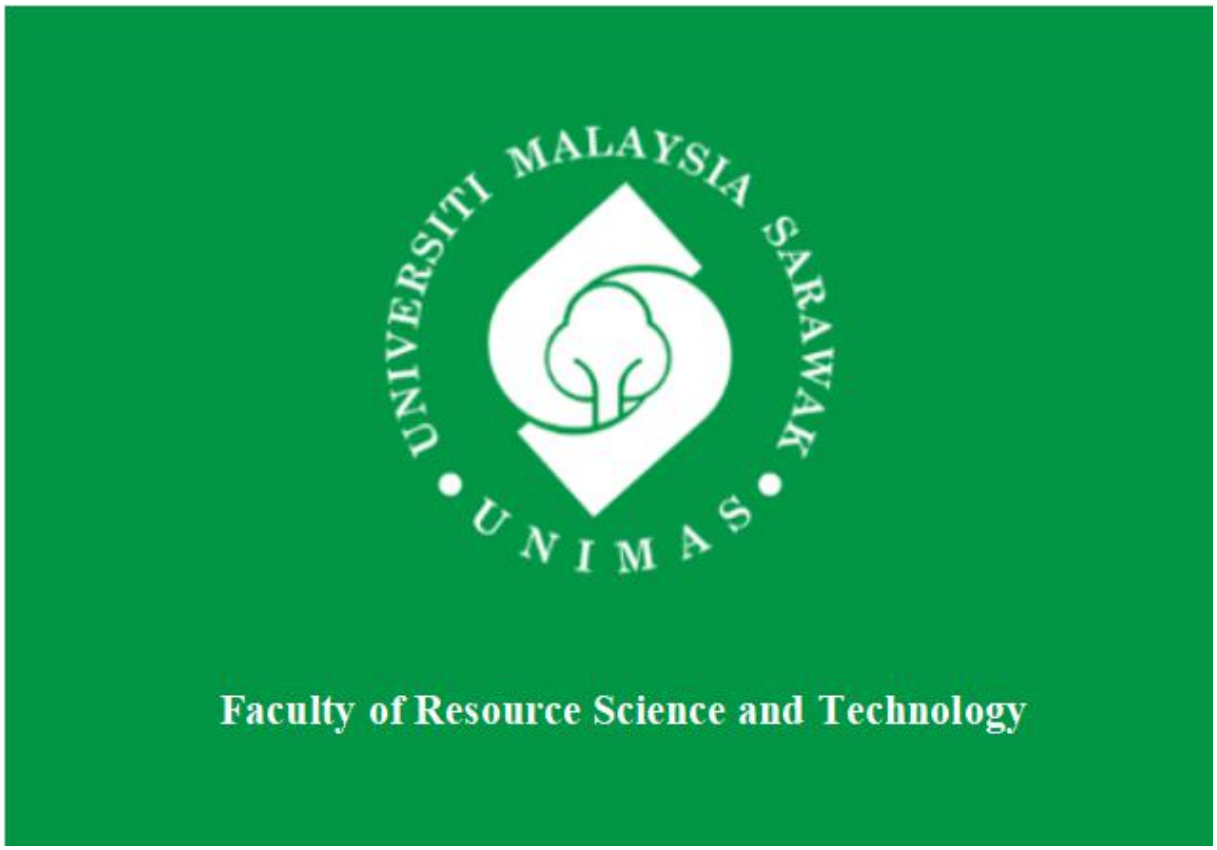

Assessment on Some Life Traits of the Bornean Strain, Black Soldier Fly *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) in Response to Food Waste and the Public Attitudes toward Food Waste Recycling

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Master of Science
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A thesis submitted

In fulfillment of the requirements for the degree of Master of Science

(Zoology)

Faculty of Resource Science and Technology
UNIVERSITI MALAYSIA SARAWAK
2020

DECLARATION

I hereby declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. It is original and is the result of my work, unless otherwise indicated or acknowledged as referenced work. This thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

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Date: 1st July 2020

ACKNOWLEDGEMENT

First of all, I would like to thank to my supervisor, Assoc Prof Dr Sim Siong Fong for her support, patience, forgiveness, and motivation to guide and assist me for the completion of my graduation journey. Also, million thanks to Assoc Prof Dr. Hamady Dieng for sharing his knowledge, laboratory skills and academic writing skills, all these were much appreciated. Likewise, I would like to thank to Prof Dr. Fatimah for her willingness to share her knowledge and gave guidance for me. Also, I'm glad to have the chance to meet with Dr Satho from Fukuoka University, Japan through the connection from Dr Hamady and thanks for his support throughout the project. Million thanks to the staff, postgraduates and researchers in Faculty of Resource Science and Technology and The Institute of Biodiversity and Environmental Conservation which have provided a lot of guidance and help during my research project. Last but not least, thanks to my beloved family and friends for being always there to support and understand me.

ABSTRACT

Over the past decades, our eating habits have changed dramatically and contributed to huge amounts of food waste being generated. In Malaysia, attempts to minimize food wastage have mostly involved improving recycling rate, but success has been seriously hindered by a rooted culture of landfilling, and lack of awareness, recycling policies and habits. Despite evidence that food waste is largely due to consumer' behaviours, there is still a paucity of comprehensive surveys addressing the different segments within consumption, particularly outdoors and in East Malaysia. Although many people love food but find its rotten form repugnant or poisoning, some animals use it as staple diet. These include *Hermetia illucens*, also known as the black soldier fly (BSF). Upon eclosion, its larvae need to immediately feed a variety of organic wastes for their entire life. Such attributes are being successfully used as waste management and resource recovery tools worldwide. All benefits from BSF depend on the successful larval development, which, in turn depends on waste source type and oviposition. Females oviposit once in their lifetime in various organic materials, which can support or impede larval development. In this regard, a better understanding of its oviposition preference is relevant. This research work aimed at (1) examining the capability of different feeding regimes (animal and plant based wastes) in supporting BSF larval development; (2) investigating the oviposition responses of BSF in response to different maturity of banana, abundance of pupal exuviae and colours of oviposition site; (3) quantifying food waste output from food servicing in Kuching; and (4) assessing the perception of Kuching citizens on food waste recycling. Under laboratory, BSF survived well when maintained on test wastes, with banana producing better pre-pupation successes. Banana produced bigger prepupae as development proceeded and when mixed with chicken. BSF prepupal size exhibited

temporal relative to regime type. Wasted banana were highly attractive to gravid BSF females particularly in advance ripened stage. Conspecific pupal remains acted as attractant and deterrent when present at low and high amounts, respectively. Colour was influential to BSF oviposition; colourful sites (pink or purple) were attractive in contrast to yellow-coloured ones. In field, the survey revealed that food waste generation from food servicing is high across the city. For many interviewees in Kuching, knowledge on food waste reuse and benefits was poor, many of whom do not practice recycling and ignored insects as important consumers of food scraps. In sum, the observations that locally generated food waste are suitable for BSF development and oviposition, suggest the possibility for developing effective, sustainable and cheap waste management strategies in Kuching and similar cities. Also, these are supported with the field evidences that high amounts of food waste are generated in Kuching whereas awareness among the citizens on food waste recycling need to be increased.

Keywords: Black soldier fly, larval development, oviposition, food waste, recycling

Penilaian Terhadap Ciri-ciri Kehidupan Lalat Askar Hitam Hermetia illucens (Linnaeus) (Diptera: Stratiomyidae) Strain Bornean dengan Sisa Makanan serta Sikap Masyarakat Terhadap Kitar Semula Sisa Makanan

ABSTRAK

Sejak beberapa dekad yang lalu, tabiat makan kita telah berubah secara ketara dan menghasilkan banyak sisa makanan. Di Malaysia, usaha untuk meminimumkan pembaziran makanan kebanyakannya melibatkan peningkatan kadar kitar semula, namun kejayaan telah dihalang oleh tapak pelupusan sampah, penimbunan sampah akibat masih banyak tanah yang belum diteroka dan ketiadaan kesedaran, dasar, serta budaya kitar semula. Walaupun bukti bahawa masalah sisa makanan kebanyakannya daripada tingkah laku pengguna, ia juga kekurangan kajian melalui tinjauan sosial yang berbeza dalam penggunaan, terutama dari rumah dan di Malaysia Timur. Walaupun orang suka makanan tetapi menganggap bentuk makanan rosak yang menjijikkan, atau keracunan, sesetengah haiwan mendapatinya berkhasiat. Salah satu pemakan sisa makanan adalah Hermetia illucens, yang juga dikenal sebagai Lalat Askar Hitam (BSF). Larva daripada BSF mempunyai keupayaan untuk mengambil pelbagai jenis sisa organik, larva perlu segera makan sisa untuk seluruh hidupnya, kelebihan ini dimanfaatkan dalam pengurusan sisa dan pemulihan sumber. Semua manfaat BSF bergantung kepada tumbesaran larva yang berjaya, yang bergantung pada jenis sumber buangan dan oviposisi. BSF betina menghasilkan telur sekali dalam seumur hidupnya dalam pelbagai bahan organik, yang boleh menyokong atau menghalang perkembangan larva. Oleh itu, adalah penting untuk memberi perhatian ke atas kefahaman oviposinya untuk memerangkap telur yang berkesan. Kajian ini bertujuan untuk: (1) memeriksa keupayaan bahan sisa makanan terpilih dan rejim pemberi makanan dalam menyokong perkembangan larva BSF; (2) menyelidiki

kesan sisa buangan pisang, sisa pupal dan warna pada tanggapan oviposit BSF; (3) mengukur penghasilan sisa makanan di segmen sektor makanan yang berlainan di bandar Kuching; dan (4) menilai amalan kitar semula sisa makanan pada peringkat individu. Dalam kajian ini, pembesaran BSF lebih baik dengan pisang, yang menghasilkan kejayaan pra-pupa yang lebih baik. Saiz pra-pupa BSF menunjukkan corak yang berbeza mengikut jenis pemakanan, dengan pisang bercampur dengan ayam yang menghasilkan individu yang lebih besar. BSF betina menunjukkan daya tarikan yang lebih besar ke laman dengan pisang yang lebih matang. Tapak oviposisi dengan banyak sisa pupal adalah tidak menarik kepada betina BSF apabila dibandingkan dengan yang kurang sisa pupal. Di tapak oviposisi berwarna, kadar oviposinya lebih tinggi di tapak merah jambu dan ungu daripada tapak kawalan yang bersaing (putih) dan tapak kuning. Kaji selidik telah mendedahkan bahawa sisa makanan dijana pada kuantiti banyak di tempat makanan di Kuching. Majoriti orang yang diwawancara mempunyai tahap kesedaran yang kurang baik mengenai potensi manfaat dari sisa makanan dan tidak menganggap serangga sebagai pengguna sisa makanan. Larva BSF tempatan dapat berjaya berkembang dengan menggunakan buangan organik yang dihasilkan tempatan, ini memperjuangkan kemungkinan strategi pengelolaan sisa yang efektif, mesra alam dan ekonomik dengan BSF di Kuching dan kota-kota serupa di seluruh negara. Kajian ini menunjukkan keperluan untuk kempen pendidikan yang lebih berkesan bagi meningkatkan tahap pengetahuan terutamanya mengenai kitar semula.

Kata kunci: *Lalat Askar Hitam, perkembangan larva, oviposisi, sisa makanan, kitar semula*

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LIST OF ABBREVIATIONS

AR	Advance ripened banana
BOW	Banana only waste
BSF	Black soldier fly
COW	Chicken only waste
OV	Control oviposition site
EMW	Equivalently mixed waste
FAO/UN	Food and Agriculture Organization of the United Nations
FWG	Food waste generation
H. illucens	*Hermetia illucens*
HP	High pupal case
LP	Low pupal case
MPMD	Matrix of pairwise mean differences
MP	Medium pupal case
MR	Mildly ripe banana
MHLG	Ministry of Housing and Local Government
MBW	Mixed waste with more banana
MCW	Mixed waste with more chicken
NEA	National Environment Agency
NREB	Natural Resources And Environment Board Sarawak
NGO	Non-government organization
PI	Pink
PU	Purple
SDGs	Sustainable Development Goals
WRAP	The Waste and Resources Action Programme
USDA	United States Department of Agriculture
Y	Yellow

CHAPTER 1

INTRODUCTION

1.1 Background

Food waste is a growing global concern where one third of the food produced (about 1.3 billion tonnes) are discarded yearly (Food and Agriculture Organization of the United Nations (FAO/UN), 2018). The environmental, aesthetic, health and socio-economic consequences of these leftovers were extensively reported (Rushton, 2003; Chrobog, 2014; Payne, 2014; Tonini et al., 2018). The magnitude of food waste and its adverse impacts are both expected to grow radically as a result of population growth, societal lifestyle and consumption patterns (Asase et al., 2009; Elks, 2018).

A structured food waste management system has been established to tackle the elevated waste generation nevertheless the treatment efficiency and financial constraints are the issues encountered (Thi et al., 2015). Insects may be used as an alternative to effectively convert and reduce the food wastes. They are known with high feed conversion efficiency, containing high level of protein, fat, vitamins as well as minerals (Khusro et al., 2012; Rumpold and Schlüter, 2013a; Ravindran, 2013). This is typical for the larva of *Hermetia illucens* (*H. illucens*), also known as the black soldier fly (BSF). It is a true fly of the family Stratiomyidae (Wang and Shelomi, 2017). Its larvae have a great demand for sustenance (Park et al., 2015). Upon eclosion, the larvae need to immediately feed on waste where their diet range can be highly varied including organic resources - fruits, vegetables, meat waste (Čičková et al., 2015), manure (Newton et al., 2005), distillers' grains (Webster et al., 2016), fecal sludge (Lalander et al., 2013), and indigestible food such as coffee (Diener et al., 2009) and beeswax (Malloch,

1917). After feeding, the larvae can be converted into animal feedstock. An average of 45% of protein and 35% of fat was found to be stored in the larvae fed with animal wastes (Newton et al., 1977; Heussler et al., 2018).

The adult BSF does not feed; they survive on water (Park et al., 2015) and teneral fat body reserves (Newton et al., 2005). Due to the importance of eggs in colony establishment, maintenance (Park et al., 2016) as well as biomass production (Nyakeri et al., 2017a), there have been many studies on the oviposition behaviour and preferences of BSF. Nyakeri et al. (2017a) reported significant variations in BSF oviposition responses in relation to food source. Adequate sunlight and readily available food were highly attractive to gravid BSF females (Park et al., 2016). Olfaction, pupal remnant and visual cue were found to play a prominent role in BSF oviposition decision. BSF females possess an ovipositor with olfactory sensors that are used to decide where to oviposit (Tomberlin, 2017). The odour intensity was further reported to be positively associated with the level of oviposition response (Nyakeri et al., 2017a). Odour is an indication of the extent of decomposition; the odour becomes stronger as the decomposition advances (Bangerth et al., 2012) signifying increase in nutritional substances which in turn become appealing to BSF (Brady et al., 1970; Rahman et al., 2014; Maduwanthi and Marapana, 2017). Visual cue is another important factor to consider when setting up the oviposition site (Solar et al., 1974; Harris and Miller, 1983). Oonincx and colleagues (2016) found that BSF possesses trichromatic vision - they are able to distinguish between primary and mixtures of colours.

1.2 Problem statement

Undeniably, larvae of BSF could provide solution to the aforementioned global problem of organic waste accumulation offering additional value to the larvae (Bullock et al., 2013;

Nguyen et al., 2015; Badenhorst, 2017; Nyakeri et al., 2017b). These beneficial impacts depend profoundly on the successful larval development, source of waste (Banks et al., 2014; Lalander et al., 2015; Badenhorst, 2017) as well as the effective egg trapping strategy to sustain the life cycle of BSF. Hence, it is important to gain better insights into these subjects. A number of studies have recorded successful development of some BSF strains nevertheless limited studies have been done on the Bornean strain BSF. BSF adults are abundantly found in the compost sites in Kuching (Tan et al., unpublished data), their behavior and potential in food waste management is unexplored. The behavioral response includes the oviposition preference with regards to food source, level of decomposition, visual cue as well as the presence of deterrent/attractant. From the management point of view, the potential use of BSF larvae for food recycling will depend on the perception, knowledge and attitudes of the public and availability of food wastes. The hypothesis of this study is to test on the feasibility of Bornean strain BSF domestication on converting locally generated food waste into nutrients to act as an effective food waste management.

1.3 Objectives

With the interest to address the aforementioned gap of knowledge, the aims of this study were:

(i) to assess the growth of a Bornean strain *H. illucens* fed with different feeding regimes (animal and plant based wastes);

(ii) to investigate the oviposition responses of BSF in accordance to maturity of banana, abundance of pupal exuviae and colours of oviposition sites;

(iii) to quantify the amount of food wastes produced in selected food outlets in Kuching for BSF rearing;

(iv) to understand the perception of residents in Kuching on food waste recycling in order to tackle the household food waste using BSF.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of food waste

Food Waste Reduction Alliance (2016) considers food waste as any organic residues that can be either solid or liquid; raw or cooked and these food is being or expected or needed to be thrown. Thi and colleagues (2015) classified food waste into three major sources, namely food losses, unavoidable food waste and avoidable food waste and formulated the following respective definitions for each of them: food losses—food lost in the processes of preparation, processing and production in food supply chain; while the two latter sources (unavoidable and avoidable food wastes) occur during the consumption stage where unavoidable is representing the parts of food that are non-consumable likes fruit core and avoidable means the lost of the edible parts.

2.2 Food waste management in Southeast Asia and Malaysia

Food waste management is always lacking in most Southeast Asia countries (Gregory et al., 1996; da Silva, 2016). For instance, municipal solid waste in Vietnam which includes organic content waste is generally left untreated and being trucked off at improper dumping site which this can cause environmental issues (Verma et al., 2016). Traditionally, open dump site is commonly practised particularly in developing countries which this can cause both environmental and social issues (Yunus and Kadir 2003, Ali et al. 2014). Other than open landfilling, improper and ineffective waste collection and transportation can also contribute to environmental hazard. In Indonesia, ineffective in waste transportation had lead their people

to use drainage system as the choice of waste disposal instead (Dhokhikah and Trihadiningrum, 2012). This is a serious and poor habit that will affect the sewage system.

In Malaysia, the disposal of food waste relies heavily on landfilling (Lim et al., 2016) in which most landfills have reached their capacity (Moh and Manaf, 2014). This method is cheap and straightforward (Lim et al., 2016), however, the substances that are unable to be degraded anaerobically could lead to emission of methane gas - a greenhouse gas that is 21 times more potent than carbon dioxide. Besides, the discharge of toxic leachate could lead to pollution in groundwater (Stuart, 2009). Besides landfilling, incineration is also commonly used in Malaysia for food waste management but it is more costly and energy-intensive (Lim et al., 2016), yet adversely causing air pollution (Zhang et al., 2014). The food waste management in Malaysia is not well-established compared to plastic and paper wastes (Lim et al., 2016). There is no large scale establishment on the end product of food waste hence the initiative to source and separate the food wastes from general wastes are not well received in the nation (Moh and Manaf, 2014).

Lim et al. (2016) suggested that the drafting of a nation food waste management policies should consider the successful models of food waste management from developed countries. In Japan, organic wastes are converted into feed, fertilizer and fuel (Ministry of Environment, 2012). In Denmark, anaerobic digestion is implemented to turn food wastes into biodiesel (Danish Environmental Protection Agency, 2001). In United Kingdom, BSF are farmed to treat tons of food waste (Brown, 2018). In San Francisco, food waste is converted into nutrient rich compost through large-scale operating technology; by law, the people including visitors are required to segregate their food waste (McClellan, 2017). The rising consciousness on the impact of food waste has led to government intervention; European Commission has set up a framework for food waste reduction by 30% by year 2025

(European Commission, 2017). This is important as policies remain the primary key to a specific goal. The Ministry of Housing and Local Government (MHLG) in Malaysia has collaborated with the Ministry of Environment in Japan with the ultimate goal in establishing a national strategic plan for food waste management in Malaysia (Chong et al., 2016).

Recently, Sustainable Development Goals (SDGs) was established focuses on all levels, at retail and consumer, to reduce 50% of the per capita global food waste by 2030. Local NGOs also take part in this effort engaging the hotels in Kuala Lumpur to donate their leftover food for a good cause (Jaaffar, 2017). Educational campaigns are organised to raise the level of understanding associated to recycling of food waste (Imam et al., 2008; Ghanadzadeh et al., 2014; Ferronato et al., 2017). Sensitivity campaigns are held to motivate and share information with communities pertaining food waste recycling (Narayana, 2009; Pakpour et al., 2014; Ferronato et al., 2017). Another set of monetary-driven strategies have also been adopted to promote waste reduction; these include tax incentives (Suttibak and Nitivattannanon, 2008) and economic incentives (Corral-Verdugo, 2012; Toretta et al., 2013; Oyekale, 2015). Programs based on monetary incentives is effectual in the long run (Gneezy and Rustichini, 2000; Gneezy et al., 2011) to boost weaken intrinsic motivations (Gneezy et al., 2011). Monetary incentive can promote recycling however it is important to inculcate self-maintained attitude for example, using recyclable bags (Pardini and Katzev, 1983; Choon et al., 2017).

2.3 Black soldier fly (BSF)

2.3.1 Systematics

BSF is categorized under order Diptera and family Stratiomyidae. It can be found in tropics and warm temperate areas (James, 1935; Callan, 1974). BSF is a non-pest insect which has the ability to decompose animal manure and sewage sludge (Sheppard et al., 2002). As reported by Diener et al. (2011a), the larval stage of BSF can be utilized to upcycle organic waste into high value animal feed. Their decomposition rate of organic waste is very rapid due to their voracious appetite (Diener et al., 2011b).

2.3.2 Life cycle

2.3.2.1 Eggs of BSF

The eggs of BSF is creamy white or pale yellow in colour. They are in cluster form and one egg mass has approximately 500 -1000 eggs (Booth and Sheppard, 1984; North Carolina Integrated Pest Management Information, 1998). It took roughly 4 days for the eggs to hatch into neonate of BSF. The hatching temperature is recommended at 24 °C where the average weight for an egg mass is 29.1 mg with 0.028 mg per egg. The oviposition site is commonly found at dry places with the presence of decaying or decomposing matter (Booth and Sheppard, 1984).

2.3.2.2 Larvae of BSF

The appearance of BSF larvae can be observed through its slight flattened body shape and whitish to yellowish body. It contains projecting head with chew-able mouthpart. The body size is approximately 1.8 mm long for neonate. Upon maturity, its body length ranges between 18 and 27 mm with 6 mm width. It takes around 14 days to 30 days for the larval stage. The BSF larvae consists of sixth instars (North Carolina Integrated Pest Management Information, 1998; Diclaro II and Kaufman, 2009; Kim et al., 2011). BSF larvae is polyphagous and insatiable; it can consume a wide range of organic wastes such as food scraps, vegetable waste and animal manure.

Newton et al. (2005) reported that BSF larvae was able to reduce 56% of swine manure mass. Its voracious appetite is similar to other larvae of scavengers such as *Stratiomys ruficornis* (Kim et al., 2011). Jeon et al. (2011) found that there were distinct bacterial strains in the gut of BSF larvae which is different from the intestinal microflora in other insects. It was hypothesized that this is the reason to the catabolic degradation capability of BSF larvae (Jeon et al., 2011). Kim et al. (2011) on the other postulated that their ability to degrade wide range of organic waste is due to its powerful jaw and effective digestive system. The survival of BSF larvae is governed by the temperature. Study reported that 74-97% of larvae survived at 27 and 30 °C as compared to only 0.1% at 36 °C (Sheppard et al., 2002; Tomberlin et al., 2009). Larvae that lived at 36 °C would grow into prepupae however there was only 0.1% of chance that they could complete pupation due to the critical weight (Tomberlin et al., 2009*).*