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SuperMorio: Optimizing the Efficiency of Darkling Beetle Larvae *(Zophobas Morio)* for Polystyrene Degradation

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ABSTRACT

Polystyrene, a widely used plastic, is notorious for contributing to long-lasting environmental pollution due to its resistance to natural degradation. This study explores the biodegradation of polystyrene by darkling beetle larvae (*Zophobas morio*) under various conditions, including substrate type, crowd density, light exposure, and sucrose additives. Results show that substrate type significantly impacts Styrofoam consumption, with the highest degradation (11.0%) occurring in the absence of alternative food sources or substrate. Optimal crowd density was found to be 20 larvae per 5 grams of polystyrene, where consumption peaked at 18.9%. Light exposure also played a crucial role, with larvae consuming the most Styrofoam in complete darkness (28.5%) compared to natural or warm light conditions. Additionally, sucrose additives substantially increased Styrofoam consumption, with a 1:2 (5g of water - 10g of sugar) sucrose-to-water solution leading to the highest rate of 68.5%. These findings suggest that optimizing environmental factors such as substrate, crowd density, and energy availability can significantly enhance the polystyrene biodegradation capacity of superworms.

Keywords: *Polystyrene Pollution, Biodegradation, Darkling beetle larvae, Zophobas morio, Styrofoam consumption, Crowd density, Light exposure, Sucrose additives, Environmental optimization.*

I. Introduction

Since 1950, global plastic production has surged from 2 million to over 450 million tonnes, mainly due to packaging (Ritchie et al., 2023; Topic: Plastic Packaging Industry Worldwide, 2024). Polystyrene, used in Styrofoam, fills 30% of landfills, is non-biodegradable, and releases harmful chemicals during decomposition and incineration, worsening environmental and health risks (The Perils of Polystyrene, 2024).

In 2019, the Philippines led in global ocean plastic waste (Ramos, 2024). The use of plastics and Styrofoam has caused significant environmental harm, (Sign to Ban the Use of Plastics and Styrofoam in Taguig, n.d.). Some municipalities have enacted single-use plastic bag policies, but their effectiveness varies, with reductions in waste as low as 4% (Schachter et al., 2022).

In Mindanao, leaders tackled plastic pollution with clean-ups, education, and reusable items on World Clean Up Day (Hisgutanang Klima Sa Mindanao: Tackling Plastic Pollution, 2024).

In contrast, Superworms (*Zophobas Morio*) have gained attention not just as animal feed but for their ability to help break down materials like polystyrene (Blackwood, n.d.).

A study conducted by Yu Yang and their colleagues in 2019 reveals that Superworms can eat and live well with Styrofoam as their sole diet. A key factor in their ability to degrade styrofoam lies in their gut microbiome. According to Sun et al. (2022), by recovering metagenome-assembled genomes (MAGs)– from superworms gut microbiome– they linked phylogeny and functions and identified genera including Pseudomonas , Rhodococcus and Corynebacterium that possess genes associated with polystyrene degradation. Additionally from the same study, within a 16 day test period, 47.7% of the ingested Styrofoam carbon was converted into CO_2 and the residue (ca. 49.2%) was egested as fecula with a limited fraction incorporated into biomass (ca. 0.5%).

Overall, this study aims to evaluate the efficiency of superworms (*Zophobas Morio*) in degrading polystyrene under various factors in specific conditions; substrate, crowd density, light exposure, and sucrose additive.

II. Methodology

2.1 Polystyrene Foam

The polystyrene foam used in this study was Expanded Polystyrene (EPS) that was identified by a qualified scientist Devorah A. Gundaya, specifically flat sheets sourced from a local hardware store in Davao. Before being provided to the superworms, the foam was washed using distilled water. The dimensions of the polystyrene foam before being cut into smaller pieces are: Length: 5.2 inches , Width: 1 inch , Height: 4 inches —

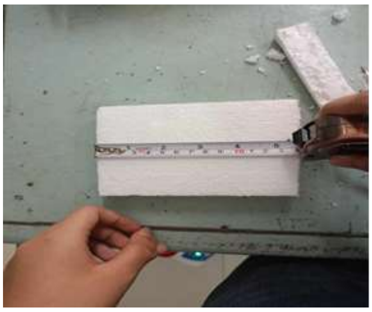

Figure 1: Length Figure 1.1:Width Figure 1.2: Height

After being chopped into smaller pieces, the dimensions of the smaller cubes will be; Length: 1 inch , Width: 1 inch , Height: 1.3 inches –



Figure 2: Length Figure 2.1:Width Figure 2.2: Height

2.2 Preparation of Enclosures and Feeds

Tempered Glass enclosures were prepared with dimensions of 10 inches in length, 7 inches in width, and 6 inches in height, manufactured from a local glass store in R. Castillo Street. Each of the enclosures were cleaned beforehand, providing a sufficient space to house 10-20 larvae.

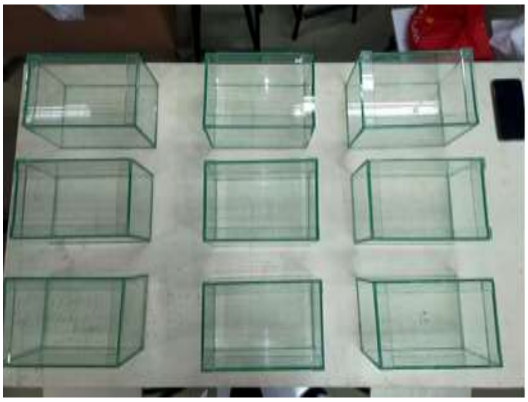


Figure 3: Containers Figure 3.1: Cleaning

Feeds were also prepared for one of the factors: cornmeal and oatmeal, which were purchased from Agdao Public Market and Davao Central Warehouse Club Inc. respectively.

2.3 Superworm

Superworms (*Zophobas morio*) were used for this study that was identified by an expert, collected from a pet shop in Gaisano Mall of Davao.

Figure 4: Superworms

Before conducting the study, the larvae was housed in a secure container with cut paper as bedding (The cut-paper bedding was removed in Figure 6.), the superworms were allowed to acclimate for seven days to guarantee correct conditioning, The length of time is corroborated by a research by Sun et al. (2022), which discovered that superworms could adapt to experimental surroundings with a comparable 7-day acclimatization period. Maintained at 27°C , the superworms were provided with a standard diet of carrots, sliced apples, and cucumber, which, according to the same study, can sustain the superworms while they are being acclimated.

Figure 5: Superworms in Container

2.4 Experimental Stages

Factor 1: Substrate Type

The styrofoam amount in each enclosure was kept constant at 5 grams. Group 1 had 15 grams of oatmeal, Group 2 with 15 grams of cornmeal, and Group 3 with no substrate.

Figure 6: Factor 1

Figure 6.1: Worm eating Styro

Starting off with day one, the worms were separated by 10 in each 9 containers. They were then misted 3 sprays of water every 2 days to ensure optimal humidity (Carolina Biological Supply Company, 2010). According to the recommended guidelines from University of Nebraska–Lincoln. (n.d.), it is crucial to mist the substrate every other day to maintain humidity. Additionally, it is important to maintain a constant temperature between 21º-27º C (70-80°F).

After a total of 6 days, the remaining styrofoam was measured to determine how much the worms consumed. Then, the researcher cleaned and sanitized the enclosures in preparation for the next factor. They made sure to dispose of the worms properly.

Factor 2: Crowd

Considering that the group with the most styrofoam consumption in factor 1 was Group 3 with no substrate. This means that in this set of experiments, the worms were only given styrofoam to eat. The styrofoam amount in this factor was kept constant. Group 1 has 10 worms in each enclosure, Group 2 with 15 worms each, and Group 3 with 20 worms.

Figure 7:Group 1

Figure 7.1: Group 2

Figure 7.2: Group 3

The remaining styrofoam was measured after 6 days to determine how much the worms consumed. The researcher then cleaned and sanitized the enclosures in preparation for the next factor. The researcher appropriately disposed of the worms.

Figure 8: Styro Consumption

Factor 3: Light Exposure

The previous factor data pointed out that the optimal crowd in each enclosure was 20 worms. No substrate, 20 worms for the crowd, styrofoam amount were kept constant throughout the remaining experiment. Group 1 were exposed to warm light, Group 2 with natural ambient lighting, and Group 3 in total darkness.

Figure 9: Warm Light

Figure 9.1: Natural Light

Figure 9.2: Total Darkness

The unconsumed styrofoam were measured after 6 days to identify the amounts that were ingested by the worms. After that, the researcher cleaned and sanitized the enclosures, and disposed of the worms according to the ethical considerations.

Factor 4: Sucrose Additive

The data from the experiment on factor 3 showed that total darkness was the most favorable light exposure to the worms to consume the optimal amount of styrofoam. No substrate, 20 worms crowd, and total darkness were kept constant in this experiment. Group 1 – Untreated Styrofoam, Group 2 – Styrofoam treated with 1:1 ratio of water and sugar, and Group 3 – Styrofoam treated with 1:2 ratio of water and sugar.

Figure 11: 1:1 (Water:Sugar)

Figure 11.1: 1:2 (Water:Sugar)

Figure 12: Factor 4 Setup

The styrofoam that were not consumed were measured after 6 days to determine which condition prompted the most optimal amount of styrofoam ingestion. The enclosures were cleaned and sanitized, and the worms were properly disposed of.

Figure 13: Styrofoam consumption

2.5 Ethical Considerations

Throughout the experiment, we will adhere to ethical guidelines to ensure the humane treatment of the superworms.

Before conducting the experiment, the superworms are housed in appropriate containers with sufficient ventilation, a substrate of shredded paper, and maintained at a stable temperature of 21-27°C. Fresh food, including carrots, apples, and cucumbers, will be provided regularly to ensure their nutritional needs are met, and hydration is maintained.

During the experiment, superworms will be handled gently to avoid injury. To prevent stress and cannibalism, overcrowding will be avoided, ensuring each superworm has adequate space according to relevant guidelines. Additionally, they will be monitored and misted with water daily to prevent dehydration.

After the experimentation with each factor, Any leftover polystyrene, sucrose, and organic waste from the experiment will be disposed of according to local waste management guidelines. Polystyrene waste will be recycled or disposed of at designated disposal sites. Biological waste, including the larvae, will be euthanized using 70% ethanol for a duration of three minutes, following established protocols from relevant studies (e.g., Santos et al., 2023). Following euthanization, the larvae will be disposed of in compliance with regulations for biodegradable materials, ensuring that all waste is handled in an environmentally responsible manner. Any organic materials associated with the larvae will also be disposed of in the same manner. Broken glass will be carefully collected using a broom and dustpan, placed in a designated broken glass disposal container, and not mixed with regular waste to avoid injury. The euthanized worms will then be buried 5 feet underground (Three Parameters Plus, Inc., n.d).

Figure 14: Fixation

Lastly, all data from this study will be accurately recorded and reported with full transparency. This transparency will help future researchers understand both the successes and limitations of our work.

III. Results and Discussion

3.1 Substrate Data

Table 1: Test of difference of percentage by EPS consumed across different types of Substrate

	Oatmeal	Cornmeal	No Substrate
R1	0.54g (10.8%)	0.37g (7.4%)	0.72g (14.4%)
R2	0.50g (10%)	0.38g (7.6%)	0.69g (13.8%)
R3	0.52g (10.4%)	0.35g (7.0%)	0.70g (14%)
Average	0.52g (10.4%)	0.36g (7.33%)	**0.70g (14%)**

F-value 295.038 ; p-value <0.001; Significant differences were seen across all comparisons.

ANOVA

ANOVA - Consumption Rate (%)

Cases	Sum of Squares	df	Mean Square	F	p
Substrate Type	68.187	2	34.093	295.038	< .001
Residuals	0.693	6	0.116		

Note. Type III Sum of Squares

Post Hoc Tests

Standard

Post Hoc Comparisons - Substrate Type

		Mean Difference	SE	t	p_{tukey}
S1	S2	3.067	0.278	11.049	< .001
	S3	-3.667	0.278	-13.211	< .001
S2	S3	-6.733	0.278	-24.259	< .001

Note. P-value adjusted for comparing a family of 3

Descriptive Statistics

Descriptive Statistics

	Consumption Rate (%)		
	S1	S2	S3
Valid	3	3	3
Missing	0	0	0
Mean	10.400	7.333	14.067
Std. Deviation	0.400	0.306	0.306
Minimum	10.000	7.000	13.800
Maximum	10.800	7.600	14.400

RESULTS

An ANOVA test was performed to assess the effect of different substrate types (no substrate, cornmeal, and plain oatmeal) on the rate of Styrofoam consumption by superworms. The results indicated a statistically significant difference in consumption rates among the substrate conditions ($F(2,6) = 295.038$, $p < 0.001$). Considering that the sum of the squares for substrate type was 68.187 with a mean square of 34.093, this shows that substrate choice is an important factor in the variations that was observed in consumption rates. On the other hand, the residual Mean Square was very small (0.116), which means that the differences in Styrofoam consumption that weren't explained by the substrate type were minimal.

The post hoc tests revealed that no substrate had the highest consumption rate, outperforming both oatmeal and cornmeal. The differences are statistically significant, with a mean difference of 0.513 between oatmeal and cornmeal. This suggests that when no substrate is present, superworms focus solely on Styrofoam consumption, leading to the highest degradation rates.

In terms of average consumption, the condition with no substance showed the highest consumption rate (0.55g, 11.0%), followed by oatmeal (0.52g, 10.4%), and cornmeal (0.36g, 7.33%).

DISCUSSION

The findings demonstrate that substrate type has a significant influence on Styrofoam consumption by superworms. The statistically significant ANOVA results ($p < 0.001$) confirm that these differences in consumption rates are not due to random chance, but rather to the specific properties of each substrate condition. The high F-value (295.038) suggests that substrate type plays a major role in determining the rate of degradation, with minimal unexplained variance.

The post hoc Tukey HSD tests revealed significant differences among substrate types. S1 (Oatmeal) had a higher consumption rate than S2 (Cornmeal), with a mean difference of 3.067 and a p-value of <0.001. However, S1 had a lower consumption rate compared to S3 (No Substrate), with a mean difference of -3.667, indicating that S3 resulted in a slightly higher consumption than S1. Furthermore, S3 had a higher consumption rate compared to S2, with a mean difference of -6.733. These comparisons demonstrate that S3 was the most consumed substrate, while S2 had the lowest consumption rate.

The practical implications of these results show that superworms consume Styrofoam most efficiently when no substrate is present. This could be due to the fact that, in the absence of alternative food sources, the worms focus exclusively on Styrofoam consumption, leading to higher degradation rates. Conversely, when cornmeal or oatmeal is introduced, the superworms may expend energy digesting these additional materials, thereby reducing their overall Styrofoam consumption.

Cornmeal, in particular, appears to hinder consumption rates (7.33%), possibly because of its texture or composition, which may interfere with the worms' digestion process. Oatmeal, while slightly more effective than cornmeal, still resulted in lower Styrofoam degradation than the no substrate condition. These findings suggest that limiting the availability of alternative substrates may optimize superworms' performance in biodegrading Styrofoam.

3.2: Crowd Data

Table 2: Test of difference of percentage by EPS consumed across different Crowd Density

	10 Worms	**15 Worms**	**20 Worms**
R1	0.47g (9.4%)	0.66g (13.2%)	0.98g (19.6%)
R2	0.41g (8.2%)	0.68g (13.6%)	0.91g (18.2%)
R3	0.44g (8.8%)	0.63g (12.6%)	0.94g (18.8%)
Average	0.44g (8.80%)	0.66g (13.2%)	0.94g (18.9%)

F-value 207.361 ; p-value <0.001 ; Significant differences were seen across all comparison

ANOVA

ANOVA - Consumption Rate (%)

Cases	Sum of Squares	df	Mean Square	F	p
Crowd	152.987	2	76.493	207.361	< .001
Residuals	2.213	6	0.369		

Note. Type III Sum of Squares

Post Hoc Tests

Standard

Post Hoc Comparisons - Crowd

		Mean Difference	SE	t	p_{tukey}
C1	C2	-4.333	0.496	-8.738	< .001
	C3	-10.067	0.496	-20.299	< .001
C2	C3	-5.733	0.496	-11.561	< .001

Note. P-value adjusted for comparing a family of 3

Descriptive Statistics

Descriptive Statistics

	Consumption Rate (%)		
	C1	C2	C3
Valid	3	3	3
Missing	0	0	0
Mean	8.800	13.133	18.867
Std. Deviation	0.600	0.503	0.702
Minimum	8.200	12.600	18.200
Maximum	9.400	13.600	19.600

RESULTS

The effect of crowding (number of superworms) on Styrofoam consumption was evaluated using the same test, ANOVA. A statistically significant effect was found by the analysis ($F(2,6) = 207.361$, $p < 0.001$). A significant amount of the variance in consumption rates can be explained by crowding, as indicated by the crowding Sum of Squares of 152.987 and Mean Square of 76.493. Mean Square 0.369 was the least unexplained variance in the residuals.

In terms of crowd effects, the post hoc analysis revealed that C3 had a significantly higher consumption rate compared to both C2 and C1 with a mean difference of -5.733 and –10.067, respectively and a p-value of <0.001.

For the average consumption, the condition with 20 superworms in every 5 grams of styrofoam showed the highest consumption rate of 18.9%, followed by 13.2% of 15 worms, and 8.80% for the enclosure with 10 worms.

DISCUSSION

The ANOVA analysis revealed a statistically significant effect of crowd size on Styrofoam consumption, with an F-value of 207.361 and a p-value of < 0.001. This indicates that crowd size substantially influences consumption rates, as evidenced by the Sum of Squares of 152.987 and a Mean Square of 76.493. The minimal unexplained variance in the residuals of 0.369 supports the robustness of these findings.

In terms of average consumption, the data showed that consumption increased with population size, peaking at 20 worms (0.94g, 18.9%). For 15 worms, consumption reached 0.66g (13.2%), while the smallest group of 10 worms consumed 0.44g (8.8%). This suggests that as the population of worms increases, they are more effective in breaking down Styrofoam, likely due to greater collective biomass and metabolic activity.

3.3 Light Exposure Data

Table 3: Test of difference of percentage by EPS consumed across different light exposure

	Warm Light	Natural Light	Total Darkness
R1	0.56g (11.2%)	0.78g (15.6%)	1.40g (28.0%)
R2	0.50g (10%)	0.74g (14.8%)	1.45g (29.0%)
R3	0.51g (10.2%)	0.79g (15.8%)	1.43g (28.6%)
Average	0.52g (10.4%)	0.77g (15.4%)	**1.43g (28.5%)**

F-value 829.056 ; p-value <0.001 ; Significant differences were seen across all comparison

ANOVA

ANOVA - Consumption Rate (%)

Cases	Sum of Squares	df	Mean Square	F	p
Light Exposure	523.227	2	261.613	829.056	< .001
Residuals	1.893	6	0.316		

Note. Type III Sum of Squares

Post Hoc Tests

Standard

Post Hoc Comparisons - Light Exposure

		Mean Difference	SE	t	p_{tukey}
LE1	LE2	-4.933	0.459	-10.756	< .001
	LE3	-18.067	0.459	-39.390	< .001
LE2	LE3	-13.133	0.459	-28.634	< .001

Note. P-value adjusted for comparing a family of 3

Descriptive Statistics

Descriptive Statistics

	Consumption Rate (%)		
	LE1	LE2	LE3
Valid	3	3	3
Missing	0	0	0
Mean	10.467	15.400	28.533
Std. Deviation	0.643	0.529	0.503

Descriptive Statistics

	Consumption Rate (%)		
	LE1	LE2	LE3
Minimum	10.000	14.800	28.000
Maximum	11.200	15.800	29.000

RESULTS

With the same ANOVA test in hand, the effect of light exposure on polystyrene consumption by superworms was evaluated. With an F-value of 829.056 and a p-value <0.001, the analysis indicated a statistically significant effect of this factor. The Sum of Squares ranging at 523.227, with a Mean Square of 261.613, showing that light exposure revealed a solid and substantial portion of the variation in consumption rates. The residual Mean Square being at 0.316, indicating that there was minimal variation in polystyrene consumption that couldn't be explained by this factor.

The post hoc analysis indicated significant differences in Styrofoam consumption across light exposure conditions. Superworms in Complete Darkness (LE3) consumed significantly more than those in Warm Light (LE1), with a mean difference of -18.067 ($p < 0.001$), and more than those in Natural Light (LE2), with a mean difference of -16.876 ($p < 0.001$). In contrast, the comparison between Warm Light (LE1) and Natural Light (LE2) showed a mean difference of -5.0, which was statistically significant with a p-value of <0.001. These findings confirm that minimal light exposure enhances superworm feeding efficiency, with complete darkness leading to the highest Styrofoam consumption

Under complete darkness, the superworms gained the highest consumption rate of 28.5%, followed by 11.7% in natural ambient light, and 10.4% in warm light.

DISCUSSION

The results were further supported by the ANOVA analysis, which evaluated the effect of light exposure on polystyrene consumption. The analysis revealed a statistically significant effect, with an F-value of 998.362 and a p-value of < 0.001, indicating that light exposure had a considerable influence on consumption rates. The Sum of Squares for light exposure was 612.329, with a Mean Square of 306.164, indicating that a significant portion of the variation in consumption rates was attributable to this factor. The low residual Mean Square (0.307) suggests minimal unexplained variation, affirming the reliability of the results.

The data demonstrate that Styrofoam consumption by superworms was significantly higher in total darkness (1.43g, 28.5%) compared to warm light (0.52g, 10.4%) and natural light (0.77g, 15.4%). This suggests that superworms thrive in low-light conditions, likely due to their photonegative behavior—the tendency to avoid light—which may reduce stress and allow them to focus more on consuming Styrofoam. The minimal difference between warm and natural light indicates that light type itself does not have a substantial impact on consumption, as long as there is exposure.

Under total darkness, superworms achieved the highest consumption rate of 28.5%, significantly outperforming those exposed to natural ambient light (11.7%) and warm light (10.4%). This further emphasizes that minimizing light exposure is crucial for optimizing Styrofoam consumption by superworms.

3.4 Sucrose Additive Data

Table 4: Test of difference of percentage by EPS consumed across different Sucrose additive

	Untreated (5.00g)	Treated (1:1) (9.00g)	Treated (1:2) (10.00g)
R1	1.45g (29.0%)	5.18g (57.6%)	6.89g (68.9%)
R2	1.46g (29.2%)	5.47g (60.7%)	6.85g (68.5%)
R3	1.43g (28.6%)	5.39g (59.9%)	6.82g (68.2%)
Average	1.45g (28.9%)	5.35g (59.4%)	**6.85g (68.5%)**

F-value 1378.751 ; p-value <0.001 ; Significant differences were seen across all comparison

ANOVA

ANOVA - Consumption Rate (%)

Cases	Sum of Squares	df	Mean Square	F	p
Glucose Additive	2579.796	2	1289.898	1378.751	< .001
Residuals	5.613	6	0.936		

Note. Type III Sum of Squares

Post Hoc Tests

Standard

Post Hoc Comparisons - Glucose Additive

		Mean Difference	SE	t	p_{tukey}
GA1	GA2	-30.467	0.790	-38.578	< .001
	GA3	-39.600	0.790	-50.143	< .001
GA2	GA3	-9.133	0.790	-11.565	< .001

Note. P-value adjusted for comparing a family of 3

Descriptive Statistics

Descriptive Statistics

	Consumption Rate (%)		
	GA1	GA2	GA3
Valid	3	3	3
Missing	0	0	0
Mean	28.933	59.400	68.533
Std. Deviation	0.306	1.609	0.351
Minimum	28.600	57.600	68.200
Maximum	29.200	60.700	68.900

RESULTS

An ANOVA test was conducted to evaluate the impact of the sucrose additive on polystyrene consumption by superworms. The analysis showed a statistically significant effect of the sucrose solution as an additive, with a p-value of <0.001 and an F-value of 1378.751. Post hoc comparisons using Tukey's HSD test demonstrated significant differences between all groups. The untreated group (GA1) had a significantly lower consumption rate compared to both the GA2 and GA3 groups. Additionally, GA3 (1:2 sucrose-to-water) exhibited a significantly higher consumption rate compared to GA2, with a mean difference of 9.133% ($p < 0.001$), further demonstrating the positive correlation between sucrose concentration and consumption.

The Sum of Squares for the sucrose additive was 2579.796, with a Mean Square of 1289.898. This suggests that a significant amount of the differences in Styrofoam consumption rates may be explained by the presence of sucrose. There was relatively little unexplained variance, as seen by the residual Mean Square of 0.936..

DISCUSSION

The results demonstrate that the sucrose additive significantly influences Styrofoam consumption by superworms. The extremely low p-value (< 0.001) indicates that the differences in consumption rates among the treatments are statistically significant. The high F-value highlights the strength of this effect, suggesting that adding sucrose can enhance the feeding efficiency of superworms.

As shown in Table 4, the superworms consumed an average of 1.45g (28.9%) of Styrofoam with no additive, compared to 5.35g (59.4%) with a 1:1 sucrose solution and 6.85g (68.5%) with a 1:2 sucrose solution. This suggests that the addition of sucrose significantly increases Styrofoam consumption, likely due to the enhanced energy availability for the superworms and acts as a nutritional attractant, drawing the worms to the Styrofoam, thereby promoting increased activity and consumption.

By utilizing sucrose additives, the efficiency of superworms in degrading Styrofoam could be maximized, leading to more effective plastic waste management solutions. Future research could investigate the optimal concentration of sucrose for even greater consumption rates.

IV. Conclusion

This study investigated the effectiveness of darkling beetle larvae (*Zophobas morio*) in biodegrading Polystyrene under various experimental conditions, including substrate type, crowd density, light exposure, and sucrose solution as an additive.

The findings indicate that substrate type significantly influences Styrofoam consumption rates; superworms exhibit the maximum degradation (0.55g, 11.0%) when no substrate is present. This suggests that limiting alternative food sources increases their efficiency in consuming Styrofoam.

The intake of superworms peaked at 20 (0.94g, 18.9%) and then began to decline at 25 (0.66g, 13.2%) and 15 (0.44g, 8.80%) superworms, indicating that crowd density was also a significant factor in polystyrene consumption. This decline may be attributed to space constraints and competition among the larvae that resulted in cannibalism.

With the third factor in hand, superworms consumed the most Styrofoam in complete darkness (1.43g, 28.5%), compared to natural light (0.58g, 11.7%) and warm light (0.52g, 10.4%). Light exposure had a substantial influence on consumption rates. This preference highlights how crucial it is to reduce light exposure in order to maximize biodegradation.

Lastly, superworms consumed an average of 1.45g (28.9%) of Styrofoam without any additives, compared to 5.35g (59.4%) with a 1:1 sucrose solution and 6.85g (68.5%) with a 1:2 sucrose solution. This indicates that the addition of sucrose considerably increased Styrofoam consumption. These results imply that superworms' capacity for biodegradation may be maximized by increasing the availability of energy through sucrose.

RECOMMENDATION

Based on the findings, It is advised to investigate other substrate types that may improve superworm effectiveness in biodegrading polystyrene. Although no substrate resulted in the maximum consumption in this study, wheat bran, a widely used substrate for superworms , should be used in future research to evaluate its possible advantages.

Furthermore, given the study's highest consumption rate was demonstrated by 20 superworms, more extensive testing with varying crowd densities on a larger scale should be conducted by researchers in the future. This will facilitate a deeper comprehension of how consumption rates in practical applications are impacted by growing worm populations and container or area sizes.

Further research should be done on the application of sucrose additives, and various concentrations should be evaluated to find the most effective balance for enhancing superworm biodegradation efficacy.

The implications of these findings extend to large-scale styrofoam management strategies, as superworms, with their demonstrated ability to biodegrade polystyrene, could serve as a viable method for waste management in urban settings. By optimizing substrate types and additives, superworm populations could be cultivated in controlled environments to effectively reduce styrofoam waste, minimizing landfill overflow and the environmental impacts of traditional waste disposal methods.

This approach not only promotes a sustainable waste management strategy but also aligns with circular economy principles, turning waste into a resource, making future large-scale studies crucial in determining the practicality and scalability of using superworms as a solution for polystyrene biodegradation.

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