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Research on the Evaluation Mechanism of the Black Soldier Fly Biological System on Campus

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Abstract: Lower birth rates and spoiling have caused students to become picky eaters, leading to campus food waste. In this study, 29 evaluation indicators for a black soldier fly biological system were established through a literature review and expert interviews. The indicators were divided into three dimensions, namely spatial composition, system and equipment, and environmental education. The 11 indicators with the highest expert consensus were identified through the fuzzy Delphi method and used as the primary indicators for evaluating the role of the black soldier fly biological system in promotion. The top 11 indicators with the highest scores mostly comprised indicators of the system and equipment dimension followed by those of the spatial composition and environmental education dimensions. However, among the indicators of the three dimensions, those of the "spatial composition" dimension obtained the highest scores. The literature review indicated that the theories related to knowledge, behavior, and attitude toward the environment should be applied to consciously motivate students to reduce food waste through explicit actions. The integration of the aforementioned system with experiential agricultural education can reduce campus food waste. Participatory learning increases the willingness of students to improve appropriate environmental attitudes and healthy diets on the basis of promoting environmental sustainability.

Keywords: black soldier fly biological system; food waste reduction; sustainability; campus

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1. Introduction

Feeding pigs with food waste is highly risky. When pigs consume raw food waste with pathogens, they become infected. Gibbens said, in 2017, that African swine fever has a 100% fatality rate, and feeding pigs is a significant potential risk pathway, so now is a critical time to remind pig keepers of the ban on swill feeding. He also mentioned: "Circumstantial evidence also strongly suggests that the classical swine fever outbreak in 2000 began after pigs were fed pork or pork products. Illegal feeding of meat to pigs is thus a real, not a theoretical, risk" [1]. The pandemics of foot-and-mouth disease and African swine fever are caused by problems associated with food waste. Although the conventional food waste processing method implemented in Taiwan benefits a circular economy, it is no longer applicable. In April 2016, the Environmental Protection Administration hosted an interdepartmental meeting to address food waste. Measures for managing voluminous food waste and calculating edible food waste were formulated, and all hypermarkets, supermarkets, and catering companies were required to report the amount of food waste that they generated in each preceding year. However, these management measures were not enforced, and the government adopted a passive stance for the submission of the aforementioned reports. This hindered the effectiveness of the management system. Nevertheless, the role of a bio-based circular economy in addressing food waste is still relevant.

Parents are always concerned about whether their children are at risk of nutritional deficits due to picky eating habits. In the 2010 study by Ekstein et al., weight and height measurements were obtained by observation and recording, and weight–length data were also calculated for these children. The findings confirmed that children with picky eating habits are at increased risk of being underweight, especially those younger than 3 years of age [2]. With a decreasing birth rate, parents can provide sufficiently nutritious meals, and some families can even afford to consume vast amounts of food. This has caused children to become picky eaters, leading to food waste in campuses. According to the research of Chilman et al., ways to decrease the likelihood of picky eating habits are responsive parents, family meals, and involving the child in the preparation of food [3]. Most students have poor knowledge of food, cooking, and agricultural production. According to the concept of social constructivism, people establish a dynamic interactive relationship with the environment through their behaviors and knowledge. A point made in the 2015 paper by Wilkie et al.: "School cafeterias are a significant source of food waste and represent an ideal opportunity for diverting food waste from landfills". More than 75% of the canteen waste measured in their study could be collected and recycled through composting or anaerobic digestion. At the same time, food waste can also be reduced by educating students and staff to improve the behaviors that lead to food waste [4]. Boulet et al. put forward a view in the 2022 paper, "food-related practices and behaviours emerge from the interactions of macro and meso-level factors". The value of the perspective when designing interventions to reduce food waste is highlighted in their study. These interventions include education, skills and whole-school activities [5]. Santagata et al. said in the 2021 paper: "In a bioeconomy perspective, qualitatively and quantitatively assessing the availability of secondary raw materials and classifying the different conversion systems is crucial for the transition to happen". Therefore, there is a better chance to reduce environmental pressure and manage resources properly. It also avoids loss of economic value and creates jobs [6]. From the perspective of a circular economy, students must personally participate in the process of food production to experience the hardships experienced by farmers and understand the value of food. Thus, food waste can be effectively reduced. In the present study, the black soldier fly biological system was integrated with the idle roof environment of a school building to actively explore solutions to campus food waste. A mechanism was also established to evaluate the system. The goals of the present study were as follows:

A. Establishment of a black soldier fly biological system for reducing campus food waste and creating a circular economy.
B. Integration of the idle roof space of a school building with a black soldier fly biological system to construct an edible landscape.
C. Establishment of an edible landscape for promoting experiential food farmer education, with the aim of increasing the willingness of students to eat vegetables and, consequently, reducing food waste.

A report by The News Lens (Alvitr, The News Lens, https://www.thenewslens.com/article/78631 (accessed on 1 May 2021)) indicated that Taiwan's existing food waste management policies have resulted in approximately 30 million tons of food waste being recycled per day, of which 15 million and 4.5 million tons are fed to pigs and used as compost, respectively. The remaining 10 million tons are buried in landfills. However, the water content of food waste is as high as 76%, and food waste ferments easily, produces a sour odor, and is difficult to incinerate thoroughly. The transportation of food waste incurs high freight charges, and liquid leakages that cause secondary pollution can occur. Consequently, most food waste is processed together with general waste at incinerators, which shortens the lifespan of incineration equipment. Food waste consists primarily of reusable organic matter, and it can be divided into raw and cooked food waste according to its functions. Raw and cooked food waste account for, respectively, 84% and 9% of all food waste; the remaining 7% consists of other types of food waste [7]. Studies have reported that the reuse of raw food waste is considerably less efficient than the reuse of cooked food waste, with most raw food waste requiring incineration.

Cooked food waste is typically cooked at a high temperature before being fed to pigs. After it is recycled by cleaning teams, it is sold in barrels to ranches, where it is crushed, heated, and fed to pigs. Raw food waste consists of discarded leaves, hard shells, and fruit pits; therefore, it cannot be fed to pigs because they cannot digest it. After raw food waste is recycled, it is outsourced to private companies for further processing. The procedures for processing raw food waste are more complex than those for processing cooked food waste. Both raw and cooked food waste can be crushed and acidified through anaerobic bacteria decomposition, which generates biogases that can be converted into green energy. The challenges of processing compost must be overcome by applying multiple measures at the time of generation; these measures include the enhancement and monitoring of fertilizer quality and the cross-ministerial development of methods for optimizing the use of the food waste (Figures 1 and 2).

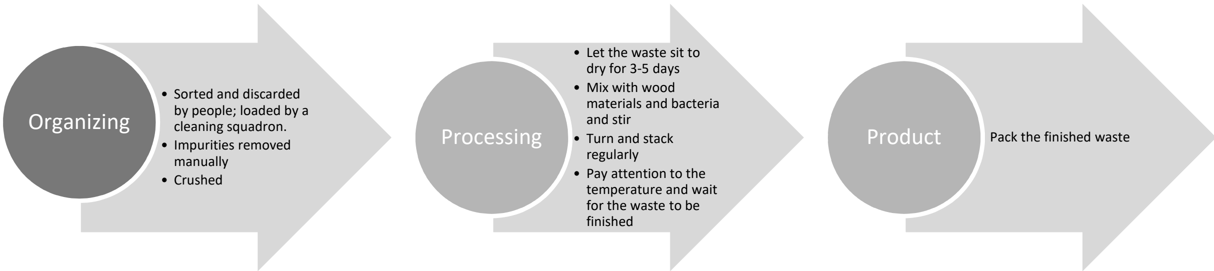

Figure 1. Processing of raw food waste (compiled for the present study. Source: Wuo-wuo. https://wuo-wuo.com/topics/enviromental/food-waste/955-2019-04-13-08-44-05 (accessed on 6 May 2021)).

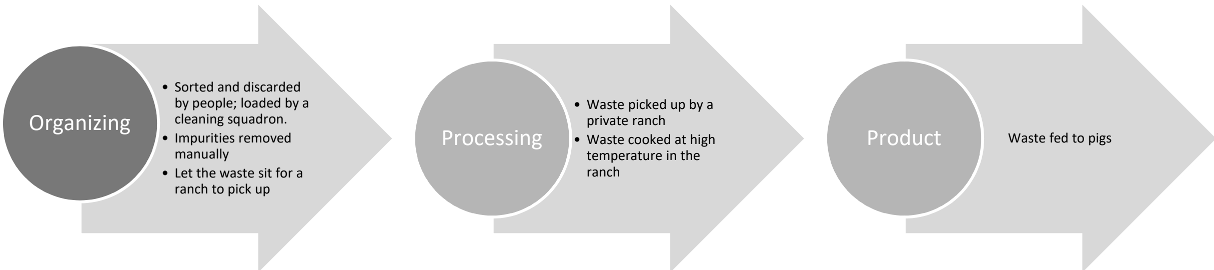

Figure 2. Processing of cooked food waste (compiled for present study. Source: Wuo-wuo. https://wuo-wuo.com/topics/enviromental/food-waste/955-2019-04-13-08-44-05 (accessed on 6 May 2021)).

Saprophagous animals (e.g., fly larvae and microorganisms) have been used to convert organic refuse for more than a century [8,9]. The black soldier fly (*Hermeteia illucens* L.), which belong to the *Stratiomyidae* family of the Diptera order (Figure 3), is a commonly used species. The larvae of *H. illucens* consume a wide variety of foods, which include organic detritus, restaurant food waste, fruit drops, and animal excrement [10]. Moreover, the larvae of black soldier flies do not transmit diseases or carry bacteria. Most adult black soldier flies do not approach humans or other animals, but typically rest in vegetation [11]. The animal excrement processed by black soldier fly larvae can be effectively used as plant fertilizer. The larvae also inhibit the oviposition of houseflies; thus reducing the number of housefly larvae and the spread of diseases. Therefore, these larvae can be bred in large numbers [12]. Furthermore, the pupae of black soldier flies (Figure 3) can be used as additives for animal feed because they are high in protein and fat [13,14]. Adult black soldier flies can be used to produce biodiesel because they contain a high amount of fat [15,16].

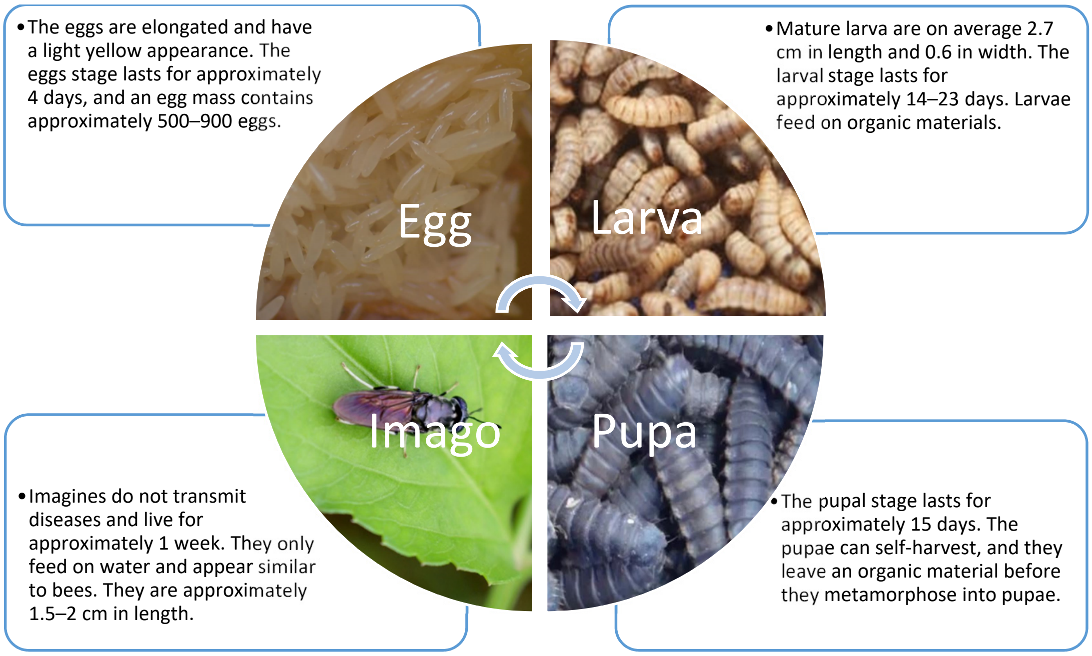

Figure 3. Life cycle of black soldier flies. (Source: Hsinchu Office of Animal Husbandry Research Institute, interview materials and pictures were organized by the author of this article).

2. Literature Review

2.1. Literature Review on Methods and Spaces for Promoting Food Farmer Education

Fang and Ku (2020) applied qualitative research methods (e.g., content analysis, in-depth interviews, document analysis, and focus group interviews) to examine and evaluate various content and models of the food farmer education activities promoted by the local governments of Taiwan [17]. Their results indicated that food farmer education is primarily promoted by three systems, namely the public sector or school education system, nonprofit organization system, and program promotion system. Local governments promote food farmer education through four types of combined models, namely: collaborations between a local government and schools; collaborations between a local government and farmers' associations; collaborations between a local government and schools and farmers' associations; and collaborations between a local government and a third-party organization. Fang and Ku contended that local governments should adopt the collaborative model involving both schools and farmers' associations to reinforce food farmer education in Taiwan; this model enables schools and farmers' associations to combine their advantages and complement each other's shortcomings. Lin and Chen (2019) conducted an 8-week action study and examined a class of 26 upper-grade students from an elementary school [18]. They discovered that students were taught to reduce food waste through food farmer education, which comprised diet education, nutrition education, and farming experience components. Avoidance of vegetables, preference for fried food, and consumption of unhealthy snacks were observed in the students. Accordingly, Lin and Chen recommended the (1) integration of food farmer education in school curricula to encourage students to eat vegetables, (2) incorporation of discussions about healthy and unhealthy snacks in parent–teacher meeting and parenting lectures; (3) promotion of campus vegetable sketching activities to improve students' relationships with vegetables; (4) formation of strategic alliances between the schools within a region to promote food farmer education.

Tsao et al. (2017) conducted a paired sample *t*-test to investigate the changes in the agricultural literacy and diet habits of elementary students after they received food farmer education [19]. Their results indicated significant changes in the students' agricultural knowledge, agricultural attitudes, and diet knowledge after they received the aforementioned education, and this occurred even though their diet attitudes and behaviors did not change substantially. However, through learning-by-doing, the diet knowledge, attitudes, and behaviors of students can gradually influence their diet habits. With the emergence of food safety concerns, the public and school authorities are paying more attention to food farmer education. Lu and Yan (2016) proposed the rebuilding and reactivation of an idle school environment for hosting educational activities relating to industrial cultures and ecology [20]. They conducted a strength–weakness–opportunity–threat analysis to promote the reactivation of the idle school environment, which was repurposed as an educational hall of ecological agriculture through a collaboration between the Dongshi branch of New Taipei City Pingxi Elementary School and the Pingxi Township Farmers' Association. They organized interviews with industry members, and suggestions on the further management of the idle campus site were collected. Through document analysis, expert interviews, and focus group discussions, Yeh and Yu (2019) explored the worldwide development of food farmer education from the perspective of sustainable development [21]. Using education for sustainable development as a framework, Yeh and Yu established the definition and key concepts of food farmer education; they also maintained that food farmer education in metropolitan and nonmetropolitan areas tends to focus on social and cultural components, respectively.

2.2. Theories of Cognition, Attitudes, and Behavior toward the Environment

Ke (2006) argued that the Taiwanese government has not adequately considered environment concerns in its policy planning [22]. Its policies have mostly been human centered and lacking in terms of considerations for ecosystems, natural cycle conservation, and the well-being of future generations. With the changes to policy paradigms and thinking brought about by the arrival of the knowledge economy, an increasingly competitive global economy, and an increasingly mature democracy, Taiwan's environment planners must construct a theoretical model of social cognition on the basis of the interaction between the environment, individuals, and their behaviors. In addition, a model on individuals' learning styles must be established. Ke maintained that individuals identify problems in their actions and learning through their interactions with the environment, and they develop solutions for improving their actions and learning accordingly. Through the application of the social cognitive theory, Bandura (1986) proposed the concept of reciprocal determinism to explain the relationship among individual cognition, individual behavior, and the environment [23]. Specifically, the behaviors and cognition of people form a dynamic reciprocal and deterministic relationship with the environment. The strength and mode of the reciprocal relationship between any two of the three aforementioned factors change according to an individual's cognition and behavior and the environment. The learning style theory proposed by Kolb (1984) stresses the key role of experience in the process of learning [24]. The four stages of experiential learning are divided into the dimensions of thinking–feeling and doing–watching, from which the four learning styles are established.

On the basis of the theory of planned behavior proposed by Ajzen (1985) [25], Tzeng et al. [26] (2013) argued that behavior is determined by behavioral intentions and influenced by behavioral attitudes, subjective norm, and cognitive behavior control. In several studies, Kaiser also contended from the perspective of education that knowledge level influences behavioral intentions, subjective norms, and cognitive behavior control [24,27,28]. Environmental behaviors can only occur when these three factors link and interact with each other. Accordingly, students who only know the essential role of knowledge in environmental protection but lack a sense of responsibility do not exhibit environmental behaviors. Similarly, those who only have a sense of responsibility but lack an understanding of environmental solutions cannot engage in environmentally friendly behaviors. According to Tzeng et al. (2013), the theory of environmental behavior is linear. That is, learners acquire knowledge about the environment (environmental knowledge), become concerned with the environment (behavioral attitudes), and consequently engage in environmental behaviors. It was also stated in the same article that empirical studies by Burgess, Harrison, and Filius (1998) [29] and Kollmuss and Agyeman (2002) [30] have indicated that environmental knowledge and attitudes are, by themselves, insufficient for triggering environmental behaviors [26].

In summary, the black soldier fly biological system should be incorporated into experiential agricultural education, with the aim of reducing food waste and encouraging students to eat vegetables through experiential learning. This effectively improves the existing spatial model of food farmer education and directly integrates edible landscapes in the learning-by-doing curriculum. Explicit actions drive students to consciously reduce food waste. Thus, appropriate environmental attitudes and healthy diets can be promoted to enhance environmental sustainability. In the present study, 10 indices (for which an expert consensus was established) were adopted to evaluate the investigated campus environment prior to the integration of a black soldier fly biological system. This enabled the effective utilization of the idle roof spaces of school buildings, development of solutions for campus food waste, and promotion of food farmer education.

3. Research Methods

The black soldier fly biological system examined in the present study consisted of two systems, namely the black soldier fly system (which allows black soldier flies to mature) and the aquaponics system. The biological system was a food waste management mechanism that incorporated the concepts of circular economy and sustainability. In the present study, a document analysis was conducted, and the preliminary findings were used as a basis for administering surveys to experts. The experts' opinions were collected through the Fuzzy Delphi questionnaire designed. Based on the 3 created great facets systems, the indicators of the evaluation mechanism of Black Soldier Fly's biological system were collected from interviews with experts, and the first time indicator choices could be obtained. Simultaneously, each expert gave the interval numerical ratings to the assessment items individually to eliminate the Black Soldier Fly's biological system. I divided semantic scales into five kinds, for the semantic understanding. To deal with cognitive differences, the fuzzy interval was given 0~10 degrees in the rating scale.

After the survey results were provided, trigonometric functions were established. To establish conservative trigonometric functions C^{i} (C^{i}_{1}, C^{i}_{2}, C^{i}_{3}) and optimistic trigonometric functions O^{i} (O^{i}_{1}, O^{i}_{2}, O^{i}_{3}) were used. (C^{i}_{1}, C^{i}_{2}, C^{i}_{3}) expressed the minimum value of conservative cognition, conservative cognition geometric mean, and the maximum value of conservative cognition of Item i of the experts. (O^{i}_{1}, O^{i}_{2}, O^{i}_{3}) expressed the minimum value of optimistic cognition, optimistic cognition geometric mean, and the maximum value of optimistic cognition of Item i of the experts. The distance between C^{i}_{2} and O^{i}_{2} was set as the "expert agglomerate consensus interval". The intersection interval generated between the X-axis by "conservative trigonometric functions" and "optimistic trigonometric functions" was "gray zone", which is also the distance between C^{i}_{3} and O^{i}_{2}. G i expressed the importance of the agglomerate consensus of Item i to the experts [31]. Because the experts had different backgrounds and, possibly, different perspectives, the Delphi method was used to analyze the results until a consensus was formed. The present study used the double triangular fuzzy numbers of the fuzzy Delphi method [32,33]. The procedures for implementing the Delphi method are as follows:

A. Each item was assigned a score from 1 to 10, with a higher score indicating the greater importance of an item.
B. A statistical analysis was performed for each item to calculate its conservative and optimistic values.
C. The triangular fuzzy numbers of the conservative and optimistic values of each item were established.
D. Expert opinions were tested to reach a consensus.

4. Life Cycle and Characteristics of a Black Soldier Fly

The length of each stage of the black soldier fly's life cycle varies greatly. The life cycle of a black soldier fly is approximately 40–43 days. In the present study, the temperature of the laboratory was set to 27 °C, and the fly's eggs usually hatch within 4–6 days under this condition. In total, 22–24 days are required for black soldier flies to metamorphose from an egg to a larva. The larval stage has six instars, and larvae in the sixth instar stop feeding. Prepupae search for suitable locations in natural environments and metamorphose into pupae; they can self-harvest, and imago black soldier flies can survive for approximately 7 days by feeding on only water. Female imagines prefer to spawn at locations with decaying food, and an imago fly can lay approximately 206–639 eggs at a time; imago flies die shortly after they spawn [34,35]. Black soldier flies utilize waste extensively during their larval and prepupal stage, and they adapt well to complex environments containing items such as food waste and feces [36]. Black soldier fly larvae grow differently in different types of wastes. They consume food waste faster than other types of foods and grow to be longer and heavier after consuming food waste [37,38]. Black soldier fly larvae like to hide in humus, but black soldier fly imagines like sunlight. Black soldier flies are saprophagous, and they can tolerate grease or salt. Therefore, they can rapidly consume food and animal waste. Taiwan currently has more than 40 species of black soldier flies. They have large appetites, reproduce rapidly, and are dispersed widely across the island, making them the most suitable candidate for the task of consuming food waste. In addition, black soldier fly larvae are rich in protein and can be used as a raw material in fish meals or animal feed, which further increases their environmental friendliness. Therefore, the behaviors and artificial farming conditions of black soldier flies must be clarified to promote the plan of using black soldier flies to process food waste for various industries or the public and enhance sustainability. The characteristics that make black soldier flies suitable for use in biological cycle treatment systems are as follows:

A. Biological and ecological characteristics of black soldier flies: Black soldier flies are holometabolous insects, and their life cycle consists of four life stages, namely the egg, larval, pupal, and imaginal stages. The larval stage can be divided into six instars. Prepupae (larvae in the sixth instar) leave their feeding environment and stop feeding and search for dry, shady, and concealed locations to metamorphose into pupae; they prefer crevices and are photophobic. Black soldier flies metamorphose into pupae in cool temperatures and rapidly mature in an environment with a stable temperature (27.8 °C). They emerge from their pupae after 12 days and can grow up to 17 mm in length; thereafter, they complete their larval stage in 21 days. Under stable room temperature, the pupal stage lasts for approximately 9–10 days, but when temperature fluctuations occur (21–28 °C), the prepupae stage can last from 15 to 150 days [39]. Black soldier flies begin reproducing after 28 days if the conditions are suitable, but they may take up to 8 months to do so if the conditions are unsuitable. The length of the pupal stage varies the most, and it can last from 1 week to 6 months. Imagines can reproduce after emergence, and they spawn after 2–3 days. In general, male imagines emerge 1–2 days before female imagines (Figure 3). In addition, black soldier flies have a strong pH tolerance and can feed on diverse foods. Imagines prefer flowers and feed on plant sap and nectar; they usually live in shrubs. Female imagines lay eggs in dry crevices near fresh organic materials when the environmental humidity is between 52% and 61%. Female imagines use their sense of smell to find suitable spawning locations. The mating behaviors of black soldier flies are affected by sunlight, temperature, and humidity. Mating usually occurs at noon under strong sunlight. Under artificial lighting, the mating rate of black soldier flies is only 61% of that observed under natural sunlight [40]. The black soldier fly is not a carrier of pathogens or diseases, and it spends most of its time in adulthood on plants rather than lingering near people or animals [11]. Animal excrement processed by black soldier fly larvae can be used to fertilize plants [41]. The larvae, which are suitable for mass breeding, have the additional benefit of reducing the number of pests, such as houseflies, by inhibiting them from laying eggs [42–44].
B. Environmental requirements for artificial farming: Black soldier fly larvae and prepupae have excellent environmental tolerance, and they can survive in environments

that contain alcoholic poison, oxidative stress, hypertonic osmotic pressure, low-concentration alcohol, mineral oil, or sodium chloride solutions. Therefore, the large-scale commercial farming of black soldier flies provides several advantages [26]. The water content of artificial feed substantially affects the growth of black soldier flies. Black soldier fly larvae cannot grow when they feed on artificial feed with a water content of 30% or less. A black soldier fly is at its heaviest during the larvae and prepupae stages, and the largest harvest of prepupae is achieved when the larvae and prepupae are fed with artificial feed with a water content of 75% or 80%. However, after larvae have grown into prepupae or have emerged as imagines, artificial feed with a water content of 65% or 70% is more suitable for them [45]. Black soldier fly pupae do not require sunlight because exposure to strong sunlight reduces their emergence rate and increases their death rate. Therefore, sunlight, feed, temperature, and humidity should be controlled during artificial farming.

C. Economic value of black soldier flies: The larvae and prepupae are rich in essential amino acids and minerals. Dried larvae comprise crude protein (42–44%), crude fat (31–35%), ash (11–15%), calcium (4.8–5.1%), and phosphorus (0.60–0.63%). Dried prepupae comprises crude protein (42.1%), fat (34.8%), water and ash (16.1%), crude fiber (7%), and calcium as the main mineral (5%) [29]. In addition to their high nutrition value, black soldier flies can also be used as environmentally friendly materials for inhibiting pathogenic microorganisms. Black soldier fly larva protein can be used as a natural antioxidant or cathelicidin antimicrobial peptide because it exhibits superior thermal stability and high stability in greenhouse environments. It can inhibit the growth of Escherichia coli and the growth and reproduction of other bacteria, and it has the unique ability to inhibit bacterial activity [46]. Black soldier flies can compete with houseflies because of the advantages that they have as maggots. They can compete with housefly maggots for food and inhibit their growth; black soldier fly larvae can inhibit the growth of 94% of the houseflies found in households. Black soldier fly imagines have a short life span, and they do not carry germs. In addition, their natural population density is low and stable, hence they are not ecological threats; they tend to not enter environments populated by humans and are environmentally safe. Therefore, black soldier flies are highly suitable for use in biological management (e.g., management of organic and food waste). A study demonstrated that biomass energy can be extracted from the dried larvae of black soldier flies [4]. Black soldier flies have various advantages such as a high reproduction rate and a short life cycle relative to biomass energy crops, which have longer life cycles and require larger areas of land to farm. Therefore, the economic, social, and ecological benefits of black soldier flies are noteworthy. A black soldier fly biological management system can efficiently and safely process organic waste, which can pollute human environments, into high value-added insect protein. Each larva can consume 2 kg of food waste within 72 h and convert it into biological protein; this process is conducive to the establishment of a circular economy and sustainable environment [36]. The residual obtained after organic materials are processed by black soldier flies is called frass [47]. Frass contains large amounts of old outer cuticles shed by larvae, and it is a semi-fermented and decomposed nutrient. It can be used in aquatic feed because of nutritional components and rich microbiota. Aquatic feed with 30% frass can improve the growth of fish. Therefore, the black soldier fly food waste management system can be integrated with an aquaponics system. From the perspective of establishing sustainability and a circular economy, the implementation of the black soldier fly biological management system (in a living environment) and the appropriate management mechanisms can reduce the burden of processing disposed food waste. The Livestock Research Institute began studying black soldier flies in 2010, and it discovered that they can rapidly consume large amounts of food and agricultural waste. The Chiayi County Yimi Community College and Minhe Elementary School in Fanlu Township studied the use of black soldier flies and reported excellent results. In particular, they investigated a black soldier fly feeding system and highlighted key points relating to the design of a black soldier fly biological system [48].

5. Key Points of Black Soldier Fly Biological System Design

The operation mechanisms of the system must be clarified to fully promote and implement it in a living environment and realize sustainable food waste recycling. Chairman Meng-Kun Wu of Chiayi County Yimi Community College has studied this topic for many years and applied for several patents. Chiayi County Yimi Community College first developed a wet feeding system for black soldier flies, which was then modified to create a dry feeding system [49]. The wet feeding system is suitable for food waste recycling activities of families and communities; by contrast, the dry feeding system is designed for large scale food waste recycling, and it is suitable for operations involving recycling plants and cleaning teams, which must effectively decompose food waste on a large scale. The wet feeding system uses normal wet food waste; this is a patented system in which black soldier flies can complete their life cycle and reproduce. The system consists of a food waste decomposition room, a pupation net house, and a wood crevice spawn area. First, wet food waste is poured into the food waste decomposition room, which is maintained at a temperature and humidity of 27 °C and 70%, respectively [39]. A large number of black soldier fly larvae are placed in the room, and the larvae consume and decompose the food waste. Mature larvae prefer to metamorphose into pupae in dry areas, and the black soldier flies can pupate in two areas. One of the pupation areas is a net house in which emerged imagines can mate. Pregnant female imagines then search for wood crevices to spawn in, and the spawn area is located directly above the food waste decomposition room, such that larvae can fall back into the food waste decomposition room when they hatch. The feeding area of the dry feeding system can decompose 500 kg of food with 50 g of larvae in 10 days. In addition, 120–150 kg of larvae can be harvested after 10 days. 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 black soldier fly larvae. Microorganisms are also added to facilitate the decomposition of food waste. The temperature of the feeding area can reach 45 °C 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 °C. The aforementioned black soldier fly feeding system comprises individual systems such as the pupation, larvae, and frass systems. The wet feeding system involves the use of simple equipment and implementation of straightforward operations. On average, each larva can consume 2–3 kg of food waste and be used as insect protein feed [50]. The Chiayi County Yimi Community College and Minhe Elementary School in Fanlu Township used these characteristics to test the black soldier fly aquaponics system (Figure 4). The aquaponics system can effectively alleviate the problem of school food waste and enable the implementation of experiential learning for promoting food farmer education. This can help students to acquire more knowledge related to biological systems and become more willing to consume vegetables. In addition, the roof space can be used for edible and green landscaping. When students stop producing unnecessary food waste, overall food waste is effectively reduced. The insect house is converted into a food waste decomposition room (Figure 5) to provide favorable environmental conditions for the growth of black soldier flies. Cooled wet food waste is poured directly into the insect house for the larvae to consume. Tubes are connected to the insect house to drain wastewater into an organic nutrient solution barrel, and the collected nutrient solution is then used to water plants.

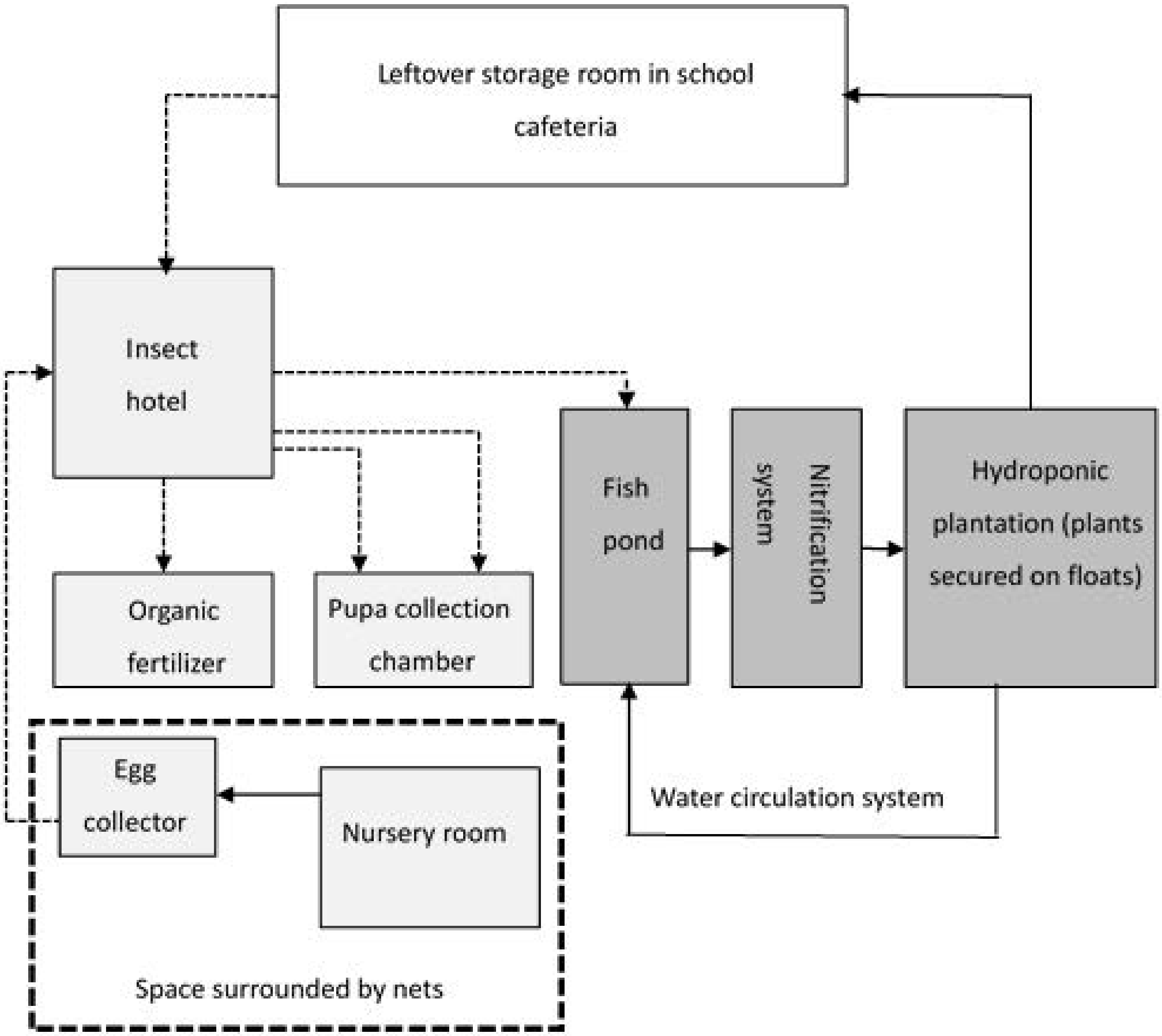

Figure 4. Black soldier fly food waste recycle system.

Two tubes located under the insect house are connected to the pupae collector. The pupae are collected and placed in the pupation net house. The pupation net house contains plants or artificial leaves, which serve as living habitats and mating sites for black soldier flies after they emerge. The dimensions (i.e., length, width, and height) of this house should be suitably large to accommodate the flight of imagines. Studies have suggested that the length, width, and height of a pupation net house should be greater than 1.5 m [50]. Egg collectors, which consist of several long wooden planks tied to fermented soy pulp barrels, are placed inside the pupation net house. The crevices of these wood planks serve as spawning sites for female imagines. The eggs hatch and enter the larval stage within 3–5 days after they are scrapped from the wooden planks.

The roof space of a campus is usually built with an overhang, but students rarely use this space. To improve the urban ecological environment, beautify roofs, reduce the greenhouse effect, save energy, and reduce carbon emissions, the Green Roof Technical Specifications was announced by the Government of Taiwan on 30 October 2013 [51]; this set of specifications is applicable to the design, construction, and maintenance of the green roofs of newly built institutions, business units, and public service facilities (e.g., culture and sports facilities). In addition, it also opened opportunities for processing food waste through the use of the black soldier fly biological system. Semi-intensive roof greening can be implemented to apply both intensive and extensive construction methods for a given roof. Various combinations can be used depending on the purpose of use. Moreover, non-toxic, pollution-free, or low-pollution control measures can be taken to create environmental conditions suitable for establishing the black soldier fly biological system. According to the relevant provisions of Article 162 of the Technical Rules for the Design and Construction of Building [52], when the overhang area is less than 1/8 of the building area or less than 25 m^2, it is not included in building volume calculations. Therefore, approximately 7/8 of the building area can still be used for roof greening. The black soldier fly biological system is not covered under Article 4 of the Building Act; hence the installation of the black soldier fly biological system does not increase the volume of the building area. The backyard space of the school canteen can be used to establish a food waste recycling room (Figure 6), and the installation of low-temperature refrigeration equipment with a shredder can provide an excellent temporary storage space for food waste. In addition, these measures can help to eliminate odors, prevent diseases caused by cockroaches and mosquitoes, maintain campus hygiene, overturn the stereotype that food waste recycling spaces are messy, maintain canteen hygiene standards, enhance the school's image, and reduce the negative perceptions of students regarding the food waste handling process. Furthermore, centralized management was adopted to increase the willingness of users to dispose food waste. General or special elevators were used to send fixed amounts of collected and shredded food waste to the black soldier fly biological system on the roof for biological food waste treatment. In the Report on National Science and Technology Plan for Agricultural Biotechnology (2005), Professor Tseng et al. from the Department of Biological Science and Technology of National Chiao Tung University discovered that fermentation odors can be removed using physical adsorption, activated carbon, or biotechnology [53]. The application of the deodorization technique to the vivarium produced a favorable odor isolation effect (Table 1). Furthermore, the roof environment can also reduce odors because of its excellent ventilation.

Figure 5. Conversion of insect house into food waste decomposition room (source: our island, https://ourisland.pts.org.tw/%E9%97%9C%E9%8D%B5%E5%AD%97/%E9%AD%9A%E8%8F%9C%E5%85%B1%E7%94%9F (accessed on 8 May 2021)).

Figure 6. Cold storage facility for waste (source: Hong-Hai Environment Tech. Co., Ltd., Taoyuan City, Taiwan. Official Website, http://www.hong-hai.com.tw/front/bin/ptlist.phtml?Category=53 (accessed on 8 May 2021)).

Table 1. Industries and processes to which biological deodorization techniques are applicable.

Industry/Process	Waste Gas from Production Process	Waste Gas from Sewage Treatment
Composting area	○	
Livestock industry (pig/chicken/cattle/deer)	(Solid–liquid separator) ○	(Anaerobic treatment of waste gas) ○
Poultry rendering plants	○	○
Fertilizer industry	○	○
Landfill sites	○	○
Leather factory	○	○
Fish trash	○	
Fodder factory	○	

Source: Tseng [53].

6. Results

The present study used the findings of relevant studies as the basis for preliminary research and analysis, and a questionnaire survey was administered to experts and scholars. Given that the different backgrounds of the research participants resulted in them holding different views, the Delphi method was adopted to analyze the results until a consensus was reached. The results revealed that the black soldier fly biological system required a greater number of indicators for spatial composition, whereas the aquaponics system required a greater number of indicators for system dimensions. When the experts and scholars reached a consensus for 70% of the items in the questionnaire, the analysis was halted and discussions and suggestions on related topics were proposed. During the research process, 45 questionnaires were distributed, and 42 were retrieved, indicating a response rate of 93.3%. The results for three dimensions were summarized on the basis of the questionnaire results, and 29 indicators were established. The questionnaire was designed based on the expert questionnaire and fuzzy Delphi method. The experts specialized in various fields, including environmental protection, agriculture, architectural space planning, education, nutrition, and fields related to the black soldier fly. Among the established indicators, the 10 indicators for which the highest levels of consensus were reached had a score of 8 or higher (Table 2).

Table 2. Indicator scores of the black soldier fly biological system.

Dimension	Black Soldier Fly Biological System			
	Black Soldier Fly		Aquaponics	
	Indicator	G	Indicator	G
Spatial composition	1. Provision of appropriate sunlight exposure and ventilation for insects in each instar	8.36	6. Status as an edible landscape	6.92
	2. Provision of independent entry and exit moving lines	7.80	7. Status as a space for promoting food farmer education	7.50
	3. Provision of a low shrub environment (where imagines can forage and live) and sufficient space (for adult emergence)	8.30	8. Use of idle space as a recreational environment	6.99
	4. Provision of dry organic materials for formation of an oviposition environment	8.27	9. Use of auxiliary space for cooking lessons	6.80
	5. Provision of a dedicated and independent environment	8.06	10. Establishment of a space with ecological views	6.86
			11. Ability to incorporate green roof design	7.46
			12. Required establishment of a dedicated space	7.74
System and equipment	13. Provision of appropriate temperature and humidity conditions for each growth stage and a mechanism for reducing food waste fermentation odors	8.19	16. Control of system for decomposing and circulating microbial species; timely adjustment of pH, dissolved oxygen, and water temperature of hydroponic environment	8.18
	14. Required use of special customized equipment	6.88	17. Visually appealing vivarium	6.75
	15. Required installation of an anti-escape equipment for insects	7.54	18. Water retention and clean ability requirements of vivarium, monitoring of blockages in vivarium filter system, and long-term and mild strategies for pest control	8.16
			19. Determination of a plant's suitability for use as a hydroponic plant; proposal for a plant to be used as a hydroponic plant	7.71
			20. Monitoring of aquaculture density	8.11
			21. Simple system design with low maintenance requirements and low energy consumption that ensures stable power	8.10
			22. Required deployment of specialized personnel for assembly process	6.86
			23. Possibility of integrating a rainwater harvesting system	7.57

Table 2. *Cont.*

Dimension	**Black Soldier Fly Biological System**			
	Black Soldier Fly		**Aquaponics**	
	Indicator	**G**	**Indicator**	**G**
Environmental education	24. Learning of ecological balance concept of energy conservation and waste reduction			8.09
	25. Provision of a straightforward farming experience			6.94
	26. Implementation of life-oriented ecological education			7.26
	27. Provision of locally sourced fresh ingredients			6.93
	28. Sense of accomplishment from learning by doing can promote sustainable food farmer education			8.08
	29. Required implementation of special course coordination			6.84

The wet feeding system is suitable for food waste recycling activities of families and communities; by contrast, the dry feeding system is designed for large scale food waste recycling. Therefore, in this study, only the discussion of the wet feeding system is limited, and the dry feeding system is not discussed.

The present study used the fuzzy Delphi method to explore the evaluation mechanism of the black soldier fly biological system for promoting food farmer education. According to the analysis results, for the construction of the evaluation mechanism of the black soldier fly biological system from the perspective of food farmer education, the top 11 indicators with the highest scores among the three dimensions are as follows:

1. (No.1) Provision of appropriate sunlight exposure and ventilation for insects in each instar.
2. (No.3) Provision of a low shrub environment (where imagines can forage and live) and sufficient space (for adult emergence).
3. (No.4) Provision of dry organic materials for formation of an oviposition environment.
4. (No.13) Provision of appropriate temperature and humidity conditions for each growth stage and a mechanism for reducing food waste fermentation odors.
5. (No.16) Control of system for decomposing and circulating microbial species; timely adjustment of pH, dissolved oxygen, and water temperature of hydroponic environment.
6. (No.18) Water retention and clean ability requirements of vivarium, monitoring of blockages in a vivarium filter system, and long-term and mild strategies for pest control.
7. (No.20) Monitoring of aquaculture density.
8. (No.21) Simple system design with low maintenance requirements and low energy consumption that ensures stable power.
9. (No.24) Learning of ecological balance concept of energy conservation and waste reduction.
10. (No.28) Sense of accomplishment from learning by doing can promote sustainable food farmer education.
11. (No.05) Provision of a dedicated and independent environment.

The indicator score of the No. 5 item of the spatial composition dimension is close to the No. 28 indicator of the environmental education dimension. It should be possible to list No. 5 as an important evaluation indicator item. Therefore, in total, 11 indicators with score higher than 8 are listed above. The top 11 indicators with the highest scores mostly comprised indicators of the system and equipment dimension followed by those of the spatial composition and environmental education dimensions. However, among the indicators of the three dimensions, those of the spatial composition dimension obtained the highest scores. Therefore, the planning and determination of spatial composition should be performed before systems and equipment are set up. In addition, the sense of accomplishment from learning by doing can lead to a greater acceptance of sustainable food farmer education among students. A black soldier fly biological management system can efficiently and safely process organic waste, which can pollute human environments, into high value-added insect protein. The residual obtained after organic materials are processed by black soldier flies is called frass. It can be used in aquatic feed because of nutritional components and rich microbiota. From the perspective of establishing sustainability and a circular economy, the implementation of the black soldier fly biological management system and the appropriate management mechanisms can reduce the burden of processing disposed food waste.

7. Conclusions

Because of the trend of sub-replacement fertility, today's children have access to a sufficient or even abundant supply of food, causing them to develop picky eating habits and adopt an unbalanced diet. Leftovers at school contribute to the problem of food waste. The present study aimed to provide proactive and new solutions through the implementation of food waste reduction and environmental design methods. In an urban setting, most students have no knowledge of food and cooking, particularly with respect to agricultural production. If they can participate in a food production process and experience the difficulties of producing food (e.g., experiencing the hard work required of farmers) through experiential learning, they can learn to cherish their food and, consequently, reduce their food waste. In addition to the use of black soldier flies for reducing food waste, the most crucial factor was the establishment of various effective food farmer education and promotion objectives. Furthermore, students can also learn about local agriculture and the establishment of a healthy dietary lifestyle and culture. During the promotion of campus roof greening, the black soldier fly biological system, which integrates the application of aquaponics and use of black soldier flies, can be incorporated into a semi-intensive roof greening plan to create environmental conditions that are suitable for insect growth. The food waste of a campus can be used to breed black soldier flies, which is a sustainable method that alleviates the food waste problem. If the aquaponics method promoted by the Yimi Community College (i.e., integration of black soldier fly biological system with use of microorganisms) is used to treat food waste in school, food farmer education through learning by doing can be promoted; this strategy can contribute toward the creation of the ideal sustainable environment for a circular economy.

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