Upcycling Takeout Waste with Black Soldier Fly Larvae

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ABSTRACT

An experiment was performed to answer whether black soldier fly larvae are able to consume compostable single-use food containers in an effort to find a way to break down processed compostable foodware with other types of organic waste. Three different diets of compostable container only, Gainesville diet, and a combination of both Gainesville and compostable container were tested to determine if black soldier fly larvae are able to consume said diets by measuring how much of their respective diet was eaten weekly. Larvae length, weight, prepupae development, and mortality are also measured weekly to determine the relationship of if larvae are able to successfully develop into their full lifecycle from feeding on their respective diet. Results show that larvae are successfully able to consume compostable containers as the proportion of food consumed increased from the loss of weight from the diets given of all trials with the compostable container over the course of the entire experiment. Larvae development was limited for the larvae consuming only compostable container as the larvae barely changed in height in weight, while the larvae on the combined diet were able to develop in similar length as the larvae on the control of Gainesville diet, but weigh less than said control. While there is evidence of larvae successfully consuming compostable containers, a combined diet with Gainesville diet is necessary to fulfill the larvaes lifecycle and consume said compostable container, and complete a sustainable black soldier fly composting setup.

KEYWORDS

Waste Management, Black Soldier Fly, Life Cycle Assessment, Composting, Plastic Alternative

SUMMARY

The main objective for my research is to determine whether newer methods of waste management are effective by finding out if black soldier fly larvae are effective composters based on if they are able to consume and break down compostable take-out containers that are supposedly made to be more biodegradable and better for the environment. My central research question is if black soldier fly larvae are able to consume compostable containers, with my hypothesis being that they would be able to as the material in compostable containers are plant fibers which larvae are shown to be able to consume. The sub questions I am asking is if the change in diet of larvae consuming compostable containers versus a more natural diet (Gainesville diet) will affect the larvaes growth (height/weight), mortality rate, and prepupae rate. My hypothesis for my sub questions is that the larvae on the compostable container only diet will have their growth rate and prepupae rate be less than the larvae on their control diet and the mortality rate be higher than those on the control diet because while the larvae can consume plant fibers, it is much more difficult for them to consume and take nutrients compared to other organic waste thus have their development slow down and be smaller, have less larvae develop into prepupae, and more likely to die due to the higher chance of starvation.

INTRODUCTION

The accumulation of trash in landfills has become a significant problem in recent times, especially with the increased use of single-use plastics (Nguyen et al. 2022). Not only are we reaching our limit in regards to the size of our landfills, the slow pace of plastic biodegradation leads to landfills filling faster than plastics can break down (Wang et al, 2021). Fortunately, some have started to take notice of this problem, and single use plastics are being swapped for biodegradable alternatives such as compostable plastics (Meng et al, 2023). With the shift towards more biodegradable waste, not only do they break down much more quickly than most plastics, they can also be composted (Meng et al, 2023). Composting more organic waste can simultaneously bring back nutrients into the soil and keep our planet healthier with less waste and greenhouse gasses (Xu et al. 2023). However, while compostable food containers are made of biodegradable and organic materials like a variety of plant fibers (Omar et al, 2022), currently

the EPA does not recommend composting compostable single-use foodware with organic waste that can biodegrade outside, despite these compostable foodwares being advertised as being able to be composted (EPA 2023). The EPA claims that the biodegradable material in compostable foodware can only be effectively broken down at significantly high temperatures rather than left outside to be broken down by decomposers, which is how most people associate what composting is (EPA 2023). This situation worsens when the fact that commercial composting facilities with machinery that can burn waste in high temperatures are necessary to break down compostable foodware, which in turn lowers accessibility and increases maintenance on removing a specific type of waste, as not every community or area in the world will have access to said equipment necessary to compost compostable food containers (EPA 2023). While processed plant material in compostable single-use foodware is far more biodegradable than plastic, the necessary steps and equipment needed to break these compostable foodwares down is not as easy and environmentally friendly as it claims to be.

The shift to more biodegradable waste and less plastic isn't the only innovation to improve waste management (Rashid et al. 2021). Composting has become more efficient by applying newer methods. An example of this is the increase in popularity of using black soldier fly larvae as composters, as they are one of the most efficient decomposers. They break down almost all types of organic waste with ease such as food waste, decomposing plants, and manure (Amrul et al. 2022). Their increase in importance is also due to the additional benefits of using black soldier flies as decomposers, with one of their other uses being recycled into livestock feed after their larval stage (Amrul et al. 2022). Even on a diet of mainly food waste, their fat and protein levels remain very high making them not just sustainable but nutritious for livestock (Gligorescu et al. 2020). However, their impact as decomposers itself is what makes them important as their efficiency in consuming both food waste and fecal waste at the same time is unmatched, as their speed in consumption was the highest when given a mix of both food and human waste (Purkayastha et al. 2023). I'd like to further understand black soldier fly larvae's limitations on what kind of organic waste can be consumed by black soldier fly larvae, and test whether they can break down and decompose other types of organic waste, specifically compostable containers that claim to be biodegradable.

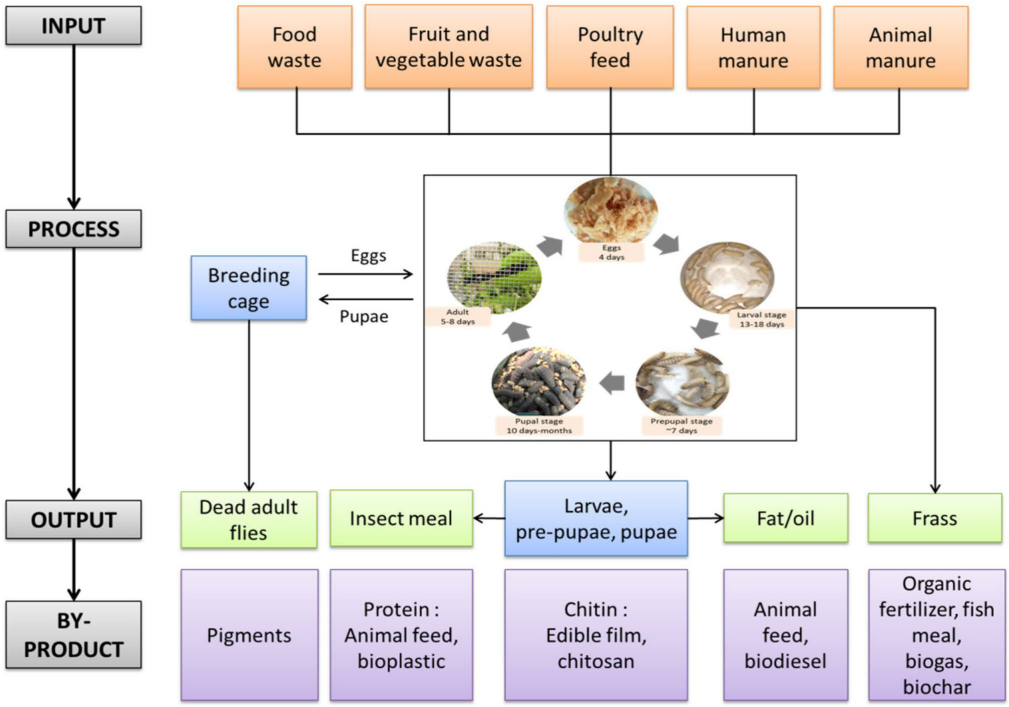

Figure 1. BSF and their role as decomposers and other uses (Amrul et al. 2022).

There hasn't been exact research done yet on whether black soldier fly larvae are capable of consuming and breaking down compostable single-use containers, and with compostable food containers being made of processed plant material instead of plastic for most disposable food containers, I'd like to find out whether black soldier fly larvae are able to do so or not. Using compostable single-use containers instead of plastic along with using black soldier flies for composting are both newer methods to improve waste management and lowering trash buildup. Because of how recent these innovations are, it is understandable that there is limited research on their full capabilities. That being said, understanding the limitations of black soldier flies and compostable single-use containers is important. This can help us determine if black soldier flies truly are the most effective composters as researchers claim them to be, and whether the fact that compostable containers cannot be composted with other organic waste limits the ability of decomposing organisms to break down compostable containers (EPA 2023). Compostable food containers are commonly composed of biodegradable and renewable plant material such as bamboo fibers (Omar et al, 2022). There has already been research done that shows certain limitations black soldier flies do have, such as larvae having more difficulty breaking down

certain vegetable waste due to high levels of cellulose (Deng et al. 2022). Given that it is known that high amounts of cellulose are difficult for black soldier fly larvae to break down, there is a possibility that larvae are not capable of breaking down compostable containers or consume containers as easily as food waste, as most compostable containers are made up of different plant fibers (Omar et al, 2022). This result would expose one of two problems: that either compostable waste isn't as easily compostable as it claims to be and changes to materials used will need to be more biodegradable or black soldier flies aren't the most effective composters for all types of compostable waste. On the positive end, if black soldier fly larvae prove to be able to break down compostable single-use containers, then the potential for significantly less waste will sky rocket as single-use plastic containers can be replaced with more biodegradable options, lowering the amount of waste building up in landfills.

RESEARCH QUESTION

In this study I ask how effective black soldier fly larvae are at breaking down compostable single-use containers. My first sub question asks if the difference in diet of single-use containers versus control affects the growth rate of black soldier fly larvae. For my second subquestion, I ask if the difference in diet of single-use containers versus control affect the mortality rate of black soldier fly larvae. Finally, my third subquestion I ask is if the difference in diet of single-use containers versus control affect the prepupae rate of black soldier fly larvae. Between compostable containers and the control diet of organic waste black soldier fly larvae would normally eat, I want to know not only if larvae are able to eat compostable containers but how the consumption rate of compostable containers compares to said control diet. For my first subquestion, I predict that larvae growth rate of both weight and length would be lower for the larvae on only the compostable container versus Gainesville diet because high cellulose content from the container made of exclusively plant material would make it difficult for the larvae to consume and get nutrients necessary for the larvae to grow (Bajra et al. 2023). Meanwhile for the second subquestion, I predict that mortality rate would be higher for the larvae on the compostable container only diet compared to control, as mentioned before, less nutrients from the compostable container would make it more difficult for the larvae to survive and have a higher risk of starvation when compared to control and combination that have nutritious food available to said larvae. Finally, I predict for my final

subquestion that the larvae on the compostable container only diet would have the least amount of larvae develop into their prepupae stage, then larvae on the combined, and then finally larvae on the Gainesville diet as high amount of nutritious food is necessary for the larvae to develop into their instars and finally into the prepupae stage as it will need a lot of energy to metamorphosize from larvae to adult (Amrul et al. 2022). All my questions will be answered through an indoor laboratory experiment, as by having a controlled setting will make sure that the changes in decomposition rate are only by what types of waste I have given to the larvae and not by some other variable. Testing through a laboratory experiment will also make the procedure easily repeatable, which can also answer that the changes in decomposition rate between the different variables of food waste, leaf litter, etc. are significant and isn't based on chance.

METHODS

Study Organism

Black Soldier Fly (*Hermetia illucens*) (abbreviated here to BSF), are the main organism that will be used in this experiment. Performing the experiment, I focused specifically on the larvae and the prepupae/pupae stages. The BSF total lifespan lasts a little over a month, with around three of those weeks spent in the larvae stage for a total of five instars before they develop into pupae. The larvaes ideal living conditions are growing in an environment that is warm and very humid. For this experiment, the larvae were kept inside at 30 celsius with a water bath to maintain humidity. Hundreds of larvae were received at just only a few days old and are raised in a warm and humid environment on a Gainesville diet (a diet for BSFL made with water blended with alfalfa, wheat, and corn) for several days until they reach their first instar before they could be used for the experiment. Once the larvae reach their first instar is when they are ready to be used for the experiment as they are not too old that the experiment will be too short, but also not too young in which they have a high chance of dying prematurely during the experiment. Me and my mentor ordered and received black soldier flies at just a few days old, the moment they hatched out of their egg, I reared the larvae on a Gainesville diet at 30 celsius in a humid environment for a few days until they reach their first instar.

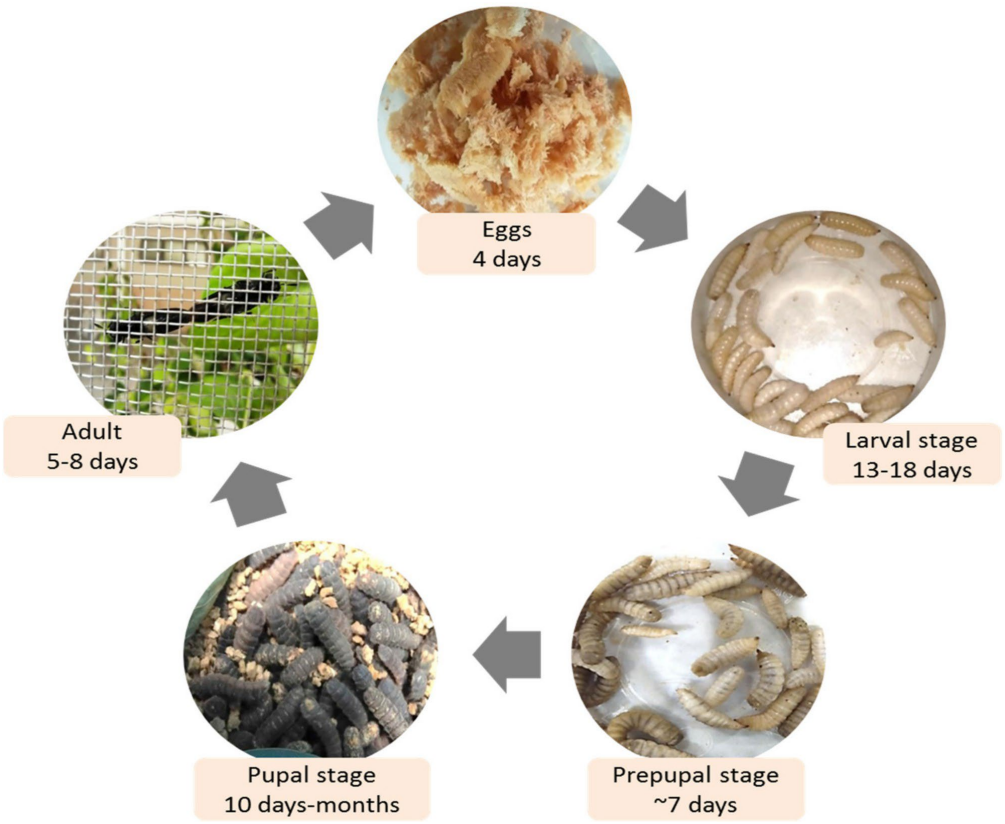

Figure 2. Lifecycle of black soldier flies (Amrul et al. 2022).

Larvae Diet Preparation

Before the experiment started, I first prepared the diets to feed the BSFL. The diet used for the control and for the combined diet is called Gainesville diet which is made of wheat bran, alfalfa meal, corn meal, and water. First I added 166 grams of wheat bran and 67 grams of cornmeal to a big container. I then added 100 grams of alfalfa meal to the container, but unlike the other two, I first blended the alfalfa in a blender on high speed for less than a minute until the alfalfa became a powder. After the alfalfa was blended, I added it to the rest and mixed everything together with a spoon. Finally, I added 756 grams of water to the container and mixed it with everything else, which combined became a Gainesville diet. I made the Compostable container diet by first tearing off pieces of the compostable container bowl, with the total weight being 250 grams. I added the torn bowl pieces to a blender and added 250 grams of water, blending on high for several minutes until it turns into a soft mashed potato texture. I drained out

the excess water from the blender as the compostable container diet should be mostly the container that is just moist enough so the larvae can consume it.

Experiment Procedure

To start the experiment, I set up the containers and perform measurements for day 0. For each trial, 50 black soldier fly larvae were kept in plastic containers (each container being 24 fl ounces) which I cut the top of each lid with ten big long slits to provide the larvae with air and ventilation. I weighed the container without the lid, food, or larvae so it can be used to find the difference when measuring how much food has been eaten every week. I added 50 grams of food to each container, with three of the containers having either 50 grams of compostable container diet, 50 grams of Gainesville diet, and 25 grams each of compostable container diet and Gainesville diet for a total of 9 containers with 3 different treatments for three containers each. I placed the containers inside a large lab oven at a consistent temperature of 30 degrees Celsius with a water bath inside to maintain a high humidity as well. When water levels dropped, I refilled the water bath to keep humidity consistent. I took larvae measurements once a week over the course of a few weeks, with the experiment ending when over half of the larvae have entered the prepupae stage for one of the diet variables, as when they enter this stage they will stop eating entirely. It should be noted that one of the trials for the control variable, which is Gainesville diet only, only had 40 larvae added. However, since food eaten is measured by percentage and larvae are counted by how many have died or become prepupae, it should not affect the results as much.

Data Collection

To collect data, I took measurements every week for the amount of food eaten, number of larvae alive, number of prepupae, and the larvaes length and weight are calculated. For each container, I picked out the larvae by hand using forceps to account for larvae mortality rate, which is determined by how many are still alive out of 50 each week. I measure the container with food only on its own for weight in grams, as the amount of food leftover is calculated with the total weight measured minus container weight. Current amount of food eaten is calculated by

the difference of 50 grams and the amount of food remaining during that week. I place the larvae on a sieve and wash them in water for a few seconds to wash out all the food that may still be stuck to the larvae and then dried with a paper towel. I take a picture of the larvae on the paper towel with a dime placed next to them, which is used in measuring the length of the larvae. I also count each larvae here individually to determine how many of them have entered the prepupae stage, which is shown when the larvae have turned dark brown/black in coloration. Finally, I place the larvae in a cup to measure the total in grams on a scale, making sure to set the scale to 0 with the cup already placed beforehand so the total weight is just the larvae and not accounting for the cup used. I repeat this eight more times with the other plastic containers of larvae. After I finished recording data for all trials, I returned the containers to the humid 30 celsius conditions and I repeat this every week until half of the larvae for one variable has started to prepupate.

Measuring Larvae

To measure the larvaes length, I use a program called ImageJ. First, I upload the picture taken of the larvae and the dime by going to File, then Open, and then selecting the image. Using the Straight Line tool, I place the line across the entire diameter of the dime and by going on Analyze then Set Scale, I change the number to the actual diameter of a dime in mm which is 17.91. Using the Line tool, I take the line and measure one larva from the head to the body and then go to Analyze and then Measure. The measurement of the larvae should show up in mm and I repeated this nineteen more times for the total of 20 measurements for each container. I repeated this for the rest of the containers for a total of 9 sets of 20 larvae measurements.

Data Analysis

For my data analysis I used the program R to run my data in comparing if the measurements collected have any significance between the different diet variables. The type of statistical test I used for food consumption is the ANOVA test as I compared the averages of more than two treatments that have also been repeated multiple times as for each variable I repeated it three more times. For the rest of the data measured, such as larvae weight, length,

mortality, and number of prepupae, I used the Kruskal-Wallace test as there was too much variability for each variable. For each of the five measurements I recorded the amount of food eaten, larvae length, larvae weight, amount of larvae alive (mortality rate), and amount of larvae that developed into the prepupae stage (prepupae rate), I graphed the data as a box plot in comparison for each of the three variables of compostable container only diet, Gainesville only diet, and combined diet of both treatments. I used a box plot to graph my data to show the amount of variability between each treatment as there are significant differences in the maximum and minimum for each treatment for each measurement as it is only repeated three times, yet the upper and lower quartiles should show a better visual on the averages of each data measured.

RESULTS

Food Consumption

While there was some food consumed in the container only diet, it was much lower compared to the food consumed on the other treatments, with larvae on the combined diet consuming more of the container than the larvae on the container only diet, and the larvae on the control diet consuming the most of their food, as shown in Figure 1. Most food consumed was the control (Gainesville diet), next being the combined diet of both and container, with last being compostable containers. While weight loss and frass from my own observations show that the larvae can consume compostable containers, it is more difficult for the larvae to eat said container compared to their usual diet. However the combined diet being in the middle shows evidence that adding other types of food that is easier to eat may have made eating the container easier,as they can get more nutrients and grow while eating something that is less nutritious (container). Overall the larvae are less effective at consuming the container compared to their control diet despite being able to consume compostable containers.

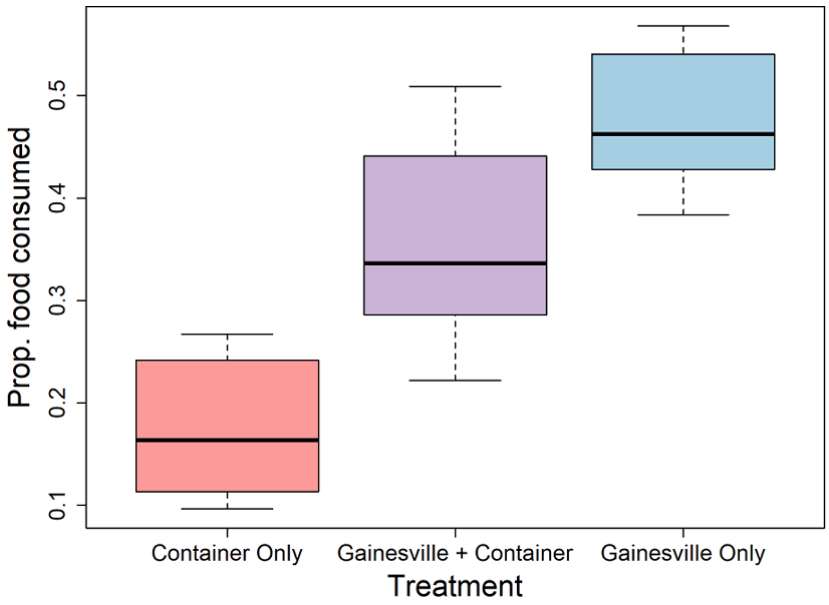

Figure 1. Proportion of food consumed by larvae (%) per treatment.

Larvae Growth

Larvae on the container only diet did not gain much weight or growing length, and barely developed throughout the experiment as shown in Figure 2 and 3 for weight and length respectively. Meanwhile, the larvae in the control diet had gained the most weight and grew a lot in length as well. Surprisingly, while the larvae on the combined diet weighed less than the control (weighed much more than container only) the average length was greater than control and overall had around the same length as control while weighing less. For larvae weight and length on the container only diet, there was barely any growth for length and weight as they barely grew from both from the start of the experiment to the end. Even my own observations showed that they did not even change from the next instar. Larvae on the combined diet showed they gained more weight than the larvae on compostable only diet,they still weighed much less than the larvae on the control. However, length in comparison to control and combined diet showed that they were very similar,with larvae on control even being a bit shorter on average compared to larvae on combined diet despite being much heavier. Results show that diet may not affect length as much as weight does if given some diet that has necessary nutrients.

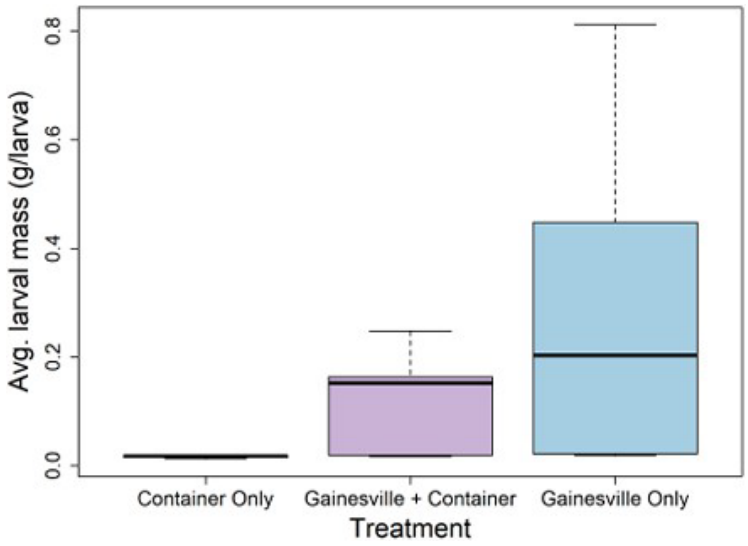

Figure 2. Average individual larvae weight (grams) per treatment.

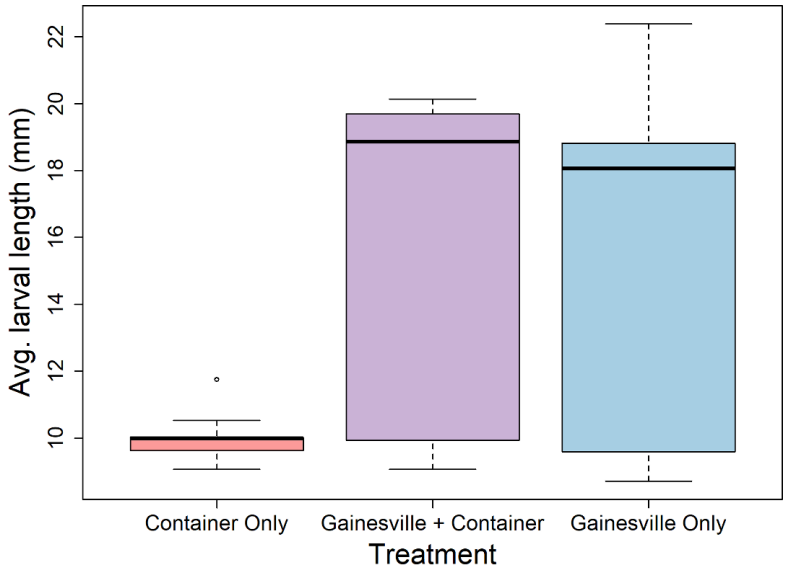

Figure 3. Average individual larvae length (mm) per treatment.

Larvae Mortality

While the larvae in the container only diet had the highest mortality rate compared to the other treatments, overall, the mortality rate was very low across all treatments, with the greatest number of losses for one trial was 8 larvae in the container only diet shown in Figure 4. Average mortality rate per trial was around 0 - 2 larvae out of 50 so not many died during the entire experiment. Difference in diet does not seem to have affected mortality rate of larvae as mortality rate for all three diets was low, only reaching a maximum of eight deaths in the compostable container only diet. While there were more deaths on average in the trials of the compostable container only diet, the amount of deaths per container never reached double digits, with the other two conditions having an average mortality rate of around 0, indicating that the dates given were not harmful to the larvae while also showing how resistance BSFL are, even when consuming a diet that has limited nutrients (compostable container), as majority of them still survived regardless if they didn't grow as much.

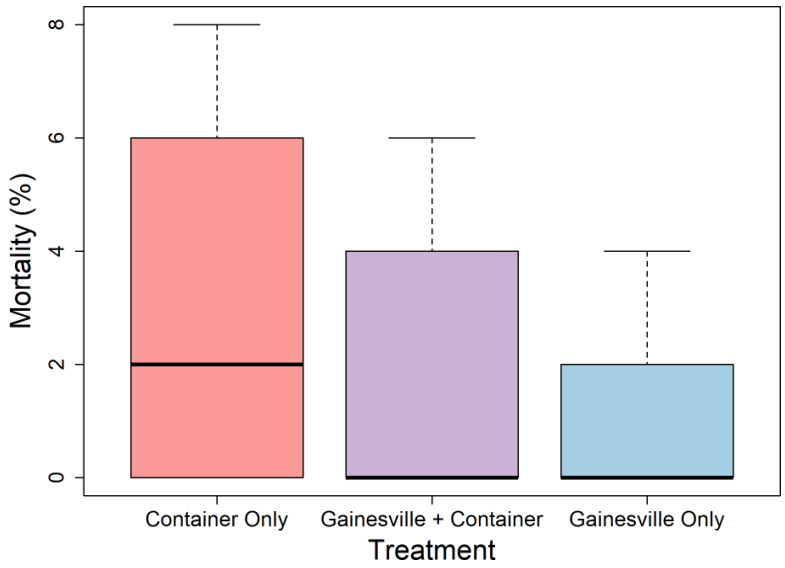

Figure 4. Larvae mortality rate (%) per treatment.

Prepupae Development

Since larvae had barely any development in the container only diet, none of them were

able to develop into prepupae throughout the entire experiment as shown in Figure 5. Figure 5 also shows that control had the most development into prepupae, with over half becoming prepupae at the end of the experiment. Surprisingly, while few became prepupae in the combined diet, one trial had almost half developed into prepupae despite weighing much less compared to larvae in the control diet. There was a big difference in how many larvae developed into the pre pupae stage between different diets. The control had the most larvae become prepupae by the end of two weeks, with an average of over half the population becoming pre pupae per container.

From my observations, I am not surprised, as the control diet is made to have the best growth outcomes for BSFL due to the alfafa, corn, and wheat being easily digestible with well enough nutrients for them to develop quickly. None of the larvae grew in the container only diet as they did not grow to begin with. The combined diet had surprising results: two of the containers had very few become prepupae, while one of the containers had over half become prepupae like the control, despite my own observations seeing that the prepupae are much smaller, and weighed much less.

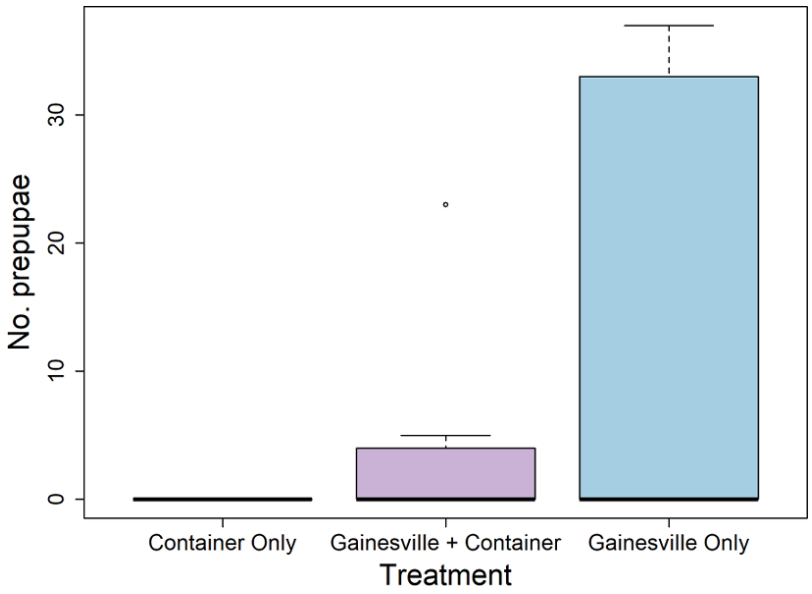

Figure 5. Average number of prepupae per treatment.

DISCUSSION

The results from my experiment show that black soldier fly larvae do have the ability to consume compostable single-use food containers, despite the lack of growth and development the larvae had when this was their only food given to them. Unfortunately, a diet of only compostable containers is not suitable for black soldier flies in a realistic composting setup as the larvae were not only able to grow in length or gain weight, but unable to metamorphosize into their prepupae stage, thus not completing their full lifecycle. However, giving food to black soldier fly larvae that is nutritious and filling with the compostable container proves to not only increase the amount of the compostable container eaten, but still give the larvae the necessary nutrients to metamorphosize into their prepupae stage and become adults. Fortunately, despite compostable food containers having little nutrients for larvae to develop, they do not seem to be toxic or dangerous for the larvae to consume as mortality rate remained the same across all diets given. What I have found from my results can not only help us understand the limitations of what black soldier fly larvae can consume from organic waste, but also show an easier method to break down compostable food containers.

Remaining Food Composition

While there were only two types of food used to feed the larvae in this experiment, as the third variable was a combination of Gainesville diet and compostable container, the contents of what was left after the experiment was finished was very different between each variable. The compostable container only diet had the least amount of change between the other two diets, which was expected as it was the least amount eaten by the larvae, with only the significant change being that the container was more dry, as shown from how the container was in more solid pieces instead of how it initially had a more oatmeal like consistency, and was more tan in coloration. Larvae frass was also found with the compostable container, shown from noticeable brown flakes not seen previously at the start of the experiment, giving evidence that the larvae were consuming the compostable container if excrements were left behind. The Gainesville diet remaining after the experiment was nothing unusual, as the contents leftover were parts of the diet that the larvae were expected to struggle to consume due to being more dry and high in cellulose (Bajra et al. 2023), with most

of what was left being bigger pieces of dried wheat and corn. The combination of Gainesville and compostable containers left surprising results on what remained as it goes against what the other two were observed individually. For example, while all three trials had the same level of humidity, the combination of both diets left behind more water and was still very moist compared to the other variables. The coloration of the combined diets also had a lighter brown color, compared to how Gainesville only had an almost black coloration when the experiment was finished. Despite the combination being more wet and lighter compared to Gainesville only, dryer and bigger pieces of wheat and corn also were also left behind while remains of the compostable container were completely gone in all trials. While the contents remaining for all three diets had noticeable variability between dryness and color, there was clear evidence that the larvae consumed their respective diets from both weight loss and observations.

Change in Larvae Weight

While I hypothesized that the relationship between the larvaes length and weight would correlate with one another meaning that if a larvae is lighter than another larvae, it would always be shorter in length, results show that larvae weight and length are independent of each other. This is shown when comparing the weight and length of the larvae on the combined diet versus the larvae on Gainesville only diet, as despite the median length of both diets being similar to one another, the larvae on the combined diet weighted much lower than the larvae on the Gainesville only diet. My own observations during the experiment also show that the larvae in the combined diet versus larvae in the Gainesville diet looked similar in appearance and size, meaning that most of the larvae from both diets were developing into the next instars at around the same time. While few of the larvae in the Gainesville diet early in the experiment developed a darker coloration, meaning that those larvae quickly developed into the prepupae stage, overall the larvae from both combination and Gainesville diet were developing into their instars at around the same rate, with the larvae on the Gainesville diet developing into their prepupae stage faster than the larvae on the combination diet. While it can be inferred that there is a correlation between larvae weight and larvae prepupae rate with larvae in the Gainesville diet being both the heaviest and having the most develop into their prepupae stage, it can also be inferred from the weight difference yet similar appearance between the larvae on

the combination diet and the Gainesville diet that larvae length is independent of larvae weight.

Larvae Survivability

The experiment performed did not show any significant difference in larvae mortality between different diets, even though larvae weight, length, and development into prepupae varied from different diets. The fact that only a few larvae died for all trials at the end of the experiment shows how resilient black soldier fly larvae really are. This is especially admirable when considering that almost all the larvae on the compostable container only diet survived, and the larvae reared on this diet barely gained any weight, grew in height, and developed into their instars. Larvae in their earlier instars are much more vulnerable to dying prematurely, and with the compostable container providing little nutrients to provide black soldier fly larvae energy, the larvae were still resilient enough to stay alive for two weeks on only water from the moisture inside and the compostable container blended and soaked in water. As long as black soldier fly larvae are provided with enough water to stay moist and avoid being dried out, said larvae can survive for at least two weeks in their first instars without any nutritious food to eat.

Prepupae Development Analysis

Despite the majority of the trials showing very little prepupae development take place when the larvae had either only compostable container diet or a combination of compostable container and Gainesville diet, one trial in the combination diet was an outlier. Compared to the other two trials of the combination diet having only 5 and 4 develop into prepupae at the end of the experiment, one trial having almost half of the larvae develop into prepupae is abnormal. This is especially true when considering the final weight of larvae reared on the combined diet being much lower than larvae on the control condition of Gainesville only diet, while those larvae on said control had over half the larvae develop into prepupae at the end of the experiment. While it could be said that having a small number of trials could have the odds of more larvae developing into prepupae like the outlier more common if more trials were done in the experiment, this statement is also proven from the fact that larvae development speed can vary outside of larvae weight. Even though weight is a significant

factor in determining what instar the larvae is and how far it is developed as it is at its heaviest weight in its final instar before prepupating, how quickly larvae develop can be due to other factors (Amrul et al. 2022). For example, Amrul's review on rearing black soldier fly larvae on organic waste show that when larvae were fed in batches, they had a faster development time versus when the larvae were fed daily, despite the larvae that were fed daily having a heavier final weight (Amrul et al. 2022). Diet can also influence black soldier fly development time as from another study on researching black soldier fly larvae development to being fed as a diet for tilapia, larvae fed on fish waste had the shortest development time when larvae fed on restaurant waste had the heaviest larvae (Pérez-Pacheco et al. 2022). Even though there is a relationship between larvae weight and development time, factors outside of weight and even diet can affect larvae development speed.

Limitations

While black soldier fly larvae are hardy and adaptable insects who can feed on almost any type of organic waste, the methods used in the experiment are not fully accurate to how black soldier fly larvae are used in a composting setup. A notable example of this is how when black soldier fly larvae are used in common rearing setups, the larvae bin is placed outside rather than being inside (Amrul et al. 2022). Not only are larvae more often reared outside, rather than inside a lab where my experiment took place, but larvae are reared in significantly higher quantities than the 50 larvae I used per trial (Amrul et al. 2022). While the experiment I performed proved that larvae isolated in smaller groups can break down compostable containers while being able to develop when given Gainesville diet, the data collected of proportion of food consumed could change when done in a larger quantity of larvae and food. Proportion of food consumed could also be shifted in a outdoor environment, as it brings in other decomposers or organisms attracted to organic waste, which could either increase with opportunities for other decomposers to break down compostable container or decrease with competition of resources from other organisms that could negatively affect the black soldier fly larvae population that are the most reliable in breaking down said organic waste.

Materials used in this experiment in compostable containers and the Gainesville diet given to the black soldier fly larvae also make the results given from the experiment less comparable to a real life scenario, as waste disposed for the larvae to eat would be much more

diverse. While Gainesville diet is made up of moist vegetative waste that larvae can reliably gain nutrients from, many different types of organic waste can be given to larvae such as fecal waste, which could affect the development of the larvae compared to what was recorded from my experiment (Purkayastha et al. 2023). Variety of waste disposed also affects the compostable containers significantly as I only tested one brand of compostable food container, which cannot be used to represent all kinds of compostable food containers produced, as the composition can affect the ability for black soldier fly larvae to consume with how much cellulose is used which larvae have a difficult time consuming (Bajra et al. 2023). Testing whether larvae can consume a variety of compostable food containers from not just different companies that produced the containers but also the materials those food containers are made of would make the results more accurate in a real life setting as realistically many different types of waste are thrown out at once for the larvae to consume together.

Future Directions

Even though the experiment was limited in the materials used when a variety of biodegradable waste are thrown out everyday, including different types of compostable food containers, this very fact could bring countless opportunities of future research to test if black soldier fly larvae could break down said waste. This can be done by repeating the experiment again but using different kinds of compostable single-use food containers outside of the one used in this experiment and see if different plant materials and amount use change the consumption rate of black soldier fly larvae. This study can also be researched further by breaking down the exact materials found in compostable food containers and finding out which materials are easier for the black soldier fly larvae to consume versus materials the larvae struggle to consume or find uninterested in eating. Finally, since larvae need to consume organic waste that provides nutrients to them along with the compostable container to be able to develop properly, another experiment could be done to determine the optimal ratio of organic waste to compostable container to find which ratio is more effective in breaking down the most compostable container while still having the black soldier fly be able to develop into their prepupae stage. Additional studies that focus on testing black soldier fly larvae in seeing what other materials found in compostable containers through different types

of compostable containers not tested in this experiment along with finding the optimal ratio of organic waste to compostable container outside of a 50% ratio of each can help move this study further into how to improve the efficiency of black soldier fly larvae in breaking down compostable containers while figuring out what materials specifically limit the larvae in consuming and giving nutrients compared to other types of organic waste.

Broader Implications

Researching both how biodegradable compostable single-use food containers are and the limitations of what black soldier fly larvae can consume through organic waste while still fulfilling its entire lifecycle revealed how even if both aren't compatible with just each other, fulfilling the black soldier fly larvae needs in organic waste that's nutritious with compostable container moist enough to mix in proves that both can fulfill their niche of being useful effective composters and being biodegradable in a short amount of time compared to plastics. While there is still information left undiscovered such as what exactly in compostable single-use food containers limits the nutrition and consumption ability of black soldier fly larvae, this study gives solid evidence that larvae can consume and break down compostable food containers. Not only does it show the adaptability of soldier fly larvae in being able to develop and almost finish their lifecycle, despite half of the food given to the larvae is nutrient deficient from the compostable container added, but it gives us an alternative to breaking down said compostable containers with a method more environmentally friendly.

Although more research is needed to find the most effective way to break down more compostable containers quickly while also having enough nutrients for black soldier fly larvae to fulfill their lifecycle to sustain a proper black soldier fly composting setup, using soldier fly larvae to breakdown compostable containers is much easier than finding a facility with equipment that can get hot enough to burn compostable single-use food containers to break it down as the EPA recommends. Waste management can only truly be effective if it is accessible to everyone to contribute in lowering the amount of trash building up in landfills everyday. By offering easy yet effective methods in reducing trash, it can not only bring awareness to how everyone can make a difference in keeping the planet cleaner, but also acknowledge a hidden hero in waste management that many of us would have never thought of in disposing our organic waste.

ACKNOWLEDGEMENTS

I'd like to thank Tina Mendez and Melissa von Mayrhauser for their patience and all the advice given on how to move forward with my thesis. I'd also like to thank Michael Crossley for being my mentor with teaching me how to rear black soldier fly larvae, how to make Gainesville diet, and how to improve my experiment. Thank you as well to the summer institute program at the University of Delaware and Crossley's Agriculture Entomology lab for allowing me to complete my experiment over the summer. Finally, I would like to thank my family and friends for all being so supportive of my thesis and my research endeavors.

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