MONITORING OF BLACK SOLDIER FLY, *Hermetia illucens* (L.) (DIPTERA: STRATIOMYIDAE) POPULATION IN SEMI-CAPTIVE CONTROLLED CONDITIONS

Mohamad Ibrahim Mohamad Isa[1] & Hadura Abu Hasan[1,2*]
[1]School of Biological Sciences,
Universiti Sains Malaysia,
11800 Penang, Malaysia
[2]Vector Control Research Unit,
School of Biological Sciences,
Universiti Sains Malaysia,
11800 Penang, Malaysia
*Corresponding author: *hadura@usm.my*

ABSTRACT

Hermetia illucens (Diptera: Stratiomyidae), or known as Black Soldier Fly (BSF), has lately been found in various regions of the world, including Malaysia. BSF has been linked to decomposing organic substances like animal manure or plant material. This species was discovered near poultry operations in Tasek Gelugor, Penang, Malaysia, and was then placed into semi-captive adult cages (2 m width × 4 m length × 2.5 m height) for colony establishment. For a period of 10 months, the population of this species was observed. The population of BSF increased but subsequently fluctuated over the months. Temperature and relative humidity were measured as well as the weight of BSF eggs. The association between climatic conditions and the weight of eggs was investigated using Spearman's correlation coefficient analysis. Kruskal Wallis test, $H(9) = 133.37$; $P<0.001$, revealed a significant variation in egg weight across months. The weight of the eggs and both climatic parameters (temperature and relative humidity) were shown to have no association. Other potential influences on egg production, including adult population density and light intensity, were also discussed.

Keywords: Black soldier fly, *Hermetia illucens*, monitoring, organic waste, population, semi-captive controlled condition

ABSTRAK

Hermetia illucens (Diptera: Stratiomyidae) atau dikenali sebagai Lalat Askar Hitam (BSF), terkini telah dijumpai di pelbagai lokasi di dunia termasuk Malaysia. BSF telah dikaitkan dengan bahan organik yang mereput seperti sisa haiwan atau sisa tumbuhan. Spesies ini dijumpai berhampiran kawasan penternakan ayam di Tasek Gelugor, Pulau Pinang, Malaysia dan kemudiannya ditempatkan di dalam sangkar dewasa (lebar 2 m × 4 m panjang × 2.5 m tinggi) dengan keadaan separa-terkawal untuk penubuhan koloni. Populasi spesies ini dipantau selama 10 bulan. Populasi BSF meningkat tetapi kemudiannya berubah-ubah selama beberapa bulan. Suhu dan kelembapan relatif di dalam sangkar telah direkodkan termasuk berat telur BSF. Hubungan di antara faktor iklim dan berat telur telah dikaji dengan menggunakan analisis pekali korelasi Spearman. Ujian Kruskal Wallis, $H(9) = 133.37$; $P<0.001$, menunjukkan terdapat perbezaan yang signifikan dalam berat telur di antara beberapa bulan. Berat telur dan faktor iklim (suhu dan kelembapan relatif) tidak menunjukkan sebarang kaitan. Faktor lain yang mungkin mempengaruhi jumlah telur yang dihasilkan termasuk kepadatan populasi dewasa dan intensiti cahaya juga dibincangkan.

Kata kunci: Lalat Askar Hitam, *Hermetia illucens*, pemantauan, sisa organik, populasi, sangkar separa-terkawal

INTRODUCTION

In warm climate countries, *Hermetia illucens* (L.) or locally known as Black Soldier Fly (BSF), can easily be spotted in most organic waste (Sheppard et al. 2002). In addition, BSF is a New World insect that has spread throughout the globe because of human food commerce (Martínez-Sánchez et al. 2011). Black soldier fly is also known as a holometabolous insect that goes through a series of transformations from egg to larva to pupa to adult (De Smet et al. 2018; Grossule & Lavagnolo 2020; Lievens et al. 2021; Surendra et al. 2020). According to Tomberlin et al. (2002), the BSF goes through a series of metamorphoses during its life cycle, which takes 43 days if enough nutrients are available. Adult BSF may survive for up to eight days and are only rehydrated by drinking water. All additional nutrients were acquired during the larval stage; thus, the adult does not need to feed. Rather than consuming waste to oviposit like other flies, the short lifespan of adult BSF was devoted entirely to mating and oviposition. Before dying, a female adult black soldier fly was observed to oviposit once, laying roughly 620 eggs (Kotzé et al. 2019; Tomberlin et al. 2009).

In comparison to other flies, the adult BSF is bigger and usually black (Benelli et al. 2014). Due to its large size, adult BSF often being mistaken as the wasp (Zhang et al. 2010). Next, the morphology of the immature stage of BSF is commonly seen in larval form with white to yellowish in colour. Fine golden hair can be spotted surrounding the larval body with ocular prominences located laterally in the head (Benelli et al. 2014).

Interestingly, BSF larvae have earned a reputation for their voracious eating behaviour on a variety of organic waste, and they have been tested in waste management systems (De Smet et al. 2018; Lalander et al. 2019; Surendra et al. 2020). Aside from that, BSF has piqued the interest of researchers and farmers since the adult was not considered a disease vector (Lalander et al. 2019; Sheppard et al. 2002; Wang & Shelomi 2017).

The insect also can be farmed in high density in a small area to aid in the recycling of organic waste into high-quality products (Nyakeri et al. 2017; Scala et al. 2020). Due to high protein and fat content, BSF larvae are favoured in the production of livestock feed additives (Barragan-Fonseca et al. 2017; Liu et al. 2017; Spranghers et al. 2017; Wang & Shelomi 2017). The larvae's amino acid composition was also comparable to fishmeal and soybean meal which is useful in feedstuff production while the high lipid content can be extracted into premium grade biodiesel (Liu et al. 2019). Because of their brief life cycles, BSF larvae are also favoured as long-term oil sources (Nguyen et al. 2017). In manure management systems, the immature stage of *H. illucens* prevents and controls the oviposition and development of the house fly, *Musca domestica* (Miranda et al. 2019).

The adult is most active during oviposition and a temperature of 30-34°C seems to be an optimal temperature for adult BSF (Booth & Sheppard 1984; Chia et al. 2018). Sheppard et al. (2002) used a 2 × 2 × 4 m screen cage in a 7 × 9 × 5 m greenhouse with good solar exposure to produce the suitable mating condition. Black soldier fly also has been known to prefer direct sunshine for mating. Thus, the following restriction of population density could have been caused by climatic conditions. The adult population density and light intensity are among other parameters that might influence the oviposition (Hoc et al. 2019; Liu et al. 2020; Park et al. 2016a).

The study aimed to monitor the population of BSF in semi-captive controlled conditions. Throughout the study, meteorological parameters such as temperature, relative humidity, and light intensity were measured. In addition, a correlation study was performed to determine if there was a link between these climatic parameters and egg density. The monitoring of the BSF population under this semi-captive controlled condition system was necessary with a reliable colonization method. This finding would encourage biological studies and the use of BSF in experiential education known as the Knowledge Transfer Program. The Knowledge Transfer Program encourages universities, research organisations, enterprises, government agencies, and the general public to share creative and innovative ideas, research findings, experiences, and skills. As a result, this programme served as a platform for local communities to communicate, train, and learn about many aspects of BSF throughout the country.

MATERIALS AND METHODS

Study Site and Semi-Captive Controlled Condition

In this study, the BSF populations at Tasek Gelugor, Penang, Malaysia was monitored by recording the weight of BSF's eggs, temperature, and relative humidity inside the adult cage. The study was carried out in a semi-captive controlled condition adult cage (2 m width × 4 m length × 2.5 m height). In this study, lighting and misting system were used to provide controlled conditions. The adult cage had a transparent polycarbonate ceiling and was surrounded by a wire mesh to increase direct sunlight exposure, while a double door system was utilised to prevent adults from escaping. During the daylight, lighting systems with halogen lights were employed to replicate natural sunlight and promote the mating process of adult BSF. Inside the cage, a misting system was installed to regulate relative humidity, and artificial plants were placed in the centre and each corner of the cage as resting areas for the adults BSF (Plate 1).

A B C D E

Plate 1. A. Eggs collection system using wooden blocks. B. Larvae growth in cemented ponds. C. Pupae development in darkroom. D. Adult cage with lighting and misting system. E. Mating and resting sites for adult black soldier flies.

Trapping of Black Soldier Fly

To entice the female BSF to lay eggs inside the trapping bins, an artificial oviposition media was created. This system was exposed for oviposition using fermented coconut waste. A mixture of 10 kg coconut waste and 10 L effective microbes (EM2) (1:1) was fermented for four days inside the trapping bins (43 cm diameter × 50 cm height). Six wooden blocks (3 cm width × 29 cm length × 1 cm height) were tied together using the elastic band (Plate 1). The wooden blocks were placed on top of the plastic containers inside each trapping bin to provide space (6-8 cm) between the fermented coconut waste. To allow the female BSF to enter the bins and deposit eggs, five to six holes (2 cm diameter) were drilled around the bins. A total of ten trapping bins were set up at a distance of 10 metres. The BSF larvae were collected 10 days after the traps were placed in the field (Hasan & Dina 2019).

Rearing of Black Soldier Fly

The system that was employed in this research was modified from Caruso et al. (2014). The larval growth area consisted of 16 rearing ponds, and the larvae were fed food waste supplied from the Seberang Perai City Council in Penang. The BSF eggs were gathered from the trapping bins and placed in plastic trays (35.5 cm length × 25 cm width × 9 cm height) for 4-5 days before the larvae were placed inside the cemented rearing pond (3 m × 3 m) (Plate 1). Every two days, 200 kg of food waste was fed to the larvae in each rearing pond. Pre-pupae from cemented pond larvae were separated from food waste residue using high-quality vibrating sifter equipment for sifting BSF (XF1000-1S, Xinxiang XianFeng Vibration Machinery Co., Ltd). The pre-pupae of the BSF were moved to the pupae room (4 m width × 5 m length × 4.5 m height) located next to the adult cage (2 m width × 4 m length × 2.5 m height). The oviposition method was developed utilising the procedure developed by Hoc et al. (2019). To make the process easier, the oviposition method was used as an egg collection system. The egg collection system consisted of six wooden blocks (3 cm width × 29 cm length × 1 cm height), spaced by cable ties, and held by elastic bands. To keep BSF from laying eggs on the substrate media, these wooden blocks were placed on a tray and covered in wire mesh. Inside the plastic tray (35.5 cm length × 25 cm width × 9 cm height), the fermented coconut waste or wheat bran was used as a feeding medium for the newly hatch larvae. After 4-5 days, the larvae were transferred to the cemented ponds (3 m × 3 m) (Plate 1) to continue feeding on food waste. Every day, the eggs were collected by detaching them from the wooden blocks. An electronic scale was used to weigh and record the eggs each day (Pocket Scale MH-Series 0.01g/100g). A hygrometer was used to record the temperature and relative humidity on a daily basis in order to investigate the relationship between these climatic factors and the generation of BSF eggs.

Statistical Analysis

The data were statistically analysed using IBM SPSS statistic v 25.0 for Windows. The egg's weight, temperature, and relative humidity were measured during ten months and the mean and standard error (SE) were computed. The Shapiro-Wilk test was used to determine the data's normality. However, the data for ten months of observations on the BSF egg’s weight, temperature, and relative humidity in the adult cage were not normally distributed (Shapiro-Wilk test; $P<0.001$). To establish the significant difference in egg weight, temperature, and relative humidity between the months, the Kruskal–Wallis test (H test) was performed, followed by Dunn's post-hoc test. The association between climatic factors and egg mean weight was then determined using Spearman's correlation coefficient analysis.

RESULTS

Mean Weight of Black Soldier Fly Eggs and Analysis of Climatic Factors

The production of BSF's eggs and climatic factors (temperature and humidity) at Tasek Gelugor was recorded for ten months. The mean weight (g±SE) of BSF eggs collected was declined in the second month (11.51±1.49g) of the study but gradually increased until the fourth month of observations (36.85±3.12g). However, the mean weight of the eggs was slowly declined from the fifth month (28.53±2.48g) until the eighth month of observations (17.74±2.10g). These values increased again from the ninth month until the tenth month of observations (Figure 1). The Kruskal Wallis test showed that the mean weight of BSF's eggs was significantly different throughout ten months, $H(9) = 133.37$, $P<0.001$. The greatest weight of BSF's eggs was produced at the final month (81.77±3.80g) whereas the lowest BSF's eggs were recorded at the second month of the study (11.51±1.49g). In addition, the Kruskal Wallis test showed that the mean temperature was significantly different throughout ten months, $H(9) = 65.37$; $P<0.001$. The highest temperature, 31.16±0.19℃ was recorded at the eighth month and the lowest temperature, 28.49±0.27℃ was recorded at the third month of observations (Figure 1). The Kruskal Wallis test also showed that the mean relative humidity was significantly different throughout ten months, $H(9) = 76.66$; $P<0.001$. The highest mean relative humidity, 81.58±1.07% was recorded at the third month while the lowest mean relative humidity, 64.83±0.7% was recorded at the seventh month of observations (Figure 2).

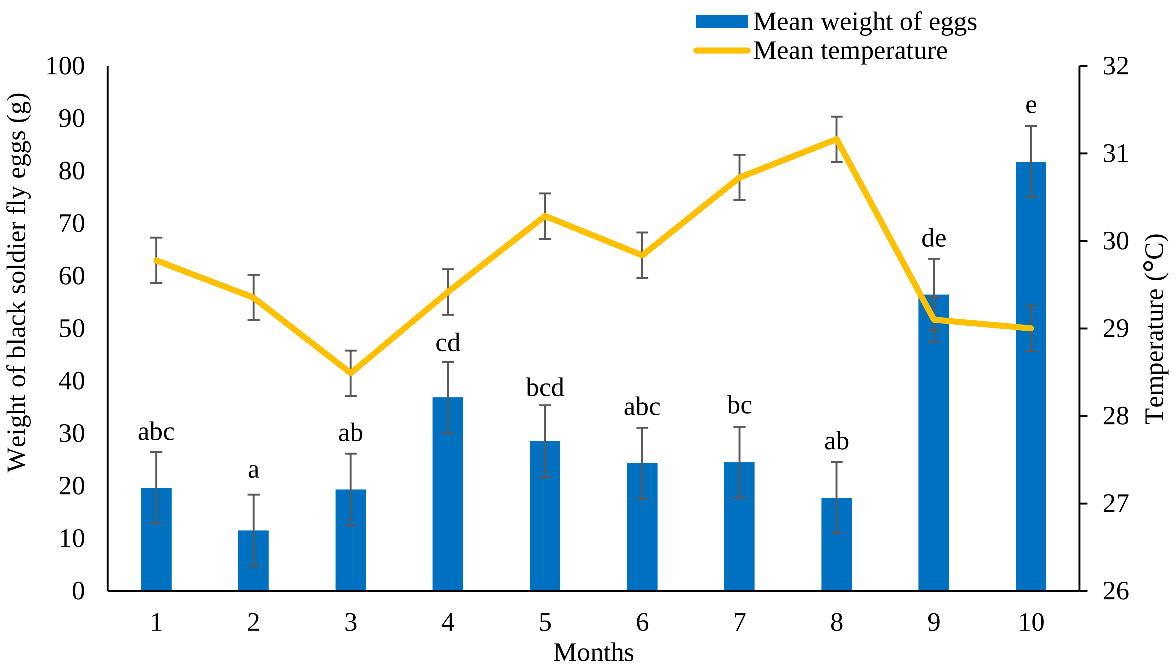

Figure 1. Mean weight (±SE) of black soldier fly eggs and temperature throughout 10 months of study period

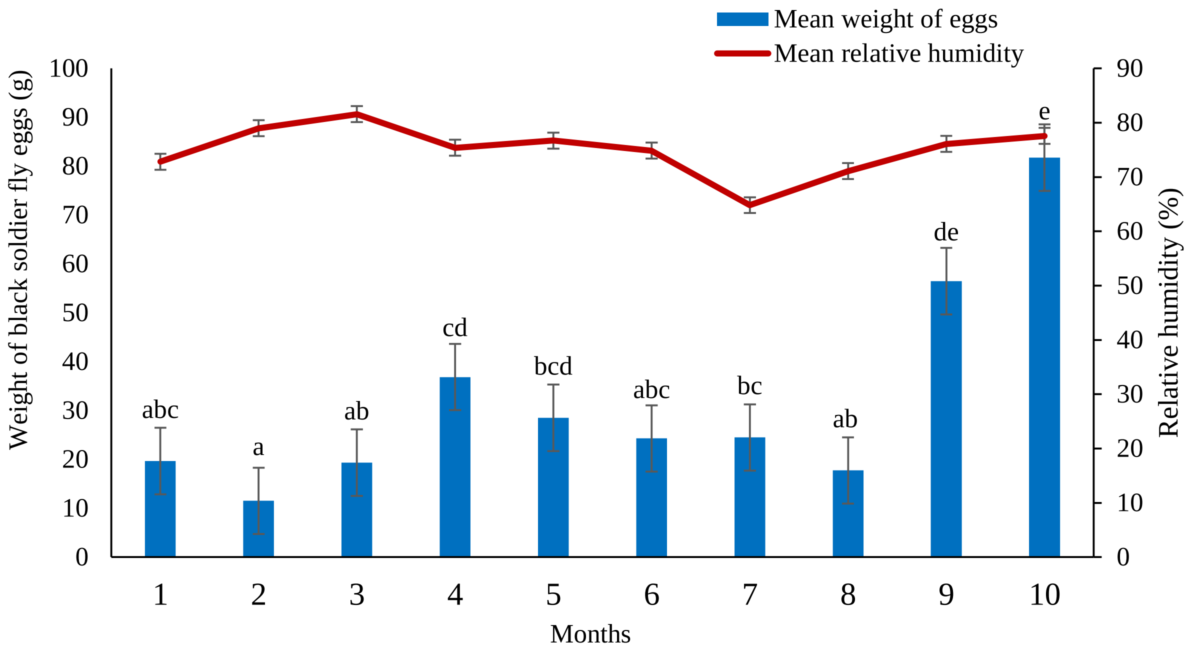

Figure 2. Mean weight ±SE of black soldier fly eggs and relative humidity throughout 10 months

Correlation of Climatic Factors with The Mean Weight of Black Soldier Fly Eggs
Spearman's correlation coefficient analysis was used to assess the relationship between the mean weight of BSF's eggs and climatic factors (temperature and relative humidity). There was no correlation between the mean weight of BSF's eggs and temperature throughout ten months, $r_s= -.09$, $P= .14$, $N= 292$. In addition, the mean weight of BSF's eggs also does not possess a correlation with the relative humidity throughout the ten months, $r_s= -.04$, $P= .52$, $N= 292$. (Appendix 1).

DISCUSSIONS

Insects are the most diverse animal and can easily be found in any part of the world. They continue to play an important role in the worldwide ecology, particularly when it comes to organic waste recycling (Halsch et al. 2021). Differences in climate parameters usually govern insect populations around the world. Thus, climate change has been linked to insect population dynamics many times. Tropical insects suffer the most from temperature changes, especially high temperatures. Among the reasons was the tropical insect has adapted to climate variability more slowly in recent decades due to the constant tropical climate. As a result, a slight temperature rise may decrease tropical species' fitness while increasing temperate species' fitness (García-Robledo et al. 2016; Johansson et al. 2020). *Hermetia illucens* is reported to withstand a wide range of environmental conditions (Barragan-Fonseca et al. 2017). Controlling the factors that promote BSF oviposition is vital for insect farming operations (Kenis et al. 2018; Tan & Sim 2020). The identification of optimum ranges for environmental parameters such as temperature, relative humidity, and light intensity at BSF's mass production site will greatly aid in optimising production in industrialised facilities (Jones & Tomberlin 2020; Pastor et al. 2015). Based on the weight of eggs recorded in Tasek Gelugor, the BSF population rose from the second to the fourth month of observations, but then gradually dropped from the fifth to the eighth month. The population of BSF, on the other hand, increased dramatically from the ninth to the tenth month of monitoring at Tasek Gelugor. Thus, climatic factors recorded at the adult cage were analysed. Certain elements, like temperature, relative humidity, and sunlight, can influence BSF oviposition. Therefore, data in climatic factors is essential in detecting fluctuations in insect population (Bertinetti et al. 2019).

Temperature and relative humidity were commonly investigated, and numerous articles also stressed the association of climatic factors with insect development (Bugajski & Stoller 2017; Chia et al. 2018; Issimov et al. 2021; Lesne et al. 2020; Liao et al. 2017; Lutz et al. 2019; Shumo et al. 2019; Skovgård & Nachman 2017; Soares & Vasconcelos 2016; Sontigun et al. 2018; Zhou et al. 2020). Previously, Chia et al. (2018) has tested several consistent temperatures (15, 20, 25, 30, 35, 37, and 40°C) on BSF development. Similar to Chia et al. (2018), this study also recorded a range of temperatures during the oviposition of BSF. In this study, the highest fecundity rate of BSF was obtained at 30°C, which was comparable to the finding of Shumo et al. (2019). Normally, at 30°C, many insects were found to have the highest fecundity (Otieno et al. 2019; Winkler et al. 2020). In addition, a closely related species to BSF, the oriental latrine fly, *Chrysomya megacephala*, showed to have the largest population in the summer where the climate is warm (Sontigun et al. 2018). Other than that, *Bactrocera dorsalis*, an oriental fruit fly, was likewise shown to have the highest fecundity with a similar temperature. The authors of oriental fruit fly study claimed that daily egg production was temperature-dependent, with an ideal oviposition temperature range of 18.8 - 32.0°C (Choi et al. 2020; Michel et al. 2021). In addition, the best temperature for maximum oviposition was found to be 23°C in *Drosophila suzukii* (Schlesener et al. 2020). Other than fly species, the warm temperature at 30°C also has been reported to affect the fecundity of edible cricket species and Lepidoptera (Aregbesola et al. 2020; Cui et al. 2018; Liao et al. 2017; Ma et al. 2017; Otieno et al. 2019). However, according to da Silva & Hesselberg (2020), the optimal conditions for stimulating mating and oviposition in BSF might vary in each study. Nevertheless, most entomologists tend to work with temperatures ranging from 20 to 35 °C, with relative humidity levels ranging from 30 to 67 % (Danieli et al. 2019; Jones et al. 2019; Julita et al. 2019).

In general, insect reproduction will be hampered by extreme temperatures especially temperatures exceeding 35°C (Liao et al. 2017). With extreme temperature, adult female BSF flies' lifespan was observed to reduce by 4-5 times (Chia et al. 2018; Shumo et al. 2019). However, in this study, the mean (SE) temperature did not surpass 35°C throughout the investigation. As compared to BSF, the fruit fly, *Drosophila suzukii* has a tight temperature threshold for reproductive oviposition at temperatures over 30°C (Shaw et al. 2018). *Bactrocera cucurbitae*, on the other hand, was found to improve its reproductive capacity when exposed to a high temperature, 45°C for a brief period (Zeng et al. 2018; Zhou et al. 2020). In blowfly species, a similar situation has been reported, where the temperature is a significant factor influencing oviposition behaviour (Bugajski & Stoller 2017; Issimov et al. 2021; Ody et al. 2017; Williams et al. 2017). As the temperature rose, oviposition in blowflies, *Lucillia sericata*, and *Phormia regina* was reported to be faster, with more eggs deposited (Hans et al. 2019). Temperature preferences of insects may differ due to climate change in each region. Frequent global warming has caused temperature variations and triggered the genes involved in oviposition (Cornelissen 2011; Zhou et al. 2020).

The recorded temperature in this study ranges from 28.49±0.27 to 31.16±0.19°C while the relative humidity ranges from 65.83±0.78 to 82.58±1.07%. Both temperature and relative humidity recorded in this study were comparable to the previous studies by Chia et al. (2018), da Silva & Hesselberg (2020), Holmes et al. (2012), and Shumo et al. (2019). The mean weight of BSF eggs does not vary much over the months since the temperature and relative humidity in this study are within the ideal range. The relative humidity was thought to be strongly linked to egg production, but this was not demonstrated in this investigation (Holmes et al. 2012; Jones & Tomberlin 2020). However, another Diptera was mentioned to be affected by relative humidity, which influences population abundance by extending lifespan and improving fertility (Bartlett et al. 2019; Tochen et al. 2016). *Drosophila suzukii* fecundity and survival rate rose dramatically as relative humidity increased (Tochen et al. 2016). The relative humidity that affects *D. suzukii* ranges from 75 to 100% (Guédot et al. 2018). It has been reported that *D. suzukii* has a greater reproductive success rate at night, and it appears to favour a microclimate with a mild temperature and high humidity (Evans et al. 2017).

The hatchability rate, population density, and sex ratio are likely to influence the mean weight of BSFs eggs in this study. Nevertheless, more eggs may not always suggest a high population density if the eggs do not hatch and grow to adulthood (Chia et al. 2018). Egg fertility may have an impact on larval output (Diener et al. 2011). These variables are intertwined because one might have a major impact on another. The population density in this study was most likely impacted by viability and hatchability. When compared to other Diptera, such as *Drosophila melanogaster*, dietary variations were thought to affect offspring survivability (Davies et al. 2019). Protein and carbohydrates, as well as other macronutrients, are critical for insect growth, reproduction, and survival (Lihoreau et al. 2016; Rodrigues et al. 2015). Carbohydrates are key energy sources for insects in the generation of edible insects, whereas proteins are needed for growth and development (Ortiz et al. 2016).

Food waste was employed as the primary diet for growing BSF in this study. The nutritious value of the food waste mixture could vary, especially in terms of protein and carbohydrate ratios. When fed with food waste, BSFs were recorded to produce the heaviest larvae, according to Oonincx et al. (2015) and Nguyen et al. (2015). Cammack & Tomberlin (2017) found that BSF larvae fed on 21% protein, 21% carbohydrate, and 70% moisture developed the fastest and survived the longest. Shumo et al. (2019) discovered that dietary quality during the larval stage influenced the BSF's fertility.

In addition, Davies et al. (2019) discovered, that female *D. melanogasters* can overcome lack of sustenance and can oviposit a significant number of eggs. Black soldier fly also mimics such a mechanism in continuing its species. During the immature stage, if a sudden nutrient absence occurred, the larvae will halt its metamorphosis. This mechanism has also been observed in female BSF which it tends to spend more time-consuming nutrient as compared to male BSF (Tomberlin et al. 2009). High fecundity in insects often been obtained through the ability to acquire nutrients which can be seen in the body size of females (Berger et al. 2008; Holmes et al. 2016; Otieno et al. 2019; Rodrigues et al. 2015; Shumo et al. 2019). Black soldier fly has also been reported to display such behaviour where nutrients gathered for reproduction have been converted into greater body size and oviposition (Georgescu et al. 2020). Aside from that, Park et al. (2016a) and Hoc et al. (2019) discovered that BSF population density and sex ratio influence fertility and oviposition.

The influence of the sex ratio on BSF fertility is widely debated. The sex ratio must be considered especially in artificial mass rearing since it has an impact on BSF fertility (Jucker et al. 2019). According to Putra & Safa'at (2020), a female-dominant population of BSF generated more eggs and this supported the findings of Hoc et al. (2019). However, Hoc et al. (2019) also pointed out that male-dominant populations have higher fertility due to more mating opportunities. In the research of fungus gnats, male-dominant populations are the best for female fecundity, which is similar to BSF (Gou et al. 2019).

The fecundity and fertility were reported to be influenced by the density of fly in the cage especially in a semi-artificial environment (Park et al. 2016a). A similar situation also was observed in polyphagous fruit flies where its fecundity was aided by the high density of larvae (Olazcuaga et al. 2019). Surprisingly, increasing the density resulted in more eggs, implying that they are more productive. However, an increase in the number of adult flies may result in competition between individuals, halting reproduction capacity (Park et al. 2016a). This can be observed in the blowfly, where competition has become an inhibitory effect in the oviposition and further lowers the capability to reproduce (Parry et al. 2017).

Insect rearing depends on the amount of area available for mating and oviposition. Cages ranging from three to 16 m^3 are commonly used in small-scale rearing in tropical locations (van Huis et al. 2020). Park et al. (2016a) found that cages with dimensions of 1.5 m width × 1.5 m length × 2.5 m height and 2 m wide × 2 m length × 2.5 m height were the most suitable for mass rearing, with both cages hosting 65 000 BSF pupae. Aside from that, Gougbedji et al. (2021) claimed that 8500 individuals/m^3 cages (75 cm width × 75 cm length × 115 cm height) resulted in the maximum oviposition. The preferred cages, according to Kenis et al. (2018), should be at least 2 m^3 because adults are more likely to mate when flying, and cages measuring 40 cm width × 40 cm length × 40 cm height would also be sufficient to facilitate mating and oviposition in BSF. For mating and oviposition, this study employed an adult cage with a 2 m width × 4 m length × 2.5 m height. Each cycle consumed around 300 kg of pupae, yielding approximately two million adult BSFs. Because of the colony's high density, the sex ratio of BSF was not examined in this study. As a result, calculating the colony's sex ratio would be time-consuming.

Light intensity is another element that influences adult BSF oviposition. According to Liu et al. (2020), the BSF needs the help of sunlight in assisting in mating and oviposition. Due to the lack of regular sunshine induced by adverse weather conditions, mating and the production of fertile eggs were both reduced. As a substitute for sunlight, artificial light sources were used in this study to support BSF mating.

In this experiment, 10 halogen bulbs (Softone 100W E27 220-240V T55 WH 1CT/5X10F, Philips Lighting) were installed under the transparent polycarbonate roof for nine hours to help with the inconsistent sunlight that passes through. On average, daily light intensity is approximately 9000 lux or 171μmolm−2s−1 (Ali et al. 2019) while halogen bulbs are used to produce a light intensity of up to 3085 lux at 57.13μmolm−2s−1. Similar to this study, Heussler et al. (2018) used a halogen lamp (QVF135HAL - TDS500W K BK CN, Philips Lighting) that stimulated oviposition in BSF at a light intensity of 59μmol$m^{-2}s^{-1}$ while Park et al. (2016b) reported that BSFs prefer to mate under direct sunlight. This shows that the BSF's mating and oviposition may benefit from a combination of artificial and natural light. The light intensity of 200μmol$m^{-2}s^{-1}$ (equal to 10 800 lux) with a wavelength of 440 or 540 nm is necessary to promote mating among BSF (Tomberlin et al. 2002). Hoc et al. (2019) and Holmes et al. (2016) claimed that a minimum light intensity between 40 – 60μmol $m^{-2}s^{-1}$ is required to induce mating and oviposition in BSF. In addition, light intensities ranging from 600 to 2000 μmol $m^{-2}s^{-1}$ (Nakamura et al. 2016) and 105.11μmol$m^{-2}s^{-1}$ (Oonincx et al. 2016) also found to be effective in encouraging mating and oviposition of BSF.

For mating and oviposition, the wavelength of light sources is also key to BSF. Insects cannot perceive wavelengths longer than 700 nm, however, it was previously established that wavelengths between 450 nm and 700 nm were important for promoting mating behaviour (Liu et al. 2020; Nakamura et al. 2016). Schneider (2020) also believes that boosting mating success can be accomplished by exposing adults to light with a high concentration of wavelengths at 440 and/or 540 nm, which is a small fraction of the intensity of full sunshine. Many studies use various wavelengths and light intensities, however, the best wavelengths and light intensities for BSF have yet to be discovered. No oviposition activity was observed at night or in complete darkness, but more research is needed to learn more about mating and oviposition at night (Barnes et al. 2015; Gemmellaro et al. 2018).

To further investigate the fluctuation in egg weight of BSF throughout the months, an artificial setup for the collection of BSF eggs was discussed. The artificial setup for oviposition in this study consists of six wooden blocks (3 cm width × 29 cm length × 1 cm height), spaced by cable ties, and held by elastic bands placed above the attractant. According to Park et al. (2016b), The most critical component driving oviposition is the medium for bulk egg deposition. Apart from wooden blocks, corrugated cardboard was the most common material utilised as an artificial oviposition arrangement (Chia et al. 2018; Meneguz et al. 2018). Corrugated cardboard, on the other hand, is not appropriate for collecting eggs. The corrugated board could have absorbed the moisture from the BSF egg, causing weight loss (Dortmans et al. 2017). Furthermore, unlike wooden blocks, corrugated cardboards are expensive because they must be replaced frequently. The use of wooden blocks, on the other hand, does not imply that oviposition will take place in a single location. Heussler et al. (2018) reported that outside of the artificial oviposition support, almost 90% of the eggs were collected. In nature, the eggs are usually oviposited in dry cracks near moist decomposing organic waste (Sheppard et al. 2002). In this study, an attractant such as fermented coconut trash was employed to centralise egg oviposition for the BSF (Hoc et al. 2019; Liu et al. 2020).

Aside from the issues with BSF oviposition, there are a few more things to consider. Regulating cultural practises may aid in the development of a stable BSF population. The facility that runs with BSF must have a regular, well-balanced food supply to avoid unwanted odours and provide a consistent and effective feeding activity (Diener et al. 2011; Lohri et al. 2017; Meneguz et al. 2018). Furthermore, as the sector grows, investigations into the mass manufacturing of BSF become more appealing. Since most studies on BSF have previously been undertaken on a benchtop scale and producing BSF at an industrial scale has proven difficult. It's critical to consider numerous parameters before applying laboratory findings to industrial-scale methods. The results may alter if benchtop data is scaled to an industrial size, which is not necessarily linear (Miranda et al. 2020; Yang & Tomberlin 2020). To be able to assure the quality and quantity of BSF production, a sustainable technology must incorporate techniques such as raw material transportation, automation, and climate control (Ortiz et al. 2016; Kinyuru 2020; Lohri et al. 2017; Kröncke et al. 2020).

CONCLUSIONS

The population of BSFs fluctuated over the months during the study. The temperature and relative humidity recorded were within the optimal range. The results of this study suggest that both temperature and relative humidity did not significantly influence oviposition behaviour. However, changes in the mean egg weight could be linked to other parameters including the number of pupae and adult sex ratio. The lack of information on adult population density and light intensity in this study limits the ability to determine other oviposition parameters.

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REFERENCES

Ali, A.A.S., Zakaria, S.A., Wei, L.J., & Shien, N.Y. 2019. Light pollution and health: Case study of the lighting fixtures applied on Penang Town Hall in George Town, Penang Island. *IOP Conference Series: Materials Science and Engineering* 636(1): 012009.

Aregbesola, O.Z., Legg, J.P., Lund, O.S., Sigsgaard, L., Sporleder, M., Carhuapoma, P. & Rapisarda, C. 2020. Life history and temperature-dependence of cassava-colonising populations of *Bemisia tabaci*. *Journal of Pest Science* 93(4): 1225–1241.

Barnes, K.M., Grace, K.A. & Bulling, M.T. 2015. Nocturnal oviposition behavior of forensically important Diptera in Central England. *Journal of Forensic Sciences* 60(6): 1601–1604.

Barragan-Fonseca, K.B., Dicke, M. & van Loon, J.J.A. 2017. Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed - a review. *Journal of Insects as Food and Feed* 3(2): 105–120.

Bartlett, J., Convey, P. & Hayward, S.A.L. 2019. Not so free range? oviposition microhabitat and egg clustering affect *Eretmoptera murphyi* (Diptera: Chironomidae) reproductive success. *Polar Biology* 42(2): 271–284.

Benelli, G., Canale, A., Raspi, A. & Fornaciari, G. 2014. The death scenario of an Italian Renaissance princess can shed light on a zoological dilemma: Did the black soldier fly reach Europe with Columbus? *Journal of Archaeological Science* 49(1): 203–205.

Berger, D., Walters, R. & Gotthard, K. 2008. What limits insect fecundity? Body size- and temperature-dependent egg maturation and oviposition in a butterfly. *Functional Ecology* 22(3): 523–529.

Bertinetti, C., Samayoa, A.C. & Hwang, S.Y. 2019. Effects of feeding adults of *Hermetia illucens* (Diptera: Stratiomyidae) on longevity, oviposition, and egg hatchability: Insights into optimizing egg production. *Journal of Insect Science* 19(1): 19.

Booth, D.C & Sheppard, C. 1984. Oviposition of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): Eggs, masses, timing, and site characteristics. *Environmental Entomology 13*(2): 421–423.

Bugajski, K. & Stoller, P. 2017. Effect of habitat on blow fly (Diptera: Calliphoridae) oviposition in Michigan. *The Great Lakes Entomologist* 50(1-2): 1-5.

Cammack, J.A. & Tomberlin, J.K. 2017. The impact of diet protein and carbohydrate on select life-history traits of the black soldier fly *Hermetia illucens* (L.) (Diptera: Stratiomyidae). *Insects* 8(2): 56.

Caruso, D., Devic, E., Subamia, W., Talamond, P. & Baras, E. 2014. *Technical Handbook of Domestication and Production of Diptera Black Soldier Fly (BSF) Hermetia illucens, Stratiomyidae*. Bogor, Indonesia: IPB Press.

Chia, S.Y., Tanga, C.M., Khamis, F.M., Mohamed, S.A., Salifu, D., Sevgan, S., Fiaboe, K.K. M., Niassy, S., van Loon, J.J.A., Dicke, M., & Ekesi, S. 2018. Threshold temperatures and thermal requirements of black soldier fly *Hermetia illucens*: Implications for mass production. *PLoS ONE* 13(11): e0206097.

Choi, K.S., Samayoa, A.C., Hwang, S.Y., Huang, Y.B. & Ahn, J.J. 2020. Thermal effect on the fecundity and longevity of *Bactrocera dorsalis* adults and their improved oviposition model. *PLoS ONE* 15(7): e0235910.

Cornelissen, T. 2011. Climate change and its effects on terrestrial insects and herbivory patterns. *Neotropical Entomology* 40(2): 155-163.

Cui, J., Zhu, S.Y., Bi, R., Xu, W., Gao, Y. & Shi, S.S. 2018. Effect of temperature on the development, survival, and fecundity of *Heliothis viriplaca* (Lepidoptera: Noctuidae). *Journal of Economic Entomology* 111(4): 1940–1946.

da Silva, G.D.P. & Hesselberg, T. 2020. A review of the use of black soldier fly larvae, *Hermetia illucens* (Diptera: Stratiomyidae), to compost organic waste in tropical regions. *Neotropical Entomology* 49(2): 151–162.

Danieli, P.P., Lussiana, C., Gasco, L., Amici, A. & Ronchi, B. 2019. The effects of diet formulation on the yield, proximate composition, and fatty acid profile of the black soldier fly (*Hermetia illucens* l.) prepupae intended for animal feed. *Animals* 9(4): 178.

Davies, L.R., Schou, M.F., Kristensen, T.N. & Loeschcke, V. 2019. Fluctuations in nutrient composition affect male reproductive output in *Drosophila melanogaster*. *Journal of Insect Physiology* 118: 103940.

De Smet, J., Wynants, E., Cos, P., Van Campenhout, L. 2018. Microbial community dynamics during rearing of black soldier fly larvae (*Hermetia illucens*) and impact on exploitation potential. *Applied and Environmental Microbiology* 84: e02722-17.

Diener, S., Studt Solano, N.M., Roa Gutiérrez, F., Zurbrügg, C. & Tockner, K. 2011. Biological treatment of municipal organic waste using black soldier fly larvae. *Waste and Biomass Valorization* 2(4): 357–363.

Dortmans, B.M.A., Diener, S., Verstappen, B.M. & Zurbrügg, C. 2017. *Eawag - Black Soldier Fly Biowaste Processing - Step by Step Guide.* Switzerland: Eawag – Swiss Federal Institute of Aquatic Science and Technology.

Evans, R.K., Toews, M.D. & Sial, A.A. 2017. Diel periodicity of *Drosophila suzukii* (Diptera: Drosophilidae) under field conditions. *PLoS ONE* 12(2). e0171718

García-Robledo, C., Kuprewicz, E.K., Staines, C.L., Erwin, T.L. & Kress, W.J. 2016. Limited tolerance by insects to high temperatures across tropical elevational gradients and the implications of global warming for extinction. *Proceedings of the National Academy of Sciences of the United States of America* 113(3): 680–685.

Gemmellaro, M.D., Bucolo, C., Musumeci, E., Hamilton, G.C. & Weidner, L.M. 2018. First observations of initial blow fly (Diptera: Calliphoridae) activity on lava fields and in subterranean environments in Sicily in cool temperatures. *Journal of Medical Entomology* 55(6): 1622–1626.

Georgescu, B., Struti, D., Păpuc, T., Ladosi, D. & Boaru, A. 2020. Body weight loss of black soldier fly *Hermetia illucens* (Diptera: Stratiomyidae) during development in nonfeeding stages: Implications for egg clutch parameters. *European Journal of Entomology* 117: 216–225.

Gou, Y., Wang, G., Quandahor, P., Liu, Q. & Liu, C. 2019. Effects of sex ratio on adult fecundity, longevity and egg hatchability of *Bradysia difformis* Frey at different temperatures. *PLoS ONE* 14(6): e0217867.

Gougbedji, A., Agbohessou, P., Lalèyè, P.A., Francis, F. & Megido, R.C. 2021. Technical basis for the small-scale production of black soldier fly, *Hermetia illucens* (L. 1758), meal as fish feed in Benin. *Journal of Agriculture and Food Research* 4(2021):100153.

Grossule, V. & Lavagnolo, M.C. 2020. The treatment of leachate using black soldier fly (BSF) larvae: Adaptability and resource recovery testing. *Journal of Environmental Management* 253 (2020): 109707.

Guédot, C., Avanesyan, A. & Hietala-Henschell, K. 2018. Effect of temperature and humidity on the seasonal phenology of *Drosophila suzukii* (Diptera: Drosophilidae) in Wisconsin. *Environmental Entomology* 47(6): 1365–1375.

Halsch, C.A., Shapiro, A.M., Fordyce, J.A., Nice, C.C., Thorne, J.H., Waetjen, E.D.P. & Forister, M.L. 2021. *Insects and Recent Climate Change* 118(2): 2002543117.

Hans, K.R., Lebouthillier, R. & VanLaerhoven, S.L. 2019. Effect of temperature on oviposition behavior and egg load of blow flies (Diptera: Calliphoridae). *Journal of Medical Entomology* 56(2): 441–447.

Hasan, H.A. & Dina, F. 2019. Co-occurrence of different insect species in oviposition media of black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *Serangga* 24(2): 1–14.

Heussler, C.D., Walter, A., Oberkofler, H., Insam, H., Arthofer, W., Schlick-Steiner, B.C. & Steiner, F.M. 2018. Influence of three artificial light sources on oviposition and half-life of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): Improving small-scale indoor rearing. *PLoS ONE* 13(5): e0197896.

Hoc, B., Noël, G., Carpentier, J., Francis, F. & Megido, R.C. 2019. Optimization of black soldier fly (*Hermetia illucens*) artificial reproduction. *PLoS ONE* 14(4): e0216160.

Holmes, L.A., VanLaerhoven, S. & Tomberlin, J.K. 2016. Lower temperature threshold of black soldier fly (Diptera: Stratiomyidae) development. *Journal of Insects as Food and Feed* 2: 255-262.

Holmes, L.A., Vanlaerhoven, S.L. & Tomberlin, J.K. 2012. Relative humidity effects on the life history of *Hermetia illucens* (Diptera: Stratiomyidae). *Environmental Entomology* 41(4): 971–978.

Issimov, A., Taylor, D. B., Zhugunissov, K., Kutumbetov, L., Zhanabayev, A., Kazhgaliyev, N., Akhmetaliyeva, A., Nurgaliyev, B., Shalmenov, M., Absatirov, G., Dushayeva, L. & White, P. J. 2021. The combined effects of temperature and relative humidity parameters on the reproduction of *Stomoxys* species in a laboratory setting. *PLoS ONE* 15(12): e0242794.

Johansson, F., Orizaola, G. & Nilsson-Örtman, V. 2020. Temperate insects with narrow seasonal activity periods can be as vulnerable to climate change as tropical insect species. *Scientific Reports* 10(1): 1–8.

Jones, B.M. & Tomberlin, J.K. 2020. Validation of acrylic paint as a marking technique for examining mating success of the black soldier fly (Diptera: Stratiomyidae). *Journal of Economic Entomology* 113(5): 2128–2133.

Jones, B.M., Tomberlin, J.K. & Stull, V. 2019. Impact of larval competition on life-history traits of the black soldier fly (Diptera: Stratiomyidae). *Annals of the Entomological Society of America* 112(6): 505–510.

Jucker, C., Leonardi, M.G., Rigamonti, I., Lupi, D. & Savoldelli, S. 2019. Brewery's waste streams as a valuable substrate for black soldier fly *Hermetia illucens* (Diptera: Stratiomyidae). *Journal of Entomological and Acarological Research* 51(2): 87–94.

Julita, U., Fitri, L.L., Putra, R.E. & Permana, A.D. 2019. Survival and reproductive value of *Hermetia illucens* (Diptera: Stratiomyidae) on vegetable and fruits waste rearing substrate. *Journal of Physics: Conference Series* 1245(1): 012002.

Kenis, M., Bouwassi, B., Boafo, H., Devic, E., Han, R., Koko, G., Koné, N., Maciel-Vergara, G., Nacambo, S., Pomalegni, S.C.B., Roffeis, M., Wakefield, M., Zhu, F. & Fitches, E. 2018. Small-scale fly larvae production for animal feed. In. Halloran, A., Flore, R., Vantomme, P. & Roos, N. (eds). *Edible Insects in Sustainable Food Systems,* pp. 239–261. Cham: Springer International Publishing.

Kinyuru, J. 2020. Book review: African edible insects as alternative source of food, oil, protein, and bioactive components. *Journal of Insects as Food and Feed* 6(3): 323– 325.

Kotzé, R.C.M., Muller, N., du Plessis, L. & van der Horst, G. 2019. The importance of insect sperm: Sperm ultrastructure of *Hermetia illucens* (black soldier fly). *Tissue and Cell* 59: 44–50.

Kröncke, N., Baur, A., Böschen, V., Demtröder, S., Benning, R. & Delgado, A. 2020. Chapter 8 automation of insect mass rearing and processing technologies of mealworms *(Tenebrio molitor*). Maroid, A.A. (ed.). *African Edible Insects as Alternative Source of -Food, Oil, Protein and Bioactive Components*, pp. 123–139. Cham: Springer.

Lalander, C., Diener, S., Zurbrügg, C. & Vinnerås, B. 2019. Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (*Hermetia illucens*). *Journal of Cleaner Production* 208: 211–219.

Lesne, P., Srivastav, S.P., El-Hefnawy, A., Parrott, J.J., Sanford, M.R. & Tarone, A.M. 2020. Facultative viviparity in a flesh fly (Diptera: Sarcophagidae): Forensic implications of high variability in rates of oviparity in *Blaesoxipha plinthopyga* (Diptera: Sarcophagidae). *Journal of Medical Entomology* 57(3): 697–704.

Liao, Q.J., Yang, Y.J., Wang, J., Pang, X., Xu, C.M., Peng, C.L., Lu, Z.X. & Liu, Y.H. 2017. Temperature-dependent development and reproduction of rice leaf folder, *Marasmia exigua* (Lepidoptera: Pyralidae). *PLoS ONE* 12(11): e0187972.

Lievens, S., Poma, G., de Smet, J., van Campenhout, L., Covaci, A. & van der Borght, M. 2021. Chemical safety of black soldier fly larvae (*Hermetia illucens*), knowledge gaps and recommendations for future research: a critical review. *Journal of Insects as Food and Feed* 7(4): 383–396.

Lihoreau, M., Poissonnier, L.A., Isabel, G. & Dussutour, A. 2016. Drosophila females trade off good nutrition with high-quality oviposition sites when choosing foods. *Journal of Experimental Biology* 219(16): 2514–2524.

Liu, C., Wang, C. & Yao, H. 2019. Comprehensive resource utilization of waste using the black soldier fly (*Hermetia illucens* (L.) (Diptera: Stratiomyidae). *Animals* 9(6): 349.

Liu, X., Chen, X., Wang, H., Yang, Q., Ur Rehman, K., Li, W., Cai, M., Li, Q., Mazza, L., Zhang, J., Yu, Z. & Zheng, L. 2017. Dynamic changes of nutrient composition throughout the entire life cycle of black soldier fly. *PLoS ONE* 12(8): e0182601.

Liu, Z., Najar-Rodriguez, A.J., Minor, M.A., Hedderley, D.I. & Morel, P.C.H. 2020. Mating success of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), under four artificial light sources. *Journal of Photochemistry and Photobiology B: Biology* 205: 111815.

Lohri, C.R., Diener, S., Zabaleta, I., Mertenat, A. & Zurbrügg, C. 2017. Treatment technologies for urban solid biowaste to create value products: A review with focus on low- and middle-income settings. *Reviews in Environmental Science and Biotechnology* 16(1): 81–130.

Lutz, L., Verhoff, M.A. & Amendt, J. 2019. Environmental factors influencing flight activity of forensically important female blow flies in Central Europe. *International Journal of Legal Medicine* 133(4): 1267–1278.

Ma, L., Wang, X., Liu, Y., Su, M.Z. & Huang, G.H. 2017. Temperature effects on development and fecundity of *Brachmia macroscopa* (Lepidoptera: Gelechiidae). *PLoS ONE* 12(3): e0173065.

Martínez-Sánchez, A., Magaña, C., Saloña, M. & Rojo, S. 2011. First record of *Hermetia illucens* (Diptera: Stratiomyidae) on human corpses in Iberian Peninsula. *Forensic Science International* 206(1–3): e76–e78.

Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M. & Gasco, L. 2018. Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae. *Journal of the Science of Food and Agriculture* 98(15): 5776–5784.

Michel A.D.K., Fiaboe, K.K.M., Kekeunou, S., Nanga, S.N., Kuate, A.F., Tonnang, H.E.Z., Gnanvossou, D. & Hanna, R. 2021. Temperature-based phenology model to predict the development, survival, and reproduction of the oriental fruit fly *Bactrocera dorsalis*. *Journal of Thermal Biology* 97: 102877.

Miranda, C.D., Cammack, J.A. & Tomberlin, J.K. 2020. Mass production of the black soldier fly, *Hermetia illucens* (L.), (Diptera: Stratiomyidae) reared on three manure types. *Animals* 10(7): 1243.

Miranda, C.D., Cammack, J.A. & Tomberlin, J.K. 2019. Interspecific competition between the house fly, *Musca domestica* L. (Diptera: Muscidae) and black soldier fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae) when reared on poultry manure. *Insects* 10(12): 440.

Nakamura, S., Ichiki, R.T., Shimoda, M. & Morioka, S. 2016. 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* 51(1): 161–166.

Nguyen, H.C., Liang, S.H., Doan, T.T., Su, C.H. & Yang, P.C. 2017. Lipase-catalyzed synthesis of biodiesel from black soldier fly (*Hermetica illucens*): Optimization by using response surface methodology. *Energy Conversion and Management* 145: 335–342.

Nguyen, T.T.X., Tomberlin, J.K. & Vanlaerhoven, S. 2015. Ability of black soldier fly (Diptera: Stratiomyidae) larvae to recycle food waste. *Environmental Entomology* 44(2): 406–410.

Nyakeri, E.M., Ogola, H.J.O., Ayieko, M.A. & Amimo, F.A. 2017. Valorisation of organic waste material: Growth performance of wild black soldier fly larvae (*Hermetia illucens*) reared on different organic wastes. *Journal of Insects as Food and Feed* 3(3): 193–202.

Ody, H., Bulling, M.T. & Barnes, K.M. 2017. Effects of environmental temperature on oviposition behavior in three blow fly species of forensic importance. *Forensic Science International* 275: 138–143.

Olazcuaga, L., Rode, N.O., Foucaud, J., Facon, B., Ravigné, V., Ausset, A., Leménager, N., Loiseau, A., Gautier, M., Estoup, A. & Hufbauer, R.A. 2019. Oviposition preference and larval performance of *Drosophila suzukii* (Diptera: Drosophilidae), spotted-wing Drosophila: Effects of fruit identity and composition. *Environmental Entomology* 48(4): 867–881.

Oonincx, D.G.A.B., Volk, N., Diehl, J.J.E., van Loon, J.J.A. & Belušič, G. 2016. Photoreceptor spectral sensitivity of the compound eyes of black soldier fly (*Hermetia illucens*) informing the design of LED-based illumination to enhance indoor reproduction. *Journal of Insect Physiology* 95: 133–139.

Oonincx, Dennis G.A.B., van Broekhoven, S., van Huis, A., & van Loon, J.J.A. 2015. Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. *PLoS ONE* 10(12): e0144601.

Ortiz, J.A.C., Ruiz, A.T., Morales-Ramos, J.A., Thomas, M., Rojas, M.G., Tomberlin, J.K., Yi, L., Han, R., Giroud, L. & Jullien, R.L. 2016. Insect mass production technologies. In Dossey, A.T., Morales-Ramos, J.A. & Rojas, M.G. (eds.). *Insects as Sustainable Food Ingredients* pp.153-201. San Diego, CA, USA: Elsevier.

Otieno, M.H.J., Ayieko, M.A., Niassy, S., Salifu, D., Abdelmutalab, A.G.A., Fathiya, K.M., Subramanian, S., Fiaboe, K.K.M., Roos, N., Ekesi, S. & Tanga, C.M. 2019. Integrating temperature-dependent life table data into insect life cycle model for predicting the potential distribution of *Scapsipedus icipe* Hugel & Tanga. *PLoS ONE* 14(9): e0222941.

Park, K., Kim, W., Kim, E., Choi, J.-Y. & Kim, S.-H. 2016a. Effect of adult population density on egg production in the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *International Journal of Industrial Entomology* 33(2): 92–95.

Park, K., Kim, W., Kim, E., Kwak, K-W., Choi, J-Y., Lee, S., Song, M. & Kim, S-H. 2016b. Oviposition site preference in black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae), in artificial rearing system. *International Journal of Industrial Entomology* 33(2): 54–58.

Parry, N.J., Pieterse, E. & Weldon, C.W. 2017. Longevity, fertility and fecundity of adult blow flies (Diptera: Calliphoridae) held at varying densities: Implications for use in bioconversion of waste. *Journal of Economic Entomology* 110(6): 2388–2396.

Pastor, B., Velasquez, Y., Gobbi, P. & Rojo, S. 2015. Conversion of organic wastes into fly larval biomass: Bottlenecks and challenges. *Journal of Insects as Food and Feed* 1(3): 179–193.

Putra, R.E. & Safa'at, N. 2020. Study on sex determination and impact of sex ratio to reproduction success in black soldier fly. *Jurnal Biodjati* 5(2): 191–198.

Rodrigues, M.A., Martins, N.E., Balancé, L.F., Broom, L.N., Dias, A.J.S., Fernandes, A.S.D., Rodrigues, F., Sucena, É. & Mirth, C.K. 2015. *Drosophila melanogaster* larvae make nutritional choices that minimize developmental time. *Journal of Insect Physiology* 81: 69–80.

Scala, A., Cammack, J.A., Salvia, R., Scieuzo, C., Franco, A., Bufo, S. A., Tomberlin, J.K. & Falabella, P. 2020. Rearing substrate impacts growth and macronutrient composition of *Hermetia illucens* (L.) (Diptera: Stratiomyidae) larvae produced at an industrial scale. *Scientific Reports* 10(1): 19448.

Schlesener, D.C.H., Wollmann, J., Krüger, A.P., Martins, L.N., Teixeira, C.M., Bernardi, D. & Garcia, F.R.M. 2020. Effect of temperature on reproduction, development, and phenotypic plasticity of *Drosophila suzukii* in Brazil. *Entomologia Experimentalis et Applicata* 168(11): 817–826.

Schneider, J.C. 2020. Effects of light intensity on mating of the black soldier fly *Hermetia illucens*, Diptera: Stratiomyidae). *Journal of Insects as Food and Feed* 6: 111-119.

Shaw, B., Fountain, M.T. & Wijnen, H. 2018. Recording and reproducing the diurnal oviposition rhythms of wild populations of the soft- and stone-fruit pest *Drosophila suzukii*. *PLoS ONE 13*(10): e0199406.

Sheppard, D.C., Tomberlin, J.K., Joyce, J.A., Kiser, B.C. & Sumner, S.M. 2002. Rearing methods for the black soldier fly (Diptera: Stratiomyidae). *Journal of Medical Entomology* 39(4): 695–698.

Shumo, M., Khamis, F.M., Tanga, C.M., Fiaboe, K.K.M., Subramanian, S., Ekesi, S., Huis, A. van, & Borgemeister, C. 2019. Influence of temperature on selected life-history traits of black soldier fly (*Hermetia illucens*) reared on two common urban organic waste streams in Kenya. *Animals* 9(3): 79.

Skovgård, H. & Nachman, G. 2017. Modeling the temperature- and age-dependent survival, development, and oviposition rates of stable flies (*Stomoxys calcitrans*) (Diptera: Muscidae). *Environmental Entomology* 46(5): 1130–1142.

Soares, T.F. & Vasconcelos, S.D. 2016. Diurnal and nocturnal flight activity of blow flies (Diptera: Calliphoridae) in a rainforest fragment in Brazil: implications for the colonization of homicide victims. *Journal of Forensic Sciences* 61(6):1571–1577.

Sontigun, N., Sukontason, K.L., Klong-Klaew, T., Sanit, S., Samerjai, C., Somboon, P., Thanapornpoonpong, S.N., Amendt, J. & Sukontason, K. 2018. Bionomics of the oriental latrine fly *Chrysomya megacephala* (Fabricius) (Diptera: Calliphoridae): Temporal fluctuation and reproductive potential. *Parasites and Vectors* 11(1): 415.

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., de Meulenaer, B., Michiels, J., Eeckhout, M., de Clercq, P. & de Smet, S. 2017. Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. *Journal of the Science of Food and Agriculture* 97(8): 2594–2600.

Surendra, K.C., Tomberlin, J.K., van Huis, A., Cammack, J.A., Heckmann, L.H.L. & Khanal, S.K. 2020. Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (*Hermetia illucens* (L.) (Diptera: Stratiomyidae) (BSF). *Waste Management* 117: 58–80.

Tan, P.C. & Sim, S.F. 2020. Study of the oviposition response of black soldier fly (BSF) in the presence of banana and pupal remains. *Asian Journal of Agriculture and Biology* 8(4): 398–404.

Tochen, S., Woltz, J.M., Dalton, D.T., Lee, J.C., Wiman, N.G. & Walton, V.M. 2016. Humidity affects populations of *Drosophila suzukii* (Diptera: Drosophilidae) in blueberry. *Journal of Applied Entomology* 140(1–2): 47–57.

Tomberlin, J.K., Adler, P.H. & Myers, H.M. 2009. Development of the black soldier fly (Diptera: Stratiomyidae) in relation to temperature. *Environmental Entomology* 38(3): 930–934.

Tomberlin, J.K., Sheppard, D.C. & Joyce, J.A. 2002. Selected life-history traits of black soldier flies (Diptera: Stratiomyidae) reared on three artificial diets. *Annals of the Entomological Society of America* 95(3): 379–386.

van Huis, A., Oonincx, D.G.A.B., Rojo, S., & Tomberlin, J.K. 2020. Insects as feed: house fly or black soldier fly? *Journal of Insects as Food and Feed* 6(3): 221–229.

Wang, Y.S. & Shelomi, M. 2017. Review of black soldier fly (*Hermetia illucens*) as animal feed and human food. *Foods* 6(10): 91.

Williams, K.A., Wallman, J.F., Lessard, B.D., Kavazos, C.R.J., Mazungula, D.N. & Villet, M.H. 2017. Nocturnal oviposition behavior of blowflies (Diptera: Calliphoridae) in the southern hemisphere (South Africa and Australia) and its forensic implications. *Forensic Science, Medicine, and Pathology* 13(2): 123–134.

Winkler, A., Jung, J., Kleinhenz, B. & Racca, P. 2020. A review on temperature and humidity effects on *Drosophila suzukii* population dynamics. *Agricultural and Forest* Entomology, 22(3): 179–192.

Yang, F. & Tomberlin, J.K. 2020. Comparing selected life-history traits of black soldier fly (Diptera: Stratiomyidae) larvae produced in industrial and bench-top-sized containers. *Journal of Insect Science* 20(5): 25.

Zeng, B., Zhu, W., Fu, Y. & Zhou, S. 2018. Influence of high-temperature exposure on the mating, oviposition and thermotaxis of *Bactrocera cucurbitae* (Coquillet) (Diptera: Tephritidae). *PLoS ONE* 13(9): e0204065.

Zhang, J., Huang, L., He, J., Tomberlin, J.K., Li, J., Lei, C., Sun, M., Liu, Z. & Yu, Z. 2010. An artificial light source influences mating and oviposition of black soldier flies, *Hermetia illucens*. *Journal of Insect Science* 10(1): 202.

Zhou, S., Li, L., Zeng, B. & Fu, Y. 2020. Effects of short-term high-temperature conditions on oviposition and differential gene expression of *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae). *International Journal of Pest Management* 66(4): 332–340.