Development of a small scale BSF rearing system and first-hand experience of the process and its lifecycle

Dzulaikha Khairuddin*1, Siti Nurhaslina Fitriyah Hassan1 and Siti Nurfatihah Abdul Ghafar1

School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor. Malaysia.
*dzulaikha@uitm.edu.my

Abstract. Black soldier fly larva (BSFL) or also known as Hermetia illucens is a type of insect that has been studied for its potential to bio convert waste into a form of protein and lipid. As the bio-conversion process of food wastage into profitable sources is robust, environmentally friendly without the need for their end-product to be managed, it is a very promising sustainable method that should be explored more. A small-scale experiment was conducted to gain first-hand experience of the BSF rearing process. A portable BSFL production system was designed, developed, and tested in this study. As an addition to the experience, an experiment on the effect of different types of diet on the development of the larvae to prepupae was conducted and several characteristics of the harvested BSFL also was recorded and compared. Results show that the system can support the rearing of BSF and the different diet consumption affected the larvae size and weight. In conclusion, the system could be employed for the small scale BSFL production that not just helping in taking care of the Malaysian food waste but they will also serve as an awareness-raising measure for circular economic solutions.

Keyword: Small scale BSFL rearing system, BSF lifecycle, Circular economy, Waste to wealth

1. Introduction

Black Soldier Fly (BSF) or its scientific name Hermetia illucens is an insects native to most tropical and subtropical region [1]. Its larvae (BSFL) are saprophagous [2], which able to consume almost any types of substrates and absorb it as a source of nutrient to help their growth. Once the larvae grow into prepupae, they will have the potential to contain sufficient amount of protein and lipid for them to be further used in other application such as animal feed, fertilizers etc. Types of substrates being fed to the BSFL can affect its growth rate and nutrient contents. Using food waste to feed BSFL and then providing it for the livestock and agricultural industry which later consumed by human can create a sustainable cycle in our ecosystem. This study will focus on assessing BSFL fed with food waste as well as analyzing its effectiveness in reducing food waste in an economically and environmentally friendly way.

Food wastage is one of the most concerning environmental problem globally. In Malaysia, as the waste disposal method mainly practiced for all type of waste including food waste is through landflling, it releases methane gas into the atmosphere which is 25 times more powerful than CO2 in contributing to global warming [3]. Landfilling could also produce leachate which can contaminate the groundwater at the landfill site as most of the landfills in this country are not sanitary landfills [4]. Other alternative such as composting [5], [6] will take up to 2-4 weeks for maturation of the compost, while incineration on the other hand are expensive to maintain and operate [7]. Therefore, the utilization of insect
bioconversion such as black soldier fly larvae is seen as a sustainable way of reducing food waste environmentally and economically in Malaysia.

Harvested BSFL have also been proven to be used as animal feed for many monogastric animals [8], soil amendment and organic fertilizer [9], and processed into biodiesel [1]. The BSF industry in Malaysia has grown as early as 2012, pioneered by Entofood Sdn. Bhd. [10] and Nutrition Technologies Group [11] which entered into research partnerships with several local and abroad universities such as Universiti Teknologi Malaysia (UTM), Universiti Sains Malaysia, Nong Lam University (Vietnam) and Kasetsart University (Thailand) for development of their products. The Entofood Sdn. Bhd. in particular have produced more than 200 tons of BSF biomass since operated. Based on the BSF application, the animal feed segment is forecasted to witness rapid growth by 2030 with market reach $3.4 billion. The fast growth of this market is mainly attributed to the growing demand for animal-derived products and subsequent increase in the demand for protein-rich animal feed. This demand will also influences the growing adoption of insects as an alternative source of protein for animal feed which offers immense opportunities for market growth[12].

Seeing the economic benefit of the BSF farming is promising, therefore, this method should be explored more in a way that it can also be exploited by small scale farmers to gain profit. As food waste is one of the domestic wastes produced every day by households in Malaysia. Therefore, with this excellent BSF potential, the waste could be put to good use. To directly start to build a large scale BSF rearing facility, it will definitely require substantial capital. Plus, a BSF farmer needs to understand and always be alert with the development of the BSF lifecycle itself[13]. Therefore, a simpler system that can support the full lifecycle of BSF that is easy to maintain and less care is very much needed. Thus, the objective of this study were (i) to develop a small scale BSF rearing system that can support the lifecycle of BSF that is easy to maintain and less care, (ii) to identify the characteristics of BSFL fed with two different type of food waste and (iii) to gain first-hand experience of the rearing process and suitability of the system to support the BSF lifecycle. The insight on the applicability of a small continuous system developed in this study, as well as the palatable food waste suitable for the BSF rearing would be the significant contribution of this study.

2. Methodology

2.1. System Development

Since the objective of this experiment is to study how the difference of food waste fed to BSFL can affect the growth behavior of BSFL. A BSFL production system was built and designed by using steel and wooden frame, high-density plastic box and netting mesh. These three types of materials were used to cater the production lifecycle stages of the BSF. The schematic design of the portable BSFL production system can be visualized in Figure 2.1.

Detail design of the system are as follows:

i. Stack 1 was designed as a box with metal frame covered with netting mesh that will support the optimum condition for adult BSF. The box also being supplied with water and equipped with corrugated cardboard for the adult BSF to lay their eggs.

ii. Stack 2 was designed to have a control condition that suitable for larvae to grow faster. This part is particularly important during the growth optimization experimental stage to ensure the maximum production could be obtained. This stack also will be provided with bedding for optimal condition for the larvae. As the BSFL need a moist condition, bedding used was the coconut peat.

iii. In the stack 2, the crawling system with 35° angle also was designed for the pupa-stage BSF to crawl avoiding the wet bedding. This phenomenon will create a self-collector system that all the pupa stage (stage that suitable for animal feeding) are self-harvested.

iv. At the bottom of this stack, a drainage system was designed for removal of excess water
and insect frass. The insect frass is suitable to be used as soil enhancer and fertilizer by directly pour to the plant soil.

The final product design is shown in the Figure 2.2. Most of the parts of this product can be dissembled that makes the maintenance of this system is easy to perform.

2.2. BSFL Preparation
A 100g of larvae at the age of 7 days old were bought from local supplier, Dr. Larva Sdn. Bhd. (Johor Bahru, Malaysia) and the experiment was only started when the larvae were at 9 days old. The BSFL obtained were claimed to be of a good quality breed, hygienic and rich in calcium.

![Figure 2.1 Schematic Design of Portable BSFL Production System](image)

2.3. Preparation of Experiment
An appropriate bedding was installed to keep the moisture condition inside the system suitable for the BSFL growth. Firstly, a layer of mesh cloth was laid onto a perforated board to prevent the layer above it from passing through the holes. Next, a layer of zeolite granules was poured on top of the mesh cloth to act as filtration and separation system for the excess moisture. Finally, 1kg of coconut chips was used as the topmost layer for its absorbing properties to provide an optimal moisture condition during the BSFL feeding process.

2.4. Food Waste Preparation
In this experiment, the food wastes were collected from kitchen waste and divided into two (2) different categories – high protein and carbohydrate (e.g., rice, bread, fish, chicken), and high fiber (e.g., papaya, mango, cucumber, broccoli, tapioca leaves). The food waste was grinded in a food processor to reduce the particle size of the feed to help eases the consumption for the larvae and allowing nutrients to be absorbed more efficiently [14]. Food waste were given to the larvae at once, addition of feed is only given when there is reduction in volume of existing feed in the feeding container. Addition was given lesser than the first feed, only enough to cover the top layer of the bedding.
2.5. Data Collection and Analysis
Data that were collected in this experiment were the larval weight before feeding, larval rearing period, prepupal weight, and prepupal length. The collected data were then analyzed accordingly and supported by the information from the exploratory study.

3. Results and Discussion

3.1. The portable Continuous Black Soldier Fly Larvae Production System
After the design of the portable continuous BSFL Production System has been developed, the materials are then being set up and assembled according to the design. Most parts and components of this system can be detached from one another which allows easy maintenance during the experiment. The figure of the fully developed system is shown in Plate 3.1

Plate 3.1 Final assembly of the BSFL system. (a) Front view showing the complete whole system, (b) Right view of the system showing the Stack 1, Stack 2 and drainage system, (c) Larvae incubator with ramp connected to collection bottle for self-harvesting system, (d) Detachable component Stack 1 from the system. (e) Left view of the system showing the Stack 1, Self-harvesting collection bottle and Stack 2

3.2. Breeding of BSFL in the BSF rearing system
For the optimal growth of the BSFL, the bedding set up as well as the filtration and drainage system was designed to prevent moisture accumulation in the larvae incubator and maintain optimal moisture condition at the same time. The bedding, filtration and drainage system did help in preventing stagnant pool of liquid in the incubator and there is no moisture discharge flow out of the frass discharge pipe as only very little amount of liquid found at the bottom of the container.

A unique finding was observed during the pre-pupae stage. These controlled moisture conditions actually complicate the self-harvesting process that is intended to be used in this system. At the age 16-days old, the prepupae was harvested manually as they failed to self-harvest through the system designed. It was suspected that the amount of zeolite granules and coconut chip used exceeded the
amount needed to control the moisture content from the food waste given to the larvae. This condition creates a dry layer at the bottom part of the zeolite and thus, creating a suitable environment for the prepupal to pupate, causing most of the prepupae to hide in the zeolite layer instead of self-harvesting. According to Devic et al., the wet bedding conditions are one of the factors that will force BSF prepupae to find a drier area by climbing the ramp provided towards the self-harvesting system[13]. Realizing this condition, the bedding part is left to become moister and soggy. With these conditions, the self-harvesting system designed in the development of this system was successfully functioned and used by the pre-pupae, where they climbed up the ramp and finally drop into the collection bottle. After the self-harvesting problem was identified, the entire BSF cycle was demonstrated again in the built system. In this cycle, the full life-cycle of BSF were successfully completed according to the expected strategy using this system whereby, the newly hatched larvae are grown in stack 2: Larvae incubator (Plate 3.1: b) until reaching the age of 12-16 days. When the prepupae reach the peak of the stage to become pupae, the pre-pupae will climb the self-harvesting ramp thus being collected in the collection bottle. The collected pupae were used as animal feed, while some of it were put back in the adult BSF cage (Plate 3.1: b and Plate 3.2) to continue the lifecycle as adult and laying their eggs in the corrugated paper installed in the system. The eggs were then hatch into larvae, thus drops into the stack 2: larvae incubator.

3.3. Characteristic of harvested BSFL
As there are two different types of food given, it is expected that the prepupae size (length and width) for the two types of food given would be different. However, both types of food waste diet yielded almost the same length and width as recorded in Table 3.1.

| Food waste                        | Length (mm) | Width (mm) |
|-----------------------------------|-------------|------------|
| High carbohydrate & protein       | 16 – 28     | 3 – 5      |
| High fibre                        | 14 – 29     | 3 – 5      |

During the first round of harvesting of prepupae, it is found that some of the larvae from the high carbohydrate and protein part manage to crawl underneath the partition into the high fibre part. From a general observation, it could be that the high fibre food waste is more palatable to the larvae due to higher moisture content from the fruit and vegetables in comparison to the other type of food waste. Thus, the total amount of prepupae harvested in the high fibre part is higher than the other with a difference of 21g of the total weight as can be seen in Table 3.2.

| Food waste                        | Total weight (g) |
|-----------------------------------|------------------|
| High carbohydrate & protein       | 87               |
| High fibre                        | 108              |

There are two factors that might affect the physical characteristic of the prepupae collected by the end of this study. Firstly, the electronic balance used is for common kitchen usage with readability of 1g at the least. A more precise electronic balance such as the one used in the laboratory (e.g., readability of 0.1mg or 0.0001mg) might have recorded the slight difference in weight between the prepupae. Another factor that might affect this could be the strain of BSFL itself. A study by Zhou et al. [15] that was performed on three different strain of BSFL shows that, its origin does affect the growth and
composition of the BSFL. The strain of BSFL used in this study was unknown but it was stated to be a high-quality BSFL. Therefore, it is believed that this could be the factor as to why different types of feed does very little effect to the prepupae weight.

3.4 Applicability of the system developed in this study

To observe the complete lifecycle of the BSF, some harvested prepupae (Plate 3.2 (a)) was kept in the Adult BSF incubator for pupation as can be seen in Plate 3.2 (b). At the age 24-days-old the prepupae has successfully emerged into an adult fly inside the incubator as shown in Plate 3.2 (c) and (d). This result shows the successfulness of the system to adopt the full lifecycle of the BSF.

Plate 3.2 BSFL growth in the system. (a) Harvested 16-days-old prepupae, (b) Prepupae left in adult BSF incubator for pupation to take place, (c) Prepupae has successfully grow into Adult BSF after 8 days, (d) Adult BSF Fly inside the incubator

4. Conclusion

It was shown in this study that the developed system for BSFL rearing cycle was successfully implemented for the full in-house rearing of the BSF. With improvement done for the self-harvesting system, the design can operate flawlessly. The breeding and characteristic of the BSFL harvested in this study shows that the different types of diet supplied to the larvae have effect on the prepupal weight, however for the prepupal size in term of length and width of the prepupae, it can be seen that the different types of diet do not have much effect on the size. In this first-hand experience, it can be seen that the system can support the full cycle of the BSF with the rearing period of 24 days.
5. Acknowledgement

Authors is in debt with the School of Civil Engineering, College of Engineering, UiTM Shah Alam, for the financial support in attending the conference and publishing this paper.

References

[1] R. Raksasat et al., “A review of organic waste enrichment for inducing palatability of black soldier fly larvae: Wastes to valuable resources,” Environ. Pollut., vol. 267, p. 115488, 2020, doi: 10.1016/j.envpol.2020.115488.

[2] T. T. X. Nguyen, J. K. Tomberlin, and S. Vanlaerhoven, “Influence of resources on hermetia illucens. (diptera: Stratomiidae) larval development,” J. Med. Entomol., vol. 50, no. 4, pp. 898–906, 2013, doi: 10.1603/ME12260.

[3] P. K. Amritha and P. P. Anilkumar, “Development of Landscaped Landfills Using Organic Waste for Sustainable Urban Waste Management,” Procedia Environ. Sci., vol. 35, 2016, doi: 10.1016/j.proenv.2016.07.016.

[4] Y. C. Moh and L. Abd Manaf, “Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia,” Resources, Conservation and Recycling, vol. 116, 2017, doi: 10.1016/j.resconrec.2016.09.012.

[5] S. Roslan, A. Z. M. Zahid, F. Baharudin, and J. Kassim, “TakaFert: Biofertilizer of Leachate Sludge and Food Wastes by Takakura Composting,” IOP Conf. Ser. Earth Environ. Sci., vol. 685, no. 1, 2021, doi: 10.1088/1755-1315/685/1/012009.

[6] N. Hamzah, N. F. Hashim, N. S. Zainuddin, J. Kassim, A. A. Halip, and N. L. Rahim, “Effect of organic matter on pathogen population during composting of municipal sludge,” IOP Conf. Ser. Earth Environ. Sci., vol. 616, no. 1, 2020, doi: 10.1088/1755-1315/616/1/012055.

[7] U. Arena, F. Ardolino, and F. Di Gregorio, “Technological, environmental and social aspects of a recycling process of post-consumer absorbent hygiene products,” J. Clean. Prod., vol. 127, pp. 289–301, Jul. 2016, doi: 10.1016/j.jclepro.2016.03.164.

[8] G. D. P. da Silva and T. Hesselberg, “A Review of the Use of Black Soldier Fly Larvae, Hermetia illucens (Diptera: Stratomiidae), to Compost Organic Waste in Tropical Regions,” Neotrop. Entomol., vol. 49, no. 2, pp. 151–162, 2020, doi: 10.1007/s13744-019-00719-z.

[9] Z. Chiam et al., “Evaluating the potential of okara-derived black soldier fly larval frass as a soil amendment,” J. Environ. Manage., vol. 286, no. February, p. 112163, 2021, doi: 10.1016/j.jenvman.2021.112163.

[10] “Sustainability is a worldwide concern.” https://entofood.com/ (accessed Nov. 14, 2021).

[11] “Sustainability | Nutrition Technologies | Black Soldier Fly Asia.” https://www.nutrition-technologies.com/sustainability (accessed Nov. 14, 2021).

[12] M. M. R. Pvt., “Black Soldier Fly (BSF) Market to Reach $3.4 Billion by 2030- Exclusive Report Covering Pre and Post COVID-19 Market Analysis and Forecasts by Meticulous Research®,” Meticulous Market Research Pvt. Ltd, 2021. https://www.prnewswire.com/news-releases/black-soldier-fly-bsf-market-to-reach-3-4-billion-by-2030-exclusive-report-covering-pre-and-post-covid-19-market-analysis-and-forecasts-by-meticulous-research-301270456.html (accessed Oct. 30, 2021).

[13] E. Devic and M. R. Fahmi, “Biology of Hermetia illucens,” in Technical handbook of domestication and production of diptera Black Soldier Fly (BSF) Technical handbook of domestication and production of diptera Black Soldier Fly (BSF) Hermetia illucens, Stratomiidae., no. 3, 2013.

[14] K. C. Surendra, J. K. Tomberlin, A. van Huis, J. A. Cammack, L. H. L. Heckmann, and S. K. Khanal, “Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (Hermetia illucens (L.)) (Diptera: Stratomiidae) (BSF),” Waste Manag., vol. 117, pp. 58–80, 2020, doi: 10.1016/j.wasman.2020.07.050.

[15] F. Zhou, J. K. Tomberlin, L. Zheng, Z. Yu, and J. Zhang, “Developmental and waste reduction plasticity of three black soldier fly strains (Diptera: Stratomiidae) raised on different livestock manures,” J. Med. Entomol., vol. 50, no. 6, pp. 1224–1230, 2013, doi: 10.1603/ME13021.