS, supporting the hypothesis that mealworms can survive on an expanded PS diet.

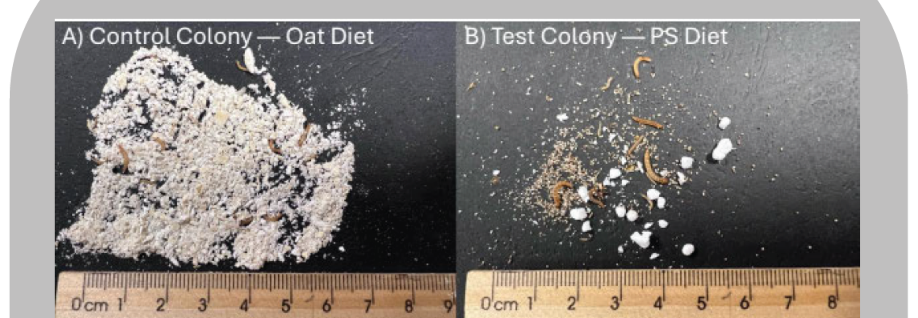

Figure 8. Photographic evidence of hatched larvae in the adult beetle colonies.

Figure 8 shows hatched larvae in both control (oat diet) and test (PS diet) colonies, indicating a second generation of mealworms. The control colony displayed dense clusters of larvae and material, suggesting higher reproductive success and survival, whereas the PS colony had fewer, more scattered larvae with visible frass and debris. Although reproduction occurred in both groups, the lower density in the PS group may reflect higher mortality or delayed development. Still, the presence of viable offspring in the PS colony confirms mealworms can reproduce and complete their life cycle on a PS diet.

Discussion

This study demonstrates that T. molitor can survive and complete its life cycle on a predominantly polystyrene (PS) diet, contrary to the null hypothesis. Larvae on PS maintained biomass, successfully pupated, and emerged as adults, with more stable biomass than the oat-fed control, likely due to PS providing a consistent substrate when supplemented with potato for hydration and micronutrients. This supports earlier work by Yang et al. (2015a, 2015b), which showed that PS degradation is aided by gut microbial symbionts.

Nutritional differences between the diets were evident: the oat-fed colony produced more pupae and adults overall, reflecting higher nutritional quality, whereas the PS-fed colony exhibited earlier pupation and adult emergence. This suggests larvae accelerated development under nutritional stress, consistent with findings by Morgan (2022) and Zhong et al. (2022), who reported altered growth and survival on plastic diets. Long-term viability remains uncertain, as it is unclear whether biomass and reproductive success can be maintained across successive generations.

Unexpectedly, mortality was higher in the oat-fed colony than in the PS-fed colony. This may be due to microbial growth or hygiene issues in the oat substrate, indicating that survival is influenced not only by macronutrient availability but also by colony conditions and micro-ecological factors. Visual evidence of PS boring and fragmentation further confirms that mealworms not only consume but also metabolise PS, aligning with recent research identifying gut bacteria such as Enterobacter hormaechei LG3 as contributors to PS degradation (Li et al., 2023). The appearance of second-generation larvae under both diets shows that reproduction is possible even with PS, though long-term colony stability on this diet remains unresolved.

Two key limitations must be considered. Potato supplementation may have confounded the role of PS as the main substrate, since survival would likely be lower without this nutritional buffer. In addition, the 80-day experimental period covered only part of the colony's life cycle, limiting insight into multi-generational impacts. Future studies should test varying PS-to-organic ratios, extend observation across generations, and include microbial analysis of frass and gut contents to clarify the extent of PS mineralisation and the potential environmental risks or applications of waste products.

Overall, these findings confirm that T. molitor can survive, reproduce, and metabolise PS under controlled conditions. While PS does not provide optimal nutrition, the ability of mealworms to degrade and assimilate synthetic polymers highlights their potential role in biologically based plastic waste management (Yang et al., 2015a, 2015b; Morgan, 2022; Zhong et al., 2022; Li et al., 2023).

Conclusion

The findings of this investigation provide strong evidence that T. molitor can survive, complete its lifecycle and reproduce when maintained on a predominantly PS diet, reinforcing their potential utility in biological approaches to plastic waste management. The PS-fed colony not only maintained a stable biomass, but it also progressed successfully through all life cycle stages, producing viable second-generation larvae. These outcomes demonstrate that mealworms can utilise PS as a functional substrate, at least in the short term, challenging longstanding assumptions about the inert and undegradable nature of synthetic polymers.

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Reference List

- Billen, P., Khalifa, L., Van Gerven, F., Tavernier, S., & Saptari, S. (2020). Technological application potential of polyethylene and polystyrene biodegradation by macro-organisms such as mealworms and wax moth larvae. Science of the Total
- Environment, 735, 139521. https://doi.org/10.1016/j.scitotenv.2020.139521 Bombelli, P., Howe, C. J., & Bertocchini, F. (2017). Polyethylene bio-degradation by caterpillars of the wax moth Galleria mellonella. Current Biology, 27(8), R292–R293. https://doi.org/10.1016/j.cub.2017.02.060
- Browne, M. A., Niven, S. J., Galloway, T. S., Rowland, S. J., & Thompson, R. C. (2013). Microplastic moves pollutants and additives to worms, reducing functions linked to health and biodiversity. Current Biology, 23(23), 2388–2392. https://doi.org/10.1016/j.cub.2013.10.012
- Farrelly, T., & Shaw, I. (2017). Polystyrene: Production, use, and environmental impacts. Environmental Science and Policy, 68, 70–78. https://doi.org/10.1016/j.envsci.2016.11.004
- Guillet, J. E., Jones, J. M., & Phillips, R. E. (1974). Biodegradation of polystyrene and polyethylene. Canadian Journal of Microbiology, 20(2), 121–124. https://doi.org/10.1139/m74-019
- Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223), 768–771. https://doi.org/10.1126/science.1260352
- Kaplan, D. I., Hartenstein, R., & Sutter, J. (1979). Biodegradation of polystyrene by mixed microbial cultures. Applied and Environmental Microbiology, 37(5), 1003–1006. https://doi.org/10.1128/aem.37.5.1003-1006.1979
- Smith, S. H., & Taylor, L. T. (2002). Extraction of various additives from polystyrene and their subsequent analysis. Chromatographia, 56(3), 165–169. https://doi.org/10.1007/BF02493206
- Teens use science to worm through plastic waste. (2016, June 21). Science News for Students. https://www.sciencenewsforstudents.org/article/teens-use-science-worm-through-plastic-waste
- Tursunay, M., Huawen, H., Aman, K., Pengya, F., Qing, Z., Xiaobiao, M., Yitian, F., Pu, L., Saurabh, K., Toshiro, S., & Xiangkai, L. (2023). Gut microbiomes of mealworms (Tenebrio molitor larvae) show similar responses to polystyrene and corn straw diets. Microbiome, 11(1), 98. https://microbiomejournal.biomedcentral.com/articles/10.1186/s40168-023-01550-w
- Kik, K., Bukowska, B., & Sicińska, P. (2020). Polystyrene nanoparticles: Sources, occurrence in the environment, distribution in tissues, accumulation and toxicity to various organisms. Environmental Pollution, 262, 114297. https://doi.org/10.1016/j.envpol.2020.114297
- Koh, D. W.-S., Ang, B. Y.-X., Yeo, J. Y., Xing, Z., & Gan, S. K.-E. (2020). Plastic agriculture using worms: Augmenting polystyrene consumption and using grass for plant growth towards a zero-waste circular economy. BioRxiv, 2020.05.29.123521. https://doi.org/10.1101/2020.05.29.123521
- Kuan, Z.-J., Chan, B. K.-N., & Gan, S. K.-E. (2022). Worming the circular economy for biowaste and plastics: Hermetia illucens, Tenebrio molitor, and Zophobas morio. Sustainability, 14, Article 1594. https://doi.org/10.3390/su14031594
- Li, Y., Zhang, X., Wang, C., Chen, H., & Zhao, J. (2023). Isolation and characterization of a polystyrene-degrading bacterium Enterobacter hormaechei LG3 from the gut of Tenebrio molitor larvae. Journal of Hazardous Materials, 452, 131328. https://doi.org/10.1016/j.jhazmat.2023.131328
- Lignin – An overview | ScienceDirect Topics. (n.d.). Retrieved from https://www.sciencedirect.com/topics/materials-science/lignin Malcolm, L. G. (n.d.). Building a mealworm tower. Retrieved from https://ligayagarden.online/chickens/chicken-feed/mealworms-life-cycle/building-a-mealworm-tower/
- Mamtimin, T., Han, H., Khan, A., Feng, P., Zhang, Q., Ma, X., Fang, Y., Liu, P., Kulshrestha, S., Shigaki, T., & Li, X. (2023). Gut microbiomes of mealworms (Tenebrio molitor larvae) show similar responses to polystyrene and corn straw diets. Microbiome, 11(1), 98. https://doi.org/10.1186/s40168-023-01550-w
- Mor, R., & Sivan, A. (2008). Biofilm formation and partial biodegradation of polystyrene by the actinomycete Rhodococcus ruber. Biodegradation, 19(6), 851–858. https://doi.org/10.1007/s10532-008-9188-0
- Mwanza, B. G., & Mbohwa, C. (2017). Polystyrene as hazardous household waste. https://www.researchgate.net/publication/313262843_Polystyrene_as_Hazardous_Household_Waste
- Montana, M. (2022). Mealworm pupa and the successful survival on a polystyrene diet: the potential for mealworms to reduce the impact of plastics in the environment. Journal of Science Extension Research, 1(1), 52-64.
- Rob, J. (2019). Stanford researchers show that mealworms can safely consume toxic additive-containing plastic. Retrieved from https://news.stanford.edu/stories/2019/12/mealworms-provide-plastic-solution
- Wright, S. L., Thompson, R. C., & Galloway, T. S. (2012). The physical impacts of microplastics on marine organisms: A review. Environmental Science & Technology, 46(21), 11026–11044. https://doi.org/10.1016/j.envsci.2012.10.019
- Zhong, L., Wang, Y., Zhang, X., & Liu, Y. (2022). Polystyrene microplastics biodegradation by gut bacterial Enterobacter hormaechei from mealworms under anaerobic conditions. Science of the Total Environment, 803, 149952. https://doi.org/10.1016/j.scitotenv.2021.149952