

2022 S.T. Yau High School Science Award (Asia)

Research Report

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Title of Research Report

Food-waste Up-cycler

Date

31 August 2022

Food-waste Up-cycler**LEUNG Kwan Yi, LAI Yik Tao, LUI Ying To****Abstract**

The food waste problem worldwide has been deteriorating over decades. Especially for Hong Kong, where the situation is getting worse disturbingly. To combat this problem, we aim to use black soldier flies, an insect consuming food waste at a fast speed to ease the burden. In this study, a complete system will be developed to maintain an optimum living environment for black soldier flies thus facilitating their food consumption rate. With the aid of the IoT system, the temperature and relative humidity were successfully controlled in the range of 25-35°C and around 70% respectively. The food waste consumption was 130g at the beginning and it was doubled with our automatic adjustment prototype compared to control. Our system also provided a stage separation compartment for the development of black soldier flies. Besides consuming food waste, black soldier fly itself has a high utilization value and can produce various products. Therefore, the black soldier fly represents a brand-new method for waste resource utilization with low energy consumption but high output value. With the aid of black soldier flies, not only do we hope to solve the food waste problem in small communities, but also contribute to making the world a better place.

Keywords: Food waste, Black soldier fly, IoT system

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Jeff Luen, alumni who provided the black soldier fly for our experiments.

Declaration

This project was submitted to the following competitions:

- (i) City I&T Grand Challenge Grand Pitch 2021
- (ii) Korea Science & Engineering Fair International 2021
- (iii) Global Youth Science and Technology Bowl (GYSTB) 2022
- (iv) 24th Hong Kong Youth Science & Technology Innovation Competition
- (v) 17th Soong Ching Ling Award For Children's Invention
- (vi) Hong Kong Student Science Project Competition 2022
- (vii) 一念一綠: 第一屆全港學界減碳創意大獎 (Chinese version only)

It is also used in participating the following competitions currently:

- (i) Young Professionals Exhibition & Competition 2022
- (ii) 55th Joint School Science Exhibition
- (iii) The Greater Bay Area Science Project Competition (GBASPC) 2022
- (iv) SMART Community Hackathon 2022

Commitments on Academic Honesty and Integrity

We hereby declare that we

1. are fully committed to the principle of honesty, integrity and fair play throughout the competition.
2. actually perform the research work ourselves and thus truly understand the content of the work.
3. observe the common standard of academic integrity adopted by most journals and degree theses.
4. have declared all the assistance and contribution we have received from any personnel, agency, institution, etc. for the research work.
5. undertake to avoid getting in touch with assessment panel members in a way that may lead to direct or indirect conflict of interest.
6. undertake to avoid any interaction with assessment panel members that would undermine the neutrality of the panel member and fairness of the assessment process.
7. observe the safety regulations of the laboratory(ies) where the we conduct the experiment(s), if applicable.
8. observe all rules and regulations of the competition.
9. agree that the decision of YHSA(Asia) is final in all matters related to the competition.

We understand and agree that failure to honour the above commitments may lead to disqualification from the competition and/or removal of reward, if applicable; that any unethical deeds, if found, will be disclosed to the school principal of team member(s) and relevant parties if deemed necessary; and that the decision of YHSA(Asia) is final and no appeal will be accepted.

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1. Introduction

1. 1 Food waste problem worldwide

Given that the food disposal has been estimated for every country in the world, in the technical report appendix to FAO (2013) [1], which builds upon the FAO's 2011 study [2], an approximate value of 545 million tons of food was wasted in 2007. Compared to the 931 million tons in 2019 estimated in UNEP food waste index report 2021 [3], the food waste has been 1.74 times higher in 10 years. The substantial differences in methodology and distance between the two data points (2007 and 2019) shows the seriousness of the food waste problem.

1. 2 Food waste problem in Hong Kong

According to the Environment Bureau (EB) of Hong Kong, in 2012, 9278 tons of municipal solid waste (MSW) was disposed of at landfills every day. Among these, around 36% (around 3337 tons) were food waste. The food waste disposal is equivalent to 250 double-decker buses [4]. Up to 2019, there were 11057 tons of MSW disposed of daily and about 30% were food waste (3353 tons) [5]. In addition, the EPD (2015) states that the amount of food waste from the Commercial and Industry (C&I) sectors has been increasing from 400 tons in 2002 to 1003 tons in 2013, indicating a degradation of the food waste problem [6]. Specifically, the waste of bread is also serious in Hong Kong as there is an expiry date. Therefore, bread will be used for our experiment.

1. 3 Current food waste treatments

There are many ways to deal with food waste, such as landfill, O'Park, and food donation as shown in Table 1.1.

Table 1. 1 Comparison of current food waste treatment

Food waste treatments	Landfill	O'Park	Food donation
Low energy consumption	/	/	/
High output value	/	✓	/
Environmental friendly	/	✓	✓
Few food waste requirement	✓	/	/
Easy to handle	✓	/	✓
Odorless	/	✓	✓

1. 4 Black soldier flies as solutions

Facing the serious food waste problem, we came up with an idea of using black soldier flies to ease the burden. Black soldier flies (Black Soldier Flies) can rapidly colonize and consume food waste of their weight over a lifetime. Comparing other existing methods of dealing with the leftovers like landfills, O. Park, food donating, etc. (Table 1.1) The Black Soldier Flies sparked a new treatment method for food waste utilization with low energy consumption, high output value, and being environmentally friendly. Also, as Black Soldier Flies are able to intake varieties of food, prepossessing or sorting of leftovers is not complex and easy to handle. Moreover, Black Soldier Flies decomposes toxic bacteria with functional antimicrobial peptides (AMPs). so that the food waste will not stink.

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2. Experiment

2.1 Efficiency of Black Soldier Flies consuming different types of food waste

To find the efficiency of Black Soldier Flies consuming food waste, 300g food waste (biscuit) was prepared and around 200g of Black Soldier Flies larvae were added. The weight of food waste was measured every 24 hours under room conditions. The experiment was repeated with bread as the food waste source. (Figure 2. 1)

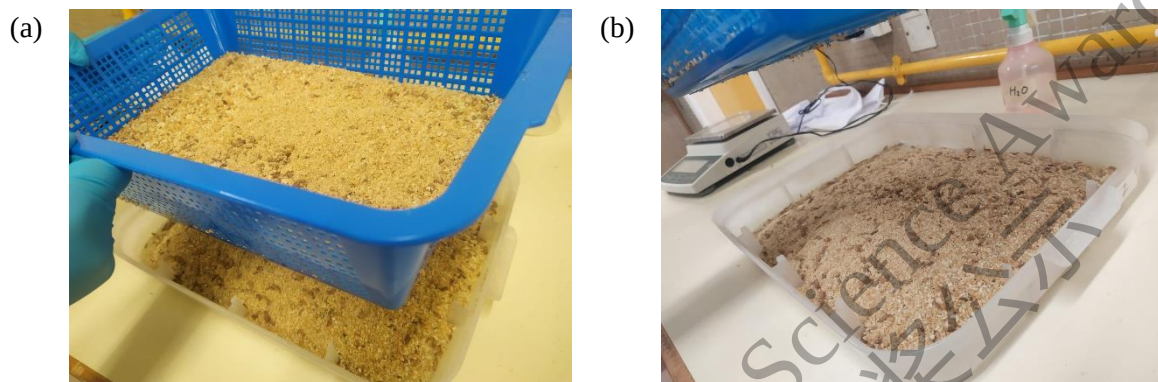


Figure 2. 1. Experiment on food consumption of Black Soldier Flies under room condition with (a) biscuit and (b) bread as the food source.

Besides biscuits and breads, other food waste from school canteen and take-away from restaurant were also used to test Black Soldier Flies' ability of consuming food waste, including rice, banana, rice noodle and yellow alkaline noodle (Table 2. 1). The weight of food waste was measured under room conditions.

Table 2. 1. Food waste from school canteen and take-away from restaurant

			
Rice	Banana	Rice Noodle	Yellow Alkaline Noodle

2.2 Automatic adjustment on optimum condition

To adjust to optimum conditions (30°C [7] and 70% of humidity [8]) automatically, a series of programs were introduced with wifi switches (Fig. 2. 2). When the temperature detected was higher than 35°C, the fan would be turned on automatically. When the temperature detected was lower than 25°C, the fan would be turned off. When relative humidity was lower than 65%, the humidifier would be turned on automatically and when

the relative humidity was higher than 75%, it would be turned off. A Wifi camera was introduced to monitor the environment, as shown in Fig. 2. 3.

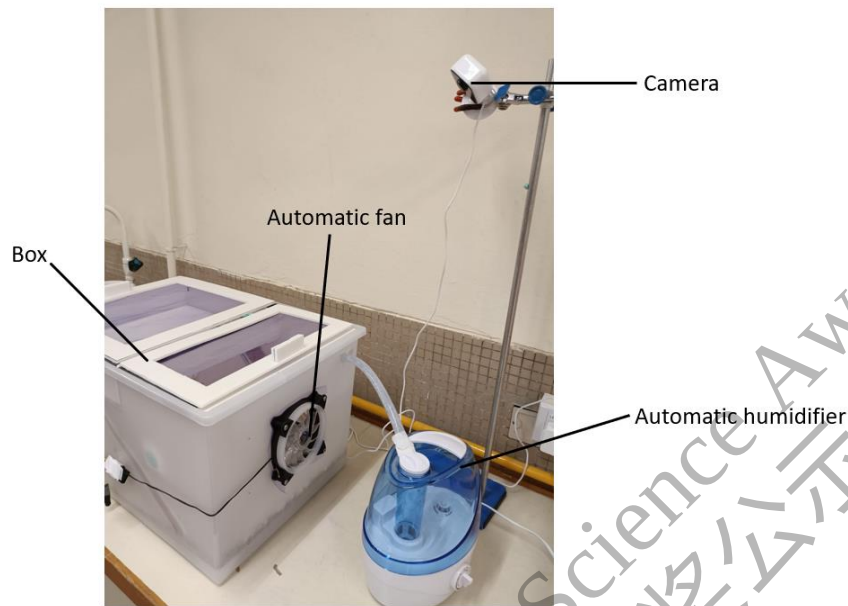


Figure 2. 2. General photos of system



Figure 2. 3. Videos of camera recorded

2. 3 Providing breeding chamber for Black Soldier flies to pupate

According to our observation and others' experience [9], when Black Soldier Flies are going to pupate, they tend to move upwards in order to leave the wet environment, searching for drier debris or soil until they mature as flies. There are two pipes as pathways for the larvae to reach the breeding chamber and pupate (Fig. 2. 4a).

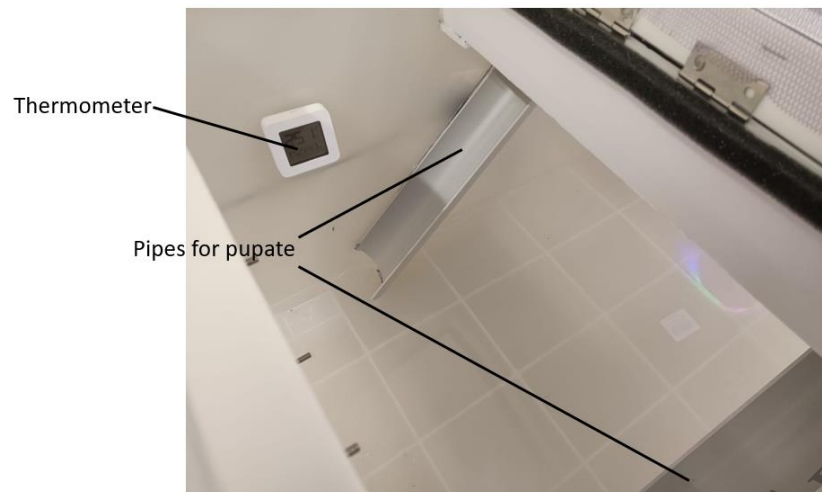


Figure 2. 4a. Pipes leading to breeding chamber

In our system, Food-waste chamber and breeding-chamber were integrated in a box. The former was allied with a fan and humidifier, ensuring optimum environment for larvae's ingestion. The latter allowed pupae eclosion and the mating for adults. They will be separated by a cupboard (Fig. 2. 4b) to facilitate product collection.

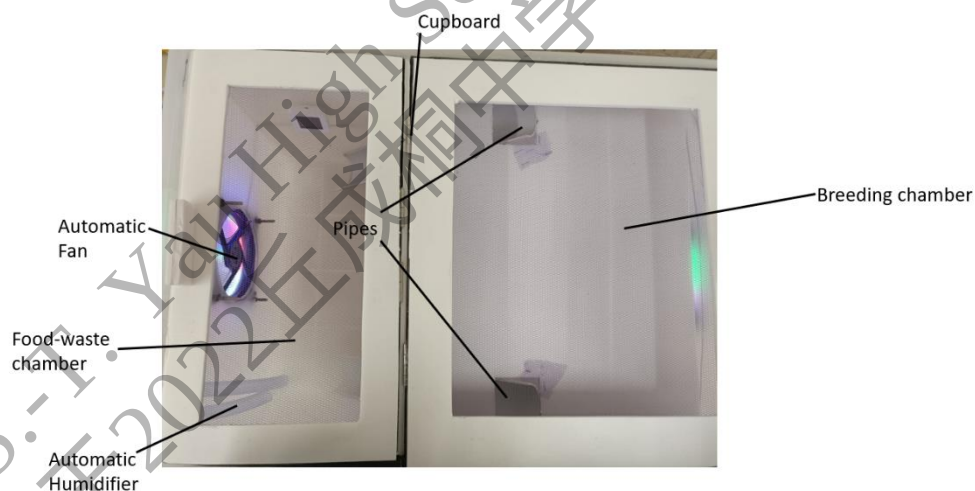
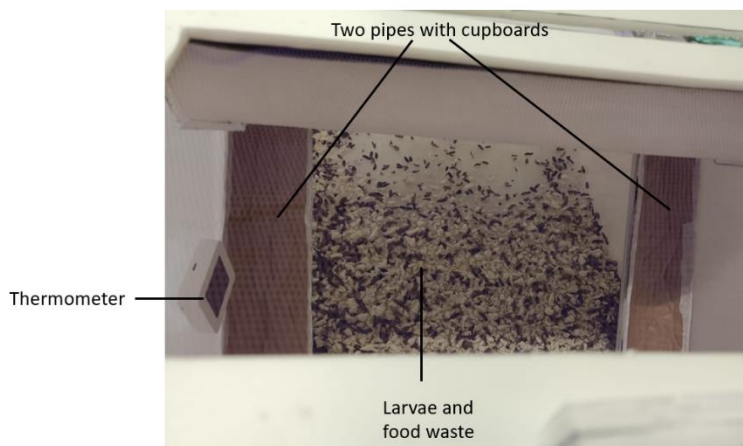


Figure 2. 4b. The breeding chambers

To reduce the difficulties for larvae to climb up when they are ready to pupate, the pipes linked to the breeding chamber were covered by cupboards to increase the friction, as shown in Fig. 2. 5.

(a)



(b)

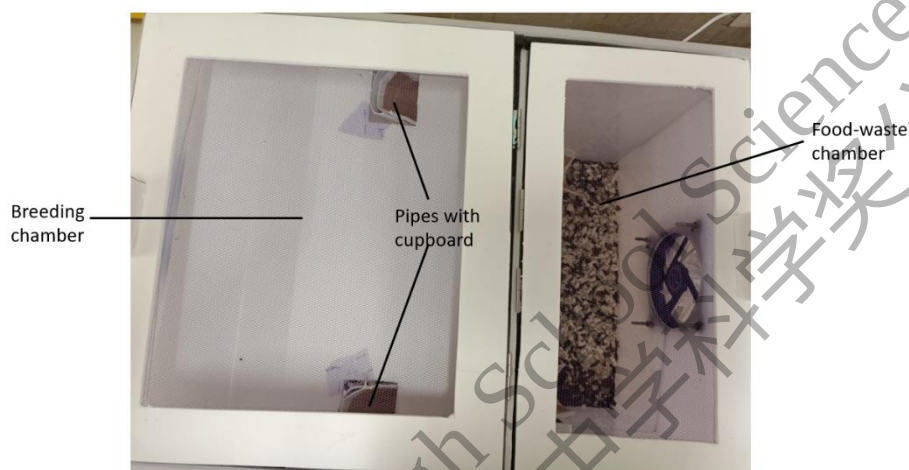


Figure 2. 5. Cupboards on pipes

2. 4 Efficiency of Black Soldier flies on consuming food under optimum condition

200g of Black Soldier Flies larvae were added to our system and control set up with a box and net only. Crushed bread was added to both boxes and the amount of food consumed was measured every 24 hours.

3. Results

3. 1 Basic efficiency of Black Soldier Flies consuming different types of food waste

As shown in Fig. 3. 1, the weight of biscuits decreased gradually by 22. 4% in 3 days, which indicates the high efficiency of Black Soldier Flies' consumption of food in a normal environment.

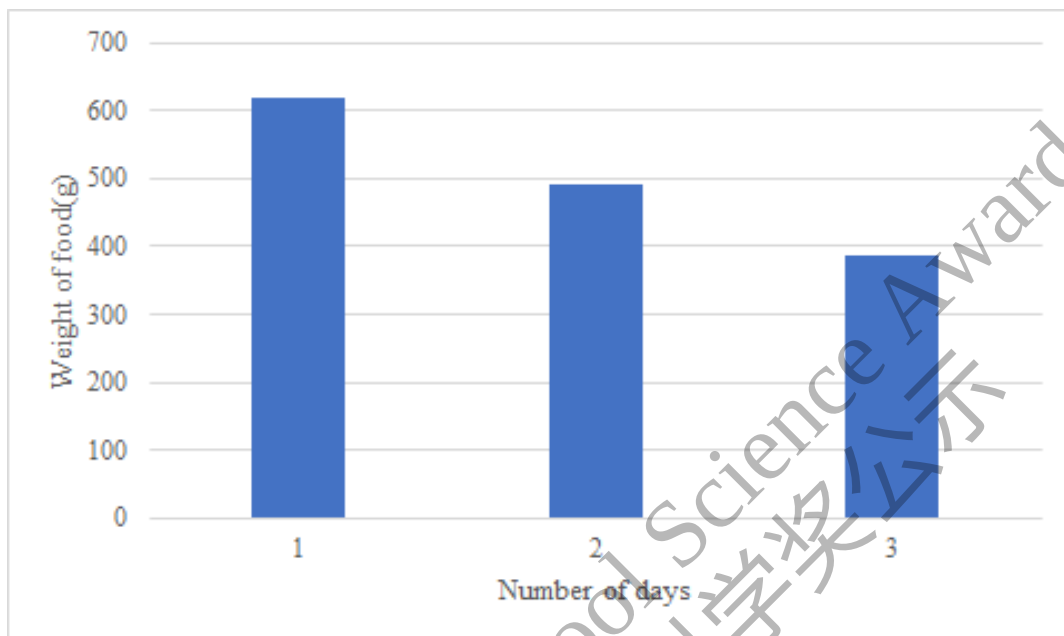


Figure 3. 1. Amount of food waste (biscuits, bread) consumption

Also, as shown in Fig. 3. 2, Black Soldier Flies can consume over 85% of all types of food waste, which shows black soldier flies' ability of consuming varieties of food waste.

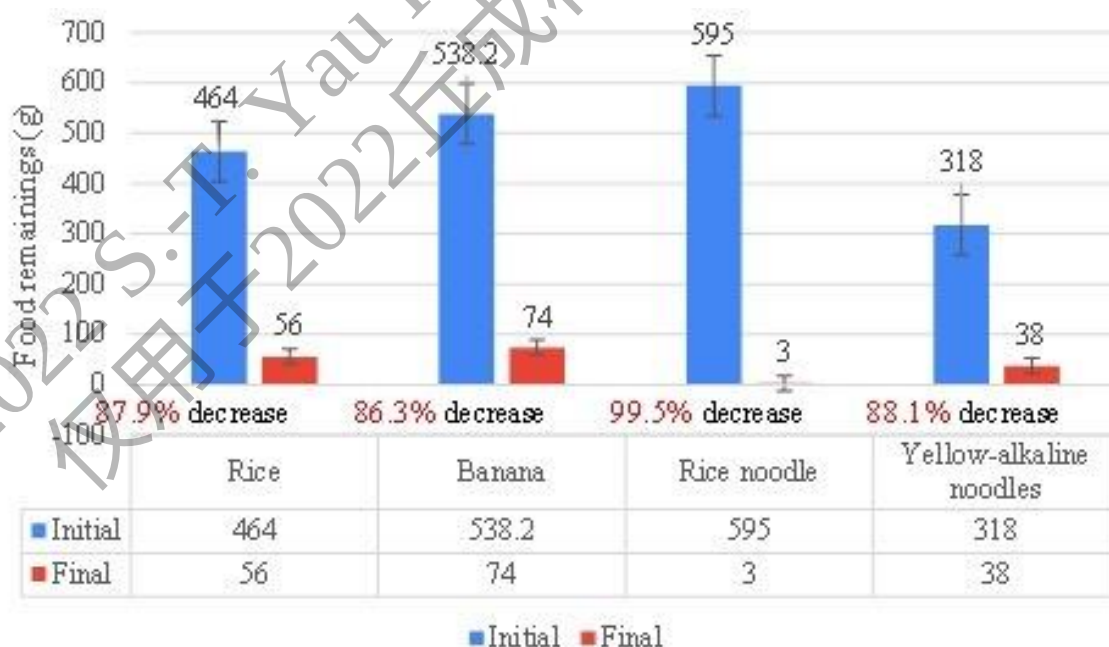


Figure 3. 2. Amount of food waste (other food waste) consumption

3. 2 Automatic adjustment on optimum condition

As shown in Fig. 3. 3 and 3. 4, the humidity and temperature were successfully kept in the range of 20-25°C and around 75% respectively. For temperature, a large amount of heat is produced when many Black Soldier Flies consume food at the same time [10], a heater is not needed.



Figure 3. 3. Temperature under automatic system

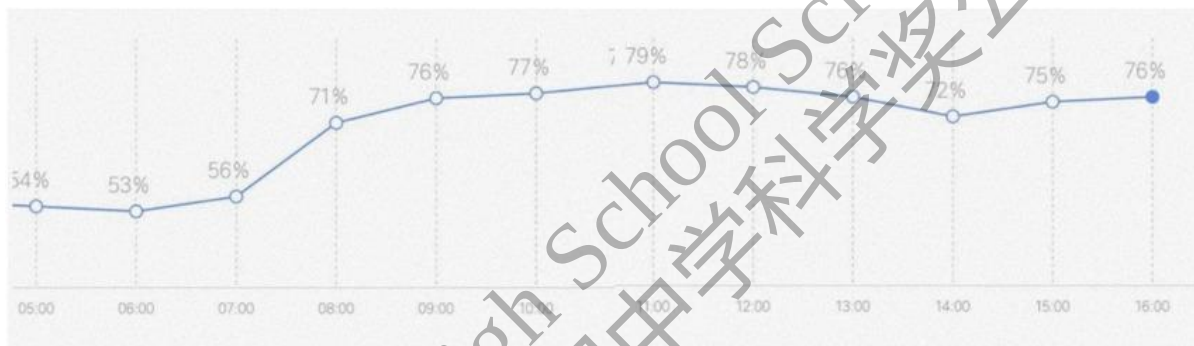


Figure 3. 4. Humidity under automatic system

3. 3 Providing breeding chamber for Black Soldier flies to pupate

Black Soldier Flies climb up to the breeding chamber when they pupate. (Fig. 3. 5a and Fig. 3. 5b) It is much more convenient to collect them for further application.

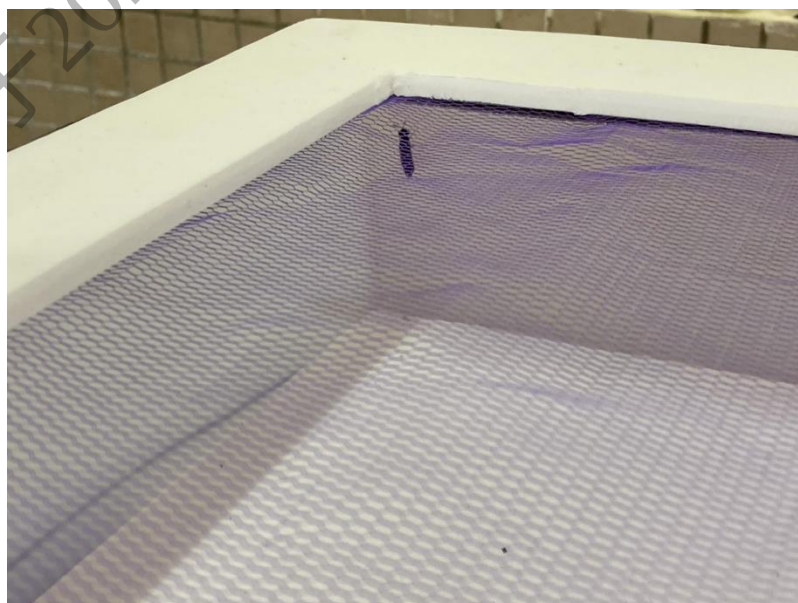


Figure 3. 5a. Flies in breeding chamber



Figure 3.5b. Collection of Black Soldier Flies pupae

3. 4 Efficiency of Black Soldier flies on consuming food under optimum condition

The amount of food consumed by Black Soldier Flies in the experimental setup (>130g) was more than that in the control system (20g), which was more than 6 times (Fig. 3. 6 and 3. 7).

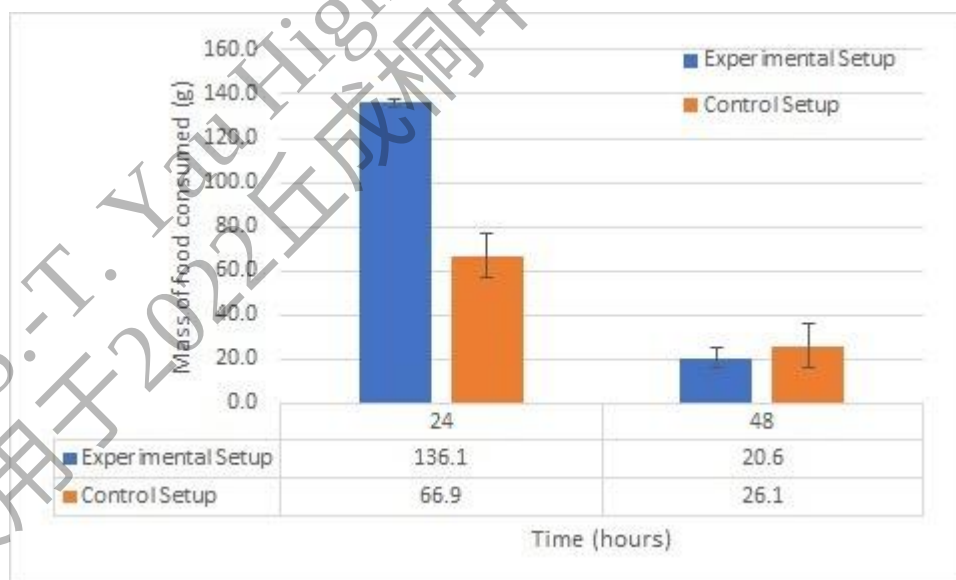


Figure 3. 6. The amount of food waste consumed by Black Soldier Flies

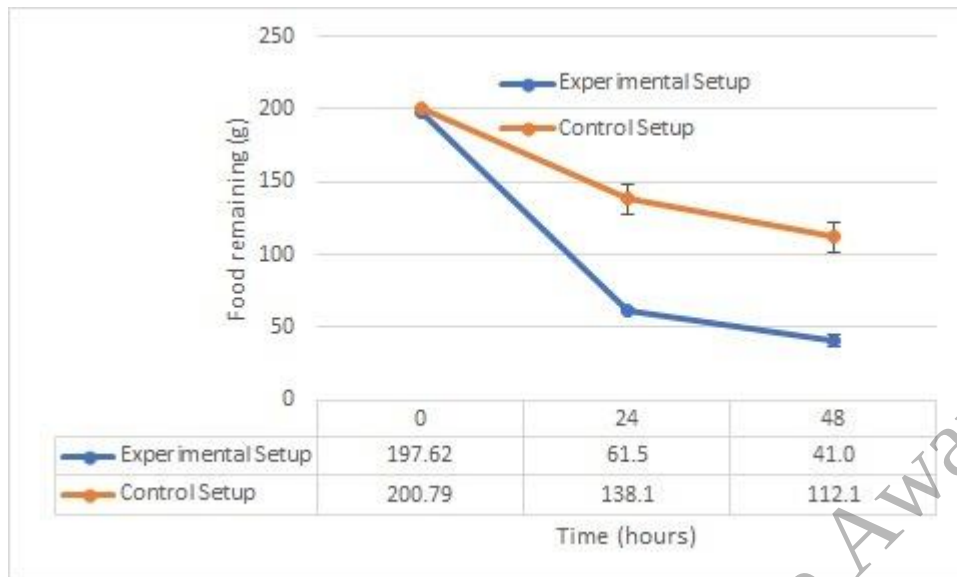


Figure 3. 7. The amount of food waste left behind

The overall percentage decrease in our system is 44%, while that in the control system is 27.66%. To conclude, our system provides a better environment for Black Soldier Flies to consume food waste. In addition, no bad smells occur.

4. Discussion

4. 1 Analysis on experiment results

According to the experiments carried out, the efficiency of black soldier flies on food waste consumption is high, in both normal room condition and optimum environment provided by our system. In experiment 2.1, the basic efficiency of Black Soldier Flies consuming food waste, 22. 4% through 3 days is high. Therefore, Black Soldier Flies can be used to consume food waste in most conditions, while experiment 2.4 showed the significant increase in efficiency of Black Soldier Flies under optimum environment, created by the system. Therefore, the system is designed for situations when by-product is needed, or the amount of food waste is large, for example, in Hong Kong. Therefore, Black Soldier Flies can consume large amounts of food waste in most conditions.

Also, in experiment 2.4, the amount of food waste consumed on the second day was noticed to be relatively less. This may be due to the fact that the larvae were prepared to pupate, and their food consumption would be relatively less. Therefore, the amount of food waste added should be decreasing when the larvae are growing up.

4. 2 Social concerns about using black soldier fly to consume food waste

In actual practice, the largest problem is whether society accepts to use Black Soldier Flies to consume food waste. Different from the public's image of smelly, dirty flies, Black Soldier Flies does not produce any bad smell during consumption. Black Soldier Flies decomposes toxic bacteria with functional antimicrobial peptides (AMPs) [11] [12], so that the food waste will not stink. Moreover, to survive, they've had to develop an odor that repels other pests so they can also be used to expel other harmful insects [13]. They are not disease vectors. They do not transfer diseases or parasites as mosquitos or ticks do. [14] Therefore, the health problems that appear on other insects do not appear on Black Soldier Flies. And as some people are concerned about whether Black Soldier Flies will escape from the system and then infect diseases to humans or even badly affect the ecosystem, there will be measurements preventing Black Soldier Flies from escaping. Under the condition that an accident occurs and Black Soldier Flies escape from the system, they still will not harm the ecosystem because Black Soldier Flies is not an invasive species. In America, the origin of Black Soldier Flies, the larvae will be eaten by mud wasps and many kinds of birds. In non-origin China, the natural enemies of Black Soldier Flies still include a variety of frogs, birds, lizards, turtles, rodents, and a variety of carnivorous insects. Therefore, in the non-originating area, the black water fly will not become uncontrollable due to the lack of natural enemies like the American white moth and become an invasive creature. [15] Even the Black Soldier Flies escape, once they reach adulthood, they do not eat but rely on the nutrients they gather as larvae. The fact that adult black soldier flies would not attack crops is very important. This means that the risks associated with a Black Soldier Flies colony getting out of hand are very low. Also, they will not attack crops or disrupt the local ecosystems. With their short life and the fact that they can't fly far with weak

wings and they're not averse to being picked up, so it'll be easier to handle if accidents happen and they escaped.

A survey was conducted in school and most of our students supported our project. Figure 4. 1a, b, c, and d show that the majority of people agree to try using Black Soldier Flies after education and propaganda. The survey was asked after introducing Black Soldier Flies to students by a video. Figure 4. 1a shows that most students know well about the food waste consumption of Black Soldier Flies, proving that education can enhance students' knowledge on Black Soldier Flies. Figure 4. 1b shows that students generally agreed Black Soldier Flies are harmless to the environment, with an average mark of 8. 57, while Figure 4. 1c shows that the majority of students agree that Black Soldier Flies is a good solution to food waste problem, with an average mark of 8. 73. This figure shows that students are positive towards using Black Soldier Flies to solve the food waste problem as it has many advantages. Figure 4. 1d shows that students are willing to have this project in our school, with an average mark of 8. 71, which was different from the public's image. Students support the system and similar education can be done in the residential region in order to encourage people to support this project, which brings many advantages.

Which stage of Black Soldier Flies can be used to eat the food waste?

(101 条回复)

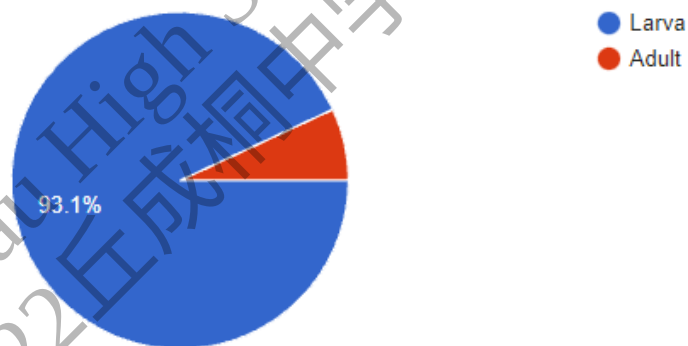


Figure 4. 1a. Survey on students' knowledge on Black Soldier Flies

Do you agree that Black Soldier Flies did not harm our environment?

(101 条回复)

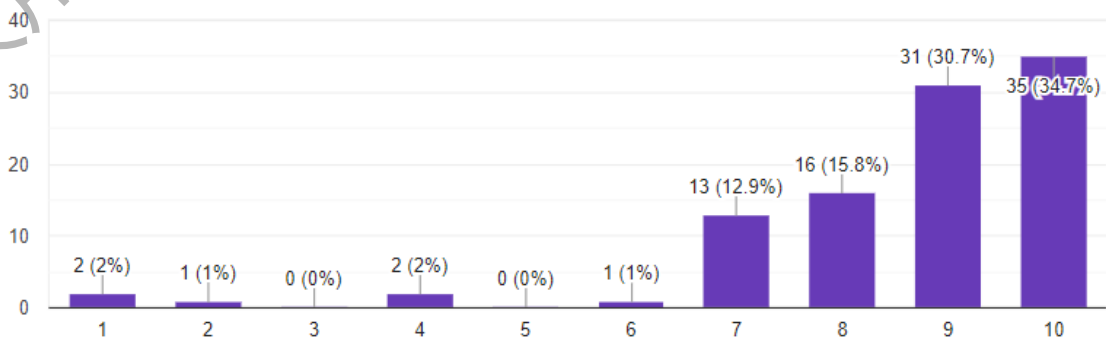


Figure 4. 1b. Survey on students on Black Soldier Flies's harm to the environment

Do you agree that Black Soldier Flies(insect in the video)is a good solution to the food waste problem?

(105 条回复)

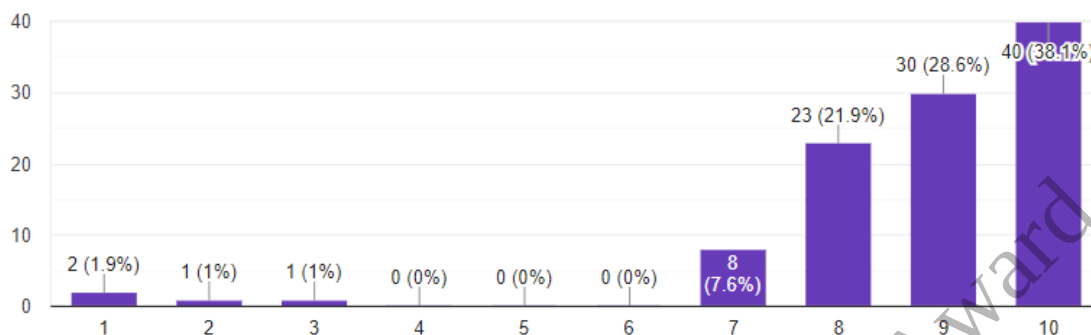


Figure 4. 1c. Survey on students on using Black Soldier Flies consuming food waste

Are you willing to have this project in our school?

(105 条回复)

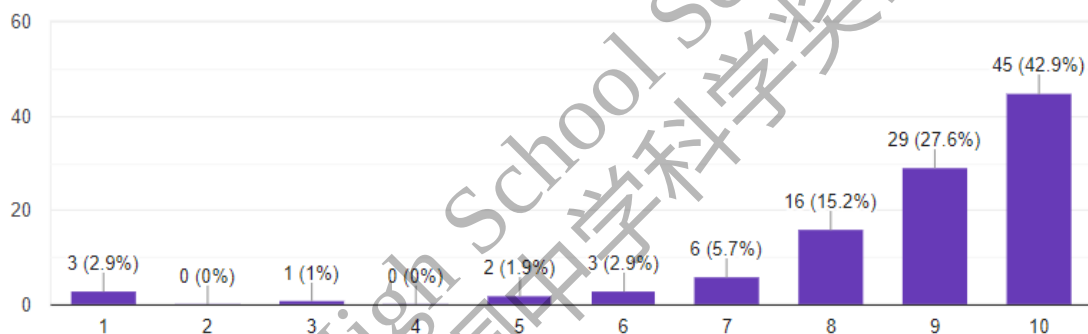


Figure 4. 1d. Survey on students on using Black Soldier Flies consuming food waste in school

4. 3 Cost-effectiveness of using black soldier fly to consume food waste

The central concept of using Black Soldier flies to consume food waste is a circular economy, as shown in Fig. 4. 2.



Figure 4. 2. Circular economy of Black Soldier Flies

After digesting food waste, excess larvae can be used as fish feed or food for livestock. Their shells contain chitosan, a flexible material that can produce various products. The rest will become fertilizer. Basically, our system is expected to attain 'low cost, high benefits'. The cost is low because once the system starts to work, 1g of Black Soldier Flies larvae can consume about 2.5kg of food waste over a lifetime. Each can produce about 700 offspring. At the same time, the transportation fee and rental cost can be greatly lowered as each housing estate can set up its own system. The whole process is easily conducted and effective. Not only it can create great benefits by becoming chitosan and fertilizer, Black Soldier Flies also benefits the whole world and even the next generation. Without transportation, the carbon footprint will be reduced and the food waste problem can be solved. Therefore, the system will be 'low cost, high benefits'.

5. Application

5.1 Workable system

A prototype is designed to provide the optimum environment for black soldier fly larvae since black soldier flies will generate heat when their shells rub against each other while food consumption, a fabric lid is used to prevent the larvae from escaping and ensure sufficient ventilation. Besides, the food consumption process tends to drain the water content in food waste, the following are electrical components for counterbalance. The optimum environment for Black soldier fly is 30°C and 70% humidity, sensors will be monitoring respective data and will be shown on a phone app made possible by IoT system. Once temperatures and humidity fall out of the ideal range, respective responses will be given by the system. A cooling system and water pump were installed as corresponding responses. A camera is installed to provide real-time footage inside the box, the activity of black soldier flies can always be easily accessed via the phone application. Finally, the system is self-sufficient as solar panels will also be installed atop the box to generate electricity. This system is expected to be used in housing estates in Hong Kong.

5.2 AI automatic programs

An application was developed to make environmental regulation fully automated, once the sensors detected environmental conditions are out of optimum range, a signal will be sent to the IoT system to make a corresponding response. The constant electricity usage will be compensated by the energy supply generated by solar panels installed on the top of the lid.

Users can feel free to trigger the fan and the humidifier manually if the box is adopted in more adverse conditions. In fact, an application (Fig. 5. 1) is being developed for Black Soldier Flies as the current one did not combine cameras. Under the new application, viewing changes in temperature, humidity, editing automatic programs, viewing pictures of cameras, can all be easily done.

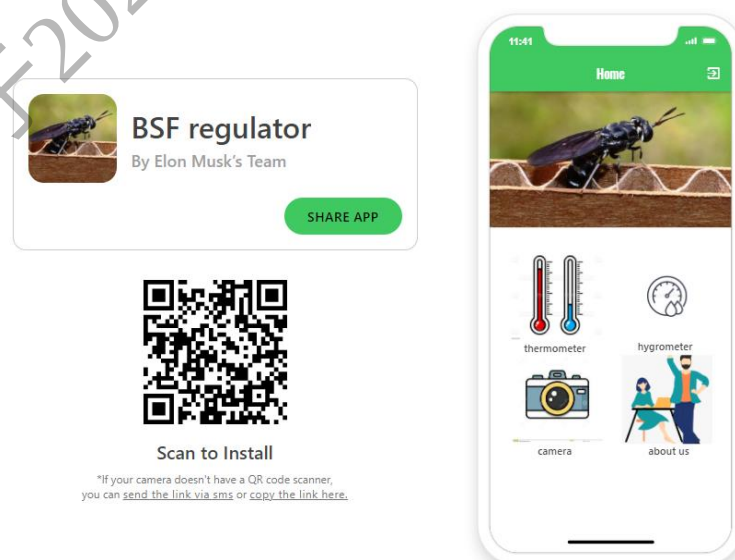


Figure 5. 1. The interface of AI automatic program for Food Waste Up-Cycler

5. 3 Targeted users

These tiny boxes are expected to be spread around urban residential areas and even local school canteens to prevent hefty transportation costs. The box is fully automated and thus will not require advanced prior knowledge in order to use the food waste consumption service.

6. Limitation

6. 1 Efficiency in different temperatures, seasons, and humidity

Due to limitations in time and resources, experiments were not able to be carried out on the speed of Black Soldier Flies in different temperatures and humidity. Instead, optimum environments were created for Black Soldier Flies in our system. Also, experiments were only conducted in autumn and winter due to limitations in time. To ensure the feasibility of our system, a higher temperature was simulated to test whether our system can lower the temperature effectively, and is feasible.

7. Further studies

7. 1 Improvement in future experiment

Experiments will be conducted in different seasons like summer for better application worldwide, especially in the Third World countries with commonly high temperature and low humidity in Africa. Furthermore, newborn larvae with a complete life cycle will be used for more detailed data.

7. 2 Products extraction and application

Black soldier fly is a saprophytic resource insect that can produce high-value animal protein feed, so that excess larva can be used as fish feed.

Black soldier fly shells can be easily collected as they are instinctively incentivized to cool in dark and dry areas so that their shells (Fig. 7. 1) can easily fall into the collection area in our prototype. Also, the shells contain Chitosan which can be used to make various products, for example, bioplastic, medicine capsules, food additives, and water purification.



Figure 7. 1. shells of Black Soldier Flies collected

In addition, frass of black soldier flies, or simply say, excrement of them, can be used for plant fertilization. Black Soldier Flies can be used to generate biofuel [16], thus solving the global energy crisis.

7. 3 Business opportunity

Chitosan and excess larvae are produced in our black soldier fly's life. Excess larvae, which contain high animal protein, can be used to feed animals, therefore farming black soldier fly can be a job to provide a food supply link of agricultural development. As the cost of farming black soldier fly is relatively low compared to traditional feed, it will become a new choice for feeding as well. Chitosan can be used to make various products, for example, bioplastic, medicine capsules, food additives, and water purification. This provides extra income when we feed black soldier flies.

8. Conclusion

To conclude, the black soldier fly represents a brand-new method for waste resource utilization with low energy consumption but high output value. 200g of black soldier fly could reduce food waste by 130g in 24 hours, with the automatic adjustment by prototype, the food waste consumption was doubled compared to control. With the aid of black soldier flies, not only do we hope to solve the food waste problem in small communities, but also contribute to making the world a better place.

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