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Natural Occurrence and Biology of Black Soldier Fly, *Hermetia illucens* L. (Diptera: Stratiomyidae) under Local Conditions of Maharashtra

Anita Sable [a*] and Komal Chavan [b]

[a] Department of Agricultural Entomology, College of Agriculture, Osmanabad, Maharashtra (413509), India.
[b] Department of Entomology, Rajarshi Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur, Maharashtra (416004), India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Black soldier fly, *Hermetia illucens* is known as promising insect for organic waste recycling. However, its natural occurrence and biology in Maharashtra is not well documented. Present study aimed to assess the natural occurrence of *H. illucens* types of organic food substrates utilized by larvae in its natural environment and to examine its biology in the laboratory. The overarching objective was to evaluate the feasibility of rearing this insect under the local environmental conditions of Osmanabad district in Marathwada region of Maharashtra. Natural occurrence of *H. illucens* at 16 locations spanning across 10 districts was reported. Larvae were observed feeding

**Corresponding author: Email: anitavsable@gmail.com;*

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on various types of organic wastes encompassing animal manures and their derivatives, kitchen scraps from households and canteens, decomposing fruits, vegetables, spoiled onions in storage structures, organic residues including crop remnants. Biology of the fly was examined in the laboratory under room temperature and humidity conditions in monsoon and in winter. Overall lifecycle of *H. illucens* was completed in 44.17 (± 6.07) to 46.46 **(**± 6.83**)** days in monsoon and 66.45 (± 6.84) to 68.24 (± 7.61) days in winter. Fecundity of female was 586.53 **(**± 36.41**)** and 531.47 (± 20.33) eggs in monsoon and in winter, respectively. Aggregation behavior was observed in maggots. Interactions of some arthropods with *H. illucens* was observed. These findings offer valuable insights into the potential for culturing *H. illucens* under local environmental conditions of Maharashtra.

Keywords: Hermetia illucens; waste management; natural occurrence; biology; circular economy.

ABBREVIATIONS

BSF: Black soldier fly

1. INTRODUCTION

Organic waste management and insufficiency of food and feed are major problems faced by the world. In 2022, households across all continents wasted over 1 billion meals a day, while 783 million people were affected by hunger and a third of humanity faced food insecurity [1]. Globally, food waste constitutes about 45% fruits and vegetables, 35% fish and seafood, 30% of all cereals, 20% dairy products and 20% of all meat and poultry [2]. In India, municipal solid waste production is 62 million tonnes per year. Of this, only 20% of waste is treated [3]. About 80% of the waste is finally dumped in landfills contributing to environmental degradation and posing risks for human health [4]. Waste generation in India is likely to be more than double by 2030, increasing up to 165 million tons per year [5]. India produced 500 MT of agricultural waste, out of which 92 MT were burned each year that causes severe environmental pollution by producing large amount of greenhouse gases [6]. Therefore, organic waste management remains a huge challenge in India. To reduce, recycle and reuse will be the motive for our survival in future [7]. By 2030, India needs to achieve sustainable development goals (SDG) adopted as a member of united nations. This will be possible by following principles of circular economy which focuses on recycling and reuse of waste material [8]. The use of insect protein produced from biomass in waste for feed purposes could be an important element of the transformation to bioeconomy [9]. Employing insects as food and feed is gaining ample interest because the production of these animals may provide high-quality proteins, with low-value input, high-value output and low environmental impact compared to traditional sources of animal protein [10]. Organic wastes are a valuable resource that contains a lot of nutrients and energy value that could be beneficial to both humans and the environment if reintegrated into the value chain using insects [11]. Black soldier fly (BSF), *Hermetia illucens* L. (Diptera: Stratiomyidae) is reported to feed on organic wastes and reduce the waste to compost. Its larvae and pupae are rich in proteins fats and can be used in animal feed [12]. Domestic waste, chicken, pig and cow manure and even human excreta were found to be easily degraded by the larvae. BSF reduce nitrogen and phosphorus waste by up to 75% and the mass of manure residue by 50% in poultry and swine systems. Residues from BSF larva are used as compost and have nutritional levels suitable for use as fertilizers and soil amendments. BSF has quite high protein and fat contents of 42% and 35%%, respectively. It also has lauric acid (36.74%) essential amino acids and fatty acids [13] making it excellent component of animal feed. Chitin, grease, biodiesel, antimicrobial peptides etc. are some other biproducts extracted from BSF [14,15]. Currently, the BSF rearing technology is becoming popular around the world.

In India, information of occurrence of BSF in nature is very scarce [16,17,18] and there are very few studies on its biology [19,20,21,22]. Scanning through literature reveals that there is scarcity of information on natural occurrence, types of organic substrates utilized by larvae in natural settings and biology of BSF in Maharashtra. It is essential to fill these knowledge gaps in order to explore the potential of BSF for feed and waste recycling. Our research was therefore aimed to document natural occurrence and food substrates of BSF in various locations of Maharashtra and study of Its biology under local environmental conditions in Marathwada region.

2. METHODOLOGY

Chance encounters of BSF occurred during field visits in various areas of Maharashtra during 2020 to 2023. During these encounters, stages of BSF found and the substrates on which BSF larvae were found feeding were recorded. Feeding behavior of larvae and the egg laying behavior of adults were observed. BSF egg clutches from wild population of Kanhapuri, Dist. Pandharpur were collected and brought to the laboratory of college of agriculture, Osmanabad. An experiment to study biology of BSF was conducted in the laboratory having wide windows from all sides ensuring plenty of sunlight availability during the day. Biology of insect was studies during June to August (Mansoon season) 2021 and November 2021 to January 2022 (winter season). Insect was reared at room temperature and humidity throughout the experiment. The average room temperature and humidity in monsoon was 29^{o}C and 71% respectively. In winter, average room temperature and relative humidity was 24^{o}Cand 60%, respectively. Poultry bird's starter feed was mixed with water thoroughly and used as larval food for young instars. Eggs were kept on the sieve such that soon after hatching, larvae fall down in the moist starter feed (Fig. 2a). Five days after hatching, larvae were transferred in the plastic container filled with organic waste upto half of its height. Food was added in the container after every four to five days until pupation started. Waste feed included kitchen waste (cooked rice, wet tea powder, dal, cooked vegetables, chicken, boiled eggs, wheat bread, waste milk, curds, etc), fruit waste (muskmelon, oranges, papaya, guava, banana, sapota, apple, ber, dragon fruit, figs, pomegranate, lemon etc.) collected from local vendors; raw vegetable waste (brinjal, beans, peas, spinach, cabbage, cauliflower, coriander, fenugreek, bottle gourds, chilli, onion, carrots, potato, garlic, drumstick, okra, cluster bean etc.), raw cereal grains (sorghum, rice, bajra, wheat etc.), raw pulse grains (green gram, black gram, chickpea), chickpea powder (*besan*), and tapioca (sago). Water was added as per the requirement such that the food will be moistened and 70% moisture is maintained. Due care was taken that larvae get consistent supply of food. Prepupae from feeding container were collected daily and kept in the separate plastic boxes containing moist fine sand. After emergence, adults were released in the rearing cage and male and female longevity was observed. Corrugated cardboard sheets and wooden stacks were kept near the organic waste container for adults to lay eggs. Observations were recorded on egg incubation period, larval duration, prepupal+pupal duration. Length of larva and pupa was measured using scale (Fig. 2c). Width of larva and pupa was measured on 3rd abdominal segment. To summarize the biological and morphometric parameters, mean and standard deviations of observed values were calculated. To observe feeding behavior of larvae, a separate set of larvae was kept in transparent plastic box and fed with the same organic wastes. Observations on other insects/arthropods in feeding trays and natural enemies of BSF life stages were recorded.

3. RESULTS AND DISCUSSION

3.1 Natural occurrence of BSF

The detailed account of natural occurrence of BSF in different localities from ten districts of Maharashtra is presented in Table 1. Live stages of BSF were recorded in all three seasons prevailing in Maharashtra viz. Monsoon (June to September), winter (October to January) and summer (February to May). In most of the locations, BSF was observed in monsoon. Larvae were found feeding voraciously on kitchen waste, agricultural wastes including cow dung, poultry manure and goat manure, moist portion of cow dung cake, *jeevamruta* (mixture of cow dung, cow urine, chickpea flour and jaggery etc.), kitchen waste, crop residues, waste vegetables and fruits, etc. In Alkuti village few adults were noted hovering on the walls near the artificial light. In Kolhapur, few pupae were noticed lying in the corners of the walls of a kitchen in a commercial mess. Since larvae could not be observed in these two locations, the larval feeding substrate could not be known. All life stages *viz*. eggs, larvae, pupae and adults were noted at Kanhapuri location. Female laid eggs by inserting ovipositor in dry and deep places especially holes, cracks and crevices of walls and between the folds of dry, waste polypropylene bags lying near the food source (Fig. 1a, 1b). Most of the encounters occurred from June to September (monsoon) or sometimes up to December. This suggests that the maximum favorable period for the population buildup of BSF is Monsoon. This might be due to the fact that during monsoon, most of the organic waste on farms or kitchen wastes dumped around residential areas become moist after monsoon showers. This favors initiation of decomposition by microorganisms. Decomposing smell of substrates attracts BSF female for oviposition. Moisture content in the feed is a

critical factor for growth and development of BSF larvae. Rainfall will increase the moisture content of waste heaps making it conducive for the development of BSF [23]. Barragan-Fonseca et al (2017) found that the moisture level in between 52-70% is the most suitable for proper larval growth [24]. Eighty percent moisture content in the feed is ideal for BSF development [25,26]. Substrate moisture below 40% was unsuitable for development of the flies [27].

a. BSF female laying eggs

b. BSF Egg clutch

c. BSF larvae in *jeevamruta*

d. BSF pre- pupae in decomposed onion

e. BSF pupae in cow dung

f. BSF pupae in sand in onion storage structures

g. BSF larvae in decomposing fruits

h. Groundnut shells not fed by larvae

i. BSF larvae in vegetable waste

j. BSF larvae feeding on kitchen waste

Fig. 1. Different stages of BSF and larval food substrates found at various locations

Table 1. Natural occurrence of BSF recorded in different localities in Maharashtra

Sr. No.	Name of the place where BSF were encountered	GPS coordinates of the location	District	Rural/Semi-Urban	Insect stage observed	Larval food	Month & year of the encounter
1	Alephata, Tal-Junnar	19^{O}10’17.9”N 74^{O}05’55.0”E	Pune	Rural	larvae & pupae	Waste onion bulbs, kitchen waste, waste fruits poultry manure	Frequent encounters from June 2020
2	Narayangaon, Tal-Junnar	19^{O}07’47.9”N 73^{O}58’33.0” E	Pune	Rural	larvae & pupae	Raw vegetable waste	August 2021
3	Rahu Tal-Daund	18^{O}35’45.7”N 74^{O}12’20.2”E	Pune	Rural	larvae & pupae	Compost	July 2022
4	Kolhapur Tal-Kolhapur	16^{O}41’15.1”N 74 ^{O}15’33.2”E	Kolhapur	Semi-Urban	Pupae	Could not be determined	September 2022
5	Rajpurpande Tal-Baglan	20°46'18.1"N 74°16'37.2"E	Nashik	Rural	Larvae & pupae	Waste onion bulbs in onion storage structures	Frequent encounters from July 2022
6	Karad Tal-Karad	17°17’23.4”N 74°10’51.3”E	Satara	Semi-Urban	Larvae	Kitchen wase	December 2022
7	Kavathe Ekand Tal-Tasgaon	16°59’12.2”N 74°37’31.3”E	Sangli	Rural	Larvae	Cow dung manure +kitchen waste	February 2023
8	Kanhapuri Tal-Pandharpur	17°55'17.4"N 75°10'58.5"E	Solapur	Rural	Egg, larvae pupae & adult	waste onion bulbs Waste garlic bulbs Waste red chilli fruits Waste sorghum grains Compost	Frequent encounters from June 2021,
9	Ter, Tal-Osmanabad	18°19'04.6"N 76°08'07.0"E	Osmanabad	Rural	Larvae & pupae	cow manure+ crop residues + kitchen waste	Frequent encounters from September 2021
10	Osmanabad, Tal-Osmanabad	18°11'22.6"N 76°01'49.6"E	Osmanabad	Semi-Urban	Larvae & pupae	Kitchen waste	Frequent encounters from March 2021
11	Bhandarwadi Tal- Osmanabad	18°16'58.7"N 76°10'47.1"E	Osmanabad	Rural	Larvae, & pupae	*Jeevamruta*	Frequent encounters from June 2021
12	Paranda	18°17'27.3"N	Osmanabad	Rural	Larvae &	*Jeevamruta*	August, 2022

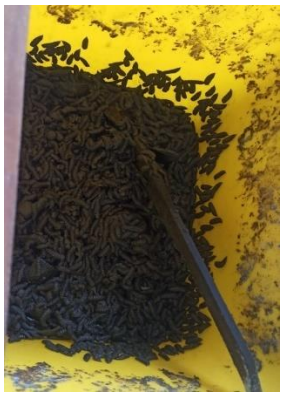
Sr. No.	Name of the place where BSF were encountered	GPS coordinates of the location	District	Rural/Semi-Urban	Insect stage observed	Larval food	Month & year of the encounter
	Tal-Osmanabad	75°28'09.2"E			pupae		
13	Dhakni, Tal- Latur	18°21'08.2"N 76°19'55.3"E	Latur	Rural	Larvae	Cow dung cake	Frequent encounters from May 2022
14	Alkuti, Tal-Parner	19°03'25.5"N 74°14'04.2"E	Ahmednagar	Rural	Adult	Could not be determined	September 2022
15	Ghargaon Tal-Sangamner	19°19'16.9"N 74°10'44.1"E	Ahmednagar	Rural	Larvae & pupae	Kitchen waste from hotel	September 2022
16	Kaij Tal Kaij	18°20'50.3"N 76°20'12.9"E	Beed	Rural	Larvae & pupae	Crop residue + kitchen waste+ cow dung manure	Frequent encounters from October 2021

a. BSF eggs kept on sieve

b. BSF larvae feeding on organic food substrate

c. BSF larva

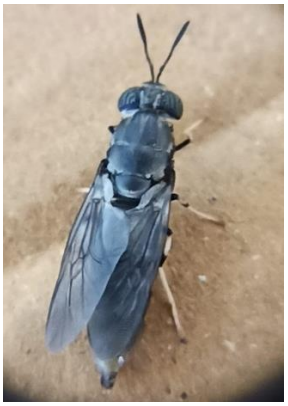
d. Magnified view (6x) of prepupa head



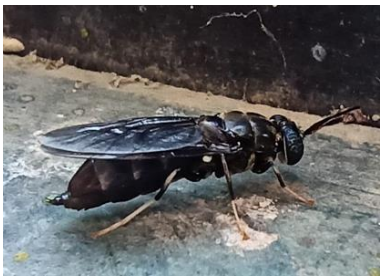
e. BSF pre-pupae on wall container

f. BSF pupae

g. BSF adult emerging from pupa



h. BSF male



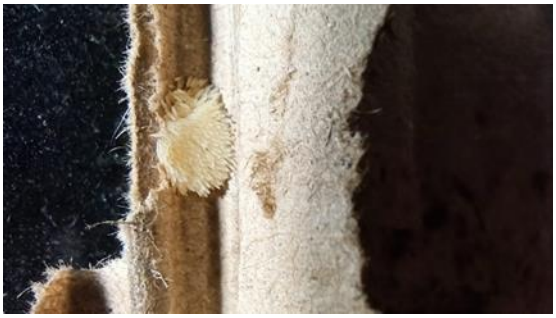
i. BSF female

j. Eggs laid on dried part of food substrate

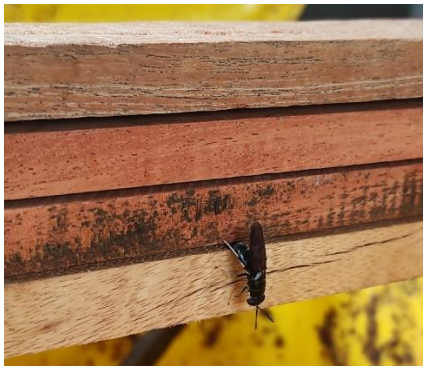
k. Eggs laid in the corner of rearing container (inside)

l. Eggs laid in the corner of rearing container (outside)

m. Female laying eggs on corrugated cardboard sheets



n. Egg laid in corrugated cardboard



o. Female laying eggs on wooden stack

p. Eggs laid on wooden stack

q. Waste reduced to compost by BSF

Fig. 2. Biology of BSF in the rearing room

Environmental factors especially temperature and humidity affect distribution, abundance, and development of insects [28,29]. Studies have reported that BSF larvae develop optimally at temperatures between 27 and 30°C and humidity between 60 and 90% [30,31]. These conditions generally prevail in the environment during monsoon season. Such conductive environment combined with plenty of substrate availability may result in population buildup of BSF during monsoon. This might be the cause of frequent encounters of BSF in monsoon. BSF larval biomass production was high during or just after the rainy season; very low during the hot dry seasons and no larvae were produced during cool dry season [32]. So far, diapause is not reported in BSF lifecycle [33]. Therefore, to utilize BSF for waste recycling and larval biomass production, it is necessary to further study how the seasonal alteration in weather parameters impacts the lifecycle, survival and abundance of BSF in Indian scenario.

3.2 Feeding Substrates of BSF

Among the food substrate observed (Table 1, Fig. 1c, d, e, f, g, h, i and j.), major food sources were kitchen wastes, animal manures, crop residues, decomposing fruits. *Jeevamruta* was also noted as BSF substrates in the current study. Previous studies have reported kitchen waste and animal manures as suitable feed for BSF larval growth [34,35,36]. Onion storage structures in Nashik and Pune districts harbored BSF. During personal discussion with farmers, it was noticed that some farmers wrongly perceived BSF larvae as post-harvest pests of onion. However, BSF Larvae start feeding on onion only after initial decomposition of bulbs by microorganisms. At Kanhapuri, four separate heaps of wastes viz. chilli, sorghum grains, onion and garlic left on the farmyard were reduced to compost by BSF. Though the larvae on each substrate were not counted, it was observed that the chilli wastes harbored notably higher no. of larvae than the rest three substrates and reduced chilli to compost comparatively faster over the other substrates. This is probably because chilli fruits are softer over the rest of the substrates and BSF maggots can more easily feed upon it. It was also noticed that larvae did not feed on egg shells, groundnut shells, coconut coir, seeds of sapota fruit etc. and fed very slowly on hard skins of fruits like watermelon, musk melon, oranges, peels of banana, vegetable stems, carrots, etc. Unsuitability of organic wastes containing high lignocellulosic content is previously reported by various authors [37,38].

In general larvae feed on soft and moist waste quickly. Interestingly, though the larvae did not feed on cotton and nylon bags, they were seen cutting the bags in the dumping yards and enter inside the bag to feed upon the decomposing organic waste.

3.3 Biology of BSF in Local Conditions of Osmanabad, Maharashtra

Biological parameters of BSF in local environmental conditions of Osmanabad in monsoon and winter seasons are summarized in Table 2 and Table 3 respectively.

Table 2. Life parameters of BSF in monsoon season (June 2021 to August 2021)

Sr. No.	Parameters	Mean (± s.d) (N=80)
1	Egg duration (days)	2.97 (± 0.80)
2	Larval duration (days)	19.25 (± 4.91)
3	Prepupa+Pupa duration (days)	16.27 **(**± 3.09**)**
4	male adult duration (days)	5.68 **(**± 1.12**)**
5	female adult duration (days)	7.97 **(**± 1.27**)**
6	Fecundity of female (No.)	586.53 **(**± 36.41**)**
7	Total duration of male (days)	44.17 (± 6.07)
8	Total duration of female (days)	46.46 **(**± 6.83**)**
9	larval length (cm)	2.53 (± 0.12)
10	larval width (cm)	0.75 (± 0.07)
11	pupal length (cm)	2.2 (± 0.20)
12	pupal width (cm)	0.7 (± 0.13)

Table 3. Life parameters of BSF in winter season (November 2021 to January 2022)

Sr. No.	Parameters	Mean (± s.d) (N=80)
1	Egg duration (days)	4.65 (± 1.09)
2	Larval duration (days)	34.16 (± 5.70)
3	Prepupa+Pupa duration (days)	22.49 (± 4.50)
4	male adult duration (days)	5.15 (± 1.59)
5	female adult duration (days)	6.94 (± 1.75)
6	Fecundity of female (No.)	531.47 (± 20.33)
7	Total duration of male (days)	66.45 (± 6.84)
8	Total duration of female (days)	68.24 (± 7.61)
9	larval length (cm)	2.51 (± 0.15)
10	larval width (cm)	0.72 (± 0.09)
11	pupal length (cm)	2.2 (± 0.23)
12	pupal width (cm)	0.7 (± 0.10)

BSF eggs were white in color, rice grain shaped when laid by female. Near to hatching, egg color changed to light yellow. In monsoon season, mean egg period was recorded 2.97 (± 0.80) days. Larvae released in the tray fed with organic wastes (Fig. 2b). Larvae are whitish or yellowish in color (Fig. 2c) and have hairs on the body. Larval duration was19.25 (± 4.91) days. Larval length and width were recorded as 2.53 (± 0.12) and 0.75 (± 0.07) cm respectively. Prepupae are black in color. They stop feeding and start rising on the walls of container (Fig. 2e). They fall on the ground and keep searching for dark and dry space for pupation. Pupae (Fig. 2f) are blackish or brownish in color with stiff body and tip of the abdomen slightly bent ventrally. Prepupa + pupa duration was observed to be 16.27 **(**± 3.09**)** days. Average length of pupa was 2.2 (± 0.20) cm and width were recorded as 0.7 (± 0.13) cm. Emergence of adult from pupa (Fig. 2g) took nearly five minutes. Male (Fig. 2h) and female (Fig. 2i) lived for mean 5.68 **(**± 1.12**)** and 7.97 **(**± 1.27**)** days respectively. Thus, the total duration of male was 44.17 (± 6.07) days and that of female was recorded as 46.46 **(**± 6.83**)** days. BSF adults were noticed resting on the walls of the rearing room. They were attracted to light. Female laid eggs in the clutches on corners of rearing containers, dried food, corrugated cardboards and wooden stacks kept for oviposition (Fig. 2j, k, l, m, n, o and p). Average fecundity was recorded as 586.53 **(**± 36.41**)** eggs/female.

In winter season, average duration of eggs and larvae was 4.65 (± 1.09) and 34.16 34.16 (± 5.70) days, respectively. Mean length of larva was recorded as 2.51 (± 0.15) and width was observed to be 0.72 (± 0.09) cm. Prepupa and pupa duration collectively 22.49 (± 4.50) days. Adult male lived for 5.15 (±1.59) days and adult female lived for about 6.94 (± 1.75) days. Thus, the total duration of male was 66.45 (± 6.84) days and that of female was 68.24 (± 7.61) days. Female laid average 531.47 (± 20.33) eggs.

Sharanabasappa et al (2019) recorded larval duration of 25 to 30 days on muskmelon

fruit [19]**.** Total lifespan (from egg to adults) in the black soldier fly, *H. illucens* (Linnaeus) was reported to be 57.8 days [20]. Sable and Tawale (2024) reported that on fruits and vegetables diet, BSF female fecundity was 489 eggs and larval duration was 28 to 34 days [22]. In the current study, lifecycle of BSF was longer in winter compared to monsoon. Previous studies have reported that the temperature, humidity, pupal substrates etc. may influence on life cycle of BSF and in some cases, life cycle may extend up to 70-80 days [39]. Larval pupal period can increase to four months if resources are limited [40].

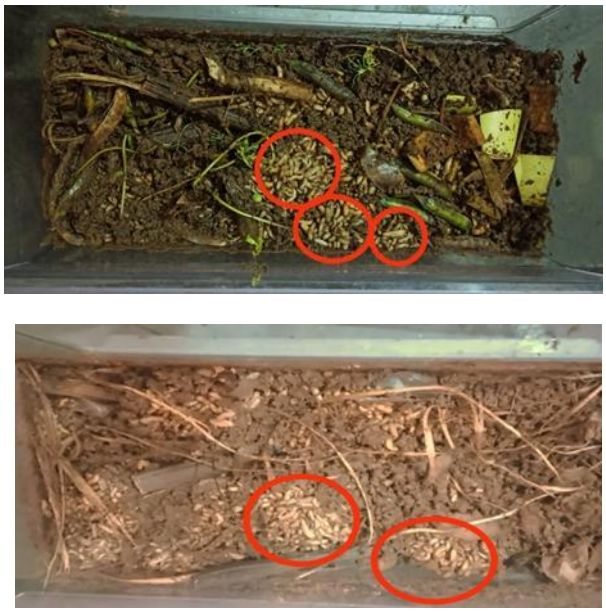
3.4 Behaviour of BSF Larvae

Larvae typically go down in the substrate during feeding. They were light-shy and those on the surface of the container start burrowing downward within food immediately when the lid is removed or the substrate container is exposed to artificial light in the night time. Larvae reduced organic waste to compost (Fig. 2q). Late instar larvae formed aggregates at different places in container (Fig. 3a) wherein, they gather in large numbers in/around food piece and pile over one another. Larval aggregates were noticed also at the corner of the rearing container (Fig.3b). Older larvae also showed roughly horizontal layer of maggots with their lateral body surfaces touching that of the nearby larvae and closely packed with one another like match sticks (Fig. 3c). Many insects form aggregates, the benefits of which might be reduced risk of predation, protection against environment and better assimilation [41]. Ko et al (2021) reported that BSF larval aggregations behave like fluids even without external fluid flows. When the container of larvae is tilted, the larvae rearrange themselves, creating a level interface. Their movement creates a new configuration minimizing the center of mass [42]. Detailed studies on the dynamics of aggregate formation behaviour in *H. ilucens* are rarely available except Shishkov et al (2019) who discovered that BSF larvae form fountains around food, replacing each other so that the food is distributed among the larvae that do not have access to food [43]. Larval aggregation produces higher temperatures that enhance food assimilation however, overcrowding slows larval development due to competition for feed [44]. In the current study, early instars formed a single, roughly horizontal (Fig. 3d) like that of older larvae or slightly angular (Fig. 3e) layer of larvae with their lateral body surfaces touching that of the nearby larvae and closely packed with one another. Based on the observed larval densities in respective containers, we presume that larvae orient themselves in pattern at lower larval densities and form crowding larval masses at higher larval densities. According to the separate study by Shishkov et al. [45] there is presence of feedback system in BSF maggots where they rearrange themselves to desired state to relieve the pressure exerted by their surroundings (food substrate, movement of conspecific larvae *etc*). Aggregation in fruit fly maggots help them to burrow in food sooner than solitary maggot [46] and it also helps for growth and better exploration of available nutrition in high-density environments [47]. Developmental rate of blow fly *Lucilia cuprina* larvae increased with increasing larval aggregations [48].

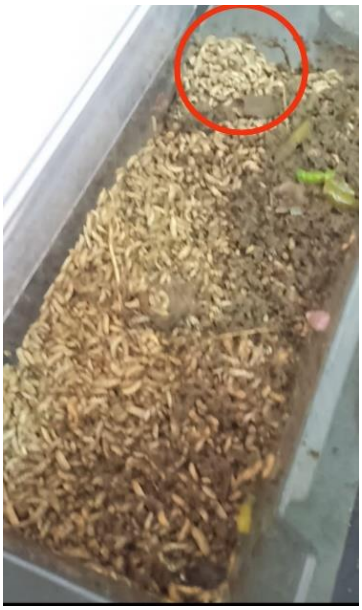
3.5 Interactions of BSF with other Arthropods in Culture

During rearing, saprophytic insects observed feeding on the feed substrate of BSF were *Fannia sp.* (Fig. 4a), *Drosphila sp., Musca domestica,* an unidentified species of flesh flies (Fig. 4b) and minute sized beetles. BSF are reported to be good competitors of houseflies and can be used for their biological control [40,49,50]. *H. illucens* can be used to get rid of flies because as a larva it is voracious feeder and eats fast which leaves little food for other flies [51]. Though, we did not see any significant impact of these co-habitant insects on the life cycle of BSF, their population should be checked to avoid mixing in BSF larvae/pupae destined to prepare animal feed.

While the prepupae fall from container and search for concealed place for pupation, they were captured and fed by unidentified species of spiders of family Pholcidae (Fig. 4c). Spider *Plexippus* sp*.* was noticed predating on newly emerged adult flies emerging from pupae (Fig. 4d.) in the rearing containers. Spiders are reported to be the predator of BSF larvae [39, 52]. In the wild population of BSF at Kanhapuri we found one BSF adult with many orange color mites attached to ventral surface of body (Fig. 4 e & f). Mites anchored the fly near eyes, undersurface of wings, thoracic sternum. Fly spent a lot of time trying to remove the mites unsuccessfully and died eventually. It could not be determined whether these were ectoparasitic mites or phoretic mites. Red mite on a black soldier fly larva [53] and adult [54] are previously reported. However, there is scarcity of literature on mites associated with BSF.

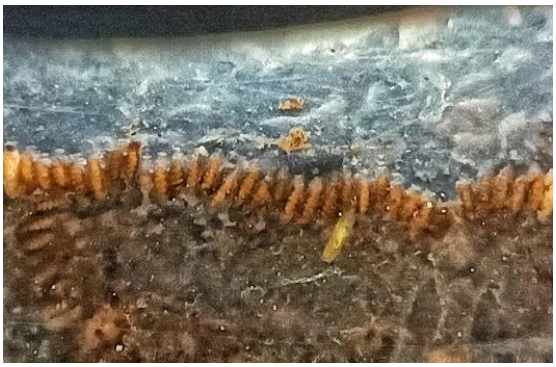


a. Larval aggregation within food



b. Larval aggregation in the corner of container

c. Older larvae closely pack themselves horizontally in the container



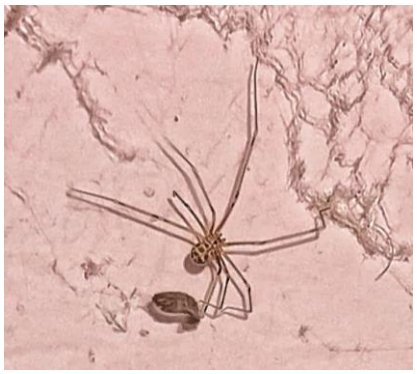
d. Younger larvae closely pack themselves horizontally in the container

e. Younger larvae closely pack themselves in slightly angular layer

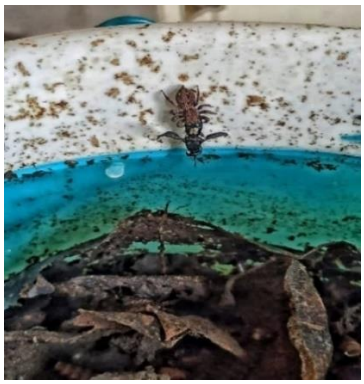
Fig. 3. Behaviour of BSF larvae

a. Fannia sp. in BSF culture (6X)

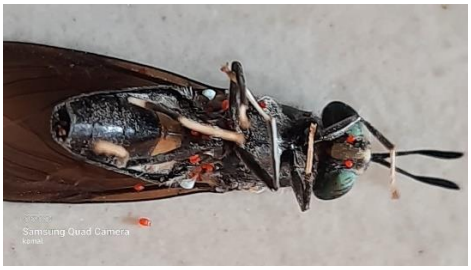
b. Unidentified dipteran species



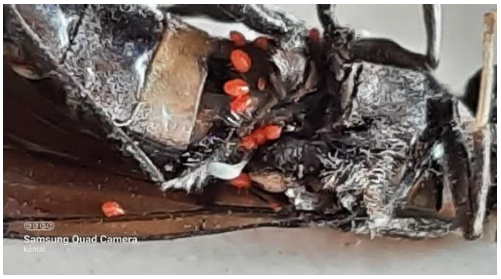
c. Pholcid spider attacking prepupa



d. *Plexippus sp*. attacking adult fly



e. Mites attached to the body of adult BSF



f. Mites attached to the body of adult BSF (closer view)

Fig. 4. Interactions of BSF with other arthropods in culture

4. CONCLUSION

Black soldier fly was found naturally in the environment feeding on different types of organic wastes in various localities of Maharashtra. It can be cultured at room temperature and humidity conditions on kitchen waste, fruit and vegetables waste. Overall lifecycle of *H. illucens* was completed in 44.17 to 46.46 days in monsoon and it is extended to about 66.45 to 68.24 days in winter. Behaviors of BSF larvae and interaction of different arthropods with BSF necessitates further studies in this aspect for mass production and commercial utilization of BSF in waste management and animal feed production. Results of the current study further opens gates for mass rearing of BSF in local conditions of Maharashtra.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that No generative AI technology such as Large Language Models (ChatGPT, COPILOT etc. and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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