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Transforming waste into wealth: an in-depth exploration of MaeJo Black Soldier Fly (MAEJO BSF) cultivation for industrial applications

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Abstract Results showed that water was the most effective attractant for adult MAEJO BSF, followed by sugar cubes, electrolyte drinks, honey, and sweet fruits. For egg-laying stimulation, molasses combined with vegetable scraps yielded the best results, while molasses mixed with food waste resulted in the highest number of larvae. Additionally, raw rice husk was the most effective substrate for inducing larval pupation, followed by sand, burnt rice husk, and soil, with no pupation observed in shredded coconut husk. These findings underscored the importance of selecting appropriate food sources, organic waste, and substrates for the rearing and propagation of MAEJO BSF in Thailand's climate, supporting efficient organic waste management and enhancing the production of alternative protein sources.

Keywords: MaeJo Black Soldier Fly, Organic waste, Alternative protein

Introduction

The Black Soldier Fly (BSF) has been proven to have high potential as an efficient organic waste decomposer and a valuable source of nutritionally rich protein for agricultural and livestock industries (Chia *et al*., 2019a; 2019b; Van Huis, 2013). BSF larvae are capable of breaking down a wide range of organic materials, including food scraps, fruit and vegetable waste, animal manure, and even waste with high levels of toxins or salt concentrations. These larvae exhibit rapid growth and resilience to diverse environmental conditions, making them highly effective in reducing organic waste volume (Diener *et al*., 2011; Lalander

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et al., 2013). The ability of BSF to decompose organic waste has garnered global attention, as it offers both environmental and economic benefits by reducing waste and producing protein for animal feed in a sustainable manner (Meneguz *et al*., 2018; Nguyen *et al*., 2015).

Maejo University initiated research and cultivation of BSF at its vermiculture fertilizer facility and has since developed a unique strain known as Maejo Black Soldier Fly "MAEJO BSF," which has been optimized for Thailand's environmental conditions. The global industry focused on BSF-derived protein is expanding rapidly. In countries like the United States, over 10,000 tons of BSF-derived protein are produced annually, serving as a cost-effective alternative protein source for aquaculture species such as tilapia and salmon, thereby reducing dependence on fish-derived protein (Oonincx *et al*., 2015). Moreover, BSF offers farmers a sustainable income source and contributes to the growth of eco-friendly industries (Tomberlin *et al*., 2009; Surendra *et al*., 2016).

Currently, the livestock and animal feed production industries face numerous challenges, particularly the reliance on animal-derived protein, such as fish, which is expensive and has significant environmental impacts. As such, finding low-cost and sustainable alternatives for protein is crucial. BSF has attracted significant attention as a high-quality protein source for animal feed. The oil produced from BSF can also be used in animal feed formulations and serves as a potential alternative protein source (Meneguz *et al*., 2018). The protein production efficiency of BSF is higher and more cost-effective than using fish protein, while simultaneously reducing the reliance on fish-based ingredients, which have a detrimental impact on marine resource sustainability (Oonincx *et al*., 2015).

Furthermore, the use of BSF contributes positively to organic waste management in agriculture, particularly in reducing organic waste on farms and in communities—an issue that has become increasingly problematic in many countries. BSF can decompose organic waste from food scraps, fruit, vegetable residues, and animal manure, including waste containing toxins, converting these materials into nutrient-rich fertilizer and valuable protein efficiently. In addition, using BSF promotes eco-friendly industries by utilizing existing resources and local materials (Tomberlin *et al*., 2009; Surendra *et al*., 2016), leading to the development of sustainable agricultural industries that do not harm the environment.

The research aimed to investigate methods for breeding and increasing the population of MAEJO BSF using various feeding formulas and theobjective was to develop an efficient breeding system that can both enhance the decomposition

of organic waste and create a profitable business model for waste management and protein production.

Materials and methods

Study of suitable food types for rearing adult MaeJo Black Soldier Fly (MAEJO BSF)

This experiment aims to identify the most suitable type of food for rearing adult MAEJO BSF. A Completely Randomized Design (CRD) was used, with five different treatments, each replicated three times:
Treatment 1: Water (Control),
Treatment 2: Sugar cubes,
Treatment 3: Honey,
Treatment 4: Electrolyte drink (Sponsor), and
Treatment 5: Sweet fruit (Longan).

The experiment was begun by selecting a shaded area and setting up a 6-inch mesh enclosure. A layer of sand, approximately 10 cm thick, was spread on the ground to create a suitable environment. Each food treatment was prepared as follows: water, honey, and electrolyte drink were absorbed into 3x3 cm sponges until saturated, wrapped in fine white cloth, and suspended from 30 cm-long strings. Sugar cubes and longan, each weighing 10 grams, were similarly wrapped in white cloth and suspended. Once prepared, 500 adult BSF were released into the enclosure. The number of BSF attracted to each food type was recorded twice daily, in the morning and evening, until all BSF had died. The collected data were analyzed to determine the optimal food type to support BSF survival and reproduction under rearing conditions.

Study of organic waste types with potential to induce egg-laying in MaeJo Black Soldier Fly (MAEJO BSF)

This experiment wasidentified the types of organic waste that can effectively stimulate egg-laying in MAEJO BSF. A Completely Randomized Design (CRD) was employed, with four different treatments, each replicated three times:
Treatment 1: Molasses + Water (1:1 ratio),
Treatment 2: Molasses + Vegetable scraps (1:3 ratio),
Treatment 3: Molasses + Fruit scraps (1:3 ratio), and
Treatment 4: Molasses + Food scraps (1:1 ratio)

A shaded area was selected for the experiment, and a 6-inch mesh enclosure was set up. A total of 500 adult BSF were then released into the enclosure. Each organic waste mixture was prepared according to the specified ratios and placed in open containers within the enclosure, allowing the flies access to each treatment. After a period of four weeks, data were collected by recording the number of larvae observed in each treatment. The results were analyzed to determine the organic waste type with the highest potential to induce egg-laying, thus identifying the most effective waste type for future BSF rearing and propagation.

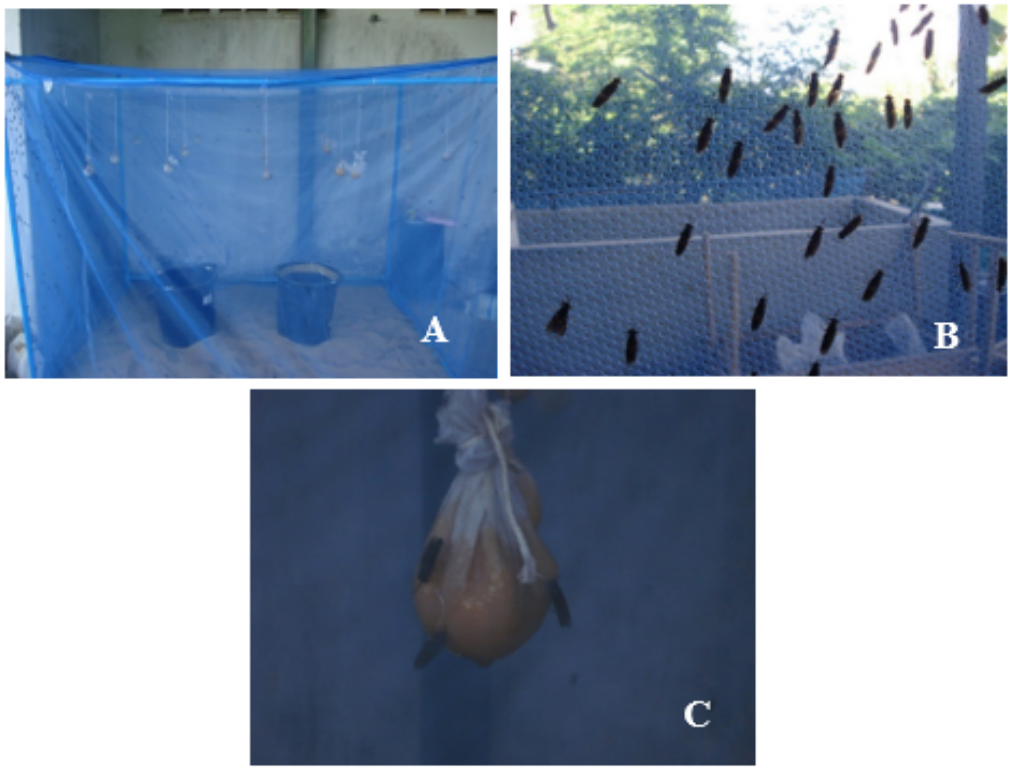

Figure 1. Illustrates the experimental setup for determining the optimal food type for adult MAEJO BSF: A shows the suspension of various food types according to the experimental design, B shows the release of 500 MAEJO BSF into the enclosure, and C shows the counting of MAEJO BSF attracted to each food type in each treatment

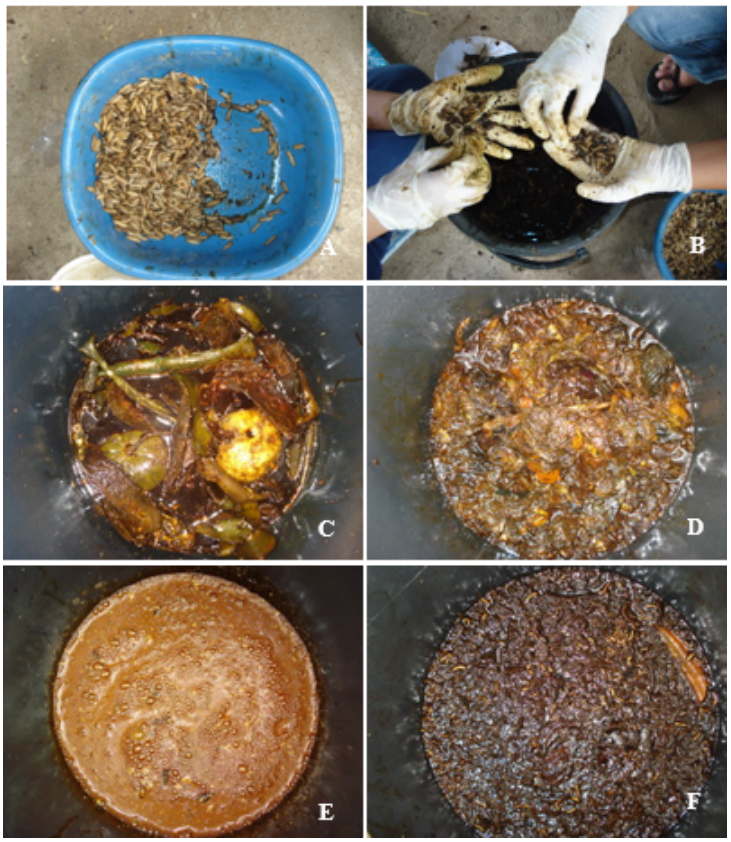

Figure 2. illustrates the experimental process for identifying organic waste types that stimulate egg-laying in MAEJO BSF: A shows the MAEJO BSF larvae, B shows the sorting of MAEJO BSF larvae, C represents the fruit scraps + molasses treatment, D represents the food scraps + molasses treatment, E represents the cow manure + molasses treatment, and F represents the vegetable scraps + molasses treatment

Study of organic substrates with potential to induce pupation in MaeJo Black Soldier Fly Larvae (MAEJO BSF)

This experiment was investigated the types of organic substrates that can stimulate pupation in MAEJO BSF larvae. A Completely Randomized Design (CRD) was used, with five treatments, each replicated three times:
Treatment 1: Soil,
Treatment 2: Raw rice husk,
Treatment 3: Burnt rice husk,
Treatment 4: Sand and
Treatment 5: Shredded coconut husk

A shaded area was chosen for the experiment, where a 6-inch mesh enclosure was set up to rear the MAEJO BSF larvae. Twenty larvae were placed in each container and fed vegetable scraps. The containers were then positioned on each organic substrate according to the assigned treatment. After eight weeks, data were collected by counting the number of pupae casings in each treatment. The collected data were analyzed to determine which organic substrate most effectively induces pupation in MAEJO BSF larvae, providing valuable insights for future BSF rearing and propagation practices.

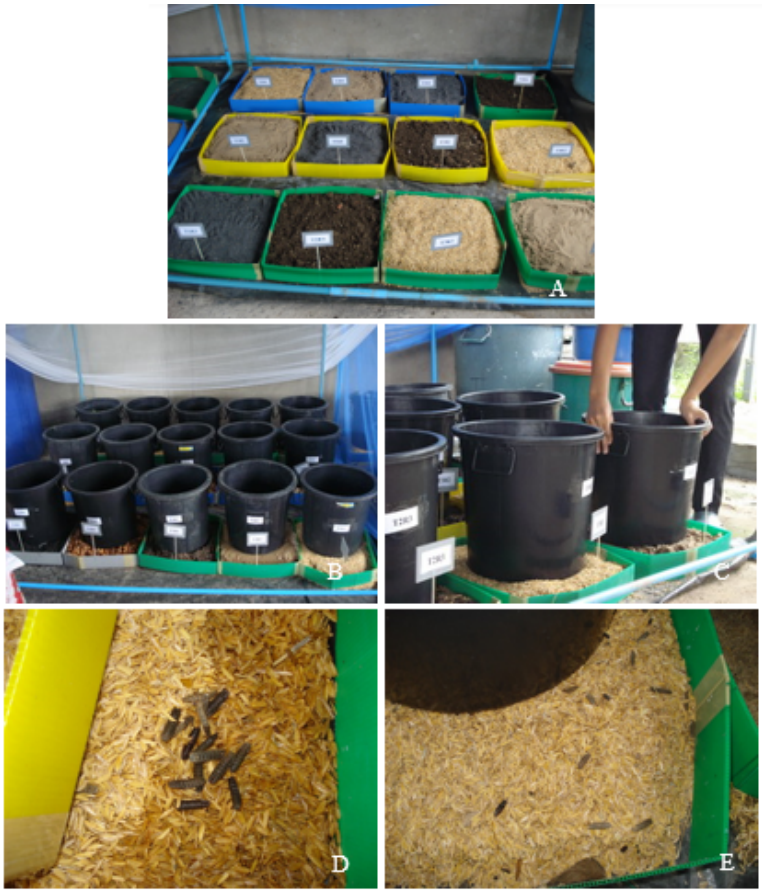

Figure 3. illustrates the types of organic substrates used to induce pupation in MAEJO BSF larvae: A shows the various organic substrates, B-C depict the setup and preparation of equipment for rearing MAEJO BSF, and D-E show MAEJO BSF pupal casings within the organic substrates

Statistical analysis

Each experiment was computed a one-way ANOVA test to evaluate differences in MAEJO BSF outcomes across various treatments, followed by post-hoc tests where significant differences were found, to identify optimal conditions for rearing.

Results

Study of suitable food types for rearing adult MaeJo Black Soldier Fly (MAEJO BSF)

This experiment examined the impact of various food types on the survival of MAEJO Black Soldier Fly (BSF), with five treatments including a water-only control to assess optimal support for BSF populations. Results showed that Treatment 1 (water control) had the highest BSF count at an average of 9.67, indicating strong survival even without supplemental nutrients, while Treatment 5 (sweet fruit, longan) yielded the lowest count at 0.33, suggesting limited suitability as a BSF food source. Other treatments—sugar cubes (6.00), honey (1.67), and electrolyte drink (4.33)—produced intermediate results, with sugar cubes closer to the control. The F-test confirmed significant differences among treatments ($p < 0.01$), and the coefficient of variation (CV%) was 66.13%, showing variability influenced by nutrient composition, moisture, and palatability. Overall, the water-only control supported the highest survival, highlighting the importance of balanced nutrients and moisture in BSF cultivation (Table 1).

Table 1. The number of MAEJO BSF observed with different food types

Treatments	Number of MAEJO BSF (Average)
Treatment 1: Water (Control) + MAEJO BSF	9.67a
Treatment 2: Sugar Cubes + MAEJO BSF	6.00ab
Treatment 3: Honey + MAEJO BSF	1.67ab
Treatment 4: Electrolyte Drink (Sponsor) + MAEJO BSF	4.33ab
Treatment 5: Sweet Fruit (Longan) + MAEJO BSF	0.33b
F-test	**
CV%	66.13 %

***Note*:** Means followed by the same letter do not significantly differ as per Duncan's Multiple Range Test (DMRT). ** denotes a statistically significant difference at the 99% confidence level.

Study of organic waste types with potential to induce egg-laying in MaeJo Black Soldier Fly (MAEJO BSF)

The study investigated the potential of various organic waste types to stimulate egg-laying in MAEJO Black Soldier Fly (BSF), examining four treatments for their effects on BSF reproduction and larval production. Results showed that molasses mixed with vegetable scraps induced the earliest egg-laying, with larvae appearing within three weeks, while molasses mixed with food scraps yielded the highest larval count, exceeding 2,000. Vegetable scraps alone produced over 1,000 larvae, demonstrating moderate effectiveness, while fruit scraps led to more than 500 larvae, indicating limited effectiveness compared to food scraps. The plain water treatment resulted in no larvae, underscoring the importance of nutrient-rich organic material in encouraging egg-laying and larval development. Overall, food scraps combined with molasses proved most effective for maximizing larval production, highlighting the role of nutrient density in supporting BSF reproductive activity (Table 2).

Table 2. The number of MAEJO BSF larvae observed in each organic waste treatment

Organic waste types	Number of MAEJO BSF Larvae
Food scraps	More than 2,000 larvae
Vegetable scraps	More than 1,000 larvae
Fruit scraps	More than 500 larvae
Plain water	None

Study of organic substrates with potential to induce pupation in MaeJo Black Soldier Fly Larvae (MAEJO BSF)

The study examined the effectiveness of various organic substrates in inducing pupation in MAEJO Black Soldier Fly (BSF) larvae, testing five substrates. Results indicated that raw rice husk was the most effective, with an average of 21.67 larvae pupating, followed by sand with 14.00, burnt rice husk with 7.33, and soil with 2.33. Shredded coconut husk did not support any pupation. Statistical analysis confirmed significant differences among treatments at a 95% confidence level, with raw rice husk showing the highest efficacy. Sand and burnt rice husk performed moderately well, while soil and shredded coconut husk proved less suitable. These findings highlight the importance of substrate type, with raw rice husk providing optimal conditions for pupation in MAEJO BSF larvae (Table 3).

Table 3. The number of MAEJO BSF pupae observed in each organic substrate

Organic substrates	Number of MAEJO BSF pupae (Average)
Raw Rice Husk	21.67a
Sand	14.00ab
Burnt Rice Husk	7.33ab
Soil	2.33b
Shredded Coconut Husk	0.00b
F-test	*
CV%	CV = 105.21%

Note: Means followed by the same letter do not significantly differ as per Duncan's Multiple Range Test (DMRT). * denotes a statistically significant difference at the 95% confidence level.

Discussion

The experiment revealed that adult MAEJO BSF responded best to water-based food, showing the highest average presence (9.67 individuals). This may be due to the MAEJO BSF's ability to efficiently absorb water through their body membranes. Water also plays a crucial role in maintaining moisture balance and supporting essential physiological processes in adult BSF (Oonincx *et al*., 2015). This finding aligns with the study by Spranghers *et al.* (2017), which found that similar insects respond well to low-concentration solutions, making water a particularly effective food for adult MAEJO BSF compared to other treatments.

In contrast, food treatments with sugar cubes, electrolyte drink (Sponsor), honey, and sweet fruit (longan) attracted fewer MAEJO BSF, respectively. The higher concentration of solutes in these treatments may create surface tension that impedes direct absorption by adult BSF, disrupting internal water balance compared to water (Gobbi *et al*., 2013). These findings highlight the importance of using low-concentration solutions in adult MAEJO BSF rearing.

In examining organic waste types to stimulate MAEJO BSF egg-laying, it was found that molasses mixed with vegetable scraps induced the earliest egg-laying, with larvae detected within three weeks. The treatment with molasses and food scraps yielded the highest larval count, exceeding 2,000 individuals. This suggests that nutrient-rich organic waste, particularly those high in minerals and carbohydrates, effectively attracts MAEJO BSF for egg-laying. This is due to BSF's natural ability to detect high-protein and high-carbohydrate food sources that benefit larval growth. Studies by Nguyen *et al*. (2015) and Meneguz *et al*. (2018) support these results, showing that nutrient-dense vegetable and food scraps significantly boost BSF egg-laying rates and growth, consistent with the current study's findings.

Environmental conditions, such as temperature and humidity, also affect MAEJO BSF egg-laying behavior. Research by Diener *et al*. (2011) notes that

an optimal temperature range of 25-30°C and humidity levels between 60-70% facilitate rapid and efficient egg-laying. This environmental factor is relevant in Thailand's hot and humid climate, which aligns with the favorable outcomes of this study, where controlled temperature and humidity conditions in the presence of nutrient-rich vegetable and food scraps promoted rapid egg-laying and larval emergence.

Regarding organic substrates for inducing pupation, raw rice husk proved the most effective, likely due to its excellent water drainage and moisture retention properties. These conditions create an environment conducive to MAEJO BSF pupation. The studies by Gobbi *et al*. (2013) and Lalander *et al*. (2013) also emphasize the importance of substrate choice, showing that substrates with good drainage and moisture balance promote efficient BSF pupation.

Other substrates, such as sand and burnt rice husk, demonstrated moderate pupation-inducing capacities, providing some moisture control and drainage, though less effectively than raw rice husk. In contrast, shredded coconut husk showed no pupation, likely due to its dense structure and poor air circulation, creating an unsuitable environment for MAEJO BSF development. This observation is consistent with Meneguz *et al*. (2018), who found that poor drainage and aeration reduce BSF pupation rates.

Overall, this study is highlighted the importance of food types, organic waste, and substrate choice in MAEJO BSF growth and development within an environment similar to Thailand's. Further research examining these factors across different regional environments may improve the application of MAEJO BSF for organic waste management and as an alternative protein source for agricultural industries.

The research finding found that water was the most effective food for attracting adult MAEJO BSF, followed by sugar cubes, electrolyte drink (Sponsor), honey, and sweet fruit. Additionally, molasses combined with vegetable scraps are effectively induced egg-laying, while molasses mixed with food scraps produced the highest number of larvae. For pupation, raw rice husk was the optimal substrate, followed by sand, burnt rice husk, and soil, while shredded coconut husk did not support pupation. To optimize MAEJO BSF rearing throughout its lifecycle, appropriate environmental conditions and food sources should be provided, including water and sugar for adults, molasses with vegetable or food scraps to stimulate egg-laying, and raw rice husk to support larval pupation.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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