COMPARATIVE STUDIES OF THE BIOLOGY, LIFE TABLES AND WATER BALANCE OF THE TURKESTAN COCKROACH *Blatta lateralis* (Walker), GERMAN COCKROACH *Blattella germanica* (L.) and BROWN-BANDED COCKROACH *Supella longipalpa* (Fabricius) (Dictyoptera: Blattidae, Blattellidae)

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UNIVERSITI SAINS MALAYSIA

2018

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by

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Thesis submitted in fulfilment of the requirements for the degree of Masters of Science

April 2018

ACKNOWLEDGEMENT

I would like to extend a heartfelt appreciation and gratitude to my supervisor, Professor Lee Chow Yang, for his incredible patience, insight, and guidance, always ready to provide support and advice throughout the course of this research program.

To Professor Zairi Jaal and Associate Professor Wan Fatma Zuharah as my co-supervisors for their advice and help.

To Professor Hsin Chi for permitting the use and extending words of advice on his age-stage two-sex life table analysis program.

To the members of Urban Entomology Laboratory, especially Sophia Liew, Chris Kim, Mark Ooi, Jong Zheng Wei, Mai Duyen and Gan Li Yan as well as seniors Dr Tee Hui Siang and Dr Lee Ching Chen who were ever ready to share their inputs and time for discussions.

Last but not least, to my family and friends for their on-going support, encouragement, understanding and love for sharing all the sweat, tears, joy and sacrifice together with me throughout this journey.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
APOP	Adult pre-oviposition
Bg	*Blattella germanica*
Bl	*Blatta lateralis*
CP	Cuticular permeability
i.e.	That is
e.g.	For example
et al.	And others
e_{xj}	Age-stage life expectancy
$f_{(i, female)}$	Female fecundity
FW	Food and water
FW3	Food and water provided once every three days
FW7	Food and water provided once every seven days
FX	Food without water
HSD	Honestly significant differences
l_x	Age-specific survival rate
m_x	Age-specific fecundity
r	Intrinsic rate of increase
R_o	Net reproductive rate
RH	Relative humidity
SE	Standard error
Sl	*Supella longipalpa*
S_{xj}	Age-stage survival rate

T	Mean generation time
TPOP	Total pre-oviposition period
XW	Water without food
XX	Without food and water
% TBW	Percentage of total body water

KAJIAN PERBANDINGAN BIOLOGI, JADUAL HAYAT DAN KEIMBANGAN AIR PADA LIPAS TURKI *Blatta lateralis* (Walker), LIPAS JERMAN *Blattella germanica* (L.) dan LIPAS JALUR PERANG *Supella longipalpa* (Fabricius) (Dictyoptera: Blattidae, Blattellidae)

ABSTRAK

Parameter biologi terpilih seperti tempoh hidup dewasa, kesuburan dan perkembangan nimfa lipas Turki, *Blatta lateralis* (Walker) di bawah persekitaran makmal terkawal telah dikaji dan dibanding dengan lipas jalur perang, *Supella longipalpa* (Fabricius) dan lipas Jerman, *Blattella germanica* (L.). Keputusan kajian menunjukkan tempoh hidup dewasa *B. lateralis* adalah paling tinggi di antara ketiga-tiga spesies sementara nisbah jantan ke betina menyimpang ke arah jantan dengan nisbah 1.12:1.00. Di antara ketiga-tiga spesies, lipas betina *B. lateralis* boleh menghasilkan bilangan ooteka yang tinggi sepanjang hayatnya secara signifikan (dengan bilangan maksimum yang direkodkan pada 39 ooteka). Walaubagaimanapun, peratusan penetasan ooteka *B. lateralis* adalah paling rendah (46.79 %) sementara perkembangan nimfanya adalah paling tinggi (163.02 ± 2.50 hari). Hasil kajian juga menunjukkan *B. germanica* adalah spesies perosak yang paling berjaya dalam mencetuskan infestasi di antara ketiga-tiga spesies. Dalam keadaan terlampau di mana ketiadaan makanan dan air, *B. lateralis* mampu bersaing dengan baik dengan tempoh hidup yang paling tinggi. Walaupun pembiakannya didapati telah terjejas apabila lipas-lipas tersebut telah dihadkan bekalan makanan atau air ataupun kedua-duanya sekali, *B. lateralis* masih mampu menghasilkan

maksimum satu ooteka yang berjaya menetas dan menghasilkan nimfa hidup. Apabila makanan dan air diberi dalam bahagian (iaitu setiap tiga hari atau setiap tujuh hari), *B. germanica* tetap menjadi spesies yang paling berjaya di antara ketiga-tiga spesies, dalam pengukuran tempoh hidup dan pembiakan. Parameter biologi dan populasi juga dikaji dengan menggunakan teori peringkat-umur, jadual hayat dua seks. Kadar peningkatan intrinsik *B. lateralis* adalah paling rendah secara signifikan di antara ketiga-tiga spesies tetapi perkembangan populasinya telah dikompensasi oleh kesuburan seumur hidup dan kadar pembiakan bersih yang paling tinggi secara signifikan apabila dibandingkan dengan *S. longipalpa* dan *B. germanica*. Di antara ketiga-tiga spesies lipas yang dikaji, *B. lateralis* memaparkan penyesuaian dan kurang kerentanan terhadap keadaan kering disebabkan oleh saiz badan yang besar, peratusan jumlah kandungan air badan (% TBW) yang rendah dan kebolehtelapan kutikal (CP) yang kurang, seperti yang diperhatikan dalam kajian keimbangan air. Walaupun keputusan kajian menunjukkan daya tahan hidup and pembiakan *B. lateralis* adalah agak kompetitif berbanding dengan dua spesies lipas utama di Malaysia dalam kajian ini, pemerhatian masih jelas menunjukkan *B. germanica* adalah lebih berjaya dalam mencetuskan infestasi disumbangkan oleh kadar perkembangan dan potensi kerintangan yang cepat sementara *S. longipalpa* pula didapati adalah lebih tahan terhadap keaadaan kering. Walaubagainmanapun, *B. lateralis* tetap menunjukkan kebolehan dan potensi untuk menjadi spesies lipas yang penting di Malaysia.

COMPARATIVE STUDIES OF THE BIOLOGY, LIFE TABLES AND WATER BALANCE OF THE TURKESTAN COCKROACH *Blatta lateralis* (Walker), GERMAN COCKROACH *Blattella germanica* (L.) and BROWN-BANDED COCKROACH *Supella longipalpa* (Fabricius) (Dictyoptera: Blattidae, Blattellidae)

ABSTRACT

The selected biological parameters such as adult longevity, fecundity and nymphal development of the Turkestan cockroach, *Blatta lateralis* (Walker) under laboratory controlled environment in comparison with the brown-banded cockroach, *Supella longipalpa* (Fabricius) and the German cockroach, *Blattella germanica* (L.) were studied. Results obtained demonstrated that the adult longevity of *B. lateralis* was the highest among the three cockroach species while the male to female ratio skewed towards the male with a ratio of 1.12:1.00. Among the three species, the adult females of *B. lateralis* were able to produce a significantly high number of oothecae (with a maximum number recorded at 39 oothecae) over their life span. However, the percentage of oothecae hatchability of *B. lateralis* was lowest (46.79 %) while its nymphal development period was highest (163.02 ± 2.50 days), making the *B. germanica* the more successful species as a pest in causing an infestation among the three species. However, under extreme conditions in the absence of food and water, *B. lateralis* compete relatively well with the highest longevity. Although the reproduction was observed to have been impaired when the cockroaches were deprived of either food or water or both continuously, *B. lateralis* was able to produce a maximum of one ootheca which successfully hatched and produced live nymphs. Nonetheless, when food and water were provided partially (i.e. every three days or every seven days), *B. germanica* still displayed itself as the more successful species among the three, in terms of adult longevity and reproduction. The biological and population parameters were also studied using the age-stage, two sex life table theory. The intrinsic rate of increase for *B. lateralis* was significantly lower among the three species, but its population growth was compensated by the significantly higher lifetime fecundity and net reproduction rate compared to *S. longipalpa* and *B. germanica*. Among the three cockroach species studied, *B. lateralis* displayed adaptability and less susceptibility to desiccation due to its large body size, low percentage of total body water (% TBW) content and reduced cuticular permeability (CP), as observed in the water balance profile study. Although the results obtained showed that the survivability and reproduction of *B. lateralis* was fairly competitive with the two common cockroach species in Malaysia that are studied here, it is obvious that *B. germanica* is still more superior in causing an infestation due to its rapid growth rate and potential in insecticide resistance while *S. longipalpa* is found to be more superior in withstanding dessication. Nonetheless, *B. lateralis* still demonstrated the ability and potential to become an important cockroach pest species in Malaysia.

CHAPTER ONE: GENERAL INTRODUCTION

Cockroaches are ancient and highly successful primitive form of insect life. It has been recorded that they were able to achieve optimum body form and have remained stable since their early evolutionary history (Cochran, 1999). Their biology and behaviour as pests has brought annoyance and undoubtedly discomfort to man. They are often associated with unhygienic practices and are mechanical vectors, capable of transmitting disease-causing pathogens through their feeding and foraging habits (Cochran, 1999; Devi & Muray, 1991; Lee, 1997; Vythilingam *et al.*, 1997; Yap *et al.*, 1991). Cockroaches were ranked at the top as the most abundant insect pest in Malaysia (Yap *et al.*, 1999).

While the German cockroach, *Blattella germanica* (L.) and American cockroach, *Periplaneta americana* (L.) are the predominant species in Malaysia, other cockroaches such as the brown cockroach, *Periplaneta brunnea* (Burmeister), brown-banded cockroach, *Supella longipalpa* (Fabricius) and Australian cockroach, *Periplaneta australasiae* (Fabricius) have acquired different degrees of relationship with humans (Lee & Lee, 2000a; Lee *et al.*, 1993; Yap & Foo, 1984; Yap *et al*., 1991; Yap *et al*., 1997).

The discovery of Turkestan cockroach, *Blatta lateralis* (Walker) at Sharpe Army Depot in Lathrope, California which is native to the Middle East was first reported in 1978, where its introduction to the country was believed to be through transportation of military goods and equipment (Kim & Rust, 2013). As the discovery is relatively recent, while its pest status is relatively new, in depth research on its biological, ecological and control aspects of this cockroach have yet to be conducted and recorded. Unlike other important household pests such as *B.*

germanica, where its pest status has been well established due to its capability in causing a rapid infestation, extensive studies have been conducted to understand the life histories of these pests so that the most effective control approaches could be designed and executed.

With limited information available on *B. lateralis*, it is crucial that we understand its life history, biological aspects and potential pest status in association with other cockroach species. Hence, this study was initiated with the following objectives:

i. To determine and compare the selected biological parameters (adult longevity, fecundity and nymphal development) of *B. lateralis* with two other species of pest cockroaches i.e. *S. longipalpa* and *B. germanica* under laboratory controlled environment and when they are introduced to different food regimes.

ii. To use the age-stage, two-sex life table theory in examining the biological and population parameters of *B. lateralis*, in comparison to that of *S. longipalpa* and *B. germanica* under laboratory controlled environment.

iii. To determine the water balance profiles and desiccation resistance composition of *B. lateralis,* in comparison to that of *S. longipalpa* and *B. germanica*.

CHAPTER TWO: LITERATURE REVIEW

2.1 Cockroach

Cockroaches are among the most ancient group of winged insects, dating back to 350 million years ago. Fossil records indicated that they were extremely abundant during the Pennsylvanian (Upper Carboniferous) period (Cornwell, 1968; Mullins & Cochran, 1987). Cockroaches are classified under the order of Dictyoptera, suborder Blattoidea which are further classified into families which include, Cryptocercidae, Blattidae, Polyphagidae, Blattellidae and Blaberidae (Cornwell, 1968). While there are 4000 species of cockroaches or more which have been identified thus far (Cochran, 1999; Lee, 1997), there are probably numerous more species which have yet to be discovered, identified and classified. Among those known to man, only about 1 % of these cockroach species are considered as pests (Cochran, 1999; Lee, 1997).

While they are versatile in their habit of adaptability to a broad variety of environmental conditions such as among or under dead or decaying leaves, bark of trees, rubbish or stones, on flowers, leaves and grass or in caves and burrows or even boring in wood, cockroaches are also considerably diverse in size and colour (Cochran, 1999). In fact, the natural habitat of cockroaches is the outdoors but they have eventually adapted to the human habitat (Cornwell, 1976). Erections of buildings and facilities, food handling practices as well as improper planning or methods of disposing waste and drainage system have provided cockroaches with favourable environment that are similar to their original habitat (Abdullah *et al.*, 1993; Cornwell, 1976; Yap *et al.*, 1999). This has undoubtedly created a similar ecosystem for the cockroaches to dwell indoors among man and animals.

In the home, cockroaches are normally found in the kitchen areas where the environment is moist and warm while food and water are readily available (Tawatsin *et al.*, 2001). With the increase of transportation, human commerce and exploration, cockroaches had unintentionally been carried to almost all parts of the world, although the success of their establishment is predominantly limited by temperature and humidity (Alexander *et al.*, 1991; Tsai & Chi, 2007; Zhai & Robinson, 1991).

2.1.1 Pest Status

Cockroaches are labelled as pest often due to their label as a nuisance where the mere sight of one cockroach will lead to unnecessary distress and often associated to as embarrassment to man. Cornwell (1978) reported the infestation of *Blatta orientalis* (L.) in the uppermost bedrooms of a hotel and kitchen of a small restaurant in London. Meanwhile in Sydney, Australia, was found with a colony of *Blattella germanica* of different developmental stages hiding below a pile of debris, cartons and refuse which caused an infestation to occur at nearby residential and industrial properties (Cornwell, 1978). These infestations had no doubt affected the image of these businesses, and not to mention affected the source of income to their respective owners.

In Malaysia, the relative abundance of cockroaches placed *Periplaneta americana* at the top followed by *Periplaneta brunnea*, *Supella longipalpa*, *Neostylopyga rhombifolia* (Stoll) and *Periplaneta australasiae* in mixed orders depending on urban and suburban areas (Lee & Lee, 2000a; Lee *et al*., 1993; Yap & Foo, 1984; Yap *et al*., 1991; Yap *et al*., 1997) while *B. germanica* is mainly found infesting food handling outlets and hotels (Lee *et al*., 1993; Yap *et al*., 1991). Similar findings of cockroach abundance profile were also reported in our neighbouring country, Thailand (Tawatsin *et al*., 2001; Sriwichai *et al.*, 2002). On the other hand, a study conducted in three North Carolina cities where cockroach was found to infest 44 % of its buildings, ranked *B. germanica* to be the most abundant followed by *P. americana* and lastly *S. longipalpa* (Wright, 1965).

Meanwhile, cockroaches had been reported as the second most important household pest after mosquitoes in Penang, Malaysia in a questionnaire-based survey in 1982 (Yap & Foo, 1984) but was later ranked as the most abundant household pest in another questionnaire and trapping survey more than a decade later (Yap *et al.*, 1999). The presence of cockroaches in homes has undoubtedly caused more distress to be ranked at the top by the community compared to any other insect pest probably due to their appearance as creepy crawlers and nature that are commonly associated with compromised sanitation.

2.1.2 Cockroach of Medical and Economic Importance

Cockroaches thrive in large numbers in areas usually linked to poor sanitation, when cleanliness is undermined and where this polluted environment becomes excellent breeding sites for household pests (Oothuman *et al.*, 1984). Trapping activity in Brown Garden, Penang, Malaysia found houses with poor sanitation to be highly infested with cockroaches while cockroach infestation could be avoided in houses which maintained good sanitation (Yap *et al.*, 1997). However, comparatively clean houses did not necessarily escape from cockroaches which were found to be colonizing in niches and was reportedly found to enter houses from the outdoors through sewage lines and manholes in search of food and shelter (Oothuman *et al.*, 1984). Moreover, their nocturnal wandering habit of regurgitating partially digested food, defaecating while feeding and foraging to various places i.e. from building to building or from sewer to human residences, makes them a prevalent and potentially dangerous mechanical vector which contaminate human food (Cochran, 1999; Devi & Muray, 1991; Lee, 1997; Vythilingam *et al.*, 1997; Yap *et al.*, 1991).

Cockroaches are sometimes blamed for the illnesses among man where they have been shown to harbour and serve as the intermediate host for pathogenic bacteria, helminths, viruses, protozoa and fungi (Cochran, 1999). As pathogenic hosts, cockroaches act as a reservoir for the multiplication of these microorganisms and hence indirectly spread diseases such as cholera, plague, antrax, tuberculosis, dysentery, typhoid, conjunctivitis, meningitis, sepsis and food poisoning (Devi & Murray, 1991; Lee & Ng, 2009; Oothuman *et al.*, 1989; Wisner & Adams, 2002).

Gastrointestinal related pathogens such as *Bacillus* sp., *Enterobacter* sp., *Streptococcus* sp. and *Klebsiella* sp. were isolated from *P. americana* (Jeffery *et al.*, 1997) which is by far the most common and widely distributed species in Malaysia (Jeffery *et al.*, 1997; Yap *et al.*, 1991; Yap *et al.*, 1997). Bacterial pathogens such as *Pseudomonas* sp., *Escherichia coli*, *Streptococcus* sp. and *Salmonella* sp. were reportedly isolated from several cockroach species trapped from paediatric wards in Peninsular Malaysia with *P. americana* and *B. germanica* recording the highest in cockroach number and bacterial isolates (Oothuman *et al.*, 1989). Such incidence could lead to outbreaks of bacterial infections not only within the hospital compound but is also able to spread outside the hospital grounds (Oothuman *et al.*, 1989). Several other studies have found isolates of similar bacteria as well as others such as *Shingella flexneri* (Castellani and Chalmers), *Proteus* sp. and *Citrobacter* sp. from various other species of cockroaches, namely *P. brunnea, P. australasiae, S. longipalpa*, *N. rhombifolia* and *Nauphoeta cinerea* (Olivier) (Oothuman *et al.*, 1989; Rampal *et al.*, 1983; Vythilingam *et al.*, 1997). A survey from a collaboration conducted by the Environmental Health Institute (EHI) and Singapore Pest Management Association (SPMA) found pathogenic bacteria on *P. americana*, among which the bacterium *Bacillus cereus* which was often linked to diarrhoea was isolated (Lee & Ng, 2009).

Cockroaches have also been associated with household allergy and asthmatic problems which can be triggered through inhalation or ingestion of cockroach allergens such as faeces and saliva where symptoms such as sneezing and skin rashes are commonly manifested (Brenner *et al.*, 1991; Lee & Ng, 2009). Occasionally, more serious pulmonary symptoms may arise such as cough, chest tightness, wheezing or shortness of breath which may lead to life-threatening episodes of anaphylaxis (Brenner *et al.*, 1991). The Oxford Dictionary of Biology (2004) defines the term allergy as a condition in which the body produces an abnormal immune response to certain antigens which then stimulates the release of histamine and serotonin, leading to inflammation and other characteristic symptoms. About eight to thirteen allergens from whole body extracts of *B. germanica* were isolated and documented (Brenner *et al*., 1991). In Thailand, *P. americana* was one of the causes among asthmatic Thai children and patients with allergic rhinitis (Tawatsin *et al.*, 2001).

Entomophobia or fear of insects is common, especially among women. Many would find cockroaches disgusting because of their association with something or somewhere that is filthy. Their speed and unpredictable movements often make one uncomfortable for fear that they might fly and cling onto one’s body or clothing. If a cockroach is found within the vicinity of the area, a person may be psychologically stressed to find cockroach infestations in the house while others may go to the extent of avoiding a place, even if it was their own home (Lee, 1997). Interestingly, an article in National Geography (Dell'Amore, 2017) mentioned that in reality, children are not afraid of cockroaches but are later found to become freaked out by the sight of cockroaches when one grows older and become adults.

Cockroach biting humans have not been reported at large but in small exceptions when infestations are extremely large and when food is extremely scarce which forces the cockroaches to forage on things they do not normally consume. This incidence had been reported to occur mainly on ships, where it had been documented that *P. americana* and *P. australasiae* gnawed on the skin and nails of sailors on board when the sailors were asleep (Lee, 1997; Internet source 1).

The omnivorous and scavenging nature of cockroaches also gives them a role as decomposers that feed on dead and decaying plants and other organic material in the tropical rain forests while contributing to the cycle of nutrient and organic matter in ecosystem (Lee & Ng, 2009; Mullins & Cochran, 1987). Of late, research has found certain species of cockroaches to be pollinators. The forest cockroach, *Blattella nipponica* adults were found to consistently visit and feed on *Monotropastrum humile* (Ericaceae), a forest-floor herb, indirectly dispersing the seed through their excreted faeces (Uehara & Sugiura, 2017). Prior to this, Nagamitsu and Inoue (1997) had reported Blattellidae cockroaches as pollinators of *Uvaria elmeri* (Annonaceae) in a lowland mixed-dipterocarp forest of Sarawak, Malaysia. The cockroaches had been found to carry the conspecific pollen grains on their bodies, which are then spread to other areas of the forest as the cockroaches forage (Nagamitsu & Inoue, 1997).

In recent years, there have been numerous articles written about cockroach farming and selling in Asia where it has become somewhat a source of income. *The National* had reported that crushed up *P. americana* has been incorporated into products such as lotions for burns and tablets for liver disease by the Chinese pharmaceutical industry (Gardner, 2014). Meanwhile, a college student in Taiwan was reported by the China Press (2017) to be farming and selling cockroaches as pet food to reptile pet owners. Cockroaches among other arthropods have also been considered as delicacies in Asian countries, such as China, where they are often mixed in spices and fried before consuming as snacks (Gardner, 2014). Some are even considering insect rich diet as a healthy alternative to meat as they are high in protein, vitamins and minerals such as iron and zinc (Lyons, 2015). Besides, entomophagy or the practice of eating insects by humans are considered as superior sustainable food source compared to other proteins such as beef and chicken as farming them are cost efficient in terms of requiring lesser space and feed while generating bigger yields (Lyons, 2015). In fact, since the report released by the United Nations Food and Agriculture Organization in 2013, which promotes the eating of insects to curb world hunger (Huis *et al.*, 2013), people around the world are starting to accept the concept and establishment of insect-eating pop-up restaurants such as that of Pestaurant by Rentokil (Internet Source 2).

New discoveries are being made daily on the economic benefits of cockroaches. In fact, an international team of scientists had discovered the nutrients in the "milk" crystals of *Diploptera punctata* to be four times as nutritious as cow's milk which they believe could aid in feeding the world's growing population in the future when food source is becoming scarcer (Bowler, 2016). Not only are cockroaches important in the food chain to various other animals such as scorpions and birds (Lee & Ng, 2009), it is also possible that one day cockroaches, among other arthropods will replace the current food source of humans.

2.1.3 Control of Cockroaches

Cockroach management has been attempted since the early mid 1800s (Lee & Ng, 2009). Previous methods of controlling cockroaches varied from burning sulphur, using arsenic and nicotine or applying turpentine as cockroach repellent (Cornwell, 1976) to the use of inorganic insecticides such as bait formulated with sodium fluoride, pyrethrum powder, silica aerogel, sodium borate and boric acid (Lee & Ng, 2009; Lee *et al.*, 2003).

Use of chemicals by far is the most effective method in the control of cockroach infestations. Application methods vary from wettable powders to emulsifiable concentrates, while others consist in the form of dusts, baits and aerosols (Cochran, 1999). Among these, baiting is a popular and reliable form of cockroach control method (Lee & Ng, 2009). The combination of food attractant and toxicant in the bait will attract cockroaches to consume the bait and at the same time transfer the slow-acting killing agent to the cockroaches which thereafter affected by the toxicant, will die (Lee *et al.*, 2003). Nonetheless, the most popular approach of chemical control is the residual treatment where the cockroaches will be affected by the insecticides when they come into contact with the treated surface (Lee *et al.*, 2003). The turnover of these chemical-based insecticides is ever changing due to the development of new insecticides while the older insecticides are being displaced due to development of resistance or government regulations (Cochran, 1999).

Besides the chemical approach, non-chemical control methods have also been employed. Sanitation is more often than not the most important step in reducing an infestation. By keeping the area clean, resources of food, water and harbourage which are the basic needs of cockroaches are reduced which then lead to the reduction of the cockroach population (Lee *et al.*, 2003). Cockroaches enter into homes and buildings from the outdoor habitat via various openings such as through gaps between doorframes and window frames with the floors, where it would be necessary to close all such openings (Cochran, 1999). Other non-chemical methods include vacuuming, use of glue traps and use of heat, cold or non-toxic gas has also been applied by professional pest control operators (Cochran, 1999).

Biological control of cockroaches is rarely used as a mode of cockroach control due to its questionable efficacies or slow efficacy under field conditions and its implications towards the environment. Nonetheless, *Comperia merceti* (Compere), a parasitic wasp which was found to lay its eggs in the oothecae of *S. longipalpa* where upon hatching, the developing wasp larvae will feed on the contents of the cockroach oothecae, had been used as a mean of biological control to suppress the infestation of *S. longipalpa* in the University of California campus in Berkeley (Slater *et al*., 1980). The parasitic wasp, *Aprostocetus hagenowii* (Hymenoptera: Eulophidae), as well as the fungus, *Metarhizium anisopliae*, are also known biological control to the *P. americana* and *B. germanica* respectively (Lee & Ng, 2009; Tee *et al.*, 2011).

With time, new discoveries were being made with the development of new generation of insecticides where integrated pest management are being applied. One example reported showed a significant reduction rate of *P. americana* numbers within the span of one week post-treatment with chlorpyrifos roach bait in houses with good sanitary conditions as opposed to houses with moderate and poor sanitary conditions (Lee & Lee, 2000b).

Cockroaches which have survived through many challenging conditions since 300 million years ago are believed to be one of the most hardy and adaptable insects that will continue to thrive in vast situations. The extensive use of insecticides has led to serious implications of insecticide resistance. Insecticide resistance in field-collected strains for *B. germanica* had shown various levels of resistance to commonly used group of insecticide such as carbamate (e.g. propoxur and bendiocarb), organophosphate (e.g. chlorpyrifos) and pyrethroid (e.g. cypermethrin, permethrin, phenothrin and deltamethrin) (Lee & Lee, 2002; Lee *et al.*, 1996a). Nevertheless, understanding on the pest as a population should be focused on in order to identify and implement the most optimum approach. In addition, no matter which measure is being implemented, it is important that the control methods adopted be ecologically safe and sustainable as well as economically accepted by the society.

2.2 *Blatta lateralis*, The Turkestan Cockroach

Blatta lateralis, also commonly known as Turkestan cockroach was first reported at Sharpe Army Depot in Lathrope, California in 1978 followed by a second infestation at Fort Bliss, El Paso, Texas, in 1979 where it is believed that the introduction to the country was due to transportation of military goods and equipment (Cochran, 1999; Kim & Rust, 2013). Since, it has become an invasive species throughout the southwestern region of the United States (Kim & Rust, 2013).

Blatta lateralis is native to the Middle East (Kim & Rust, 2013). It is essentially a desert species being distributed widely in Central Asia including Kashmir, Iran, Afghanistan and Iraq (Cochran, 1999). They are considered as household pests in homes with clay floors in central Asia (Kim & Rust, 2013). *Blatta lateralis* thrives in a variety of natural and altered habitats which includes rocky hills, desert, semi-desert, plantation and urban areas (Rios & Honda, 2013).

It finds harbourage in and under ground-cover vegetation or object that is lying on the ground (Cochran, 1999). It has also been observed in storehouses, steam tunnels, water meter boxes, potted plants, tree holes, compost piles and sewer systems (Rios & Honda, 2013). Although it was thought of to be more prevalent in the home with evidences of occasional spotting indoors (Kim & Rust, 2013), *B. lateralis* has been observed to prefer the outdoor environments and only occasionally invade the indoors (Rios & Honda, 2013). They have obtained the peri-domestic status in Iraq (Kim & Rust, 2013). *Blatta lateralis* was reported by pest control professionals to occupy similar habitats and in several occasions, displaced its closely related species, *B. orientalis* (Kim & Rust, 2013; Rios & Honda, 2013).

Information and the life history of *B. lateralis* and its ecological impact are still relatively scarce compared to other cockroach pest species known to men.

2.2.1 Morphology

The *B. lateralis* is a moderate-sized cockroach with the adult males (Plate 2.1A) measuring approximately 26 mm to 27 mm while the adult females (Plate 2.1B) measuring approximately 23 mm to 24 mm in body length (Kim & Rust, 2013). The adult males possess a pair of fully developed wings that extend beyond the tip of the abdomen and are yellowish-brown in colour (Cochran, 1999; Kim & Rust, 2013). The adult females are brachypterous or have greatly reduced wings with each forewing bearing a short cream-coloured strip (Cochran, 1999; Kim & Rust, 2013). The nymphs (Plate 2.1C) of *B. lateralis* are bi-coloured with the head and thorax being reddish brown while the abdomen is very dark brown in colour (Cochran, 1999; Kim & Rust, 2013). Meanwhile, the oothecae (Plate 2.1D) which

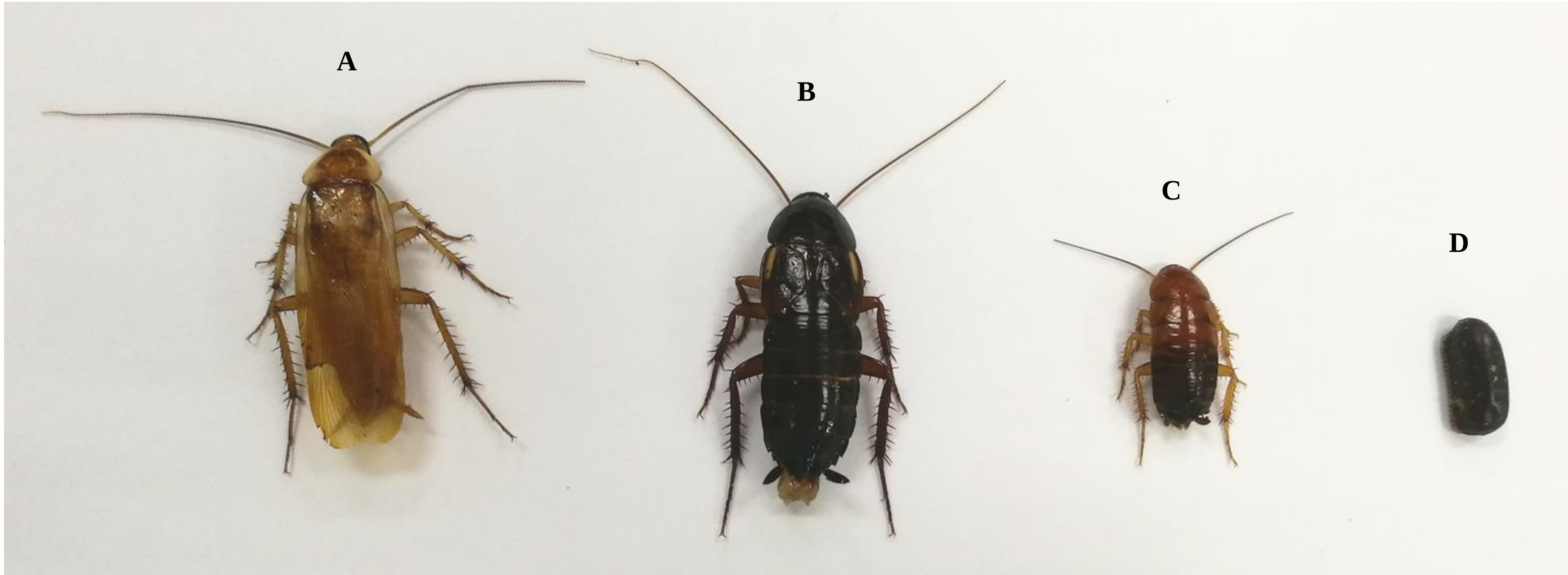

Plate 2.1: *Blatta lateralis*. A) Adult male. B) Adult female. C) Nymph. D) Ootheca.

are also dark brown in colour, are rounded at one end and truncated dorsally at the other end and closely resemble the oothecae of *B. orientalis* and *P. americana* (Cochran, 1999; Kim & Rust, 2013).

2.3 *Supella longipalpa*, The Brown-banded Cockroach

The brown-banded cockroach of tropical origin which was prior known as *Supella supellectilium* (Serville) before later classified as *S. longipalpa,* is native to Africa and has become a secondary cosmopolitan pest through trading (Tsai & Chi, 2007). It was first reported in the United States by Rehn in 1903 (Hull & Davidson, 1958). *Supella longipalpa* had been reported in Malaysia in 1984 (Jeffery *et al.*, 1984; Oothuman *et al.*, 1984) and was frequently found in flats in the urban area (Yap *et al.*, 1997).

A report by Hull and Davidson (1958) mentioned that the habits of *S. longipalpa* are different from other home-inhabiting cockroach species. Being omnivorous in nature, which enables it to eat anything organic, in addition to its ability to adapt to drier conditions where food may be limited, than most cockroaches, *S. longipalpa* could inhabit a wider array of building spaces and conditions (Hull & Davidson, 1958; Sriwichai *et al*., 2002). It is generally found in drier areas of the household such as in the bedroom, dining room and under furniture or shelves in closets and behind picture frames, although they are sometimes found in small numbers in the kitchen (Hull & Davidson, 1958; Lee & Lee, 2000a; Lee *et al.*, 1993). *Supella longipalpa* are also occasionally found inside motor vehicles as well as restaurants (Jeffery *et al*., 2012). They are also found outdoors in warmer climate areas (Cochran, 1999). It was reported that *S. longipalpa* have also infested hospital buildings (Nasirian, 2016; Oothuman *et al.*, 1984). The success of *S.*

longipalpa in the institutional building (Slater *et al.*, 1980) could be attributed by its preference for starchy food such as the sizing of books and glue under wallpaper (Cochran, 1999).

The habit of *S. longipalpa* of gluing its oothecae on the inside of furniture and hidden in a protected location make this species of cockroach extremely difficult to control and at the same time aid in their continuous dispersal (Cochran, 1999; Nasirian, 2016). The adult male *S. longipalpa* are reported to readily fly especially when disturbed (Cochran, 1999).

2.3.1 Morphology

The *S. longipalpa* are relatively small cockroaches with the adult males (Plate 2.2A) measuring approximately 13 mm to 14.5 mm while the adult females (Plate 2.2B) measuring approximately 10 mm to 12 mm in body length (Cornwell, 1968). The adult males are slender and possess a pair of fully developed wings that extend beyond the tip of the abdomen and are yellowish-brown in colour (Cochran, 1999; Cornwell, 1968; Nasirian, 2016). The adult females have a broader body with wings that rarely reach the tip of the abdomen and are chestnut brown to black in colour (Cochran, 1999; Cornwell, 1968). The lateral edges of the pronotum of both the male and female adults are transparent while the center area of the pronotum is of a paler shade (Cornwell, 1968). The nymphs of *S. longipalpa* (Plate 2.2C) are attractive in appearance due to their considerable colour variations with two very distinct brown bands while the remainder of the body is light brown or yellow in colour (Cochran, 1999; Cornwell, 1968). Meanwhile, the oothecae (Plate 2.2D) which are reddish-brown in colour, are the smallest oothecae among other domiciliary cockroaches (Cornwell, 1968). They are purse-like shaped with prominent dentricals on the keel

Plate 2.2: *Supella longipalpa*. A) Adult male. B) Adult female. C) Nymph. D) Ootheca.

with vertical furrows on each side corresponding with the position of the eggs within (Cochran, 1999; Cornwell, 1968).

2.4 *Blattella germanica*, The German Cockroach

Blattella germanica, or also known as the German cockroach, is believed to have originated from North Africa (Cornwell, 1968) but was later said to be originating from the tropics of Asia (Cochran, 1999). Nonetheless, this species has since been distributed by commerce to virtually all parts of the world, leading it to possess the cosmopolitan status and be described by man as the "world's most successful commercial traveller" (Cornwell, 1968).

Although *B. germanica* are more prevalent as pests in hotels and food handling outlets (Lee, 1998; Lee *et al.*, 1993; Oothuman *et al.*, 1984, Yap *et al.*, 1991), this species had eventually found its way into residences (Vythilingam *et al.*, 1997) and apartment buildings (Lee & Lee, 2000a). They are commonly found inside ducts that connect between buildings (Alexander *et al*., 1991).

In addition to its insecticide resistance development, control of *B. germanica* is a rising concern in the pest management industry due to its high reproductive capability which enables it to establish a sizable population within a short period of time (Lee & Lee, 2000a; Lee *et al.*, 1996b). Moreover, the capability of *B. germanica* to survive in much less favourable conditions has made it the most important cockroach pest, thriving at practically everywhere humans reside (Cochran, 1999).

2.4.1 Morphology

The *B. germanica* are also relatively small cockroaches with the adults measuring approximately 10 mm to 15 mm in body length (Cochran, 1999; Cornwell, 1968). They are generally yellowish-brown in colour with two distinct dark parallel bands on the pronotum (Cornwell, 1968). The adult males (Plate 2.3A) are slender while the adult females (Plate 2.3B) appear more stout-looking and are of a slightly darker shade of brown than the adult males (Cochran, 1999; Cornwell, 1968). The nymphs (Plate 2.3C) which are generally black in colour also posses the two distinct dark parallel bands but are normally broader (Cochran, 1999; Cornwell, 1968). Meanwhile, the oothecae are rather large, measuring approximately 7 mm to 9 mm long and are usually being carried by the adult females (Plate 2.3B) until the eggs hatches (Cochran, 1999; Cornwell, 1968). There are distinct indentations on the surface of the oothecae which correspond to the position of the eggs within (Cochran, 1999; Cornwell, 1968).

2.5 Life Table

Life table studies provide detailed information in understanding population ecology and hence contribute to the development of sustainable pest management of a target pest (Chi, 1988; Chi, 1990). A life table is often used by ecologists to keep track of stage specific mortality in the study of population (Kakde *et al.*, 2014). Comprehensive descriptions such as the demography and general biology which include survival rates, stage differentiation, development times, fecundity and life expectancy of a certain group of population can be obtained from the life table (Chi, 1988; Chi, 1990).

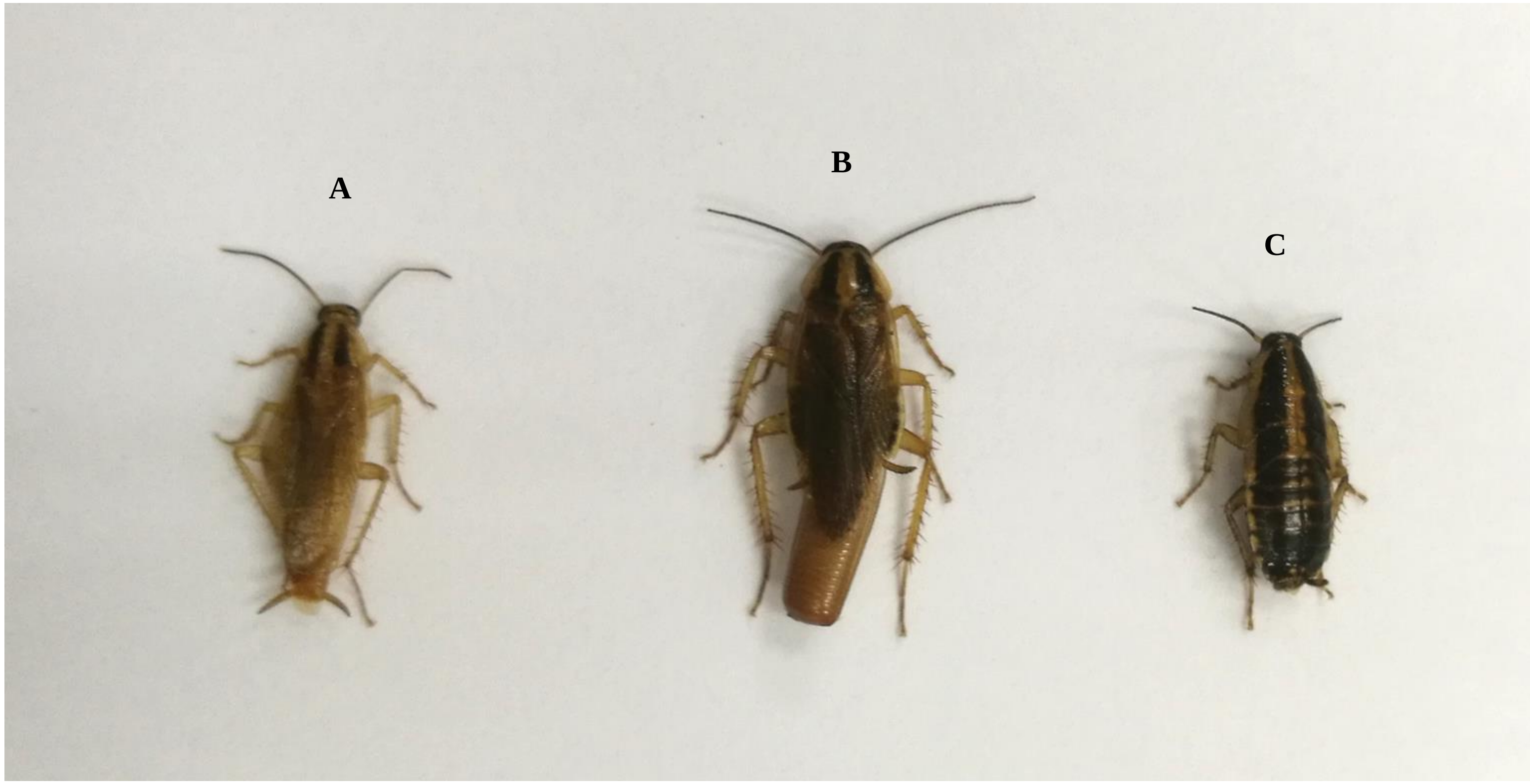

Plate 2.3: *Blattella germanica*. A) Adult male. B) Adult female carrying ootheca at its abdomen. C) Nymph.

Traditional life tables had been developed previously but the information generated was limited to only the female populations where the male as well as the stage differentiation of a population were being ignored (Huang & Chi, 2011). This has inevitably resulted in erroneous life table analysis and interpretation as the data from the male population have been omitted from the calculations of demographic parameters such as intrinsic rate of increase, net reproductive rate and the mean generation time (Chi & Liu, 1985; Huang & Chi, 2011) which does not reflect the actual occurrence in the wild. Moreover, most insects have different developmental rates between sexes and among individuals (Huang & Chi, 2011). Chi and Liu (1985) and Chi (1988) had developed an age-stage, two-sex life table theory which can precisely reveal the actual life history of an insect species by taking the variable developmental rate and male population into account.

2.6 Water Balance Profile

Water is the main constituent of living organisms and is important to all living organisms with no exception to insects, where it comprises 70 % of the body weight and functions as a medium to maintain physiological equilibrium (Danks, 2000; Oswalt *et al.*, 1997). Water balance in an insect is vital for its survival, reproduction and distribution, and can be expressed as the difference between water gain and water loss (Benoit & Denlinger, 2010; Tejeda *et al*., 2014).

Insects which are generally small in body size and therefore have a larger surface area to volume ratio, are extremely vulnerable to dehydration or water loss (Addo-Bediako *et al.*, 2001; Gibbs *et al.*, 1997). Certain insects such as one of a blood-feeding arthropod (e.g. adult female mosquitoes and ticks), which over hydrates following a blood-feeding meal and suppresses dehydration while off the host, is required to continually switch from water conservation to elimination of unwanted water contained in the blood throughout its life cycle in order to survive (Benoit & Denlinger, 2010).

In general, water is lost through several routes such as the insect cuticular loss (cuticle), respiratory loss (spiracles), defecation (anal openings) and secretion (anal openings) while water is gained through ingestion, water vapour absorption and metabolism (Benoit & Denlinger, 2010; Oswalt *et al*., 1997). Loss of water through insect cuticle or also known as cuticular permeability accounts for a significant portion of water lost by an insect (Benoit & Denlinger, 2010) and is affected by abiotic factors such as temperature, humidity, airflow and exposure to insecticides, which increases with higher temperatures and lower relative humidities (Appel & Tanley, 1999). Cuticular resistance to water loss are also affected by acclimation (Appel & Rust, 1985). Therefore, it is necessary that an insect resist cutaneous water loss which is in part, accomplished via a waterproofing layer of cuticular lipids in order to survive (Appel *et al.*, 1983; Oswalt *et al.*, 1997). Lipid reserves may also affect water loss rates in insects (Mazer & Appel, 2001). Insects are also found to have increased body water content in order to overcome the desiccation stress imposed by their habitats (Bazinet *et al.,* 2010; Benoit & Denlinger, 2010; Danks, 2000; Gibbs *et al*., 1997). Besides the physiological adaptation of the cockroaches, studies have also been conducted to explain their adaptability to withstand high temperatures and dryness (Appel *et al*., 1983).

CHAPTER THREE: COMPARATIVE STUDIES ON THE BIOLOGY OF *BLATTA LATERALIS, SUPELLA LONGIPALPA* AND *BLATTELLA GERMANICA* UNDER DIFFERENT FOOD REGIMES

3.1 Introduction

Since the first discovery of *Blatta lateralis* or commonly known as Turkestan cockroach in 1978, it has been introduced and infestations reported in several countries (Kim & Rust, 2013). With the species easily available for purchase via the Internet by animal breeders needing live insects (Kim & Rust, 2013), it is expected that it is only a matter of time that *B. lateralis* becomes a pest cockroach in Malaysia.

Besides that, human commerce has also closed the distance of travel and may increase the access of this cockroach species unintentionally to various countries. During these transportation periods, these cockroaches may be subjected to harsh environment such as temperature and limited access to food. Meanwhile, when they have arrived at a new location, their colony establishment as well as the success level of their infestation is also dependent on the environmental conditions, availability of food and water as well as shelter.

One of the control measures to cockroach infestation is sanitation through reduction of food and water source. In this chapter, we shall observe and compare the biology of *B. lateralis* with that of two other existing important cockroach pest species, namely *Supella longipalpa* and *Blattella germanica* in terms of adult longevity, fecundity and nymphal development under controlled laboratory conditions as well as different food regimes.

3.2 Materials and Methods

3.2.1 Cockroach Cultures

The laboratory susceptible strains of Turkestan cockroach, *B. lateralis*, brown-banded cockroach, *S. longipalpa*, and German cockroach (ICI strain), *B. germanica*, were obtained from established populations in the Urban Entomology Laboratory, Vector Control and Research Unit, Universiti Sains Malaysia.

All three species of cockroaches were reared in plastic aquarium tanks measuring 45 (L) x 29 (W) x 30 (H) cm under the conditions of 26.2 ± 3.0^{o}C in temperature and 60.5 ± 12 % relative humidity and a consistent 12-hour photoperiod. The upper interior surface of the aquarium tanks was smeared with a thin layer of petroleum jelly (Vaseline®, Unilever) to prevent escape. Water and cat biscuits (Tesco Cat Food, Perfect Companion Group Co. Ltd., Thailand) as food were provided *ad libitum*. Label claims on the food packaging indicated that the cat biscuits contained 30 % crude protein, 9 % crude fat, 4 % crude fibre and 10 % moisture. Rolled corrugated cardboard was placed inside the aquarium tank to serve as harbourages. The aquarium tanks were cleaned weekly to prevent acaroid mites and phorid flies contamination as well as fungal growth in order to keep the cockroach population healthy.

3.2.2 Adult Longevity and Fecundity

Late instar cockroaches were selected carefully using a glass vial and transferred into a separate aquarium tank. They were checked daily for newly emerged adults. Upon reaching adulthood, one male and one female adult of the larger sized cockroach, *B. lateralis* were paired in polyethylene containers (9.5 cm diameter x 4 cm height) while the male and female adult of the smaller sized