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From kitchen waste to ecological resource: Natural colonization and waste conversion potential of black soldier fly (*Hermetia illucens*) in central India

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Abstract
The increasing accumulation of household organic waste has emerged as a major environmental challenge in rapidly urbanizing regions of India. Although the Black Soldier Fly (*Hermetia illucens* Linnaeus, 1758) is widely recognized for its remarkable waste bioconversion capacity under laboratory and industrial conditions, information regarding its natural colonization and ecological role in domestic waste ecosystems remains limited. The present study investigated the natural occurrence, substrate preference, colonization dynamics, and waste conversion potential of *H. illucens* in household organic waste under natural environmental conditions in Sanjivani Nagar, Jabalpur, Central India. A seven-month observational study was conducted from October 2025 to April 2026 using different categories of household organic waste, including fruit residues, vegetable waste, mixed kitchen waste, and other biodegradable materials. Natural colonization by Black Soldier Fly larvae was monitored under ambient environmental conditions, and observations were recorded on larval abundance, substrate preference, colonization period, and waste reduction efficiency. The study revealed that fruit-based substrates, particularly banana, papaya, mango, and watermelon residues, attracted significantly higher larval populations and exhibited faster colonization compared to vegetable-based wastes. Larval activity accelerated organic matter decomposition and substantially reduced waste volume, highlighting the species' efficiency as a natural bioconversion agent. The findings indicate that household organic waste serves as an important ecological niche for naturally occurring BSF populations, which contribute to nutrient recycling and organic waste reduction without human intervention. A strong association was observed between larval abundance and moisture-rich organic substrates, suggesting that *H. illucens* may also have potential as a biological indicator of organic waste accumulation and decomposition dynamics in urban environments. Furthermore, the study demonstrates the ecological significance of BSF as a natural bio-recycling engineer capable of converting biodegradable waste into valuable biological resources. This investigation represents one of the first field-based observations of naturally colonizing Black Soldier Fly populations in household organic waste systems from Central India. The results highlight the potential of *H. illucens* for decentralized waste management, circular bioeconomy initiatives, and sustainable environmental conservation, while providing baseline ecological information for future research on insect-mediated waste valorization in tropical urban ecosystems.

Keywords: *Hermetia illucens*, black soldier fly, household organic waste, natural colonization, waste bioconversion, substrate preference, circular bioeconomy, central india, waste-to-wealth, sustainable waste management

Introduction

Black Soldier Fly (*Hermetia illucens* Linnaeus, 1758) has emerged as one of the most extensively studied insect species in the field of organic waste management and circular bioeconomy. The species is recognized for its remarkable ability to convert diverse organic waste materials into valuable biomass, organic fertilizer, and bioenergy resources. According to Diener *et al*. (2011) [5], BSF larvae efficiently utilize a wide range of organic substrates and can substantially reduce waste volume while producing nutrient-rich larval biomass. Their study established the foundation for modern BSF-based waste bioconversion systems.

Substrate quality plays a critical role in determining larval growth, survival, and waste conversion efficiency. Gold *et al*. (2018) [6] reported that nutrient-rich organic wastes support faster larval development and greater biomass accumulation compared to fibrous substrates. Similarly, Siddiqui *et al*. (2022) [20] demonstrated that fruit-based organic residues provide favorable conditions for larval growth due to their high moisture content and nutrient availability. These findings suggest that substrate composition is one of the most important factors influencing BSF colonization and productivity. The ecological adaptability of *H. illucens* has also attracted considerable scientific attention. Tomberlin *et al*. (2009) [23] reported that temperature and humidity strongly influence larval development, survival, and reproductive performance. Tropical and subtropical climatic conditions were found to be particularly suitable for BSF population establishment. Because Central India experiences similar environmental conditions, natural colonization of household organic waste by BSF populations may be expected under favorable circumstances.

Several studies have emphasized the role of BSF larvae in waste reduction and nutrient recycling. Amrul *et al*. (2022) [1] reviewed global BSF research and reported that larval activity can reduce organic waste volume by approximately 50–80%, depending on substrate characteristics and environmental conditions. The conversion of waste into protein-rich biomass and nutrient-rich frass has positioned BSF as an important component of sustainable waste-to-wealth systems. Parodi *et al*. (2021) [17] further highlighted the importance of insects, particularly BSF, within circular

bioeconomy frameworks aimed at reducing environmental pollution and enhancing resource recovery. Beyond waste management, BSF biomass has gained recognition as a sustainable alternative protein source. Wang and Shelomi (2017) [24] reported that BSF larvae contain substantial levels of proteins, lipids, and essential amino acids, making them suitable for animal feed production. Similar observations were made by Lu *et al*. (2022), who demonstrated the nutritional value of BSF-derived biomass for aquaculture and poultry industries. These findings have contributed to increasing interest in BSF as a sustainable solution for future food and feed security challenges.

Recent investigations have also focused on the microbial ecology of BSF systems. Klammsteiner *et al*. (2020) [8] reported that larval gut microbiota play an important role in organic matter degradation and nutrient assimilation. Bruno *et al*. (2019) [3] further demonstrated that BSF larvae may suppress certain pathogenic microorganisms through competitive interactions and antimicrobial activity. These findings suggest that BSF contributes not only to waste reduction but also to substrate sanitation and environmental health. Although extensive research has been conducted on BSF bioconversion technologies, studies examining natural colonization under household conditions remain limited. Most published investigations have been performed under laboratory or industrial rearing systems where environmental variables are controlled. Information regarding natural occurrence, colonization dynamics, and substrate preference of BSF populations in domestic organic waste ecosystems is still scarce, particularly in developing countries.

In India, research on BSF remains relatively limited compared to Europe, North America, and Southeast Asia. Available studies primarily focus on waste bioconversion efficiency, feed applications, and larval nutritional composition. Ecological studies evaluating naturally occurring BSF populations under household conditions are rare. Furthermore, no detailed investigations have been reported from Central India regarding the natural colonization of household organic waste by *H. illucens*. This represents a significant knowledge gap in understanding the ecological role of BSF within domestic waste ecosystems. The present study was therefore undertaken to investigate the natural colonization pattern, substrate preference, and waste conversion potential of *Hermetia illucens* in household organic waste under natural environmental conditions in Jabalpur, Central India. By focusing on naturally occurring populations rather than artificially introduced larvae, the study aims to provide new ecological insights into the role of BSF as a natural bio-recycling agent and its potential contribution to decentralized household waste management systems.

Materials and methods

The present study was conducted at a residential premises located in Sanjivani Nagar, Jabalpur, Madhya Pradesh, India, to investigate the natural colonization, substrate preference, and waste conversion potential of Black Soldier Fly (*Hermetia illucens*) under household environmental conditions. Jabalpur experiences a tropical climate with warm temperatures and seasonal fluctuations in humidity, conditions that are considered favorable for the development and colonization of BSF populations (Tomberlin *et al*., 2009) [23]. The study was carried out over a period of seven months, from October 2025 to April 2026. The investigation was designed as a field-based observational study focusing on naturally occurring populations of *H. illucens*. Unlike most previous studies conducted under laboratory or industrial rearing systems (Diener *et al*., 2011; Gold *et al*., 2018) [5, 6], no eggs, larvae, or adults were artificially introduced during the study period. Instead, household organic waste was exposed to ambient environmental conditions, allowing natural colonization by BSF populations. Different categories of household organic waste, including banana peels, papaya residues, mango residues, watermelon waste, mixed fruit waste, mixed kitchen waste, vegetable waste, and dry organic residues, were collected and placed separately in open plastic containers under shaded outdoor conditions. Previous studies have reported that substrate composition and moisture content significantly influence larval attraction, development, and biomass production in BSF systems (Lalander *et al*., 2019; Siddiqui *et al*., 2022) [9, 20]. Therefore, the use of different waste categories enabled comparative evaluation of substrate preference under natural conditions. The containers were inspected daily for the presence of eggs, larvae, prepupae, pupae, and adult Black Soldier Flies. Species identification was performed using external morphological characteristics described in standard taxonomic and entomological literature (Marshall *et al*., 2015; Wang & Shelomi, 2017) [13, 24]. Particular attention was given to recording the time required for initial colonization, larval abundance, developmental progression, and adult emergence.

To evaluate substrate preference, the abundance of larvae observed on each waste type was recorded throughout the study period. Earlier studies have demonstrated that fruit-rich substrates generally support higher larval growth and survival compared with highly fibrous organic materials (Holmes *et al*., 2013; Gold *et al*., 2018) [6, 7]. Therefore, comparative observations were conducted to determine whether similar patterns occurred under household conditions in Central India. Waste conversion efficiency was assessed by measuring the weight of organic waste before exposure and after completion of larval feeding activity. The reduction in waste mass was used as an indicator of bioconversion efficiency following approaches commonly employed in BSF waste management studies (Diener *et al*., 2011; Amrul *et al*., 2022) [1, 5]. Waste reduction percentage was calculated by comparing the initial and final substrate weights. Environmental parameters including ambient temperature and relative humidity were monitored throughout the study period because these factors strongly influence larval development, survival, and waste conversion performance (Tomberlin *et al*., 2009; Padmanabha *et al*., 2020) [16, 23]. Seasonal observations were also recorded to evaluate the relationship between environmental conditions and colonization dynamics.

The collected data were compiled and analyzed using descriptive statistical methods. Colonization time, larval abundance, substrate preference, and waste reduction efficiency were compared among different substrate categories. Results were expressed as means, percentages, and graphical representations to facilitate interpretation of ecological patterns associated with naturally occurring BSF populations. Similar approaches have been widely adopted in ecological and waste bioconversion studies involving *H. illucens* (Gold *et al*., 2018; Amrul *et al*., 2022) [1, 6]. The

study was entirely observational and involved only naturally colonizing populations of *H. illucens*. No endangered or protected species were collected or manipulated, and all observations were conducted under normal household environmental conditions.

Results and discussion

The present study documented the natural colonization of household organic waste by Black Soldier Fly (*Hermetia illucens*) under ambient environmental conditions in Sanjivani Nagar, Jabalpur, Central India, during the period from October 2025 to April 2026. Throughout the study period, BSF larvae were repeatedly observed on decomposing organic waste without artificial introduction of eggs, larvae, or adults, indicating the natural occurrence of the species in urban household ecosystems. Among the various substrates examined, fruit-based organic wastes consistently attracted higher numbers of larvae than vegetable-based wastes. Banana peels, papaya residues, mango waste, and watermelon residues showed rapid colonization and sustained larval activity. In contrast, vegetable waste and dry organic materials exhibited comparatively lower larval abundance and slower colonization. Similar substrate preferences have been reported by Gold *et al*. (2018) and Lalander *et al*. (2019) [6, 9], who demonstrated that moisture-rich and nutrient-dense substrates provide optimal conditions for larval development and biomass accumulation.

Natural colonization generally occurred within a few days after waste exposure, particularly in moist fruit residues. The rapid attraction of BSF adults to decomposing substrates suggests that the species can efficiently locate and exploit temporary organic resource patches under natural conditions. This observation agrees with findings reported by Tomberlin *et al*. (2009) [23], who emphasized the ecological adaptability and reproductive efficiency of *H. illucens* in warm environmental conditions. A noticeable reduction in organic waste volume was observed in substrates colonized by BSF larvae. Active larval feeding accelerated decomposition and transformed waste materials into a dark residual product resembling frass. Previous studies have reported that BSF larvae can reduce organic waste volume by approximately 50–80%, depending on substrate quality and environmental conditions (Diener *et al*., 2011; Amrul *et al*., 2022) [1, 5]. The observations recorded during the present study support the view that naturally occurring BSF populations contribute significantly to organic waste degradation and nutrient recycling at the household level.

Larval abundance appeared to be strongly associated with substrate moisture and nutrient availability. Fruit-rich substrates consistently supported larger larval aggregations than drier organic materials. This pattern is consistent with the findings of Siddiqui *et al*. (2022) [20], who reported that substrate composition plays a critical role in determining larval growth performance and waste conversion efficiency. The preference of BSF larvae for fruit waste observed during the present investigation suggests that household fruit residues may represent one of the most suitable natural substrates for BSF colonization in Central India.

Environmental conditions also appeared to influence colonization dynamics. Greater larval activity was observed during warmer periods characterized by moderate to high humidity, whereas larval abundance declined during relatively cooler conditions. Similar temperature-dependent responses have been documented by Tomberlin *et al*. (2009) [23], who demonstrated that larval development, survival, and feeding activity are strongly influenced by environmental temperature. These findings indicate that climatic conditions in Central India are generally favorable for the establishment and persistence of BSF populations.

The present study further revealed that household organic waste serves as an important ecological niche for naturally occurring BSF populations. Continuous colonization of waste substrates throughout the observation period indicates that urban household environments may provide suitable habitats for the species. Such observations are particularly important because most previous investigations have focused on laboratory-reared or industrially managed BSF systems, whereas information regarding naturally colonizing populations remains limited (Parodi *et al*., 2021) [17].

An important outcome of this study is the potential role of *H. illucens* as a biological indicator of organic waste accumulation. The repeated association of BSF larvae with decomposing household waste suggests a close ecological relationship between species abundance and organic resource availability. Similar characteristics are commonly recognized in ecological indicator organisms (McGeoch, 1998; Markert *et al*., 2003) [12]. Although further quantitative investigations are required, the findings provide preliminary evidence supporting the possible application of BSF as a bioindicator of organic waste ecosystems.

The study also highlights the broader environmental significance of Black Soldier Fly in decentralized waste management systems. By naturally converting biodegradable waste into larval biomass and nutrient-rich residual material, the species contributes to waste reduction, nutrient recycling, and environmental sanitation. These ecosystem services support the growing recognition of BSF as a natural bio-recycling engineer and an important component of circular bioeconomy frameworks (Parodi *et al*., 2021) [17]. Overall, the findings demonstrate that *Hermetia illucens* is naturally established within household organic waste ecosystems of Central India and exhibits considerable potential for waste bioconversion under natural conditions. The observed substrate preference, rapid colonization, and waste reduction capacity emphasize the ecological and practical importance of the species for sustainable household waste management. Furthermore, the study provides baseline ecological information that may support future investigations on BSF population ecology, waste conversion efficiency, and bioindicator applications in tropical urban environments.

Fig 1: Mature larvae of Black Soldier Fly (*Hermetia illucens*) collected from household organic waste in Sanjivani Nagar, Jabalpur, Central India.

Table 1: Types of Household Organic Waste Used in the Study

Waste Category	Examples	Moisture Content	BSF Attraction
Fruit Waste	Banana, Papaya, Mango, Watermelon	High	Very High
Mixed Kitchen Waste	Cooked food residues	Moderate-High	High
Vegetable Waste	Potato, Tomato, Cabbage residues	Moderate	Moderate
Dry Organic Waste	Dry leaves, bread pieces	Low	Low

Table 2: Natural Colonization Pattern of Hermetia illucens on Different Organic Wastes

Substrate Type	First Colonization (Days)	Larval Abundance	Colonization Success
Banana Peel	2–3	Very High	Excellent
Papaya Waste	2–4	Very High	Excellent
Mango Waste	3–4	High	Very Good
Watermelon Waste	3–5	High	Very Good
Mixed Kitchen Waste	4–6	Moderate	Good
Vegetable Waste	5–7	Low	Moderate
Dry Organic Waste	Rare	Very Low	Poor

Table 3: Seasonal Occurrence of Black Soldier Fly During the Study Period

Month	Temperature (Approx.)	Relative Activity of BSF
October 2025	28–32°C	High
November 2025	24–29°C	Moderate
December 2025	18–25°C	Low
January 2026	15–23°C	Very Low
February 2026	22–28°C	Moderate
March 2026	28–34°C	High
April 2026	30–38°C	Very High

Table 4: Ecological Functions of Black Soldier Fly Observed During the Study

Ecological Function	Observation
Organic Waste Reduction	Rapid decomposition of fruit waste
Nutrient Recycling	Conversion of waste into frass-like residue
Biomass Production	High larval biomass observed
Waste Stabilization	Reduced foul smell and faster decomposition
Resource Recovery	Potential conversion of waste into valuable biomass

Table 5: Comparison of Black Soldier Fly with Common House Fly

Character	Black Soldier Fly (H. illucens)	House Fly (Musca domestica)
Role in Waste	Beneficial decomposer	Mainly nuisance species
Disease Transmission	Very Low	High
Waste Conversion Ability	Excellent	Poor
Protein Production	High	Negligible
Environmental Importance	High	Low

Interpretation of Tables 1–5: The observations recorded during the present study demonstrated that different categories of household organic waste varied considerably in their suitability for the natural colonization of *Hermetia illucens*. Fruit-based wastes, particularly banana, papaya, mango, and watermelon residues, consistently attracted higher larval populations and exhibited faster colonization compared with vegetable and dry organic wastes. The high moisture content and nutrient availability of fruit substrates likely contributed to their greater attractiveness and suitability for larval development, a finding that agrees with previous studies on BSF substrate preference (Gold *et al*., 2018; Siddiqui *et al*., 2022) [6, 20]. Seasonal observations further indicated that BSF activity was strongly influenced by environmental conditions, with greater larval abundance observed during warmer months and reduced activity during cooler periods, supporting the temperature-dependent developmental patterns reported by Tomberlin *et al*. (2009) [23]. Active larval feeding accelerated the decomposition of organic matter, resulting in substantial waste reduction and the production of nutrient-rich residual material, thereby contributing to nutrient recycling and organic waste stabilization. These observations reinforce the role of BSF as a natural bio-recycling engineer and an effective agent of waste-to-resource conversion (Amrul *et al*., 2022; Parodi *et al*., 2021) [1, 17]. Furthermore, comparison with the common housefly revealed that BSF possesses greater ecological and environmental value due to its efficient waste conversion ability, lower association with disease transmission, and significant contribution to sustainable resource recovery (Wang & Shelomi, 2017) [24]. Collectively, the results indicate that household organic waste in Central India provides a suitable natural habitat for BSF populations and highlights the species' potential application in decentralized waste management, circular bioeconomy initiatives, and future bioindicator studies.

Conclusion

The present study provides valuable insights into the natural colonization, substrate preference, and waste conversion potential of Black Soldier Fly (*Hermetia illucens*) under household environmental conditions in Central India. Observations conducted from October 2025 to April 2026 in Sanjivani Nagar, Jabalpur, demonstrated that naturally occurring BSF populations readily colonized household organic waste, particularly fruit-based substrates such as banana, papaya, mango, and watermelon residues. The study confirmed that moisture-rich organic wastes are highly attractive to BSF larvae and support rapid colonization and development. The results further revealed that larval feeding activity significantly accelerated the decomposition of organic matter and contributed to substantial waste reduction, highlighting the ecological importance of BSF as a natural bio-recycling engineer. The transformation of household organic waste into larval biomass and nutrient-rich residual material illustrates the species' potential role in decentralized waste management and circular bioeconomy systems. These findings support previous studies that have recognized *H. illucens* as an efficient biological agent for organic waste valorization and resource recovery.

An important outcome of the study is the documentation of naturally occurring BSF populations under real household conditions rather than laboratory or industrial rearing systems. This provides ecological evidence that urban

household waste can serve as a suitable habitat for BSF populations and that the species is already performing important ecosystem services at the local level. The repeated association of larvae with decomposing organic waste also suggests that *H. illucens* may possess potential as a biological indicator of organic waste accumulation and decomposition dynamics, although further quantitative investigations are required to validate this application. Overall, the study demonstrates that Black Soldier Fly represents a promising nature-based solution for sustainable organic waste management in Central India. Its ability to reduce waste volume, recycle nutrients, generate valuable biomass, and potentially serve as a bioindicator highlights its ecological and environmental significance. Future research focusing on population dynamics, seasonal ecology, waste conversion efficiency, and bioindicator applications will further strengthen the role of *H. illucens* in sustainable waste management and environmental conservation programs.

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