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Optimizing agricultural waste for black soldier fly larvae feed: A case study in Kanchanaburi, Thailand

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Abstract The results indicated that larvae fed papaya and mixed fruit diets showed higher weights, body sizes, and prolonged growth periods compared to those fed bananas. Although the differences in larval weight and size, the survival rates of the diets were similar. The fruit waste diet was significantly affected the sex ratios, with the mixed fruit diet providing the highest male proportion (0.55) and the pomelo diet the lowest (0.44). Furthermore, different fruit wastes influenced the ratio of abnormal adults with larvae fed on papaya and banana showing the highest incidence, whereas those fed on chicken feed displayed the lowest. Larvae fed with mixed fruit generated the highest amount of frass (70 g dry weight), followed by chicken feed (60 g) and papaya (55 g). The findings indicated that a mixed fruit diet improves larval growth, development, and waste recycling efficiency, creating prospects for small scale farmer, especially in areas with insufficient waste management infrastructure.

Keywords: Agriculture, Development, Diptera, Waste reduction, Waste management

Introduction

Thailand's population exceeds 71.6 million, with agriculture as the predominant occupation (Sapbamrer *et al.*, 2024). This presents significant challenges for the country's management of agricultural waste, particularly to local farm productivity. This difficulty leads to the accumulation of approximately 43 million tons of agricultural waste that is considered worthless (Tengkaew and Wiwattanadate, 2014). This waste largely consists of agricultural produce having both internal and exterior imperfections, such as uneven shapes, non-standard sizes, and varied levels of ripeness. Though agricultural waste is naturally biodegradable, its large volume causes challenges that may result in unpleasant odors, the spread of disease-carrying insects, and soil pollution.

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Farmers either burn these remaining parts, dispose of them in landfills, or leave them in the fields as agricultural trash. Farmers use the wastes as compost or animal feed. However, the process is laborious, time-consuming, and requires financial investment (Jaitia, 2013).

Kanchanaburi is a major agricultural area, cultivating rice, sugarcane, corn, and cassava, along with a variety of fruits and vegetables. Large agricultural areas, including highland sugarcane and lowland paddy rice, play a crucial role in the sugar and agricultural industries (Santiphop *et al*., 2012). Farming processes produce significant waste, such as peels and pulp from harvesting, which can be recycled via composting, animal feed, and bioenergy generation. Current efforts in Kanchanaburi focus on the recycling of agricultural waste, its conversion into bioenergy, and the investigation of novel techniques for producing value-added products. Nonetheless, small-scale waste management remains a difficulty due to insufficient infrastructure and constrained resources, which limit effective waste utilization at the local level.

The black soldier fly, or BSF, is not a vector for diseases and is not classified as a pest (Sheppard, 2002). BSF larvae can consume a variety of organic materials, such as kitchen and organic waste, as well as agricultural by-products including fruit peels, palm kernel cake, and animal manure from farms. This method reduces the amount of organic waste (Tomberlin and Sheppard, 2001). The utilization of BSF larvae in the decomposition of organic waste is gaining recognition for its effectiveness in waste reduction, shortened life cycle, and rapid decomposition (Mutafela, 2015). The use of BSF larvae for organic waste decomposition is acknowledged as an effective approach to mitigate methane gas emissions, which are major contributors to greenhouse gases linked to climate change (Alyokhin and Chen, 2017). This process demonstrates reduced greenhouse gas emissions relative to conventional composting methods, as shown by Rindhe's 2019 studies. Furthermore, European countries permit the inclusion of insect protein, specifically BSF larvae, in the formulation of animal feed for fish, livestock, and other animals (Tomberlin and Sheppard, 2001). BSF protein is recognized as a high-quality and efficient alternative that promotes a circular and green economy, thus aiding in sustainable food security. The black soldier fly industry has undergone considerable expansion in recent years (Derrien and Boccuni 2018). BSF frass is gaining recognition for its economic and ecological value as a fertilizer, which enhances the circularity of the production process.

It is crucial to provide smallholder or small-scale farmers with fundamental information on the effective utilization of BSF in the context of local agricultural waste, especially in areas where agricultural waste presents challenges. This study aimed to assess the efficacy of BSF larvae in decomposing local agricultural waste, including banana, papaya, and pomelo, in Kanchanaburi Province, and to examine the impact of different fruit waste diets on the development, survival rate, and adult morphology of the BSF.

Materials and methods

Black soldier fly colony maintenance and fruit waste materials

Black soldier fly larvae were obtained from a population maintained at the Natural History Museum at the National Science Museum, Pathum Thani Province, Thailand. All larvae were raised at a temperature of 26-28 ℃, relative humidity of 60-70%, and a photoperiod of 12:12 hours (day:night). The larvae used throughout this study were five days old. Fresh agricultural waste, specifically selected to represent the local produce of Kanchanaburi, including bananas, papayas, pomelo, and mixed fruits, was collected from local markets in Khonkaen province, Thailand. The fruits were promptly packaged and transported to the industrial insect laboratory in the Facuty of Agriculture, khonkaen University, Thailand. To prevent microbial degradation, all fruits were stored at a temperature of 7 °C. The control treatment utilized chicken feed obtained from a commercial animal feed supplier in Thailand, comprising 22% crude protein, 6% fat, 3.5% crude fiber, and 5% crude ash.

Black soldier fly larval growth and yield on various substrates

The experimental design was performed with a Completely Randomized Design (CRD) to evaluate decomposition efficiency and larval growth. The experiment includes four treatments, with five replications. The experiment comprised four treatments, each with five replications. The treatments were divided the substrate provided to the BSF larvae as follows: 1. chicken feed as a control 2. banana 3. papaya 4. pomelo 5. mixed fruit. In each treatment, 5-day-old larvae were placed in rectangular plastic trays (76 cm length × 27.5 cm width × 10 cm depth) situated within a temperature-regulated cabinet maintained at 26±5 °C. Each box contained 100 larvae and 500 grams of fruit. The control treatment was given with commercial chicken feed mixed with molasses and water. Each rearing substrate was hydrated to attain a moisture content of approximately 60.0 ± 5% by weight, as verified with a moisture sensor with two 12-cm-long probes (HydroSense CS620, Campbell Scientific, Logan, USA). The conditions used in the experimental rearing room were sustained at 27 ± 2 °C, 60–70% relative humidity, and a photoperiod of 12 hours light and 12 hours dark. The developmental duration of larvae, larval mass, pupation rate, mortality rate from larval to adult stage, adult fly fertility, sex ratios, and larval frass production quantity were recorded. Every three days, a stereo microscope assessed the weight and individual size, preparing 30% of the larvae for pupation. According to the method of Onincx *et al*., (2015), this meaning depends on a change in color from milky white to dark brown or black, which shows that the larval stage is almost over.

Statistical analysis

Data analysis was computed using One-Way ANOVA to compare differences among treatments, followed by pairwise comparisons if significant differences are identified. Data analysis was computed using the SPSS software in accordance with the copyrights of Rajabhat Kanchanaburi University.

Results

Effects of different fruit waste diets on larval development

The development time of black soldier fly larvae varied significantly depending on the fruit waste substrate used. The larvae fed with papaya and mixed fruit substrate presented the highest average weight, ranging from 210 to 260 milligrams per individual. This weight was highly significant differences ($p = 0.001$) compared to those fed with other types of substrates. The duration of fifth instar larvae to the pre-pupal stage showed that larvae consuming papaya substrate had the longest development time, averaging 30 days. In contrast, those fed with banana acquired 27 days, and mixed fruit substrate acquired 24 days (Figure 1).

Effects of different diets on larval development and adult morphology

The size of the larvae followed a similar trend to weight gain, with papaya and mixed fruit-fed larvae achieving the largest body sizes, followed by banana-fed larvae. Pomelo-fed larvae were consistently smaller. Despite differences in weight and size, the larval survival rate did not differ significantly among diets ($F = 0.86$, $p = 0.4904$). Although the pupation rate varied among treatments, no statistically significant differences were detected ($F = 2.66$, $p = 0.1004$). A significant difference in the sex ratio was observed among treatments ($F = 9.94$, $p = 0.002$). The highest proportion of males was found in the mixed diet (0.55), whereas the lowest was recorded in the pomelo diet (0.44). The sex ratios for the other treatments were within a similar range (0.47–0.51), indicating a balanced male-to-female distribution. The percentage of abnormal adults was significantly affected by diet (F = 4.44, p = 0.032). The lowest incidence of abnormal adults was recorded in the chicken feed treatment (2 ± 0.0%), while the highest percentages were observed in larvae reared on papaya (7 ± 0.0%) and banana (6 ± 0.0%) diets. The mixed diet resulted in a moderate abnormality rate (5 ± 0.0%), whereas pomelo-fed larvae exhibited a relatively lower incidence (3 ± 0.0%) (Table 1, Figure 2).

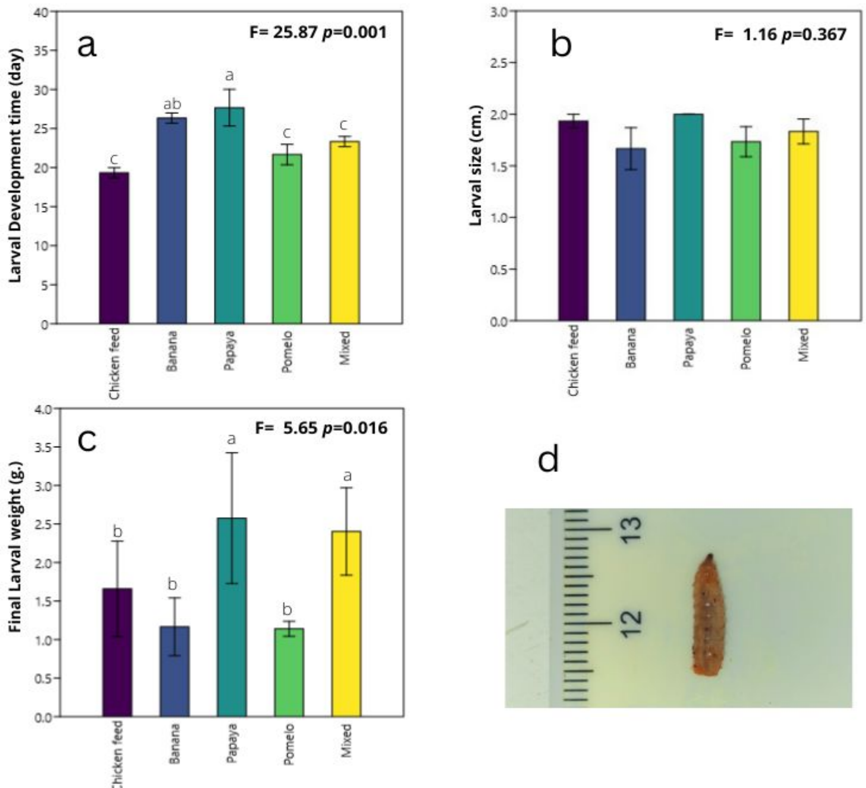

Figure 1. Effects of different diets larval development metrics: (a) Duration of larval development (b) Size of black soldier fly larvae (c) Weight of black soldier fly larvae (d) Measuring length of black soldier fly

Table 1. Effects of different diets on larval development and adult morphology

Diet (g)	Larval Survival rate (%)	Pupation Rate (%)	Sex ratio	Abnormal Adult (%)
chicken feed	95.5 ± 0.85	70 ± 0.81	0.47 [b]	2 [b]
banana	96.1 ± 1.25	55 ± 1.31	0.51 [b]	6 [a]
papaya	97.9 ± 0.81	66 ± 0.85	0.50 [b]	7 [a]
pomelo	94.3 ± 1.15	40 ± 0.64	0.44 [b]	3 [a]
mixed	97.2 ± 0.72	70 ± 1.23	0.55 [a]	5 [a]
F value	0.86	2.66	9.94	4.44
P value	0.4904	0.1004	0.002	0.032

Note: * Mean values followed by the same letter in the same row do not vary significantly ($p < 0.05$). The values are means ± SE

Adult sex ratio = *N* males/(*N* males + *N* females) Ancona *et al*., 2017

0 = only females in the population and 1 = only males in the population

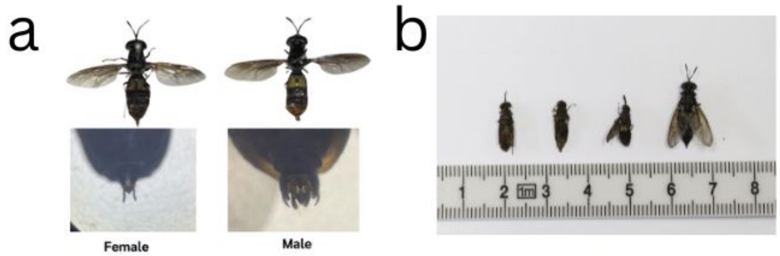

Figure 2. Characteristics of adult black soldier fly (Male and Female), (a) Morphological characteristics of adult male and female (b) Characteristics of abnormalities in adult flies

Quantity of frass obtained from black soldier fly larvae fed on different diets

100 BSF larvae converting 500 grams (fresh weight) of different fruit waste into fertilizer was observed. The larvae fed with a mixed fruit substrate produced the greatest quantity of frass, averaging 70 grams (dry weight), above the other treatment groups. Subsequently, larvae fed with a chicken meal showed an average production of 60 grams, whereas those fed on a papaya substrate presented an average yield of 55 grams (Figure 2). Furthermore, the study revealed that BSF fed on a mixed fruit substrate exhibited the highest egg production, with an average of 100 to 170 egg clusters per group. The pupation rate was raised, reaching up to 70%. In contrast, larvae fed with papaya substrate yielded 90 to 160 egg clusters per group, with a pupation rate of 68% (Figure 3).

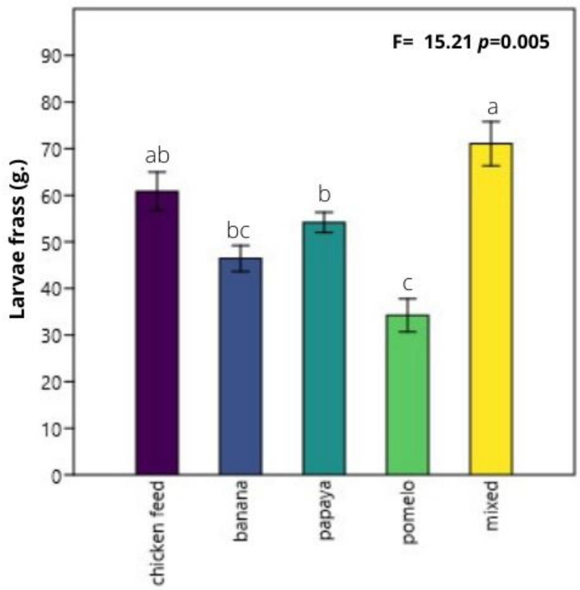

Figure 3. Quantity of frass obtained from black soldier fly larvae fed on different substrate

Discussion

The present study investigated the impact of different diet treatments on the developmental performance, morphology, and waste conversion efficiency of *Hermetia illucens* larvae. The results presented to the optimization of substrates for sustainable insect-rearing and waste management applications.

The larval weight and size were varied considerably among the diets, with the highest weights (210–260 mg per individual) and the largest body sizes being achieved by larvae fed on papaya and mixed fruit substrates. Because these substrates are well-balanced and full of nutrients, they are likely to provide the right amount of carbohydrates and proteins for larval growth (Barragán-Fonseca *et al*., 2017). In larvae, mixed fruit diet may provide a wide range of nutrients, potentially enhancing energy metabolism and protein synthesis. Similarly, papaya, which is known for its high sugar content and digestibility, may increase the availability of energy for larval growth. However, larvae fed papaya took longer to develop (30 days) than those fed mixed fruit (24 days) or banana (27 days) suggests that, even though papaya is high in nutrients, it may also contain substances that slow development, like antinutritional factors, enzyme inhibitors, or a lot of water, which could change the metabolism or growth efficiency of the larvae (Nguyen *et al*., 2020). The fact that papaya contains different nutrients than other foods may also explain why larvae that consume it take longer to grow. This could indicate that their bodies have to work harder to break down the food, which takes more energy and delays their growth. Additionally, the high moisture content in papaya may result in the dilution of nutrients, which can result in a delayed assimilation of essential compounds. Previous research showed that substrate composition, such as moisture levels and nutrient balance, can have effect on how insects grow (Chia *et al*., 2019; Bekker *et al*., 2021). In contrast, larvae were fed a mixed fruit diet exhibited a shorter development time (24 days) while still attaining high weights and large body sizes. This might be because of the higher levels of essential nutrients, this balanced composition may also help faster growth and development by making enzyme activity and nutrient absorption better (Lalander *et al*., 2019).

The larvae that were fed a mixed fruit substrate made the most frass (70 g dry weight). This finding suggests that the varied range of nutrients in mixed fruit waste treatment makes substrates simple to use and digest. By giving larvae, a wide range of macro- and micronutrients, mixed substrates may improve enzyme activity and nutrient uptake, leading to higher metabolic efficiency and waste conversion. This aligns with recent studies indicating that varying substrates in the larval gut enhance microbial activity, thereby facilitating digestion and nutrient absorption (Holtof *et al*., 2019; Lalander *et al*., 2019). We also found the large amounts of frass produced (60 g and 55 g, respectively) by chicken feed (control treatment) and papaya diets treatment show that waste can be converted efficiently. Chicken feed is a commercially formulated product that is designed to provide balanced nutrition, which may account for its relatively high frass production. However, its application in large-scale insect cultivation may be less sustainable or cost-effective compared to fruit waste substrates. The importance of frass production is not limited to waste management; it is also a valuable byproduct. Black soldier fly frass is an alternative to chemical fertilizers due to its high concentration of organic matter, nitrogen, phosphorus, and potassium. Larvae fed with mixed fruit treatment high frass yields underscore their potential for dual benefits: the production of high-quality organic fertilizers and the efficient conversion of refuse. This finding is very important for circular economy models that want to close the loop in farming systems by turning organic waste into compost that is full of nutrients (Franco *et al*., 2021). Additionally, frass production is inextricably linked to the efficacy of substrate conversion and larval growth. This shows how important to find the best substrate composition to balance larval growth, development time, and the efficiency of waste conversion. More research needs to be done on its chemical makeup when it comes from different substrates and how well it works as a fertilizer. This method is promoted community-level waste management systems, which provide opportunities for local entrepreneurship and employment, particularly in regions with inadequate waste infrastructure.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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