UTTAR PRADESH JOURNAL OF ZOOLOGY

42(5): 64-72, 2021
ISSN: 0256-971X (P)

REARING THE BLACK SOLDIER FLY, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) IN LOCAL ENVIRONMENTAL CONDITIONS OF BARAMATI (INDIA)

VITTHALRAO B. KHYADE[1*]

[1]Department of Zoology, Shardabai Pawar Mahila Mahavidyalaya, Shardanagar Tal, Baramati Dist, Pune – 413115, India.

AUTHOR'S CONTRIBUTION

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

Editor(s):
(1) Dr. P. P. Dubey, Guru Angad Dev Veterinary and Animal Sciences University, India.
Reviewers:
(1) Thiago Bernardi Vieira, Federal University of Pará, Brazil.
(2) Victor Adolfo Gómez López, National University of Asuncion, Paraguay.

Received: 11 February 2021
Accepted: 04 March 2021
Published: 25 March 2021

Original Research Article

ABSTRACT

The efficiency of black soldier fly, *Hermetia illucens* (Linnaeus, 1758) (Diptera: Stratiomyidae) For the efficient role in decomposition of the organic waste matters deserve appreciations and exert environmental significance. On an average life span of the adult is about twelve to thirteen days. The optimal temperature and relative humidity (RH) for average life span of the adult black soldier fly, *Hermetia illucens* is 31°C and 80% respectively. As RH goes down (up to sixty percent), the lifespan of the adult get decreased by six days. Larval life was observed to have a lifespan of twenty days (20.0 ± 1.05) days at the temperature 30.15 ± 0.26°C. Larval life was observed to have prolonged span of their lives during season with rain and temperature of about 28°C (from July to November). The adults of the black soldier fly, were reported to lay the eggs even in the absence of decomposing organic matter. Collection of the eggs was carried out from various places such as sponges, cardboards, and in the meshes of the nets used for caging. Near 477 ± 10.69 eggs per batch was the reading for the egg count. The fertilized eggs were observed in the process of development and hatching within 4.5 days on the temperature of 30.15° (± 0.26). Freshly laid eggs were observed to measure 0.901 (± 0.013) millimetre. The duration for emergence of the adult flies from the stage of prepupa was 14.7 (± 1.07) days at the conditions of 30.15° (± 0.26). Total lifespan (from egg to adults) was reported to be 57.8 days at at the conditions of 30.15° (± 0.26). Significant and distinct feature of the black soldier fly, *Hermetia illucens* (Linnaeus) is to exhibit five morphological instars (or stages). The larval instars of the black soldier fly were found to have a strong positive olfactory reception to decomposed organic wastes than other food sources. The average length (millimetre) of the body of the first, second, third, fourth and fifth instar were 2.35 ± 0.02, 6.45 ± 0.07, 10.26 ± 0.11, 15.92 ± 0.23 and 17.34 ± 0.09. Mean length of the body of the adult fly was 16.92 ± 0.21 millimetre. Mean wingspan of adult male and adult female was 12.25 ± 0.21 millimetre and 13.02 ± 0.23 millimetre respectively.

**Corresponding author: Email: vbkhyade.2016@gmail.com;*

Keywords: Black Soldier Fly (BSF); instars; decomposing; organic waste matter.

1. INTRODUCTION

In India, the management of organic waste is made by the Ministry (Union) of Environment, Forests and Climate Change (MoEF&CC). This MoEF&CC released the rules for the Solid Waste Management (SWM) in 2016. This Indian policy has acknowledged and included the informal sector (pickers for wastes). Management of waste material has become a challenge in most of the developing countries. This may be due to increasing generation of wastes. The rural local authorities often lack financial resources and proper organization for the waste management. There is possibility of leading various ill effects through the improper waste management [1]. The organic solid waste fractions have proven to be the effective agent for the spread of microbial diseases (if the waste materials are not collected and not treated in a proper manner). The spread of microbial diseases by the organic solid waste fractions is through sheltering and feeding various organisms (that act as disease vectors) with adverse effects on the environment too. In most of the countries, in contrast to collection methods of streams, the wastes often end up in open dumps (or other more unfavourable locations). The composting and production of biogas (commonly used to recycle organic solid wastes, composting) is not creating a high value product. It is also unusable for peoples of urban area (who face lack of space as a major issue). For the successful production of the biogas, it requires a rather large investment at initial phase.

At the same time, it has to be noted that, the prices of poultry feed and fish feed from fishery resources are steadily rising. This rise in prices of fish feed may be due to overfishing. Day by day, there is exploitation of agricultural lands. It is leading into depletion of essential crop nutrients. The management of waste disposal for sustainable practices often (should) become an environmentally and friendly method. The environmentally and friendly methods deals with an efficient way of managing degradable organic solid wastes. Since the ancient times, the method of composting through the worms and grubs is in practice. This bio-composting method is known method of organic waste treatment commonly used in rural areas. This type of practice is in most preferably in regions with high activities of agriculture and livestock [2,1,3]. Besides the use of worms and grubs for composting too presents the approach with innovative and less restrictive research.

The utilization of the Larvae of Black Soldier Fly (LBSF) for the purpose of composting is being practiced informally across the world for many years. The utilization of LBSF for the purpose of composting has been documented in many of the recent literatures [4]. The larvae of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) use to spend the most of their life duration for feeding on organic wastes. They are turning organic wastes into fat, protein and calcium. Biologically, turning organic wastes into fat, protein and calcium by the black soldier fly is for metamorphosis into pupae (and later, into adults) [5,4]. In the adult phase of life, there are no functional mouthparts. There are no functional mouthparts and neither feed nor bite. Non-feeding behaviour of the adult phase of life, the black soldier fly, is associated with non-transmitting diseases to the human body [5]. The LBSFs are known for their efficient ability to feed voraciously on a wide range of organic wastes (including vegetables, fruits, meat, and manure) [5]. During the feeding on the solid wastes, the larvae of Black Soldier Fly (LBSF), there is exudation of liquid to drain off. This exudation of liquid from the bed of the larvae of Black Soldier Fly (LBSF) could be collected and applied to the agricultural fields as a fertilizer. The exudation of liquid from the bed of the larvae of Black Soldier Fly (LBSF) mostly consists of their excreta together with undigested matter. Both, the larval excreta are constituting excellent source of natural nitrogen to the agricultural crops through the soil. Utilization of the larvae of Black Soldier Fly (LBSF) is supposed to be excellent alternatives for the disposal of food waste or kitchen waste. It has the potential to bring environmental and economic benefits. The benefits of utilization of the larvae of Black Soldier Fly (LBSF) include: reduced Green House Gas emissions from landfills; decreased commercial fertilizer usage; decreased water use; increased soil carbon storage and decreased erosion of the soil [6]. It is easier for manipulation and rearing of the larvae of Black Soldier Fly (LBSF) on large scale if and only if the bionomics of this insect is fully understood. On this much background, the present attempt on the rearing of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in local environmental conditions of Baramati (India) has been planned.

2. MATERIALS AND METHODS

The work was carried during 2019-2020 and 2020 - 2021 in the insectary (Green House) of Shardabai Pawar Mahila Mahavidyalaya, Shardanagar Tal. Baramati, Pune, India (Fig. 1). The culture was initiated through keeping household organic waste (Kitchen Waste). The content of the organic waste

(Kitchen waste) was with sour milk, waste tea powder, vegetable waste (cabbage and fruits of papaya). This content of the organic waste (Kitchen waste) was taken in a box and labelled as "tray with rearing bed" (or Larval Rearing Bin). This box (Larval Rearing Bin) was designed in the shape of a rectangular wooden box with the dimensions of 2x1.5x1.5 feet with ventilation holes on the top lid, and a rectangular plank was placed at an inclined position making an angle of 45° with the bottom so as to facilitate the self-harvesting of mature larva as they turn into pre-pupa. Little amount of water was used to spray on the contents in a tray. Spraying the water on organic waste initiates the process of decomposition through bacteria. After a few days as the wastes began to decompose [7]. The fertilized egg mass of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) was procured from Mangal Agro Farm Miri Rd, Maka, Maharashtra 414501 India. The egg mass (Fig. 2) was kept suspended over fresh food (slices of fruits of papaya, *Carica papaya* L.). For uniform hatching, it requires a humid and cool place with fresh airflow. Hatching of the eggs take place within twenty-four of hours of provision of favourable conditions to the fertilized eggs.

On fifth day after hatching, the larvae from incubation box were transferred to box with rearing bed (Larval Rearing Bin). The larvae were allowed for feeding and their development. The mature stages of prepupa of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) were collected from this stock culture. The mature stages of prepupa of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) were transferred to the rearing cages once in three days. This transfer of the mature stages of prepupa of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) is to the rearing cages observe different life stages. The cages with the mature stages of prepupa of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) were placed inside the insectary (Green House) of Shardabai Pawar Mahila Mahavidyalaya, Shardanagar Tal. Baramati, Pune, India. After three days, the stages of prepupa of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) from the rearing cages were placed in a small plastic bucket containing soil and kept inside the rearing cage in order to provide a place for pupation. The condition of humidity of the cage was maintained at 70-80%. This was achieved through keeping a water source with sponges soaked in it as well as by spraying water three to four times a day [8,7,9]. The source of lighting was provided daily for twelve hours. The light provision is to stimulate adult mating. The card boards were made hung in various locations. The provision of the card boards is to mimic sites for laying the eggs by the adult female black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) [7,10,11,4,12]. The observations were recorded on egg hatching; the period of development of the larval, pupal and adult stages and the morphology of the life stages. The sex ratio was determined through random sampling performance and observations of the genitalia of randomly collected adults.

Fig. 1. The insectary cum greenhouse at Sharadanagar campus) (Dist. Pune India)

Fig. 2. Egg mass of Black Soldier Fly (BSF)

For the purpose of determination of frequency of mating of newly emerged adult flies of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) and egg laying capacity (fecundity), ten sets of identical plastic containers capacity: 2 L) were taken. Newly emerged adult male and adult female were kept in pairs plastic containers. All these setups were then placed in the insectary (Green House) of Shardabai Pawar Mahila Mahavidyalaya, Shardanagar Tal. Baramati, Pune, India. They were provided with artificial lighting (60 W) and humidity (70-80%) [8,9,13,14,15,16]. The observation on the determination of the egg laying sites (ovipositional sites); egg laying period (ovisitional period) and the life span was carried every twelve hours. The eggs were collected from this set up. The eggs were allowed to hatch under varying conditions. This attempt was for the purpose to determine period of incubation and the ability of the eggs to tolerate unfavourable temperatures. The eggs and larvae were collected daily from the rearing bin. Larvae were taken back to laboratory. The larvae were washed thoroughly to remove impurities. The larvae were knocked out by freezing and measured using coulometer to record total body length, body width, and length of mouth hook. The Dyar's rule was followed for the purpose of determination of the morphometry of the larvae. It was carried through the determination of number of larval instars in its life cycle of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) [17,18,19,20,21,22]. The olfactometer was utilized for the determination of behaviour of the feeding and the preference of food waste by the larval stages of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae). For consistency in the results, each attempt was repeated at least for three times. The collected data was subjected for analysis through the statistical method.

3. RESULTS AND DISCUSSION

Results on the attempt on the rearing of the black soldier fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in local environmental conditions of Baramati (India) is presented in Table 1 and explained away through the points: egg laying (oviposition); frequency of mating and egg laying; morphometry and behaviour of feeding.

The Process of Egg laying (or oviposition): The process of laying the eggs by the adult female of the black soldier fly was found influenced by illumination. In comparison with the natural day light, the provision of artificial light was found stimulated the process of mating and increase in the rate of egg laying (oviposition). At the room temperature of 27.3°C (± 0.32), the process of laying the eggs was rarely observed in the cages. Keeping the source of water in the cages and spraying the water at frequent intervals, the process of laying the eggs by the adult female of the black soldier fly was found observed in the subsequent days. The present attempt is reporting 30.15°C (± 0.26) and 70% relative humidity (RH) as the optimal conditions for the egg laying by the adult female of the black soldier fly. Eggs laid by the adult female of the black soldier fly were found observed at various locations (egg cards, sponge, on the lid of larval rearing bin and on the interior walls of rearing bin). The number of eggs laid by the adult female of the black soldier fly was 697 (± 16.627). 1:2 was the reading for mean sex ratio in the population of the adult of the black soldier fly in present attempt.

Frequency of Mating and Egg Laying (Oviposition): Adult individuals of the black soldier fly were found to be sensitive to all sorts disturbances. Therefore, opportunities of observations of a mating pair were very rare (except on a few occasions). The adult female individuals of the black soldier fly were observed laying the eggs on the sixth day to seventh day after emerging from the stage of pupa. Eggs laid by the adult female of the black soldier fly were found observed at various locations (egg cards, sponge, on the lid of larval rearing bin and on the interior walls of rearing bin). The number of eggs laid by the adult female of the black soldier fly was 697 (± 16.627). 1:2 was the reading for mean sex ratio in the population of the adult of the black soldier fly in present attempt. More eggs were laid when the Male: Female ratio was 1:2 or higher and always a single female laid only a single batch of eggs. Time period taken to hatch eggs (incubation period) was recorded varied with room temperature. The incubation period was recorded as 4-5days in the tenure of April to July (30.15°C ± 0.26). No eggs were noticed in the bin during October to December (27.20°C ± 0.30). The present attempt is reporting non-hatching of the eggs laid during January to February (29.71°C ± 0.21). During January to February (29.71°C ± 0.21), the eggs were laid but not hatch. With reference to number of larval instars, it was found that Dyar's law accurately modeled growth of the black soldier fly. The instar number is easily determined by mouth hook length (Fig. 1). On the basis of larval mouth hook length, it was confirmed that the larvae of the black soldier fly undergo five distinct morphological stages (instars) during the tenure of larval age.

3.1 Morphometric Parameters

Being an insect, the black soldier fly exhibit the stages like egg, larva, pupa and adult in it's life cycle. Eggs were found laid always in clusters all at once. The nature of the eggs was exactly like tiny rice granules with creamy yellow colour. The colour of the fresh eggs appeared was off white/pale yellow. During the development, the egg colour was observed to changing into yellow. At the time of ready to hatch, the eggs appeared as brown in colour. At the time of hatching, a black spot was observed in each egg. Eggs were found laid always in clusters all at once and at the time of hatching, a black spot was observed in each egg [23,24,25,26]. The larval life of the black soldier fly (BSF) is with five instars. The reading 2.36 (± 0.03) mm belongs to the length of the first larval instar of the black soldier fly (BSF) in present attempt. The reading 6.47 (± 0.13) mm belongs to the length of the second larval instar of the black soldier fly (BSF) in present attempt. The reading 10.28 (± 0.826) mm belongs to the length of the third larval instar of the black soldier fly in present attempt. The reading 15.93 (± 1.213) mm belongs to the length of the fourth larval instar of the black soldier fly in present attempt. The reading 17.36 (± 1.047) mm belongs to the length of the fifth larval instar of the black soldier fly in present attempt. All five instar stages of the black soldier fly in present attempt reported eleven segments in the body. On each lateral side, the brisk of hairs were found in between two neighbour segments. The entire body of each larval instar was observed with the covering of minute hairs. The length of the body and the length of the hook were positively correlated to each other. In the process of growth through metamorphosis, the size of the body of the larval instars in the black soldier fly use to increase, keeping the general morphological pattern constant. In general, the larval instars of the black soldier fly are segmented, pale brown in colour with a pink colour hook which is slightly curved at the tip. The pre-pupal stages of the black soldier fly were black in colour and exactly similar in appearance to that of mature larvae. The reading 17.66 (± 1.786) mm belongs to the length of the pre-pupal stage of the black soldier fly in present attempt. The pupal stage of the black soldier fly in present attempt appeared like the pre-pupa (except the fact that, it was not immobile). The pupal stage of the black soldier fly in present attempt had a ventrally bent hook region and this was considered as a distinct morphological character. The reading 17.73 (± 2.347) mm belongs to the length of the fully grown and mature pupal stage of the black soldier fly in present attempt. The food

availability and environmental conditions were found influencing the body weight and body size of the pupal stage of the black soldier fly in present attempt.

The adult flies of the black soldier fly in present attempt were found exhibiting analogy with the morphology of the wasps. This may be due to its narrow anterior abdomen. The reading 12.261 (± 1.274) mm belongs to the length of the fully grown male adult stage of the black soldier fly in present attempt. The reading 13.982 (± 1.589) mm belongs to the length of the fully grown female adult stage of the black soldier fly in present attempt. The first sternal plate of the abdominal region of the adult black soldier fly in present attempt was found appearing transparent (or translucent). The two tergal plates of the thoracic region of the adult black soldier fly in present attempt were fused together and appeared like an armour. Pair of wings of the adults was overlapped while at rest. The distal end of all three pairs of the legs were white/pale yellow in colour. The remaining parts of the body of the adult black soldier fly were reported alternated with black and white colour. The colour of the two compound eyes on the head of the adult black soldier fly was not entirely black, rather the compound eyes appeared as a mixture of blue and yellowish-green. The entire body of the adult black soldier fly in present attempt was observed with the covering of the minute (microscopic) hairs. The mouthparts of the adult black soldier fly belong to the "lapping type". The adult black soldier fly utilize the "lapping type of mouth parts" solely for drinking water. The two antennae of the adult black soldier fly were black in colour. Each antenna of the adult black soldier fly consisted of three segments. The genitalia of the male adult black soldier fly were with flower shape and protractible. The genitalia of the female adult black soldier fly were forked in shape and protrusible. The genitalia in both, male and female adult black soldier fly were entirely covered by microscopic hairs. Respectively, the readings 00.78 (± 0.06) mm and 0.95 (± 0.07) mm belongs to the length of male genitalia and female genitalia of the black soldier fly in present attempt.

The pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were observed to anchor themselves through the use of their bent hook. The bent hook of the pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt was observed for using for locomotion. The pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were observed to possess the behaviour of wandering, seeking dry and dark places to settle, especially cracks, holes, under the stones and carpets. The pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were recorded to move 1.5 meter on a floor of cement. This movement of pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt, on cement floor may be for searching suitable (dark and dry) place for the successful pupation.

Behaviour of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) for feeding: The larval instars of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in the present attempt were found to actively feed on the food source. The larval instars of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in the present attempt were found to decompose all forms of organic matter supplied as food material. The larval instars were found to be always near the surface of the source of food material to enable them to breathe naturally. Burying habit of the larval instars of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) may be to avoid sun light. The observations based on the "Lactometer experiment", the larval instars of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) were observed to have a strong response towards decomposing organic wastes through efficient utilization of the sense of smell. The pre-pupal stages of black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were observed to stop feeding soon after change their colour to black colour. It was followed by initiation of the wandering behaviours. The adult flies of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were observed avoiding solid food material, but preferred the source of water more. They drank water from sponges soaked in water or whenever their cage was sprayed with water. Keeping water in large cups resulted in high mortality of adult flies due to drowning. The adult flies of the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in present attempt were found exhibiting analogy with the morphology of the wasps.

Table 1. Biological parameters of the Black Soldier Fly, *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in local environmental conditions of Baramati (India)

Parameter	Minimum	Maximum	Mean (± Standard Deviation) (N=25)
Egg Life Duration (days)	4.5	6	5.25 (± 0.53)
Larval Life Duration (days)	20.67	28.8	24.735 (± 4.78)
Life Duration (Days) of Pupa	11.48	19.50	15.49 (± 5.88)
Life Duration (Days) of Adult	12.90	15.75	14.325 (± 2.64)
Life Duration (Days) of Pre-oviposition	8.50	10.60	9.55 (± 4.625)
Fecundity (No. of eggs per female individual)	643	751	697 (± 16.627)

-Each figure is the mean of three replications. The figure with ± sign is the standard deviation

4. CONCLUSION

Through the process of composting, the black soldier fly (BSF), *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) established the recognition for its pivotal role in sustainable management of organic waste material. The adults of the black soldier fly, *Hermetia illucens* (Linnaeus) were reported to lay the eggs even in the absence of decomposing organic matter. Collection of the eggs was carried out from various places such as sponges, cardboards, and in the meshes of the nets used for caging. 477 ± 10.69 eggs per batch was the reading for the egg count. The fertilized eggs were observed in the process of development and hatching within 4.5 days in the temperature of about 30.15° (± 0.26). Freshly laid eggs were observed to measure 0.901 (± 0.013) millimetre. The duration for emergence of the adult flies from the stage of prepupa was 14.7 (± 1.07) days at the conditions of 30.15° (± 0.26). Total lifespan (from egg to adults) in the black soldier fly, *Hermetia illucens* (Linnaeus) was reported to be 57.8 days at the conditions of 30.15° (± 0.26).

ACKNOWLEDGEMENT

The research work received support Agricultural Development Trust Baramati (Dist. Pune – 413115 India).

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. EFL. Status of Waste Management in Sri Lanka; 2017.
Available:http://efl.lk/v3/2017/06/14/status-waste-management-sri-lanka/
(Accessed: 2nd September 2018).
2. Appelhof M. Worms eat my garbage. Kalamazoo, MI: Flower Press; 1982.
3. Martin DL, Gershung G. The Rodale book of composting. Emmaus, PA: Rodale Press, V.
4. Shields EB. Raising earthworms for profit. Eagle River, WI: Shields Publications; 1982.
5. Loerch CR, Cameron EA. Determination of larval instars of the bronze birch borer. *Agrilus anxius* (Coleoptera: Buprestidae). Ann Entomol Soc Am. 1983; 76(6):948-952.
6. Olivier PA. Utilizing lower life forms for the bioconversion of putrescent waste. Black Soldier Fly Blog -Official Website; 2009.
7. Pedro CD, Mehab H, Guillermo FDJ, Selin Y. Development of a food waste composting system using black soldier fly larvae. 3rd annual R&D Student Competition-Greenovate NYS [Online]; 2014.
Available: https://www.rit.edu
(Accessed: 30th September 2018).
8. Briscoe AD, Chittka L. The evolution of color vision in insects. Annual Review of Entomology. 2001;46:471-510.
9. Zhang J, Huang L, He J, Tomberlin JK, Li J, Lei C, Yu Z. An artificial light source influences mating and oviposition of black soldier flies, *Hermetia*

illucens. Journal of Insect Science. 2010;10: 202.

10. Sheppard C, Newton GL, Thompson SA, Savage S. A value added manure management system using the black soldier fly. Bioresource Technology. 1994;50:275-279.
11. Sheppard DC, Jeffery K, Tomberlin, Joyce JA, Kiser BC, Sonya M. Rearing methods for the black soldier fly (Diptera: Stratiomyidae). J. Med. Entomol. 2002;39(4):695-698.
12. Tomberlin Jeffery, Craig Sheppard D. Factors influencing mating and oviposition of black soldier flies (Diptera: Stratiomyidae) in a colony. Journal of Entomological Science. 2002;37:345-352.
13. Savonen Carol. Big maggots in your compost? They're soldier fly larvae. OSU Extension Service – Gardening. Oregon State University; 2005.
14. Spranghers Thomas, Ottoboni Matteo, Klootwijk Cindy, Ovyn Anneke, Deboosere Stefaan, Meulenaer Bruno De, Michiels Joris, Eeckhout Mia, Clercq Patrick De, Smet Stefaan De. Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates". Journal of the Science of Food and Agriculture. 2017;97(8):2594–2600.
DOI: 10.1002/jsfa.8081.
ISSN: 1097-0010. PMID: 27734508.
15. Lalander C, Diener S, Zurbrügg C, Vinnerås B. Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (Hermetia illucens). Journal of Cleaner Production. 2019;208:211–219.
DOI:10.1016/j.jclepro.2018.10.017.
ISSN 0959-6526.
16. Wang, Yu-Shiang, Shelomi Matan. Review of black soldier fly (*Hermetia illucens*) as Animal Feed and Human Food. Foods. 2017;6(10):91.
DOI:10.3390/foods6100091.
ISSN: 2304-8158.
PMC: 5664030.
PMID: 29057841.
17. Craig Sheppard D, Jeffery KT, John AJ, Barbara CK, Sonya MS. Rearing methods for the black soldier fly (Diptera: Stratiomyidae). J. Med. Entomol. 2002;39(4):695-698.
18. Goldson SL, Neill MRM, Proffitt JR, Baird DB. Seasonal variation in larval –instar head – capsule sizes of Argentine stem weevil, *Listronotus bonariensis* (kuschel) (Coleoptera; Curculionidae). Australian J Entomol. 2001; 40(4):371-375.
19. Mohammed SMG. Determination of larval instars of black cutworm *Agrotis ipsilon* (Hufnagel) (Lepidoptera, Noctuidae). Jordan Journal of Biological Sciences. 2011;4(3): 173-176.
20. Bonelli Marco, Bruno Daniele, Brilli Matteo, Gianfranceschi Novella, Tian Ling, Tettamanti Gianluca, Caccia Silvia, Casartelli Morena. Black Soldier Fly Larvae Adapt To Different Food Substrates Through Morphological And Functional Responses Of The Midgut. International Journal of Molecular Sciences. 2020;21(14): 4955.
DOI:10.3390/ijms21144955.
ISSN: 1422-0067.
PMC: 7404193.
PMID: 32668813.
21. Bruno Daniele, Bonelli Marco, De Filippis Francesca, Di Lelio Ilaria, Tettamanti Gianluca, Casartelli Morena Ercolini, Danilo, Caccia Silvia. McBain, Andrew J. (ed.). The Intestinal Microbiota of Hermetia I Llucens Larvae is affected by diet and shows a diverse composition in the different Midgut regions. Applied and Environmental Microbiology. 2018;85(2):e01864–18.
/aem/85/2/AEM.01864–18.atom.
DOI: 10.1128/AEM.01864-18.
ISSN: 0099-2240.
PMC: 6328772.
PMID: 30504212.
22. Holmes LA, Vanlaerhoven SL, Tomberlin JK. substrate effects on pupation and adult emergence of Hermetia illucens (Diptera: Stratiomyidae): Table 1. Environmental Entomology. 2013;42(2):370–374.
DOI: 10.1603/en12255.
PMID: 23575028.
23. Nakamura Satoshi, Ichiki Ryoko T, Shimoda Masami, Morioka Shinsuke. Small-scale rearing of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), in the laboratory: Low-cost and year-round rearing". Applied Entomology and Zoology. 2016;51: 161–166.
DOI: 10.1007/s13355-015-0376-1.
S2CID: 52864114.
24. Bruno Daniele, Bonelli Marco, Cadamuro Agustin G, Reguzzoni Marcella, Grimaldi Annalisa, Casartelli Morena, Tettamanti Gianluca. The digestive system of the adult *Hermetia illucens* (Diptera: Stratiomyidae): morphological features and functional properties". Cell and Tissue Research. 2019; 378(2):221–238.
DOI:10.1007/s00441-019-03025-7.
ISSN: 0302-766X.
PMID: 31053891.
S2CID: 143432117.

25. Rumpold Brigit A, Schlüter Olivier K. Potential and challenges of insects as an innovative source for food and feed production. Innovative Food Science & Emerging Technologies. 2013;17:1–11.
DOI: 10.1016/j.ifset.2012.11.005.
26. Barros Luana Machado, Gutjahr Ana Lúcia Nunes, Ferreira- Keppler, Ruth Leila, Martins Renato Tavares. Morphological description of the immature stages of *Hermetia illucens* (Linnaeus, 1758) (Diptera: Stratiomyidae). Microscopy Research and Technique. 2019;82(3):178–189.
DOI:10.1002/jemt.23127.
ISSN: 1059-910X.
PMID: 30511417.
S2CID: 54566833.