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黑水虻的飼養方法比較

Comparison of Feeding Methods of Black Soldier Fly

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Due to limited time and experience, the thesis cannot avoid shortcomings. I hope to receive valuable contributions from Professors and interested readers.

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摘要

黑水虻可處理廚餘，並轉換為動物飼料、生產生質柴油及有機肥。本研究目的是開發一種黑水虻養殖創新方法，並與盆養、塑料托盤和池塘養殖三種方法進行比較。創新方法包括基於循環經濟原則的全自動和半自動化設施，比較項目包括方法的操作簡便性、產品數量和質量。結果顯示採用全自動方法的黑水虻飼養方法提供了最好的產量和質量。此外，在黑水虻 飼養方法中，全自動方法 是最容易控制並節省生產者時間的方法。

關鍵詞：黑水虻、全自動方法、循環經濟

ABSTRACT

The black soldier fly (BSF) is a special insect, bringing a lot of valuable benefits such as kitchen waste treatment; use as animal feed; production of Biodiesel oil; organic fertilizer production. The purpose of this study is to develop an innovative method of feeding BSF and compare it with three common methods including plastic trays, and trough. The innovative method includes fully automatic and semi-automatic facilities based on the principles of the circular economy. All of the methods were compared by the operation convenience, the quantity, and the quality of the products. The results show that the BSF farming method with a Fully Automatic Method (FAM) gives the best yield and quality. In addition, FAM is the easiest to control among BSF rearing methods and saves time for the producer.

Keywords: Black Soldier Fly (BSL), Fully Automatic Method (FAM), Circular Economy

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CHAPTER ONE
PREFACE

1.1 Introduction

The world is struggling to ensure global food security sustainably. Besides, food is a big challenge for today's growing population. Therefore, innovative strategies are needed to transform our current food system into a circular sustainable system that also focuses on reintroducing nutrients into the system by converting waste into biomass (De Smet et al. 2018). “Industrial farming of specific edible insects is a promising strategy, as insects provide an energy-efficient source of high-quality protein for feed/food and/or a sustainable strategy to enhance different waste streams by converting them to biomass” (De Smet et al. 2018).

Research interest in BSF over the past year has grown exponentially. Because it is related to the ability of BSF to convert low-value excess organic strains into high-value protein products for fish and animal feed production and biofuels or compost (Bosch et al. 2020)

Besides, BSF has “a short life cycle of 40 to 45 days” (Fig.1.1) (Tomberlin et al. 2002). Black soldiers fly adults (BSFA) do not eat anything but drink water, do not approach people, do not bite or sting, and do not transmit or spread any specific disease (Wang and Shelomi 2017). Pre-pupa black soldiers fly is 44% dry matter and consists of 42% protein and 35% fat, including essential amino acids and fatty acids (Hale 1973). Feeding studies indicate that these prepupae are a good source of nutrition for roosters, pigs, and tilapia (Sheppard et al. 2002).

Black soldier fly larvae (BSFL) can feed on a wide range of organic matter and have been used in small-scale waste management purposes using substrates such as manure, straw, food waste, distilled grains, manure sludge, offal animals, kitchen waste, … (Wang and Shelomi 2017). The variety of substrates they can process and the efficiency with which they do so may be the highest among flies (Kim et al. 2011). BSFLs accumulate lipids from their diet to use as energy for BSFA, to the point where they can be converted into biodiesel (Wang and Shelomi 2017). What they do not consume, combined with their nitrogen-rich manure, can be used as fertilizer. Larvae development time over three weeks is longer than that of flies such as houseflies and carnivorous flies (<5 days), meaning that a single larva will consume a large amount of substrate and produce larger pupae (Čičková et al. 2015). BSFL is also edible and is reported to contain a wide range of nutrients (Wang and Shelomi 2017).

Another key factor that has made BSFL one of the most interesting insects for bioconversion on an industrial scale is the ease of rearing, as the larvae can grow on many substrates, from organic lines to manure (Čičková et al., 2015). Because of the benefits and values that black soldier flies bring, researches on methods of raising black soldier flies are currently very interested and developed.

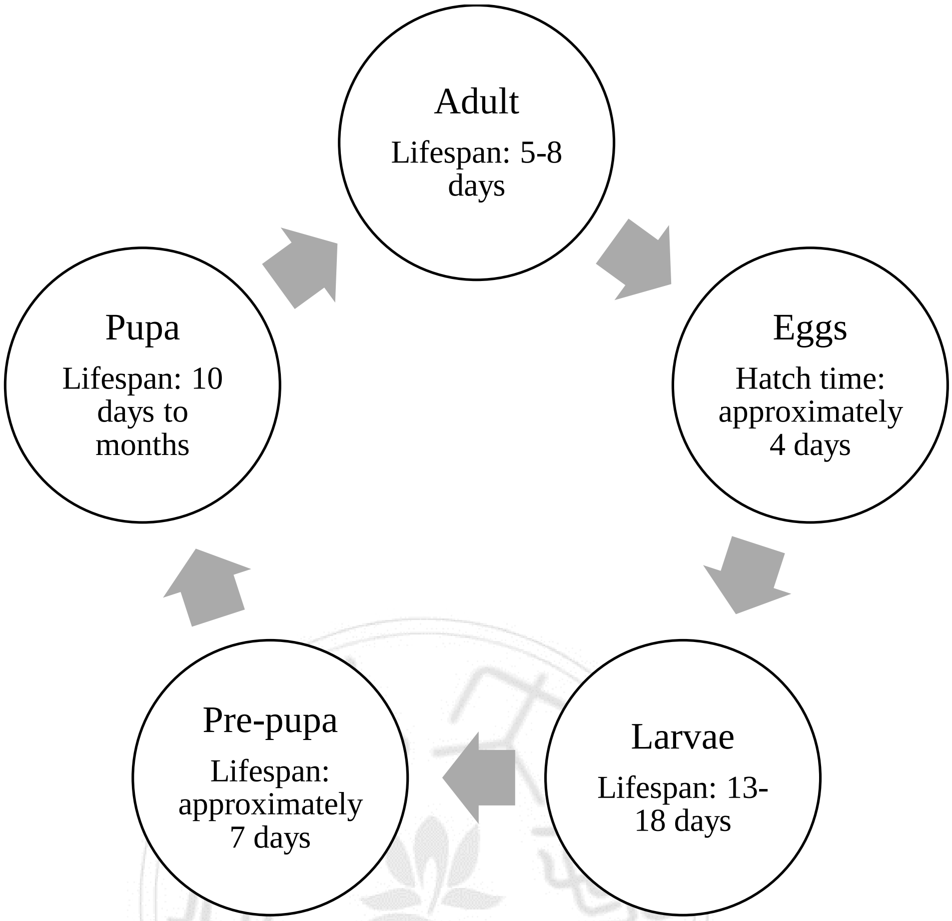

Figure 1.1: The life cycle of the black soldier fly (Hermetia illucens)

Source: De Smet et al. 2018

Figure 1.2: After the 5th instar, the black soldier fly larvae gradually turned dark brown, hardened the body wall, stopped feeding, and entered the prepupa stage

Source: This study

1.2 Research Objective

One study determined that a transition to “a circular economy would reduce each country's greenhouse gas emissions by up to 70%” (Wijkman and Skånberg 2017). How to optimally use BSF's capacity to contribute to a more circular food production economy will be an important area for future research.

The BSF diet and feeding method are important to the economics of BSF production due to the trade-off between the cost of the feed substrate (resource) and the nutritional quality and its impact on the environment with larval development and body composition, environmental footprint, and safety of product insects (Bosch et al. 2020).

Information on feeding BSF has now been studied a lot, with traditional methods of troughs and plastic trays and then improved semi-automatic and fully automatic farming (Fig.1.3). Furthermore, “larvae can be used to manage a wide variety of wastes” (Van Huis and Tomberlin 2017). To quantify the efficiency of food conversion for black soldier fly larvae, various methods have been applied (Bosch et al. 2019). The motive of this study is to raise BSF for better economic growth, in addition to BSF food, the operator's feeding skill is also an important factor. If a feeding method with the same nutritional value and the same amount of feed is applied, but the feeding time is easy to control, the control of feed cost can be significantly reduced, therefore, this study would like to mention the feasibility of feeding methods in the rearing of BSF. And find out which method is best. This study aimed to compare methods of raising BSF. Find out which method is most effective, and gives the best yield and quality of BSF. This will help research the biology and use of BSF in value-added waste management systems. In addition, it helps farmers make the best choice when it feeds black soldier flies and creates a sustainable circular economy.

This study collects and analyzes data samples from BSL at the greenhouse in the College of Science and Technology.

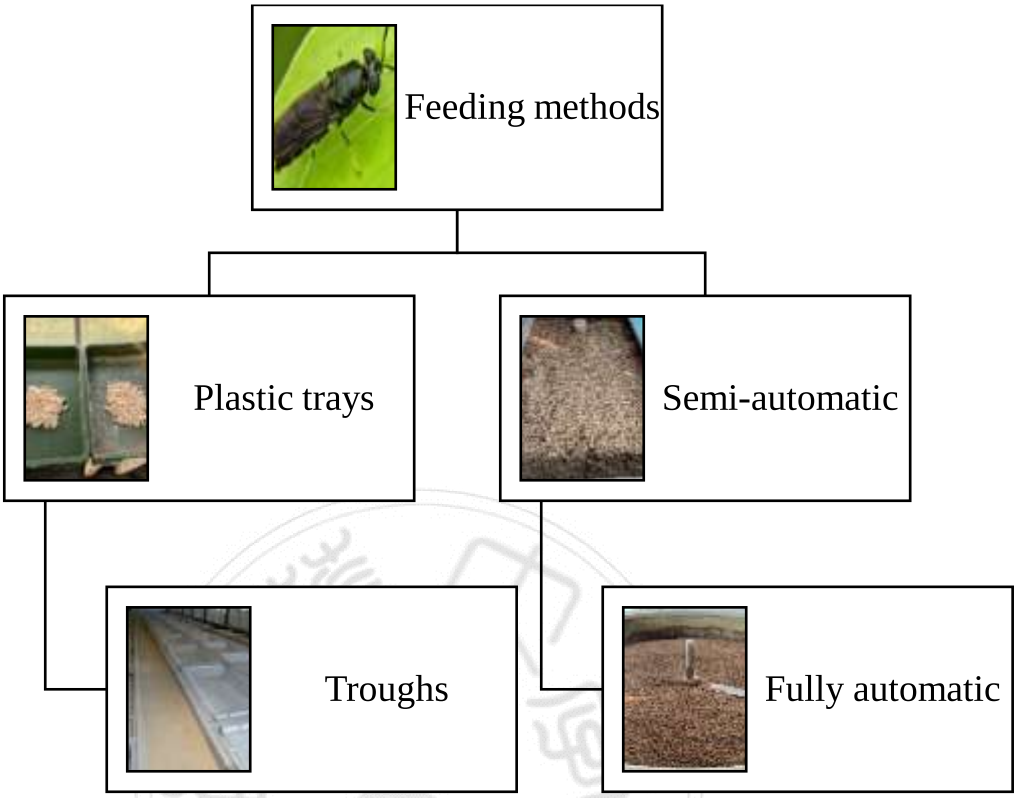

Figure 1.3: BSL feeding methods

Source: This Study

1.3 Procedure and Research Structure

Conducting the research process includes the following steps. First of all, the study has chosen the topic of Comparison between traditional and modern feeding for BSL. After the idea of carrying out this study, the research modified various studies to have the most complete view of this issue. The research background, objectives, and motivation be determined, leading to the development of the research. After that, a literature review was shown about the relationship between the 2 research methods above.

The research process is depicted in Figure 1.4 as shown below:

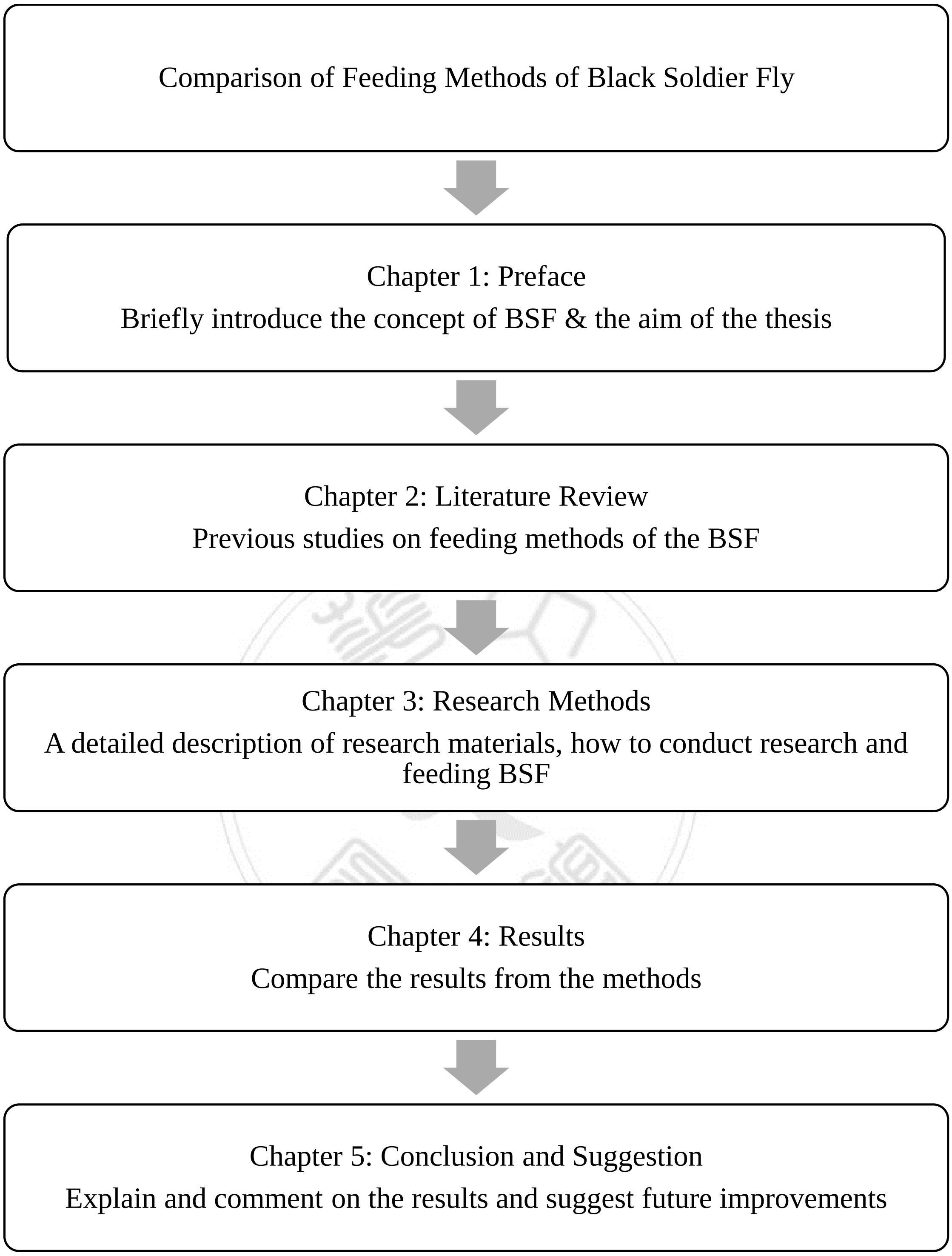

Figure 1.4: Flow of Chart of the Research Process

Source: This study

The content of this study is divided into 5 chapters: Preface, Literature Review, Research Methods, Results, Conclusion, and Suggestion.

Chapter one introduces and explains what was the background of the research and what was the motivation to investigate this research; research purposes and purposes; research questions, contributions, topics, and scope; then relies on the research and setting process to advance the goals. Besides, it also shows the general process and structure of the research.

Chapter two presents an overview of the literature related to BSL, traditional feeding methods, and modern feeding methods. From the review of previous studies, including the assessment of the important characteristics of each factor, explain the definition of the research variables. It then leads to the basis for the content of chapter three.

Chapter three presents the research methodology and research design. In this chapter, the research model has been established. Accordingly, the construction of scales to investigate the relationship between method and research design has been outlined. Besides, the sampling plan, data collection, and data analysis procedures are also discussed in this chapter to ensure the comprehensiveness of the research model and accomplish the aims of the study.

Chapter four presents data analysis and implied results. Displays descriptive statistics for the tests.

Chapter five presents the conclusions and summarizes the main results of the study after discussion, its findings, implications, contributions, and limitations. Based on the results, suggestions for future studies are also presented.

CHAPTER TWO

LITERATURE REVIEW

2.1 Black Soldier Fly

2.1.1 Definition

The black soldier fly (BSF) also known as soldier fly with bright flat horns, scientifically "Hermetia illucens (L.), is a species of true fly (Diptera) in the family Stratiomyidae. Originally native to the Americas, it is now distributed throughout warm temperate and tropical regions and can live in a wide variety of decomposing plants and animals" (James 1935, McCallan 1974). "This insect is of interest because of the dense larval populations that reduce the housefly, Musca domestica L., yield by 94–100% and fecal dry matter by 42–56% (Sheppard 1983), and nitrogen content was 62% (Sheppard et al. 1993) when compared with untreated feces of the same age. Besides, this insect has become one of the world's most important insects for bioconversion, farmed by many companies on an industrial scale in tons per week or month" (De Smet et al. 2018).

In addition, the first publication of BSFL as food probably dates back to 1973 (Hale 1973). An earlier publication addressed the natural control of the house fly, Musca domestica L. (Diptera: Muscidae) by BSFL in feces (Furman et al. 1959). Another application is the use of BSF as a tool for waste management, especially manure (Sheppard et al. 1994).

BSF is characterized by "a short life cycle of 40 to 45 days" (Tomberlin et al. 2002). After about 4 days, the larva emerges from the egg and goes through five stages as a larva for 13 to 18 days, followed by the pre-adult and pupal stage from which the adult fly emerges. Adults no longer feed (their mouths degenerate), live for about 5 to 8 days, and only exist to mate. The female then lays between 500 and 900 eggs. The pre-pupal stage before the larvae become pupae can still move and crawl to dry places. BSFL can process a wide variety of organic substances and convert them into a body mass composed mainly of proteins, fats, and chitin (Čičková et al. 2015). "High-quality proteins can be used as animal feed, while other compounds can be used as raw materials in the chemical industry" (De Smet et al. 2018). The fat fraction can be extracted and converted into biofuel. Chitin can be processed into chitosan for use in a wide range of applications from wastewater treatment to bioactive coatings.

Food and Drug Administration (FDA) approval for the use of dry BSFL in broiler/layer feed is also pending for 2018. Given the potential of this insect and with the expansion of new markets, several BSF breeding companies around the world are expanding their scale and optimizing production. These developments led to the identification of BSF as an insect of industrial use and that it is also considered a farm animal (De Smet et al. 2018).

Morphological features of BSF: adult body about 12 mm long, with broad, flat, and long antennae, body black with a purplish tint, with faint white spots on the anterior ventral sides, tibia of the feet colored white, and the rest of the body is black. Larvae are creamy white, hairy, fat, first half, about 20 mm long when mature. A pupa is a pupa with a dark brown surrounding, hard surface, and smooth skin, before pupation, there is a stage of preparation for pupation, body-color is like a pupa, does not eat food, and can move. Eggs are oval, translucent at first, then gradually turn pale yellow. Before hatching, two red eyes can be seen (Liu Jie 2016).

2.1.2 Development time and egg production

The development time of BSF depends on abiotic factors (e.g. temperature, relative humidity, phophatase) and biotic factors (e.g. diet, density, and strain) (Table 2.1).

Table 2.1: The time until pre-pupae and pre-pupae weight for BSF

Temperature (°C)	**Time (d) until pre-pupa**	**Pre-pupae weight (mg)**	**Reference**
27 and 30	17.7-20.1	128.0-160.0	Tomberlin et al. 2009
25 and 30	24.7-32.8	153.0-156.0	Shumo et al. 2020
27.6 and 32.2	10.3-15.8	127.0-178.0	Harnden and Tomberlin 2016
27.0	22.5-24.1	104.0-111.0	Tomberlin et al. 2002

Source: Van Huis et al. 2020

BSF spawns only once or twice. “The time of first spawning in black soldier flies can be as early as 3-5 days after spawning” (Tomberlin et al. 2002), “but can also occur 10-17 days after spawning” (Oonincx et al. et al. 2016; Zhang et al. 2010). The lifetime egg production of BSF is presented in Table 2.2. Although for some time it was believed that the mouth of the BSFA degenerated and therefore did not feed (Tomberlin and Cammack 2017). “Egg production per female can be tripled when BSFA are given milk instead of water” (Bertinetti et al. 2019).

Table 2.2: Fertility of female BSF

Number of eggs	Reference
206-639	Tomberlin et al. 2002
603-689	Tomberlin 2001
205-820	Stephens 1975
412-1.060	Bertinetti et al. 2019
500-1000	Furman et al. 1959
185-1.235	Rachmawati et al. 2010
546-1.505	Booth and Sheppard 1984

Source: Van Huis et al. 2020

2.2 Feeding

BSF prefers to pupate in dry environments. During that stage, they are at their maximum size, with large reserves of fat to sustain them through metamorphosis. For the BSF, this leads to self-exploiting behavior; they leave the substrate to pupate and turn into adults. "Containers can be created to automatically collect preparatives" (Van Huis et al. 2020).

In the tropics, BSF are commonly kept in cages 3-16 m^3 wide that are exposed to sunlight. However, in temperate regions, where low temperatures and short days in winter are problematic, artificial light sources are required. In addition, the BSF may require some investment in sophisticated navigation equipment (Van Huis et al. 2020). In the tropics, BSF are commonly kept in cages 3-16 m^3 wide that are exposed to sunlight. However, in temperate regions, low temperatures and short days in winter are problematic, requiring artificial light sources (Heussler et al. 2018; Schneider 2020). In addition, the BSF may require some investment in sophisticated navigation equipment (Kenis et al. 2018).

Environmental impact on BSF. There are only a handful of published studies on the environmental impact of BSF production. Environmental impact was recalculated for 1 kg of dry, defatted insect meal by Smetana et al. 2016 using data for the BSF shows: "Data on global warming potential (1.2-15.1 kg.CO_2.eq), energy (1.5-99.6 MJ) and land use 0.03-5.32 (m^2). The selected substrate has a large influence on the environmental impact of livestock systems, as well as the potential alternative uses of such substrates" (Oonincx 2017). For example, if these substrates are used alternatively to produce energy through anaerobic digestion, energy usage could be relatively high. For example, digestion of pig manure mixed with corn cobs by black soldier fly larvae reduced CH_4, N_2O, and NH_3 emissions compared with conventional composting usually close to 73%, almost 100% when optimal humidity is used (Chen et al. 2019).

Organic wastes are the main food source for black soldier flies. Cultivation waste: Damaged vegetables, tubers, and fruits (Do not choose pesticides that have been used because it is easy to cause larvae to die when eaten). Livestock wastes: Including animal manures such as cow dung, buffalo manure, pig manure, goat manure, chicken, duck, etc. (If farmers have the conditions to treat these fertilizers with microorganisms first, they will provide better nutrients to the larvae). Industrial wastes: Beer residues, soybean residues, rice residues,... become waste). Waste in household activities: Including leftovers, and rancid food.

❖ **Precautions when feeding**

Although BSF is highly resistant to stress, inappropriate environmental conditions severely affect their growth and survival. Therefore, the following should be noted (Liu Jie 2016):

- Temperature and humidity: BSFL are very sensitive to temperature and humidity, if the temperature is too low, the amount of food will decrease and growth will be slow, if the temperature is too hot, the larvae will stop eating and run away. Too much humidity is the biggest harm, besides causing disease, sticky and wet food will make most larvae die due to poor ventilation, while too dry food will affect the feeding efficiency of larvae.

- Breathability: although BSF will not die if submerged in water for a few days, good breathability is still important for black soldier fly farming. In case of poor ventilation and high ambient temperature, black soldier flies with mass escape will occur.

- Nutritional requirements: BSFL is rich in antibacterial substances, but under conditions of high temperature, high humidity, and too simple raw food, it is easy to become mushy. Room for raising adults and larvae must have protective measures to prevent birds and other natural enemies from stealing food.

2.3 Traditional Methods

BSFL from hatching to larval formation are small in size and do not eat much. The process of feeding black soldier fly larvae is relatively simple, using trough or plastic trays as farming tools, peanut bran and wheat bran as the main food; humidity should not be lower than 60%, and the humidity in the dish should not be higher than 80%; cover fly nets, change food every 24 hours, the development time of newly hatched larvae into third-generation larvae from 6 to 7 days. The 3rd instar larvae are the same size, milky white body, healthy, vivacious, then put into biological treatment process for kitchen waste, livestock manure, and spoiled vegetables. To improve the efficiency of distributed feeding and the survival rate of BSF, the optimal solution is to nurture eggs until the 3rd instar larvae before entering the culture process (Liu Jie 2016).

Small and medium-scale BSL farming requires no special equipment, and the general requirements are as follows (Liu Jie 2016):

- Medium and large net rooms: used to raise BSFA and complete mating, spawning, and other behaviors.
- Air-conditioned rooms 1-2 (adjustable temperature): used to incubate black soldier fly eggs and nurse young larvae.
- 1-2 sets of artificial climate boxes: used to precisely control the environmental conditions for BSF to hatch.
- Some plastic boxes and insect trays: are used to feed newly hatched and young BSFL.
- Peanut bran, wheat bran, fish meal, or soybean meal: as food to feed BSF.
- Small amounts of preservatives such as sodium dehydrogenate and sodium salicylate.
- Some wooden or stainless steel racks: are used to place insect trays.
- 1 refrigerator: used to store livestock materials or store pre-pupa.

In summary, in this study, two traditional feeding methods with plastic trays and troughs were used.

2.4 Innovation Methods

Currently, there are two innovative methods of feeding BSF: Fully automatic and semi-automatic. The two methods have a similar mechanism of action.

A large number of BSFLs are placed in the room of the greenhouse, which will consume and decompose the leftover food. Adult larvae prefer to pupate in dry places, while black soldier flies can pupate in two areas. One of the pupa areas is a net house in which imaginary animals appear to be able to mate. The imaginary female then looks for crevices in the wood to lay eggs, and the spawning area is directly above the food waste decomposition room, so "the larvae can fall back into the food waste decomposition room when they bloom." (Yang M.L 2022).

Through in-depth interviews and analyses, Professor Wu Meng Kun of Chiayi County Yimi Community College studied the use of BSL and reported excellent results. In particular, they investigated a black soldier fly rearing system and highlighted the key points involved in the design of a black soldier fly biosystem - that is, a fully automated black soldier fly feeding system implemented in Kouhu Township, Yunlin County. And semi-automatic farming from Yimi Sheda Ecological Teaching Farm, Zhongpu Township, Chiayi County.

2.5 Basic BSF feeding procedure (Sheppard et al. 2002)

Step 1: Incubate eggs

- Preparation: Fly eggs, hatching trays, leftovers.
- Put leftovers into the composting tray, and mix well. Then mix in the eggs. Cover the tray to prevent insects. Incubate eggs in a cool place, away from sunlight.

Step 2: Place in the feeder

- After incubation for 4 days, the hatched eggs are placed in a 2m2 trough.
- Growing for another 14 days will yield 4-6 kg larvae/tray.

Step 3: Cultivate into pupae

- Deep culture 14 days and bring out soil troughs, continue feeding.
- Note that you should not feed too much, it will produce a bad smell.
- If the soil trough has water, it should be treated with noodles to absorb the water.

Eggs and larvae are usually kept at 27^{0}C but can also tolerate a wide range of conditions (up to 36^{0}C). The humidity is 70% (Yu et al. 2009).

It is advisable to measure the temperature of the feed during culture, as it may deviate from the ambient temperature. If the surface temperature is increased by more than 5°C above ambient, it is recommended to reduce the surface thickness and/or increase ventilation to reduce the surface temperature. (Bosch et al. 2020).

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Study Area

Experimental data were obtained from the greenhouse at the College of Science and Technology of Nanhua University, located in Dalin Township, Chiayi District, Taiwan. Figure 3.1 depicts the location of the study area. The reason for choosing this area is because it belongs to Nan Hoa University, which is easy and convenient for conducting research. Besides, this area has suitable nurturing conditions such as temperature, light intensity, and spectral composition, photoperiod, relative humidity of the air. Thus becoming a good area for research and analysis.

Figure 3.1: The greenhouse in the College of Science and Technology

Source: This study

This greenhouse is used for 2 experiments: feeding with plastic trays and semi-automatically.

Besides, experimental data of feeding by trough method were collected from Yimi Sheda Ecological Teaching Farm in Zhongpu Township, Chiayi County, Taiwan. Figure 3.2 depicts the location of the study area. The reason for choosing this area is because it already has established breeding systems that are easy to conduct research. In addition, a fully automatic black soldier fly breeding system was deployed in Kouhu town, Van Lam district. Currently, because of the COVID-19 situation, it is not possible to come directly to the interview, but through cooperation from the manufacturer, we have obtained the necessary data for this study.

Figure 3.2: The greenhouse in the Yimi Sheda Ecological Teaching Farm

Source: This study

3.2 Research Materials

3.2.1 Food for BSF

Since BSF eats organic products, this study used bran, cornmeal, soybean meal, fish meal, and rice bran,... mixed, then added twice the amount of clean water (micro bio) and stir well to put all the ingredients in sealed sacks to ferment naturally for 2 days. The finished product will look like Figure 3.3 below. And call this mixture bean residue.

Figure 3.3: Organic products: bran, cornmeal, soybean meal, fish meal, rice bran,...

Figure 3.4: Food for BSF after fermentation (bean residue)

Source: This study

3.3 Data analysis method

3.1.1 Plastic trays

This experiment was carried out from October 14, 2021 to November 27, 2021, for 45 days at Nanhua University's greenhouse. The greenhouse temperature is from 27^0C to 36^0C and the humidity is 70% (Yu et al. 2009).

Feed the larvae with a plastic tray, the first thing is to put some incubated beans in the tray, then put a 3-legged food rack in the middle, above the rack put a net, then put 4g of eggs on top of the net. To reduce the contact temperature between the egg and the food (because the food after incubation is at a high temperature compared to the egg's tolerance). Then spread the rice husk around the plastic tray to prevent the larvae from coming out of the plastic tray to find food. (Figure 3.5)

Besides, since the egg stage will not be able to withstand the sun, we will cover the black mesh cloth around the shelf used to hold the plastic tray.

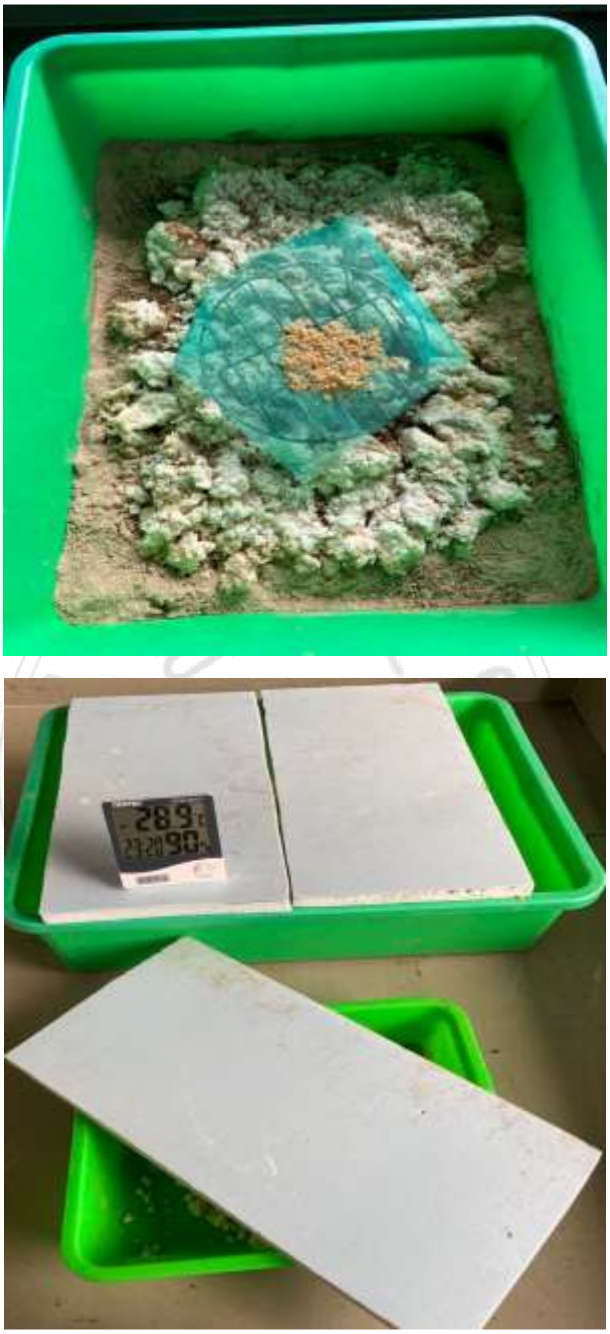

Figure 3.5: The first step to feeding BSF with a plastic tray

Source: This study

For the next 4 days, no more food will be added to the tray. After 4 days, the eggs have hatched into larvae, separate them into 2 separate trays (2g eggs each), because the area of 1 tray will not be enough for the larvae to develop. Each tray put 0.5kg of food per day.

The next 2 days (ie the 5th and 6th day after starting) separate 2 trays into 4 trays (each tray will contain 1g eggs), because the larvae grow very fast every day, otherwise they will be put in a new tray, it will limit their ability to change, will not obtain quality larvae. The amount of food at this time is still 0.5kg per tray/day.

For the next 4 days (from day 7 to day 10) each larval tray will feed 1kg per day. And from the 11th to the 20th day, the amount of food will gradually increase to 2kg per tray/day.

After day 20 the larvae will not eat anything else and they turn into the pre-pupal stage.

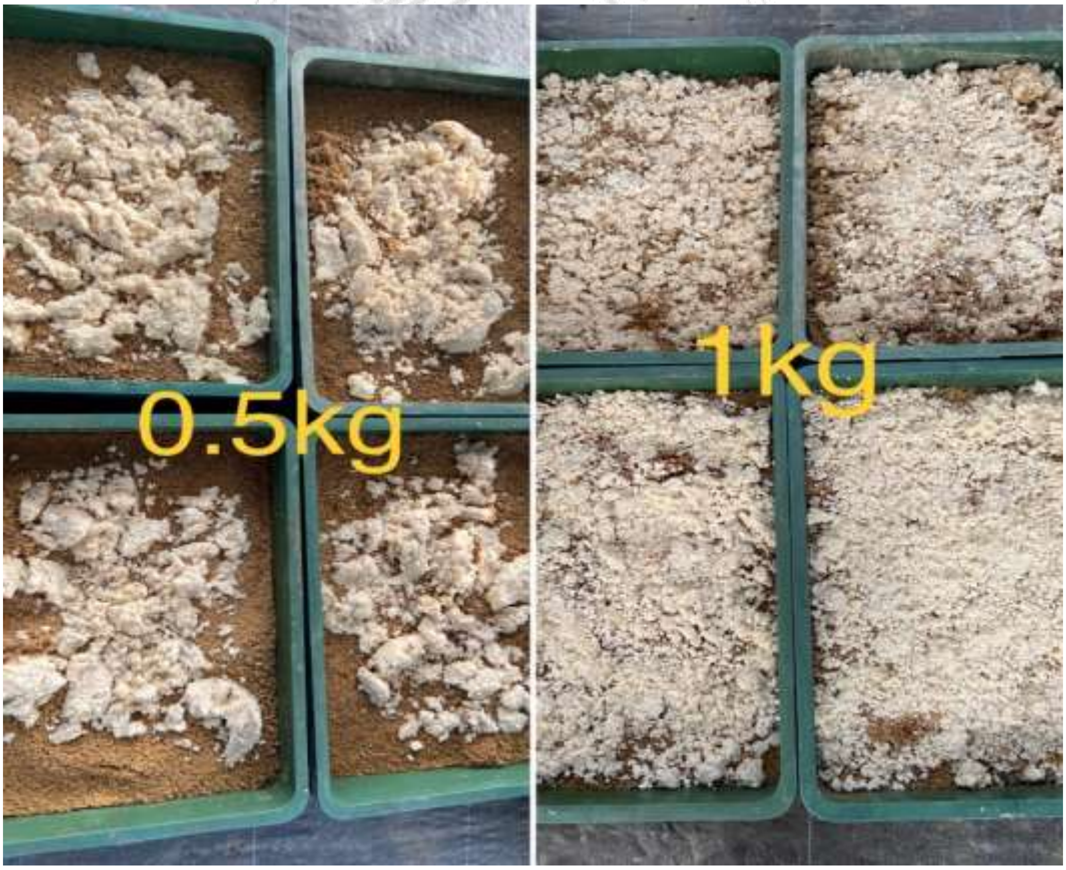

Figure 3.6: Feeding with plastic trays

Source: This study

Figure 3.7: The rack is used to hold a plastic tray for black soldier flies and is covered with black mesh cloth around it

Source: This study

3.1.2 Troughs

This experiment was conducted for 45 days in the greenhouse of Yimi Sheda Ecological Teaching Farm. The greenhouse temperature is between 27^0C and 36^0C and the humidity is 70% (Yu et al. 2009). Wet feeding systems suitable for home and community food waste recycling operations are maintained at 70% humidity by the addition of sawdust, wheat bran, and rice bran; this is the BSFL preferred humidity level. Microorganisms are also added to facilitate the breakdown of leftovers. The temperature of the feeding area can reach up to 45^0C due to the movement and friction of the larvae, affecting the larval activity as they are not used to higher temperatures. Therefore, temperature control devices are used to maintain the temperature at 27^0C.

In this experiment, each trough was used, with a length and width of 2mx2.5m, respectively, and a height of 30cm (Figure 3.8). The amount of food increased gradually each day and more than the traditional method. And after the 20th day, the larvae won't eat anything else and they go into the prepupal stage.

Figure 3.8: Trough feeding without BSF

Source: This study

Figure 3.9: Troughs Feeding with BSF

Source: This study

Figure 3.10: Difficult to control humidity trough farming

Source: This study

3.1.3 Semi-automatic

This experiment also was carried out from October 14, 2021, to November 27, 2021, for 45 days at Nanhua University's greenhouse. The greenhouse temperature is from 27^0C to 36^0C and the humidity is 70% (Yu et al. 2009). The dry feeding system is maintained at a humidity of 70% by adding sawdust, wheat bran, and rice bran; this is the humidity level preferred by BSFL. Microorganisms are also added to facilitate the decomposition of food waste. The temperature of the feeding area can reach 45^0C because of larvae movement and friction, which affect larvae activity because they are not accustomed to higher temperatures. Therefore, temperature control devices are used to maintain the temperature at 27^0C. On average, each larva can consume 2–3 kg of food waste and be used as insect protein feed.

It is almost the same as the plastic tray method, but because the semi-automatic method has a larger feeding area and has an additional drain at the bottom, it is convenient for pre-pupa harvesting.

In this experiment, two semi-automatic chambers were used, each containing 10g of eggs, and there was variation in the feeding process. The amount of food increases gradually every day and is much more than the traditional method. And after day 20 the larvae will not eat anything else and they turn into the pre-pupal stage.

Figure 3.11: Semi-automatic feeding

Source: This study

3.1.4 Fully automatic

This experiment was also carried out for 45 days at the BSF production facility in Khouhu Township, Yunlin County. The temperature is between 270C and 360C and the humidity is 70% (Yu et al. 2009). The wet feeding system (from food residues) was maintained at 70% humidity by the addition of sawdust, wheat bran, and rice bran; this is the BSFL preferred humidity level.

Similar to the semi-automatic method, but the feeding area is much larger and the feeding time can be set, there is a tool to flatten the amount of food each time, and use less time to look after, and has an additional drainage channel at the bottom, so it is convenient for pre-harvest pupae.

The amount of food increased gradually every day and more than with the traditional and semi-automatic method. And after the 20th day, the larvae won't eat anything else and they go into the prepupal stage.

Figure 3.12: Fully automatic system

Source: This Study

Figure 3.13: Where to collect pre-pupae

Source: This study

CHAPTER FOUR
RESULTS

4.1 Traditional Method

4.1.1 Plastic trays

Table 4.1 below shows the amount of food provided per day, totaling 148.2kg for 4 boxes. In which, each box used up a total of 24-25.1 kg. The amount of BSFL obtained in each box is from 0.5-0.7kg. Multiply by 4 boxes to get 2-2.8kg. Assuming multiplying by 10 boxes, only get 5-7kg. Meanwhile, the amount of time spent taking care of BSF is a lot and it takes a lot of effort to feed every day.

Table 4.1: Table to track the amount of food used to feed each day with plastic trays

Day	Tray 1 (kg)	Tray 2 (kg)	Tray 3 (kg)	Tray 4 (kg)
1	0.1			
2	0			
3	0			
4	0			
5	0.5	0.5		
6	0.5	0.5		
7	1	1	1	1
8	1	1	1	1
9	1	1	1	1
10	1	1	1	1
11	2	2	2	2
12	2	2	2	2
13	2	2	2	2
14	2	2	2	2
15	2	2	2	2
16	2	2	2	2
17	2	2	2	2
18	2	2	2	2
19	2	2	2	2
20	2	2	2	2
Total	25.1	25	24	24

Source: This study

4.1.2 Troughs

According to the interview data obtained from the actual farming place by the trough method. 300g eggs used 2500kg of leftovers to feed BSF, 650 kg of BSFL could be obtained in the same harvest time from the plastic tray method. Although more larvae are obtained than the method of rearing with plastic trays, this method also consumes a lot of time and effort to take care of. Because the wet feeding method (directly with leftovers) is used without treatment, it can easily lead to over-wetting. If not regularly checked and looked after, the larvae will suffocate and cannot be harvested.

4.2 Innovation Mehtod

4.2.1 Semi-automatic

Table 4.2 below shows the amount of food provided per day for 2 rooms totaling 553.3kg, each room start with 5g eggs. In which, 1 room used up 278.6 kg and 1 room 279.3 kg. The mass of BSFL obtained in each box was 6kg and 7kg, respectively, for a total of 13kg. Assuming that the egg is increased to 300g, the amount of BSFL obtained is only 390kg (still far below the amount of BSFL obtained from the fully automated method). In addition, assuming that increasing the number of eggs to 200g will only yield 260kg (less than the trough method).

Table 4.2: Semi-automatic daily feed monitoring table

Day	Room 1 (kg)	Room 2 (kg)
1	0.5	0.5
2	0.5	0.5
3	1.5	1.5
4	1.8	1.9
5	2.1	3
6	5.5	6
7	9	9
8	13.5	13
9	13.9	13.5
10	18	18
11	22	22
12	26	26
13	19.3	20.6
14	21	21
15	20	20
16	19	19.2
17	20	20
18	23	22
19	21	21
20	21	21
Total	278.6	279.7

Source: This study

4.2.2 Fully automatic

According to data obtained from interviews with the BSF production facility in Kouhu Township. 300g of eggs used up 3000kg of leftovers. And get 280kg BSFL in the summer because, at this time the temperature is too high (even if cooling is used), the larvae will also stop eating and escape (or the worm body is too small) leading to the larva comb. obtained less in winter (400-500kg). Although BSFL grows slowly in winter (falls into hibernation due to low temperatures) the high temperature can be adjusted up to close to what the BSFL can tolerate. And in winter can reduce feed for BSFL from 3000kg to 1500kg depending on the actual situation.

4.3 Compare methods

Table 4.3: Comparison of total feeding time of BSF feeding methods

Methods	Number of feedings per day	Time of each feeding (minute)
Plastic trays	2	30
Troughs	2	120
Semi-automatic	2	30
Fully automatic	1	15

Source: This study

The results in Table 4.3 show that the fully automatic method is to only feed a fixed amount of food daily in the morning (then set the time to automatically provide food for BSF). Save a lot of time, can do other stages such as harvesting eggs, cleaning breeding places, ...

Although the trough feeding method yields the most BSFL but is time-consuming to feed, the plastic tray feeding method is time-consuming and cumbersome to implement. The semi-automatic method, although not time-consuming, is still not as effective as the fully automatic method.

Calculating 200g of eggs for each method, the results are shown in Table 4.3.

Table 4.4: Results of a comparison of BSF feeding methods

Methods	Amount of food provided (kg)	Amount of larvae obtained (kg)
Plastic trays	7410	100-140
Troughs	1666.7	433.3
Semi-automatic	11066	260
Fully automatic	2000	266.7-333.3

Source: This study

The results of the 4 methods showed that the plastic tray and semi-automatic method used the most feed and also harvested the least BSFL. Although raising by trough method harvests many BSFLs, it leads to a large number of larvae suffocating because it is difficult to control humidity. Two new innovative methods, semi-automatic and fully automatic, both save time in care, although the amount of leftover food decomposes a lot, the BSFL yield is also not small.

Comparing the time to feed each day, and the operations performed to take care of and look after the BSF, the fully automatic method is the most optimal until now. In addition to being able to set a fixed feeding time, it is also possible to set the amount of food to be given each time, and there is a tool to flatten the amount of food, avoiding the situation that BSFL gathers in one place with food. feeding, resulting in uneven growth (Figure 4.1). This method is suitable for large production facilities, both achieving high profits and saving a lot of time to perform other stages.

Figure 4.1: The result of feeding is not flat

Source: This study

CHAPTER FIVE
CONCLUSIONS AND SUGGESTIONS

5.1 Research Conclusion

The results showed that the plastic tray and semi-automatic method used the most feed and also harvested the least BSFL. Although raising by trough method harvests many BSFLs, it leads to a large number of larvae suffocating because it is difficult to control humidity. Two new innovative methods, semi-automatic and fully automatic, both save time in care, although the amount of leftover food decomposes a lot, the BSFL yield is also not small.

Comparing the time to feed each day, and the operations performed to take care of and look after the BSF, the fully automatic method is the most optimal until now. In addition to being able to set a fixed feeding time, it is also possible to set the amount of food to be given each time, and there is a tool to flatten the amount of food, avoiding the situation that BSFL gathers in one place with food. feeding, resulting in uneven growth. This method is suitable for large production facilities, both achieving high profits and saving a lot of time to perform other stages.

In addition, the semi-automatic method is also more suitable than the two traditional methods of rearing with plastic trays and troughs if the household wants to carry out BSF farming. This method will save more time and effort than the two traditional methods, besides the yield is also effective and of good quality.

5.2 Research Discussions and Implications

This study is to compare BSF farming methods in Taiwan. And the main goal of this study is to choose the best and most effective method. Specifically, from the viewpoint of a sustainable and circulating economy, the implementation of the black soldier management system and appropriate management mechanisms can reduce the burden of food waste treatment. BSF can be effectively treated and safe for organic waste that can pollute humans into high-value insect proteins. It can be used in aquatic foods because of its rich nutritional components and microbiological systems.

However, the results of the reality show that regardless of the method, depending on the difference in livestock culture, the environment and external impact factors greatly affect the maturity of BSF.

This study has contributed a small part in describing in detail BSF farming methods that there have not been any previous studies that specifically investigated these feeding methods. Previous studies have only looked at BSF foster care conditions and settings, and their benefits, in general terms. Through this study, it will help producers to have more references for starting to raise BSF, to choose the best method and suitable for rearing conditions.

The black soldier fly, which is a new environmental protection resource insect and a forage resource insect, has great advantages in the treatment of livestock manure and the production of animal protein feed. If many technologies to treat black soldier fly manure can be promoted, it will fundamentally solve the current problem of discharge and pollution of livestock manure, so that many places that are not suitable for breeding can be deployed such as cities, or around the river to solve the problem of separating the production and consumption areas of our country's livestock and poultry products, and at the same time further optimize the industrial structure of the livestock and poultry industry.

5.3 Research Limitation and Future Research Suggestions

This research has certain limitations that need to be solved by future studies. Due to limited facilities and experimental systems, only 2 out of 4 methods can be self-implemented: plastic trays and semi-automatic, and 2 methods of the trough and fully automatic culture - all through interviews to obtain comparative data. Therefore, the results cannot represent all BSF farming methods in Taiwan

Hopefully, in the future, there will be more in-depth and more specific research on BSF farming methods, because currently in the process of searching documents talking about BSF farming are only general documents on rearing conditions, and there is no detailed description of farming methods. And very few documents clearly talk about semi-automatic and fully automatic farming.

Future research should be further studied with a larger size and specific samples.

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