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COMPOSTING WITH MEALWORMS FOR PLASTICS DEGRADATION

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ABSTRACT

Recycling plastics is an energy intensive process, but entomoremediation (the use of insects to transform environmental contaminants), and insect-driven plastics degradation (plastivory) may offer a natural, low energy, cost effective approach to plastics waste reduction. Polystyrene and some polyethylene materials are amenable to degradation by darkling ground beetle (Tenebrionidae) adults and larvae, and a wide range of polyethylene can be degraded by waxworm moth larvae. Mandibular activity of the insects chewing on plastics serves to increase the surface area of the polymers that can be attacked by insect digestive enzymes and gut bacteria that can degrade the polymers into individual monomers and other low molecular weight compounds. The objective of this work was to determine the feasibility of an innovative solution to the plastics waste problem using a holistic, low technology, low cost, and low maintenance technique. Plastivory by ground beetle mealworm larvae was tested using small batch, mixed food and plastics waste compost bins. Different combinations of food waste and plastics were assessed and ultimately modeled through a continuum model of mealworm population dynamics. Our idealized, coarse-grained continuum population model suggests that a modestly-sized compost bin can support a steady population of ~1100 mealworms that can degrade plastic at a rate of ~2 g of polystyrene foam per week. It is anticipated that this model will allow for assessing the extrapolation of empirically derived plastics degradation rates at various scales such as individuals and households, to industrial scales that would comply with municipal regulations.

1. INTRODUCTION

A common need on DoD/Army installations and throughout the world is to find efficient and less harmful means for waste reduction and novel sources of manufacturing feedstocks. Polyethylene (PE) or polystyrene (PS) are ubiquitous, recalcitrant plastic materials with breakdown times estimated at 400 years for many plastics (Parker 2019). PE and PS (Styrofoam) consist of long, linear, and/or branched chains of ethylene or styrene molecules, respectively. PS constitutes the most common class of plastics, least sustainable (Brandon et al.„ 2020), and the most difficult to transport and eliminate. Many recycling centers do not accept PS due to its bulky nature, so it is generally placed in landfills where it persists (Brandon et al., 2020).

Recycling plastics is both energy intensive and often cost prohibitive. An interesting and still very embryonic means for plastics waste reduction is to use insect-driven plastivory, or entomoremediation. Many forms of PS and some PE materials are amenable to breakdown by either darkling ground beetles in their adult and larval (mealworm) forms (Coleoptera: Tenebrionidae: *Tenebrio molitor* and Zophobas morio), or waxworm moth larvae (Lepidoptera: Pyralidae: *Achroia grisella* and *Galleria mellonella*) (Brandon et al., 2018; Kundungal et al., 2019; Urbanek et al., 2020; Yang et al., 2014; Yang et al., 2018; Yang et al., 2020; Yang et al., 2015a; Yang et al., 2015b). The surface area of the plastic polymers is increased by the insects chewing (mandibular activity) on plastics which allows for access by insect digestive enzymes and gut bacteria that can degrade the polymers into low molecular weight compounds or completely mineralize them into CO_2 (Brandon et al., 2018; Yang et al., 2015a).

Mealworms have been shown to consume numerous types of styrene polymers, but limited types of PE materials (as reviewed by (Pham et al., 2023)). In one feeding experiment, simple mono-compound PE and PS were introduced to mealworms separately and in combination (Brandon et al., 2018). Feeding and degradation of both plastics occurred at a high level separately but there was a preference for the specific type of PE used when the plastics were introduced together. This study observed shifts in the gut microbiome community structure when insects were feeding on different plastics as food sourc-

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es, but the dominant bacterial phyla were unchanged. It was observed that minor microbial phyla in the gut were more variable between PE and PS diets indicating that numerous bacteria may work together to degrade plastics in a nonspecific manner (Brandon et al., 2018). Isolated cultures of gut bacteria have been shown to degrade different plastics but the feasibility of commercialization of these processes is currently confounded by practical limitations. Among these obstacles, implementation of a plastics degrading bioreactor would have to be maintained in a liquid environment with strict oversight of the plastics being introduced and constant monitoring to assess the health of the system. Although this could be an exciting technology, it would require intensive engineering and extensive capital investment. The use of mealworms as a bioreactor could overcome many of these limitations. For example, an insect system could be regarded as a semi-autonomous, self-perpetuating reactor constantly introducing new plastics into the gut microbiome system, while reproducing to create more bioreactors. It is envisioned that this system would be largely self-sustaining as the mealworms and adults are mobile and capable of finding new sources of plastic in a mixed reactor setting or moving away from less desirable conditions. Furthermore, darkling beetles have a wide temperature tolerance as they are found in most ecosystems, typically scurrying along the ground, amongst leaves or detritus, or under rotting trees and logs throughout the year in more temperate environments. As a model system and something that could be used by anyone, the beetles are cosmopolitan throughout the world (non-invasive), flightless, non-biting, extremely low maintenance, highly reproductive, and inexpensive. Although the beetles can eat plastics exclusively, their health and eating vigor is vastly improved when offered a variety of other food sources such as grains, fruits, and vegetables. This suggests that the plastivory of these insects might best be leveraged in mixed waste, plastics-composting at a small, contained scale such as for households or small installation composting bins.

The goal of this effort is to provide a simplistic solution to the food and plastics waste problem by demonstrating the use of beetles/mealworms to facilitate plastics degradation using small-batch, food compost bins for either individual households or food service facilities. Extrapolation of previous experimental benchtop-scale rates of degradation of low-density polyethylene (LDPE), polystyrene (PS), and high-density polyethylene (HDPE) in a pliable form like shopping bags (~0.5 mg, 0.25 mg, and 0.05 mg plastics degraded/mealworm each day, respectively) will inform the end-user regarding the number of mealworms needed, effective ratios of food to plastics waste, and expected speed of plastics degradation.

As referenced in the Army Installations Strategy (https://apps.dtic.mil/sti/citations/AD1118920), Army installations are often dependent on infrastructure and services in surrounding communities, making them vulnerable to adversarial threats as well as subjecting them to regulations and standards of the specific municipalities. Ever-changing, municipality-specific regulations lead to inevitable gaps in Army-wide Facility Investment Plans for waste disposal, including food waste and recyclable materials. For example, the state of California signed SB54 (https://calrecycle.co.gov.gov/laws/rulemaking/sb54regulations/) into law in 2023 mandating that 30% of single use plastic packaging and food-ware must be recycled, increasing to 40% by 2028, 65% by 2030, and 100% of all packaging must be recyclable or compostable by 2032. Furthermore, the California Composting Law SB1383 (https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383) went into effect January 2022 requiring households and organizations to separate organic, compostable material from other garbage with the goal of a 75% reduction in statewide disposal of organic waste into landfills. Other municipalities may have less stringent or no projections for waste reduction, but they too will likely follow California's lead eventually. Fines for non-compliance may be high and it is still unclear how this will be monitored. An innovative, inexpensive method of reducing compostable food waste and select plastics material, while at the same time reducing disposal costs and potential fines and improving public perception of Army installations would be an easily achievable goal with a high return on investment.

2. MATERIAL AND METHODS

2.1 Supplies

Mealworms (*Tenebrio molitor*) were originally ordered from Carolina Biological Supply Company (Burlington, North Carolina) and sustained on a mixture of PS #6 foam (Uline Catalog No. s-23554, Pleasant Prairie, Wisconsin), HDPE #2 and LDPE #4 (Uline Catalog No. s-19363), and organic rolled oats (Bob's Red Mill, Milwaukie, OR). Mealworms were maintained over successive generations as reported in Jung, et al., 2024 at 25°C, in the dark, and at approximately 50% humidity.

2.2 First compost trial

Food wastes and plastics were added at a 50:1 ratio to a 3.8 L (23 × 23 × 11 cm) bin containing 100 g of oats and 5 g cardboard. Approximately 274 mealworms of various sizes weighing 13.6 g were added to each of three experimental and three control (no food waste) bins. All food and plastics wastes were itemized and weighed (Table 1). This trial was terminated after 36 days.

2.3 Second compost trial

Mealworms of various sizes were collected over a 2-week period and stored in 4°C. Healthy worms (n=1000; 48 g collective wieght) of various sizes were collected into three separate containers and weighed. These mealworms were added to 15 L (42.5 × 30.2 × 17.8 cm) bins with both food and non-food waste (food:non-food = 2.5:1); no bran or oats were added (Table 2). This trial was terminated after 30 days.

2.4 Large compost trial

Food and plastics waste from a cafeteria trash bin was sorted and recorded as type, form, and weight and distributed evenly to three experimental (mealworm-containing)

TABLE 1: Itemized food and plastics waste added to first compost trial. Exp=experimental trial.

	Exp A	Exp B	Exp C	Control A	Control B	Control C
Egg carton - foam (PS)	0.8	0.7	0.7	0.6	0.6	0.7
Biohazard bag (HDPE)	0.3	0.2	0.3	0.2	0.2	0.3
Storage bag (LDPE)	0.6	0.5	0.7	0.7	0.6	0.5
Foam Packing (LDPE)	0.4	0.3	0.3	0.4	0.4	0.4
Styrofoam blocks (PS)	0.9	0.9	0.9	0.9	0.9	0.9
Cardboard	4.8	5.1	4.8	4.2	4.5	4.9
Non-food waste (g)	**7.8**	**7.7**	**7.7**	**7.0**	**7.2**	**7.7**
Grapes	76.90	72.00	67.30			
Strawberry	71.10	71.20	69.70			
Apple	138.9	152.9	152.9			
Bread	23.60	23.70	26.30			
Raspberry	43.30	45.50	45.20			
Blueberry	30.10	30.30	30.80			
Total food (g)	383.9	395.6	392.2			
Ratio food:non-food	**49.22**	**51.38**	**50.94**			

and one control bin without mealworms. Roughly 1500 mealworms (83 g collective wieght of each batch) were added to each of the three bins which were 49 L (56 × 43 × 30.5 cm) and contained both food and non-food waste (food:non-food = 0.4:1) (Table 3) and 36 g oats. This trial was terminated after 100 days.

TABLE 2: Itemized food and plastics waste added to second compost trial. Exp=experimental trial.

	Exp A	Exp B	Exp C	Control (no worms)
Packing foam (PS)	13.8	15.8	16.9	14.9
Egg carton (PS)	6.20	5.90	6.30	6.80
Clamshell for berries (PET)	10.1	10.2	9.50	9.80
Small bubble wrap (PE)	2.70	2.80	2.90	2.80
Small crouton bag (PE)	0.43	0.43	0.43	0.43
Small storage bag (PE)	0.25	0.25	0.25	0.25
Large plastic bag (PE)	12.7	14.3	12.0	10.5
Cardboard	35.2	35.4	35.6	35.6
Non-food waste (g)	**46.2**	**49.7**	**48.3**	**45.5**
Croutons	17.5	17.6	17.7	13.3
Apple	30.2	37.5	38.0	36.6
Lettuce	4.90	5.50	5.20	5.30
Avocado shell	4.30	4.70	4.30	5.70
Strawberry	58.1	58.8	67.0	58.4
Grapes	43.1	45.6	42.5	43.6
Raspberry	13.8	12.9	13.7	12.6
Eggshell	2.90	3.30	3.10	4.00
Blueberry	16.2	13.4	15.9	19.2
Red onion	10.9	9.20	10.1	7.90
Total food (g)	**202**	**209**	**218**	**207**
Ratio food:non-food	**2.48**	**2.45**	**2.59**	**2.55**

2.5 Modeling to extrapolate to large-scale composting

Accurately tracking the number of mealworms in a population over time is a daunting task. An adult female darkling beetle can lay hundreds of eggs over her lifetime, and these eggs are very small and adhere to surfaces, making them difficult to even see, much less separate from a compost bin and count. During the early instars of their larval lifecycle, mealworms are likewise almost invisible to the naked eye. As the insect population grows over time, these counting difficulties are only exacerbated. To predict the long-term size of the mealworm population supported by differently sized compost bins, and thereby estimate the expected rate of plastic consumption, we devised an ODE (ordinary differential equation)-based population dynamics model. This model tracks the subpopulations of *T. molitor* in five different lifecycle stages: egg, larva, pupa, reproducing beetle, and non-reproducing beetle. The adult population is divided into two subpopulations since female darkling beetles do most of their egg laying within the first two months of their adult lives, even though their overall lifespan lasts ~6 months.

Assuming a roughly equal sex ratio across the total population, the temporal subpopulation of eggs, denoted as $N_E(t)$, will grow at a rate proportional to half the size of the young adult (reproducing) beetle subpopulation, $N_b(t)$. The constant of proportionality, which we term the fecundity, f, estimates the average number of eggs each young female lays in a week. The number of eggs is depleted as the eggs hatch into larvae. The rate of this process will be proportional to $N_E(t)$, with a constant of proportionality, η_e, which we dub the egg hatching rate. These considerations lead to the following differential equation for $N_E(t)$:

$$\frac{dN_E(t)}{dt} = \frac{1}{2} f N_b(t) - \eta_e N_E(t) \quad (1)$$

The subpopulation of larvae, which we denote N_L (t), will grow at a rate $\eta_e N_E$ (t), since all eggs are assumed to even-

TABLE 3: Itemized food and plastics waste added to third compost trial. Exp=experimental trial.

	Exp A	Exp B	Exp C	Control (no worms)
Clamshell plate (PS)	55.7	34.0	48.9	35.0
Large drink cup (PS)	25.4	20.8	25.5	26.8
Small food bowl (PS)	9.50	7.60	11.4	8.40
Soft drink bottle sliced (PE)	9.90	8.10	13.3	12.6
Clear pie tray clamshell (PS)	8.90	9.80	8.60	9.60
Small fry tray	6.20	6.20	7.40	8.70
Coffee cup	23.3	20.7	14.9	16.1
Napkins	70.2	53.1	106.4	53.9
Non-food waste (g)	209	160	236	171
Food waste (g) (bananas, cornbread, collard greens, pie crust, broccoli, rice, hull peas)	71.2	77.4	74	78.1
Ratio food:non-food	0.340507	0.482845	0.313029	0.456458

tually hatch. This is an approximation, of course, but not an unreasonable one, so long as we assume the system is maintained at optimal breeding conditions. Larvae are lost to two processes: pupation and death, both of which should occur at rates proportional to $N_L(t)$. We approximate pupation as occurring at a constant rate, ρ, but we assume that the death rate should also depend upon the total population of larvae and adults, $N_T(t)$. In particular, we assume that the system has an optimal carrying capacity, K, determined by the external conditions and the available surface area available to the organisms, and the death rate should increase the more the total population of feeding organisms (i.e., excluding eggs and pupae) exceeds this capacity. These considerations lead to the following differential equation:

$$\frac{dN_L(t)}{dt} = \eta_e N_E(t) - \rho N_L(t) - \frac{\mu_L}{K} N_L(t) N_T(t) \tag{2}$$

wherein μ_L is the fixed mortality rate of larvae at capacity (N_T=K).

The population of pupae, $N_P(t)$, should grow at a rate $\rho N_L(t)$ and decline at a rate $\eta_p N_P(t)$, wherein η_p is the pupal hatching rate. This leads to the following differential equation for $N_P(t)$:

$$\frac{dN_P(t)}{dt} = \rho N_L(t) - \eta_p N_P(t) \tag{3}$$

Unlike darkling beetle eggs, which hatch at very high rates under optimal conditions, pupae have a much lower successful hatch rate, so we will assume that the young beetle population, $N_b(t)$, grows as $x_P \eta_p N_P(t)$, wherein $x_P \in [0,1]$ estimates the fraction of pupae that successfully emerge as adult beetles. The young beetle population will decline as a function of both their aging out of the reproductively active stage (parametrized at a rate α) and their death, modeled using a logistic term similar to that in Equation 2 (with the same capacity, K, but a different mortality rate, μ_B). These considerations lead to the following differential equation:

$$\frac{dN_b(t)}{dt} = \chi_P \eta_p N_P(t) - \alpha N_b(t) - \frac{\mu_B}{K} N_b(t) N_T(t) \tag{4}$$

Finally, the nonreproductive beetle population, $N_B(t)$, will grow as younger beetles age into the class and decline exclusively through death (with the same mortality rate, μ_B):

$$\frac{dN_B(t)}{dt} = \alpha N_b(t) - \frac{\mu_B}{K} N_B(t) N_T(t) \tag{5}$$

The total population of feeding organisms, $N_T(t)$ will always equal the sum total of the larval and adult populations:

$$N_T(t) = N_L(t) + N_b(t) + N_B(t) \tag{6}$$

Together, Equations 1-6 constitute a closed, nonlinear dynamical system that can be solved numerically. We will be principally interested in the long-time behavior of solutions, which, as we will discuss in the proceeding section, can be characterized analytically.

3. RESULTS AND DISCUSSION

3.1 First compost trial

The food:non-food ratio for the first trial was 50:1, using primarily fruit and bread, and the plastics were largely the plastics they had been exposed to previously (Figure 1). Approximately 274 mealworms (13.6 g) of various sizes were added to each bin and they were housed in the dark at 25°C. At 36 days the mealworms were counted (Figure 2) and the plastics were itemized, weighed, and the percent consumption by mealworms was determined (Figure 3). Interestingly, the experimental group experienced 71% attrition which was likely due primarily to the presence of fungi which had overtaken the experimental groups. In the absence of decomposing fruit, the control group only exhibited 35% attrition. The control group performed better due to numbers and health of survivors.

3.2 Second compost trial

The food:non-food ratio for the second trial was 2.5:1, using primarily fruits and vegetables, and the plastics were collected from household waste (Figure 4). Approximately 1000 mealworms (48 g) of various sizes were added to each bin and they were housed in the dark at 25°C. A larger container was used to provide enough space for the plastics. At 30 days the trial was terminated due to massive fungal growth. Numerous mealworms were floating in the decaying liquid of the food and few, if any, survivors were

FIGURE 1: First compost feeding trial showing mealworms added to an (A) experimental bin and a (B) control bin without food.

seen. This was surprising since there was more space available for the mealworms to climb away from the liquid and there was much less food available for decay than the first trial. However, it is possible that the plastic may have prevented natural evaporation of the decaying food, and this may have been remedied with the addition of oats as dry bedding and food that could have absorbed some of the moisture.

3.3 Large compost trial

Food and plastics waste (food:non-food = 0.4:1) from a cafeteria trash bin was sorted and distributed to three experimental bins containing 1500 mealworms (83 g) each and one control bin (49 L each) (Figure 5). The trial was terminated at 100 days and observations were made and plastics sorted and weighed. Unfortunately, the need to weigh the starting material as wet weight meant that after 100 days in a semi-arid environment the liquid from the food waste had evaporated and/or food had been consumed, so the light plastic materials did not exhibit significant differences in weight between the mealworm (MW) and control treatments. However, visual inspection showed a different picture with obvious signs of biting and consumption of most PS plastics and paper waste material by the mealworms after 100 days in the experimental groups but not in the control (Figure 6). The small food bowl was the only material that showed a marked decrease in weight in the MW treatment compared to the control (Figure 7). There was no visible consumption of the clear plastics. No food remained in the experimental bins and very little oats

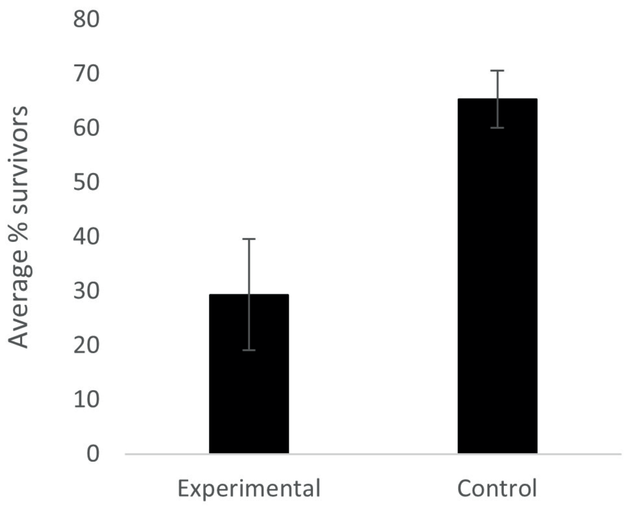

FIGURE 2: Percent survivors after 36-day compost feeding trial.

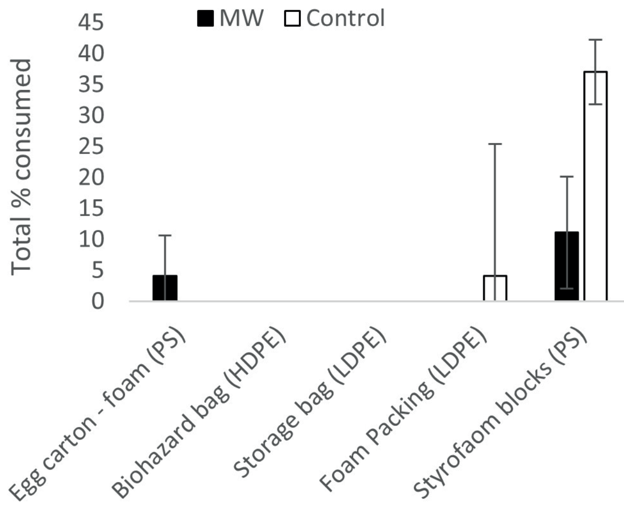

FIGURE 3: Percent of plastics consumed over 36 days.

FIGURE 4: Second compost feeding trial showing (A) food and (B) non-food materials added to bins.

FIGURE 5: A) Food and non-food waste collected from a cafeteria trash bin and sorted into (B) experimental and (C) control bins.

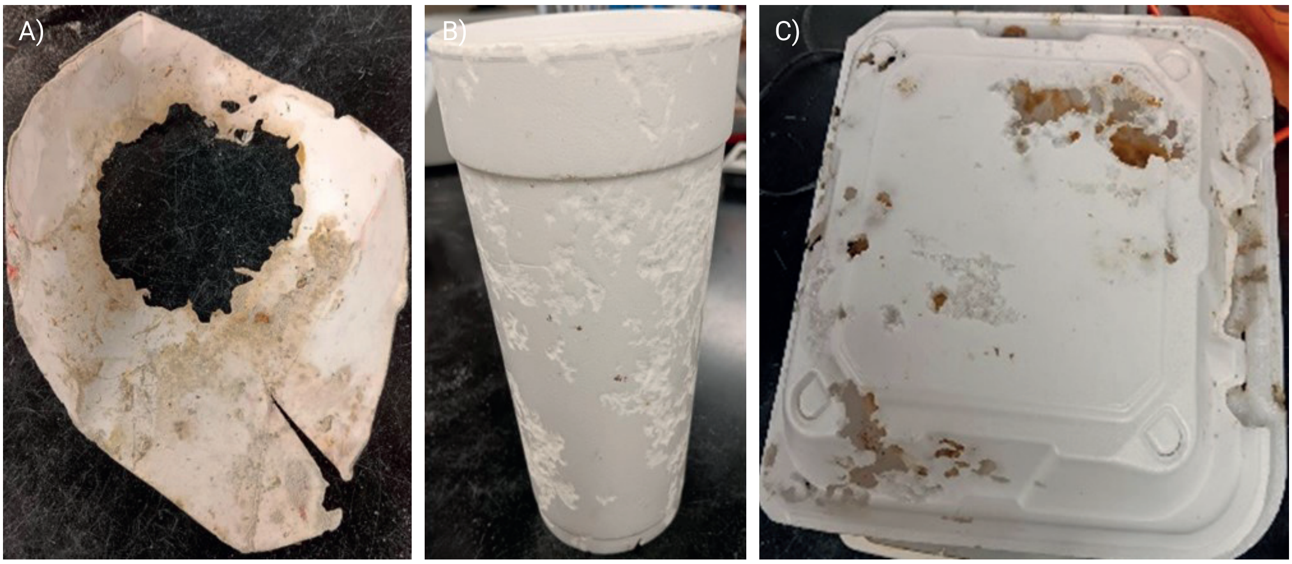

FIGURE 6: (A) Paper and (B&C) PS plastics showing bite marks and consumption of the material by mealworms during the 100-day large compost trial.

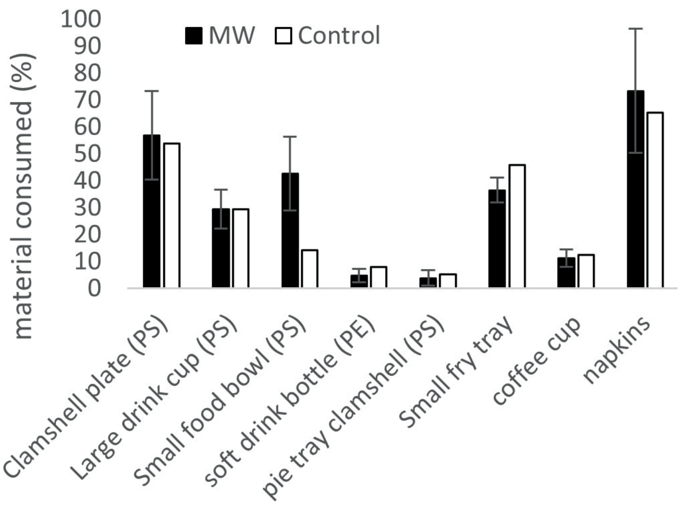

FIGURE 7: Percent consumption by weight of waste material after 100 days in the large compost trial.

remained. Mold/fungi was present, but it was not as overwhelming as the previous compost trials.

Overall, the higher diversity and lower quantity of composted food proved to be a better combination for survival of the mealworms. Although each of the experimental bins started with approximately 2500 larvae, only about 10% remained at a measurable size after 100 days (157 ± 21). There were numerous adults (103 ± 20) and pupae (34 ± 6), and too many early instar larvae (<1mm) to count.

3.4 Modeling for scale-up

Mathematical modeling provides an alternative means for predicting the amount of plastic that will be consumed by a dynamic population of *T. molitor*. Assuming this population is confined to a compost bin in which an excess of edible materials is perpetually maintained, it will eventually reach a steady state wherein the birth of new organisms is offset by the death of older ones. For times much longer than that required to reach this stationary state, the average rate of plastic consumption should remain constant, since it will directly depend upon the steady population of feeding organisms. To estimate this population, we look for the fixed points of the dynamical system defined by Equations 1-6.

This system has only a single physically accessible fixed point (fixed points involving negative organism counts are discarded). We can solve for the value of this fixed point analytically. Defining the steady state subpopulation $N_x(t\to\infty)$ as N_x (with no temporal argument), we find:

$$N_E = \frac{f}{2\eta_e} N_b,$$

$$N_L = \left(\frac{\left(\frac{\alpha\mu_L}{\mu_B} - \rho\right) + \sqrt{\left(\frac{\alpha\mu_L}{\mu_B} - \rho\right)^2 + \frac{2f\mu_L\chi_P\rho}{\mu_B}}}{\frac{2\mu_L\chi_P\rho}{\mu_B}} \right) N_b \equiv \lambda N_b$$

$$N_P = \frac{\rho}{\eta_p} N_L$$

$$N_B = \frac{\alpha N_b^2}{\chi_P\rho N_L - \alpha N_b}$$

$$N_b = \frac{\chi_P\rho\lambda - \alpha}{\frac{\mu_B}{K}\left(\lambda + 1 + \frac{\alpha}{\chi_P\rho\lambda - \alpha}\right)} \quad (7)$$

We can estimate the various parameters of this population model from the existing body of literature (https://www.breedinginsects.com/yellow-mealworm-life-cycle/), (Eberle et al., 2022; Liu et al., 2020; Palumbo et al., 2024). Under optimal conditions, mealworm eggs are estimated to hatch over the course of 7-10 days, so we can estimate an average hatch rate of η_e=0.824 weeks^{-1}. Female darkling beetles can lay as many as 500 eggs during their lives, mostly during the first two months of adulthood, leading to an estimation of the fecundity as f=62.5 weeks^{-1}. Although the rate of egg laying is not uniformly distributed over this interval, the parameter f represents an average rate across the entire subpopulation of young adult beetles.

Mealworm larvae can start pupating after 10-12 weeks, giving an estimated pupation rate of ρ=0.091 weeks^{-1}. Assuming ample nutrients and space are available to the population, as much as 97% of the larval subpopulation can survive to pupate, suggesting an estimated larval mortality rate of μ_L=0.088 weeks^{-1}. Note that under these optimal conditions, the effects of cannibalism will be minimal. The optimal population density for *T. molitor* has been estimated at 0.25 individuals per square centimeter, suggesting that the carrying capacity of the model should be K=0.25 A, wherein A is the surface area available to the population within the composting container in units of square centimeters. This area will be estimated as the exposed cross-sectional area of the composting container.

Pupae commonly hatch after only about a week, so we estimate η_P=1.0 weeks^{-1}. Only about 75% of pupae actually hatch, under optimal conditions, so we set x_P=0.75. As already mentioned, adult female beetles are only fertile for about two months, so this suggests we set the aging rate α=0.125 weeks^{-1}. Beetles can live between 3-6 months, so we estimate the average beetle mortality rate as μ_B=0.056 weeks^{-1}.

Using the above parameter values and the average rates of larval plastic consumption cited earlier, we plot the estimated total mass of consumed plastic as a function of exposed composting surface area in Figure 8. Because we found that adult beetles consume minimal plastic, and because their steady subpopulation is orders of magnitude lower than the steady subpopulation of larvae, we can estimate the total plastic consumption using N_L rather than N_T.

Despite the complexity of the steady-state subpopulation expressions in Equation 7, a simple linear relationship between the feeding surface area and the average plastic consumption rate emerges. The amount of time required for a system to reach this limiting consumption rate will naturally vary as a function of the initial population size. A smaller seed population of mealworm larvae will take longer to reach steady state than a larger seed population. As mentioned, these estimates also depend upon the composting site being regularly refilled so that edible resources (both food and non-food) remain in excess as well as being maintained at an optimal temperature and humidity level. As our experiments have demonstrated, enforcing this latter constraint without allowing mold and mildew to infiltrate the system represents a significant practical challenge.

4. CONCLUSIONS

The primary objective of this research was to determine the feasibility of breaking down plastics in a novel fashion using plastivorous mealworms in a food and mixed plastics waste compost. The combination of food and plastics waste would be most beneficial to household food composting, but our results demonstrate a need for separate composting, as food waste may be too heavy and wet for the mealworms. The positive takeaway is that unlike recycling, where food scraps need to be removed from the plastics material, food remnants would likely be beneficial in a plastics waste compost, as might small quantities of cardboard and paper waste.

Our coarse-grained continuum population model suggests that even a modestly-sized compost bin, after sufficient time, can support a mealworm population substantial enough to degrade plastics at an appreciable rate—far faster than their natural degradation rate in a landfill. For example, choosing the smallest bin size used in our experiments, our model predicts that it can support a steady population of ~1100 mealworms that can degrade plastic at a rate of ~2 g of polystyrene foam per week. Although it is difficult to understand how this might translate to an individual or household, one estimate states the average American generates approximately 1,800-2,900 g per year (35-56 g per week) (https://www.sandiego.gov/sites/default/files/appendix_b_air_quality_and_greenhouse_gas_emissions_estimates_0.pdf), making composting with mealworms at a household scale seem feasible.

The accuracy of the model predictions remains in question for the present, due to the difficulties in tracking the size of a *T. molitor* population over time, but we can at least say that its predictions represent, at best, a crude upper-bound on the plastic consumption rate of mealworms. This is because our model relies on the assumption of an idealized system environment that, as we have demonstrated, is difficult to achieve even in the laboratory, much less in the compost bin of an Army installation.

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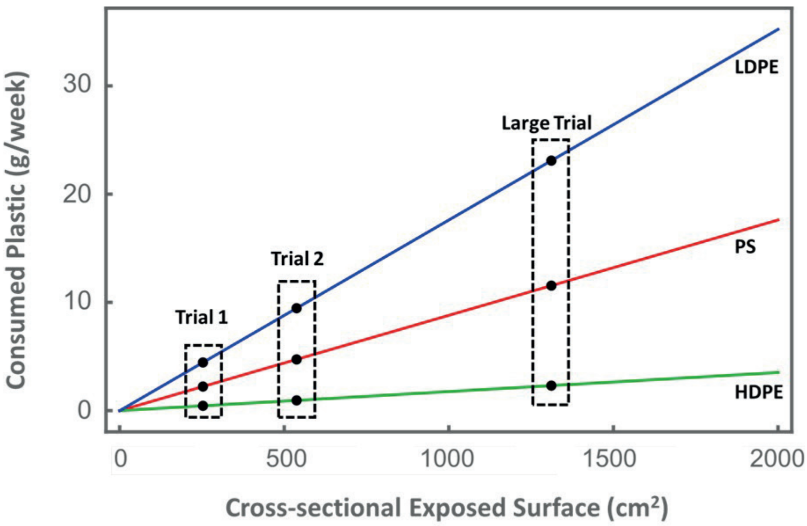

FIGURE 8: Predicted plastic consumption (in grams per day) for steady T. molitor populations as a function of the accessible feeding surface (approximated as the exposed cross-sectional area of the compost bin (in cm2). The curves, from top-to-bottom, represent systems in which the insects are exposed to a mixture of food and either LDPE, PS, or HDPE plastics, respectively. The bin sizes for the three experimental trials are indicated on each curve for reference.

mealworm colony and compost maintenance. Opinions, interpretations, conclusions, and recommendations are those of the authors and are not necessarily endorsed by the U.S. Army.

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