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**ORIGINAL ARTICLE**

# Growth Performance of Black Soldier Fly (*Hermetia illucens*) Fed Oriental Melon Waste and Analysis of the Frass Value

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## Abstract

Agricultural by-products are generated throughout all agricultural production processes. Currently, the by-products are often treated using non productive methods, such as incineration, storage, or abandonment. In South Korea, oriental melons are predominantly cultivated in specific regions. However, this is associated with a significant amount of waste due to immature or low-grade production. Therefore, an environmentally friendly and efficient method to upcycle these waste melons is necessary. The utilisation of black soldier fly (BSF) larvae could be a potential solution. This study investigated the growth performance of BSF larvae fed oriental melon waste and analysed the composition and fertiliser efficacy of the frass produced by the larvae. The results of the larval growth experiment indicated that, compared with BSF larvae fed calf feed or food waste as control groups, the oriental melon waste-fed larvae exhibited a delayed growth period and reduced weight and size, although no significant difference in the survival rate was observed. BSF larvae decomposed approximately 81% of the waste melon, of which it can bio-convert approximately 12%. Composition analysis of the frass produced by BSF larvae fed oriental melon waste showed that it met the standards of fertiliser regulations. Furthermore, fertiliser efficacy analysis demonstrated that lettuce treated with frass from oriental melon waste-fed larvae significantly increased in leaf length, root weight, fresh weight, and dry weight compared to those in the untreated group. These results indicate that BSF larvae can effectively decompose oriental melon waste, and the resulting larvae and frass have sufficient industrial value for practical use.

**Key words** : Black soldier fly (*Hermetia illucens*) larvae, Oriental melon waste, Fertiliser effectiveness.

## 1. Introduction

The increase in the global population has led to a corresponding increase in agricultural production (UN, 2022). This escalation has resulted in the generation of substantial amounts of agricultural by-products at every stage of production, processing, and distribution. According to a report by the Food and Agriculture Organisation (FAO) in 2017, 13.8% of food waste in 2016 occurred during the production and distribution processes, amounting to approximately 400 billion US dollars (FAO, 2017). Although methods such as converting these by-products into food, feed, compost, or energy exist, they are insufficient for processing all agricultural waste effectively. Therefore, a critical need exists for environmentally friendly disposal methods enabling the upcycling of agricultural by-products.

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One promising approach for efficient processing and upcycling of agricultural waste is the utilisation of black soldier fly (BSF) (*Hermetia illucens*). BSF larvae decompose a wide variety of organic materials (Banks et al., 2014; Oonincx et al., 2015; Mohd-Noor et al., 2017; Cai et al., 2018; Chun et al., 2019; Lim et al., 2019). After decomposition, these larvae can be processed into protein or fat sources for animal feed, and the resultant frass can be used as fertiliser in accordance with standard fertiliser regulations (Choi et al., 2013; Lee et al., 2013; Salomone et al., 2017; Spranghers et al., 2017; Meneguz et al., 2018; Chun et al., 2019; Wang et al., 2020). Additionally, BSF consume only water instead of organic matter during the adult stage. Therefore, they do not transmit diseases (Furman et al., 1959; Diener, 2010). Thus, BSFs are advantageous in industrial applications.

In South Korea, the production of oriental melons (*Cucumis melo var. makuwa*) in 2023 was 208,542 t, constituting approximately 11.9% of the total vegetable and fruit production,i.e., 1,753,172 t, of thenation. Approximately 95.7% of the oriental melons produced in the country are produced in Gyeongsangbuk-do (Korean Statistical Information Service, 2024), of which a substantial portion is produced in Seongju-gun (171,654 t) (Agriculture Technology Center of Seongju-gun, 2024). The extensive production in Seongju-gun led to an increase in the production of low-grade, immature, or rotten fruits. To manage this surplus, Seongju-gun purchased and processed approximately 3,399 t of low-grade or waste-oriented melons at approximately 21 billion South Korean won. Unprocessed waste oriental melons are often used as feed or compost, which has limited effectiveness, and many rely on nonproductive treatments such as landfills and storage (MAFRA, 2020).

Here, we aimed to investigate the decomposition rate of waste oriental melons and the growth of BSF larvae fed with this substratein order to process waste oriental melons in an environmentally friendly manner and utilise resources efficiently. Furthermore, we analysed the fertiliser properties of the frass produced after decomposition and conducted fertiliser efficacy tests on leafy vegetables such as green skirt lettuce (*Lactuca sativa*). In this study, we explored the potential of upcycling waste oriental melons using BSF, with the aim of contributing to sustainable agricultural waste management practices.

## 2. Materials and Methods

### 2.1. Insect culture and growth performance of BSF larvae

3$^{rd}$ instar BSF larvae were used in this study. The BSFs were cultured as described by Koo et al.(2023a) and Park et al.(2016). After BSF eggs that hatched simultaneously were collected, 6-day old BSF larvae were used in this experiment. Five hundred larvae used as the experimental group were kept in a plastic container (23× 12.5× 16.5 cm) and were fed oriental melon waste. Two control groups of BSF larvae, one fed calf feed and the other food waste from the National Institute of Agricultural Sciences cafeteria, were reared under identical conditions.

Low-grade or rotten oriental melon waste was obtained from Seongju-gun, Republic of Korea. The substrates used for the BSF feed were stored at 4°C. The experiments were conducted at 26°C, 14:10 (L:D), and 60% relative humidity. Twenty BSF larvae per experimental group were randomly collected, and the weight and the length of each BSF larvae were measured with a scale (BP190S, Sartorius AG, Germany) and calipers (CD-10CP, Mitutoyo Corp., Japan) every 4 days until over 40% of larvae reached the pre-pupal stage. One hundred BSF prepupae per experimental group were counted to calculate the larval survival rate. We assessed the fecundity rates by counting the number of BSF adults after one hundred BSF prepupae were randomly selected from each experimental group.

### 2.2. Calculations of BSF larvae fed oriental melon waste

BSF larvae, oriental melon wastes, and frass from the BSF larvae were oven-dried at 105℃ for 3h (SOF-155, Daihan Science, Republic of Korea) (Shreve et al., 2006) to calculate the feeding performance. Feeding performance was calculated for different substrates using Equations (1) and (2) (Liu et al., 2018). W is the total dry weight of the substrate supplied, R is the total dry weight of the residue after the experiment, and G is the difference between the last instar of BSF larvae (40% of larvae became pre-pupae) and initial BSF larvae (6-day old BSF larvae from eggs).

$$Ratio\ of\ reduced\ waste\ dry\ matter\ (\%) = \frac{W-R}{W} \times 100 \quad (1)$$

$$Bioconversion\ efficiency\ (\%) = \frac{G}{W-R} \times 100 \quad (2)$$

### 2.3. Analysis of fertiliser components and fertiliser effectiveness of frass test

After the BSF larvae were fed oriental melon, 500 g of frass was obtained. The organic matter, salinity, and eight heavy metals (arsenic, cadmium, mercury, lead, chromium, copper, nickel, and zinc) in each frass were analysed. The frass analysis was commissioned by the Korea Agriculture Technology Promotion Agency (KOAT) and conducted using physicochemical testing methods in the Fertiliser Control Act in South Korea (MOLEG, 2024). The fertiliser effectiveness of the frass experiment was commissioned and analysed by HyunNong Co., Ltd., using green skirt lettuce as the test plant. A horticultural potting soil was used in this study. Each frass from larvae fed oriental melon waste and food wastes were applied at a rate of 125 kg/10a. As controls, both plants were planted in pots with no fertiliser treatment. After 21 days post-planting, we harvested each group of green skirt lettuce and measured leaf length, root weight, fresh weight, and dry weight.

### 2.4. Statistical analyses

Statistical analyses were performed using the IBM SPSS Statistics 27.0.0.0 software. Data were analysed using a one-way analysis of variance with a significance level of $p<0.05$, followed by Duncan's multiple-range test.

## 3. Results and Discussion

### 3.1. Analysis of growth and feeding performance of BSF larvae fed with oriental melon waste

BSF larvae fed oriental melon waste required 44 days to reach the end of the larval stage. Compared with the developmental time of BSF larvae fed calf feed or food waste, that of BSF larvae fed oriental melon waste was delayed by 24 days (Table 1). The developmental time of BSF is correlated with various growth conditions, such as density, pH, and substrate texture (Parra Paz et al., 2015; Liu et al., 2018; Meneguz et al., 2018; Scala et al., 2020). Substrate quality is an important factor affecting the developmental time of BSF (Gobbi et al., 2013; Oonincx et al., 2015; Jucker et al., 2017). If the larvae do not receive sufficient food, they may not receive the necessary nutrients for proper growth, resulting in smaller larvae and a longer pupation period

**Table 1.** Larval developmental time, larval survival rate, and fecundity rate of adult black soldier flies fed different substrates

| Parameter | Food waste | Calffeed | Orientalmelon waste |
|---|---|---|---|
| Larval developmental time (d) | 20 | 20 | 44 |
| Larval survival rate (%) | 98.5±1.15[a] | 99.5±0.25[a] | 82.1±13.73[a] |
| Fecundity rate (%) | 100±0[b] | 100±0[b] | 78.0±6.98[a] |

After 40% of larvae fed oriental melon waste became pre-pupae, larval developmental time and survival rate were investigated. After the pupae of BSF became adults, the fecundity rates of adults were counted. Larval survival and fecundity rate data are shown as the mean values ± standard deviation (larval survival; n = 500, fecundity rate; n = 100).

(Nijhout, 2003). According to a nutritional analysis of oriental melon waste, it consists of approximately 84.1% water (Koo et al., 2023b). This high water content indicates insufficient nutrients for BSF larval growth, and the developmental time of the BSF larval stage will be delayed. However, the survival rate of larvae fed oriental melon waste was 82.1±13.73%. The survival rate of BSF larvae was lower than that of the larvae fed calf feed and food waste (99.5±0.25%, 98.5±1.15%). However, no significant differences were observed in the survival rates of the three substrates (Table 1). Jucker et al.(2017) reported that low levels of carbohydrates in the substrate may lead to a lower survival rate of BSFs. The amount of carbohydrates inoriental melon is 11.7%, and itscarbohydrate content is highest afterits water content (MFDS, 2024). This result suggests that oriental melon waste does not affect the larval survival rate of BSF.

### 3.2. Growth performance of BSF larvae fed different substrates

After harvesting the BSF larvae, the average weight of those fed oriental melon waste was 0.10±0.021 g (Fig. 1A), and those of BSF larvae fed calf feed and food waste were 0.16±0.018 g and 0.27±0.028 g, respectively. The weight of BSF larvae fed oriental melon waste was 1.6 times lower than that of BSF larvae fed calf feed and 2.8 times lower than that of the BSF larvae fed food waste. The average length of BSF larvae fed oriental melon waste was 17.3±1.38 mm. The test larvae were significantly shorter than the BSF larvae fed calf feed and food waste (18.8±0.93 mm and 22.6±0.89 mm, respectively) (Fig. 1B). These results indicate that oriental melon waste is not suitable for BSF larval growth, compared with calf feed and food waste, because of its poor nutritional content. Koo et al.(2023b) also showed that BSF larvae fed two fruit by-products, mandarin waste and apple pomace, were smaller than BSF larvae fed calf feed as a control. Further, the growth performance of BSF larvae is significantly related to good-quality nutrient content, especially protein (Gobbi et al., 2013; Nguyen et al., 2013; Oonincx et al., 2015; Jucker et al., 2017; Tinder et al., 2017). The reduced weight and length of BSF larvae fed oriental melon waste could be attributed to the poor nutritional composition of the oriental melon waste, particularly its protein content of only 1.2% (Koo et al., 2023b).

### 3.3. Analysis of feeding performance of BSF larvae fed oriental melon waste

The reduction rates of oriental melon waste, food waste, and calf feed by BSF larvae were 80.5±0.22%, 79.0±1.21%, and 62.1±0.46%, respectively (Table 2). These results show that BSF larvae are more efficient at reducing oriental melon waste thanfood waste or calf feed. Gold et al.(2020) reported that BSF larvae could reduce 46.7–60.0% of fruit and vegetable waste. Another study reported that BSF larvae fed mandarin

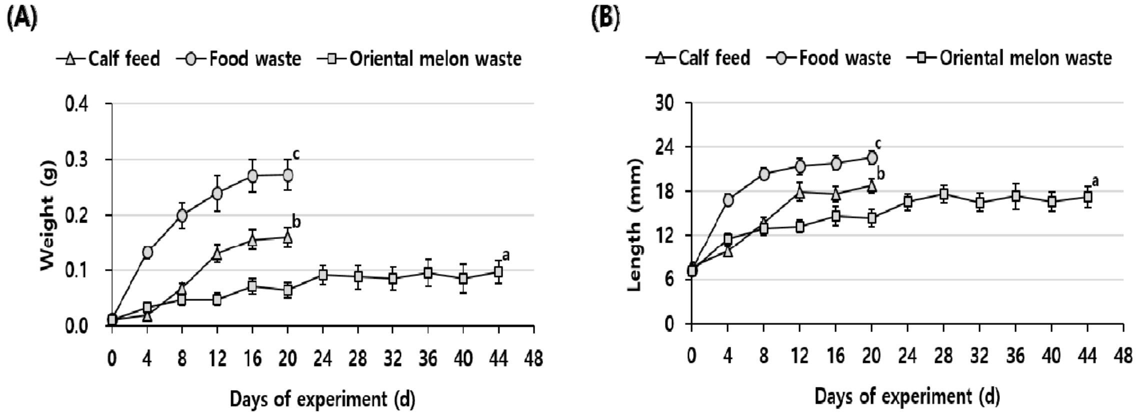


**Fig. 1.** Growth performance of BSF larvae fed oriental melon waste. BSF larvae (6 day-old from eggs) were oriental melon waste, calf feed and food waste respectively. (A) Change in weight of BSF larvae fed oriental melon waste. (B) Change in length of BSF larvae fed oriental melon waste. Data are shown as the mean values ± standard error of the mean (n = 20). Different letters indicate significant differences in the weight or the length of control and test animals ($p<0.05$, analysis of variance)

**Table 2.** Analysis of feeding performance of BSF larvae after being fed oriental melon waste

| Parameter | Food waste | Calf feed | Oriental melon waste |
|---|---|---|---|
| Ratio of reduced waste (%) | $79.0\pm1.21^{a}$ | $62.1\pm0.46^{b}$ | $80.5\pm0.22^{a}$ |
| Bioconversion efficiency (%) | $30.7\pm0.62^{a}$ | $19.0\pm0.32^{b}$ | $11.8\pm0.37^{b}$ |

Ratios of reduced waste (%) and bioconversion efficiency (%) were analysed using the dry matter of BSF larvae and BSF larval frass for different substrates. Data are shown as the mean values ± standard error of the mean (n = 30). Different superscript letters indicate significant differences at $p<0.05$

waste and apple pomace could reduce these wastes by 61.5% and 48.0%, respectively (Koo et al., 2023a). Therefore, BSF larvae appear to be particularly effective in reducing oriental melon waste, which is likely due to their semi-liquid physical properties. This waste has a high water content and soft, semi-liquid texture. Furthermore, the crude fibre content of oriental melon waste is substantially lower than that of mandarin waste and apple pomace (Koo et al., 2023b). Bruno et al.(2020) noted that BSF larvae prefer to digest semi-liquid substrates because fibres are negatively correlated with the waste reduction ratio (Liu et al., 2018). The bioconversion efficiency of BSF larvae fed with oriental melon waste was 11.8±0.37%, which was significantly lower than that of food waste and calf feed (Table 2). However, Surendra et al. (2020) noted that BSF larvae fed different fruit and vegetable wastes showed bioconversion efficiencies ranging from 4.1% to 10.8%. The bioconversion efficiency observed for oriental melon waste was within a range similar to that of other fruit and vegetable wastes.

### 3.4. Fertiliser nutrient composition analysis and fertilising effect experiment of frass produced by larvae of BSF fed oriental melon waste

Fertiliser analysis was conducted by harvesting the frass produced by BSF larvae fed oriental melon waste, the organic matter content of which was 40.29% and the salt content was 0.23%. Additionally, testing for eight heavy metals revealed either trace amounts or no detection,

**Table 3.** Analysis of contents of frass produced by BSF larvae fed food waste and oriental melon waste

| Parameter | Food waste | Oriental melon waste | Standard value |
|---|---|---|---|
| Organic matter (%) | 82.67 | 40.29 | 30% above |
| Salinity (%) | 2.28 | 0.23 | 2% below |
| As (mg/kg) | ND | ND | 45 below |
| Cd (mg/kg) | ND | ND | 5 below |
| Hg (mg/kg) | ND | 0.07 | 2 below |
| Pb (mg/kg) | ND | ND | 130 below |
| Cr (mg/kg) | ND | 2.31 | 200 below |
| Cu (mg/kg) | 1.77 | 36.07 | 360 below |
| Ni (mg/kg) | ND | ND | 45 below |
| Zn (mg/kg) | 14.18 | 105.06 | 900 below |

Amounts of organic matter, moisture, salinity, and eight heavy metals in BSF frass were measured. ND implies "not detected." As, arsenic; Cd, cadmium; Hg, mercury; Pb, lead; Cr, chromium; Cu, copper; Ni, nickel; Zn, zinc

**Table 4.** Growth performance of lettuce after applying frass of BSF larvae fed oriental melon waste

| Parameter | Leaf length | Root weight | Fresh weight | Dry weight |
|---|---|---|---|---|
| NT | 10.7±1.64a | 1.1±0.53a | 4.8±2.16a | 0.8±0.52a |
| Food waste | 11.6±1.46a | 2.3±0.70b | 7.9±2.13b | 1.1±0.56a |
| Oriental melon waste | 14.2±1.09b | 2.4±1.00b | 10.2±3.03c | 2.0±1.16b |

NT: No treatment. After lettuce was fertilised with frass from BSF larvae fed oriental melon waste, leaf length, root weight, and fresh and dry weight of lettuce were measured. Data are shown as the mean values ± standard deviation (n = 15). Different letters indicate significant differences in the weight or the length of the control and test plants ($p<0.05$, analysis of variance)

confirming that all the contents met the official fertiliser standards for BSF frass (Table 3). Compared with frass from BSF larvae fed with food waste, that from oriental melon waste-fed BSF larvae showed an approximately 42.38% lower organic matter content and approximately 2.05% lower salt content. An efficacy analysis was conducted on the leaf length, root weight, fresh weight, and dry weight of green skirt lettuce (*Lactuca sativa*) treated with the frass of BSF.

larvae fed oriental melon waste. The results showed a significant increase in leaf length, root weight, fresh weight, and dry weight compared with those of the untreated group (Table 4). A comparison of lettuce treated with frass from BSF larvae fed general food waste and that from BSF larvae fed oriental melon waste feed revealed no significant difference in root weight. However, the leaf length, fresh weight, and dry weight were significantly higher in the group treated with frass from oriental melon waste-fed BSF larvae. These findings suggest that the organic matter content of the BSF frass is sufficient to support the growth of green skirt lettuce. Contrastingly, the higher salt content in frass from food-waste-fed BSF larvae likely adversely affected lettuce growth compared with that from oriental melon waste-fed BSF larvae. Supporting evidence from other studies indicates that frass from BSF larvae fed food waste increased grass growth compared with that in untreated grass. However, as the application rate increased, the higher salt content led to a decrease in grass weight (Choi et al., 2013).

## 4. Conclusions

BSF larvae offer an eco-friendly method for decomposing agricultural by-products and efficiently upcycling organic matter. We evaluated the feasibility of using BSF larvae to process oriental melon by-products, specifically surplus oriental melons, produced in Seongju- gun, South Korea. When fed oriental melon waste, the growth period of BSF larvae was prolonged compared with that of BSF larvae fed food waste or calf feed. However, the survival rates remained unaffected. The weight and length of BSF larvae fed oriental melon waste were less than the control. The larvae were capable of decomposing up to 80.5% of the melon waste, achieving a bioconversion rate of 11.8%. Analysis of the frass resulting from the decomposition of oriental melon waste revealed that the organic matter, salinity, and heavy metal levels complied with fertiliser regulatory standards. Further testing of leafy vegetables indicated that compared with untreated soil, frass application significantly increased leaf length, root weight, fresh weight, and dry weight. Compared with frass from larvae fed with food waste, those of melon-fed BSF showed significantly higher leaf length, fresh weight, and dry weight, likely because of differences in salinity levels. These findings suggest that when using BSF larvae for industrial purposes, it may be more effective to combine melon waste by-products with other organic materials to develop an optimised feed source for larvae.

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