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The Efficiency of Black Soldier Fly Larvae with Vegetable, Fruit and Food Waste as Biological Tool for Sustainable Management of Organic Waste

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

This study investigated the sustainable management of wet organic waste using Black Soldier Fly Larvae (BSFL) for an innovative biological approach to waste management. The organic wet wastes such as fruit, vegetable, and food wastes were processed and fed to BSFL larvae from day 5 and the bioconversion process was carried out at Black Soldier Fly Unit, Tamil Nadu Agricultural

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University for 21 days. Among the three wastes, the highest bioconversion efficiency was recorded in fruit waste with 67% Substrate Reduction, 10.8% Efficiency of Conversion of Digested feed, 5.7% Bio Conversion Rate, and 4.18 Waste Reduction Index after 21 days. Whereas vegetable and food waste achieved similar bioconversion efficiency. The results suggest that BSFL-based bioconversion can be an effective and eco-friendly waste management and resource recovery technique to significantly lower the volumes of organic wet waste while converting it into high-value biomass and leading to a circular economy model.

Keywords: Black soldier fly; bioconversion efficiency; organic wet waste management; waste reduction indices; waste to biomass conversion.

1. INTRODUCTION

Black soldier fly larval (BSFL) farming is getting popularized nowadays as an innovative approach to waste to wealth, which is said to meet 12 out of 17 sustainable development goals (no poverty, zero hunger, good health and well-being, gender equality, clean water and sanitation, decent work and economic growth, industry, innovation and infrastructure, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace, justice and strong institutions) [1]. This process involves employing larvae of BSF *Hermetia illucens* L. (Diptera: Stratiomyidae), a voracious feeder of organic wet waste [2]. BSF larvae consume around 8-10 times their body weight and transform them into protein and fat, and store them in their bodies.

The management of biowaste, resulting from agricultural processes, urbanization, and population growth, has become a global concern with profound implications for food security, poverty alleviation, and the environment. The improper disposal, subpar treatment, and unregulated landfilling of biowaste in low- and middle-income nations pose significant threats to the environment and public health [3]. According to the Food Waste Index Report by Dutta et al. [4] an alarming quantity of 931 million tonnes of food waste was generated in 2019, accounting for 17% of total global food production. This food waste is distributed across various sectors, with 61% occurring in households, 26% in food service establishments, and 13% in retail. Alongside the pressing issue of food waste generation, the exponential growth of the global population has led to an increased demand for animal-based protein [5]. This heightened demand, in turn, triggers the overexploitation of natural resources. Insect-based bioconversion has emerged as a solution, gaining significant attention for several reasons. BSF reduces the volume of biowaste, mitigating the need for landfilling and decreasing greenhouse gas emissions associated with waste decomposition. The protein-rich larvae can be used as a sustainable source of animal feed, reducing the pressure on traditional protein sources like soy and fishmeal, which often rely on resource-intensive agricultural practices. Additionally, the resulting frass (larval waste) from BSF bioconversion is a nutrient-rich fertilizer, closing the loop in nutrient cycling and promoting soil health [6]. This study was planned to assess the bioconversion efficiency of the BSFL in managing food waste, vegetable waste, and fruit waste.

2. MATERIALS AND METHODS

2.1. Procurement of Organic Waste

This study was carried out at the BSF Unit, Department of Environmental Science, Tamil Nadu Agricultural University (TNAU), Coimbatore by procuring organic wet waste materials from three key locations in the Coimbatore, Tamil Nadu, India: Uzhavar Sandhai (Farmers' Market, Cowley-Brown Road - 11°00'50'N 76°56'40"E), a local fruit stall (Lawley Road - 11°00'48"N 76°56'23"E) and student mess (University Mess, TNAU - 11°00'30"N 76°55'57"E). This experiment is designed based on the modified BSFL farming methodology followed by Dortmans et al., [7].

2.2. Rearing of Larvae

The BSF eggs were purchased from Hindustan Protein, Palladam, Coimbatore and incubated in the hatchery unit. Newly hatched larvae were nurtured with three protein feeds viz., rice bran powder, wheat bran powder, and poultry feed to meet nutritional needs for the initial five days, a critical period in larval development. The five days old larvae were introduced to process three types of organic waste viz., fruit waste, vegetable waste, and food waste, ensuring a feeding rate of 200 mg/larva/day [8].

2.3 Waste Processing

The collected waste undergoes a pretreatment process before being fed to BSFL (Fig. 1).

The fruit, vegetable and food waste used in this study were shredded and chopped into 2 cm after the removal of non-biodegradable materials. Additionally, the moisture content was reduced to 60%, optimizing conditions for efficient BSFL consumption. Initial weight and volume measurements were recorded to establish baselines for evaluating subsequent reductions during bioconversion. Pre-treatment techniques for enhancing substrate biodegradability and nutrient viability [9].

2.4 Experimental Setup

This study utilized five-day-old BSFL for each treatment, in triplicates to minimize the error. Rearing took place under controlled conditions, maintaining a relative humidity range of 40-60% and a temperature of 32°C ± 3°C. Rectangular trays (60 x 45 x 15 cm) were used to maintain a controlled environment for larval development [10]. This experimental setup is aimed at assessing the larvae's bioconversion efficiency in processing different organic waste types. Using a pestle and mortar, whole insects were ground before analysis. The insect samples were dried in a drying oven at 100°C to determine their moisture content using Equation (1) AOAC, [11].

$$Moisture\ content = \frac{(A+B-C)}{B} \times 100 \qquad (1)$$

A - Crucible weight, B - Sample weight, C – Weight of crucible after oven drying process.

The experiment spanned until 70% of the larvae had transformed into prepupae, concluding after 22 days post-hatching [12]. The trays containing the larvae were weighed to determine both the final larval weight and the residual weight, which comprised the frass (larval excrement) and any unprocessed waste. Fig 2 explains the methodology of bioconversion experiments.

2.5 Waste reduction indices

The Waste Reduction Index (WRI) serves as a metric for assessing the larvae's efficiency in diminishing feeding substrates, with higher values indicative of a heightened capability to reduce organic matter [13]. The waste reduction index (WRI) can be used to assess BSFL's ability to decompose waste within a certain period (Eq. (2) & (3)).

$$D = \frac{w-R}{w}; \qquad (2)$$

Where D is a percentage of degraded waste weight, W is a total amount of waste used, R is a final residual weight after the completion of the experiment, t is a duration of the experiment

$$WRI = \frac{D}{t} \times 100; \qquad (3)$$

The efficiency of conversion of digested food (ECD) by larvae during the rearing period is calculated using eq. (4) given by Pliantiangtam et al., [14].

$$ECD = \frac{Larval\ and\ prepupae\ weight\ (g)}{Distributed\ substrate\ (g) - Residual\ substrate\ (g)} \qquad (4)$$

The bioconversion rate (Waste to Biomass conversion) of BSFL is calculated according to Gold et al., [15] using the eq. (5)

$$BCR = \frac{Larvae_{gain}(g)}{Feed_{mass}(g)} \times 100 \qquad (5)$$

The substrate reduction are calculated according to Jucker et al. [16] using the following eq. (6)

$$SR = W - \frac{R}{W} \times 100 \qquad (6)$$

W = total amount of feed provided,
R = remaining substrate

3. RESULTS AND DISCUSSION

3.1 Waste Conversion

The pre-processing of the wastes led to efficient waste reduction with substrate reduction between 60 to 68% in three organic wet wastes. Organic waste pre-processing such as particle-size reduction, excess water removal and inorganic waste elimination were required for the biowaste treatment, which promotes the larval growth and improve the substrate digestion [17]. The inorganic waste materials like large chunks of plastic packaging materials were removed during waste processing as larvae take a longer time to degrade and are hazardous for their further growth [18].

Fig. 1. Pre-processing of organic wet waste

Fig. 2. Bioconversion of organic wet wastes

The moisture content of the waste was reduced from 79 – 84% to 51 to 56%. An almost similar range of initial moisture content between 82 - 89% ensured the highest bioconversion efficiency during larval development as it plays a major role in food absorption capacity of BSFL [19,20]. The organic carbon in three wastes showed >60% reduction at the end of the ingestion cycle with a substantial reduction in the frass of fruit waste (12.32%). Total organic carbon and the carbon-to-nitrogen ratio significantly decreased as a result of BSFL feeding efficiency, whereas the feedstock's total nitrogen, total phosphorus, and total potassium contents increased [3].

3.2 Waste Reduction Indices

Table 1 explains the versatile efficiency of BSFL in reducing fruit, vegetable, and food waste over the observed days. The reported WRI values further illustrate this variation, with fruit waste yielding the highest reduction index of (4.18) followed by vegetable waste (3.83), and food waste (3.75). These results are similar to 4.36 WRI in fruit peel waste Priyambada et al., [21] whereas 4.77 and 2.72 WRI were observed in fruit and vegetable wastes respectively [22]. These results highlight the significance between waste type and the duration of the bioconversion process, emphasizing the need for approaches to optimizing the efficacy of BSFL in waste reduction and bioconversion initiatives. This study provides a comprehensive overview of the biomass obtained and the efficiency of digestible feed conversion (ECD %) for three organic waste types (vegetable waste, fruit waste, and food waste) that are utilized in BSFL bioconversion. Examining each waste type individually reveals distinct performance characteristics. Fruit waste stands out with the highest biomass obtained at 0.80 kg *(dw)* and ECD of 10.8%, indicating superior conversion efficiency of digestible feed into valuable biomass which is much higher than the results of Fitriana et al., [23]. Vegetable waste follows closely with a biomass of 0.72 kg and an ECD of 9.7%, whereas food waste exhibits slightly lower biomass of 0.68 kg and an ECD of 9.2% with a significant difference.

The bioconversion rates also known as waste to biomass conversion for BSFL fed with three organic wastes were determined based on the weight change from larval initiation to the point where 50% of larvae transitioned into prepupae. The bioconversion rate of BSFL in vegetable waste, fruit waste, and food waste was observed to be 5.1%, 5.7%, and 4.8% respectively. These results suggest high significance in converting larval biomass, emphasizing the larvae's adaptability and effectiveness in bio-converting different organic waste substrates which is similar to 4.1% of BCR for fruit and vegetable waste [24].

The SR value of vegetable waste, fruit waste, and food waste by BSF were 61.3%, 67%, and 60% respectively (Fig. 2) which are quite similar to the 60 to 67% SR value observed in organic waste treatment [25]. These results showed high statistical significance among the different waste feedstocks ($p < 0.05$) which was similar to the results of reduction efficiency in fruit waste combined with sludge in an equal ratio (50-70%) [3]. However, bioconversion efficiency was affected by the nutritional composition of feeds which affects the gut microbiota of BSFL [26]. Therefore, BSFL-induced bioconversion proved to be an efficient method for organic waste management. However, the efficiency of both separate waste (specific to a fruit or vegetable) and mixed agro-industry waste (mixed fruits, mixed vegetables, or restaurant wastes) need to be studied specific to the nutrient content of the wastes and environmental conditions of the region to bring a sustainable solution to industrial waste management [27].

Table 1. The waste reduction indices of fruit waste, vegetable waste, and food waste

Feedstock	**Substrate reduction (SR %)**	**Efficiency of conversion of digested food (ECD %)**	**Waste to Biomass conversion (BCR %)**	**Waste Reduction Index (WRI)**
Vegetable waste	61.3±0.83	9.7±0.08	5.1±0.01	3.83±0.06
Fruit waste	67±1.34	10.8±0.19	5.7±0.03	4.18±0.03
Food waste	60±0.57	9.2±0.11	4.8±0.1	3.75±0.04

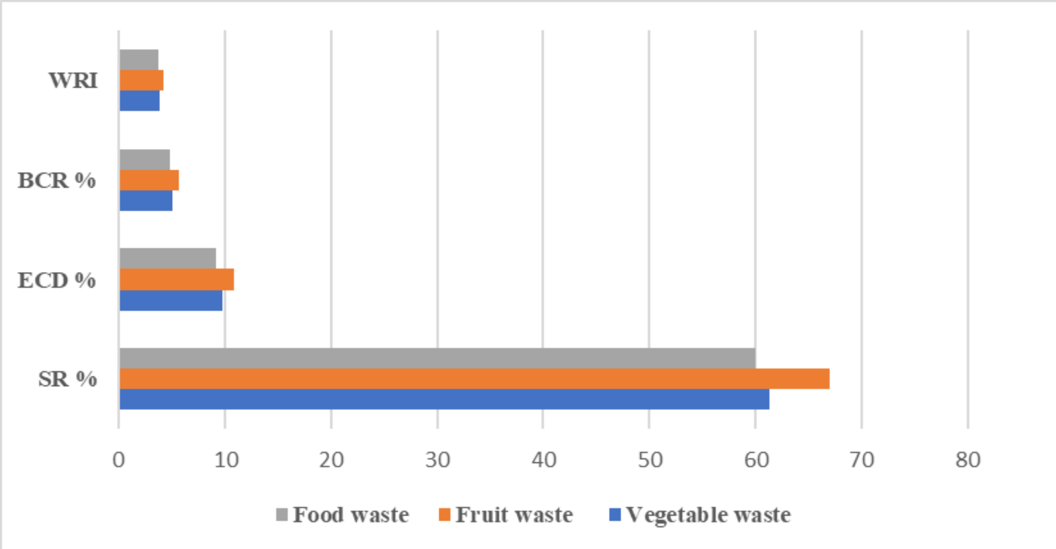

Fig. 3. Organic wet waste bioconversion with BSFL

4. CONCLUSION

The current study highlights the remarkable potential of BSFL in bio-converting wet organic wastes, (fruit waste, vegetable waste, and food waste) achieving a significant substrate reduction of 60 to 67 percent in 20 days. The waste reduction index, efficiency of conversion of digested food, and bioconversion rate exhibited the bioconversion efficiency of BSFL with the highest efficiency recorded in fruit waste as 4.18, 10.8%, and 5.7% respectively. Notably, the waste reduction index reflects the percentage decrease in waste over time, with fruit waste exhibiting the highest reduction, followed by vegetable waste and food waste. This hierarchy suggests that BSFL is particularly proficient at processing fruit waste, possibly owing to its composition and nutritional content. However, further studies may be taken up to further enhance of Bioconversion Rate by optimizing the climatic and substrate/ waste characteristics.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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