ECOLOGICAL FACTORS AFFECTING TERMITE INFESTATION AND DISTRIBUTION AND POPULATION MANAGEMENT OF Coptotermes spp (BLATTODEA: RHINOTERMITIDAE) USING CHLORFLUAZURON BAIT

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by

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ºC	degree Celcius
%	percentage
g	gram
rH	relative humidity
±	central range
>	more than
<	less than

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FAKTOR YANG MEMPENGARUHI INFESTASI DAN TABURAN ANAI-ANAI DAN PENGURUSAN POPULASI *Coptotermes* spp (BLATTODEA: RHINOTERMITIDAE) DENGAN UMPAN CHLORFLUAZURON

ABSTRAK

Anai-anai memainkan peranan yang penting dalam ekosistem semulajadi sebagai pengurai dengan berkebolehan mencerna selulosa. Walau bagaimanapun, ia dikira sebagai makhluk perosak sekiranya memberikan impak negatif kepada ekonomi dan kehidupan seharian manusia. Anai-anai jenis bawah tanah, dari spesies *Coptotermes* spp adalah spesies makhluk perosak yang paling utama. Struktur binaan bangunan tidak mempengaruhi faktor pemilihan untuk anai-anai menyerang sesuatu bangunan selagi setiap bangunan menyediakan sumber selulosa iaitu makanan utama anai-anai. Dalam kajian ini, struktur binaan bangunan dalam kategori bangunan kerajaan yang terdiri dari rekaan rumah pangsa merupakan struktur binaan bangunan yang mempunyai kadar serangan yang paling tinggi iaitu 47.4% dari semua jumlah bangunan yang diserang diikuti bangunan tunggal, rumah teres setingkat, dan rumah teres dua tingkat. Tanpa mengambil kira struktur binaan bangunan, anai-anai mempunyai pola yang sama dalam menyerang sesuatu kawasan di dalam sesuatu bangunan. Anai-anai lebih cenderung untuk menyerang rangka cermin (18.9%) diikuti pintu (13.5%) dan kabinet (13.5%). Daripada keseluruhan 21 kawasan yang ditinjau, sejumlah 6 genus (*Coptotermes*, *Microtermes*, *Hospitalitermes*, *Globitermes*, *Macrotermes* and *Microcerotermes*) yang melibatkan 7 spesies anai-anai (*Coptotermes gestroi*, *Coptotermes curvignathus*, *Macrotermes gilvus*, *Microcerotermes* sp, *Microtermes* sp, *Hospitalitermes* sp, and *Globitermes sulphureus*). Di dalam kajian ini, anai-anai daripada spesies *Coptotermes gestroi* dan *Coptotermes*

curvignathus adalah dua spesies anai-anai yang sering dijumpai menyerang bangunan. Banyak faktor yang yang mempengaruhi anai-anai dalam mencari makanan dan setiap spesies anai-anai mempunyai tindakbalas yang berbeza-beza terhadap faktor-faktor ekologi. Sewaktu aktiviti pencarian makanan, jumlah anai-anai pekerja dan jumlah anai-anai askar adalah saling mempengaruhi (r=-1.000). Selain itu, kelembapan juga mempengaruhi kadar jumlah kayu yang dimakan (r=-.814). Kelembapan udara juga mengaruhi jumlah pekerja anai-anai (r=-.792) dan jumlah askar anai-anai (r=.792) dalam mencari makanan. Tambahan pula, suhu juga memberi kesan kepada jumlah anai-anai (r=.718) dan jumlah askar anai-anai (r=-.718). Dalam erti kata lain, suhu dan kelembapan udara mempunyai kesan kepada nisbah anai-anai dalam mencari makanan tetapi pH tanah dan kelembapan tanah kurang mempengaruhi aktiviti anai-anai. Terdapat pelbagai jenis kaedah untuk mengawal anai-anai dan salah satu kaedah yang terkenal adalah dengan menggunakan kaedah pengumpanan. Koloni anai-anai telah berjaya dihapuskan dengan menggunakan medium umpan yang mempunyai chlorfluazuron sebagai bahan aktif. Keseluruhannya, koloni anai-anai mampu dihapuskan dengan menggunakan medium umpan kurang daripada 300g dan mengambil masa 4 hingga 8.6 minggu untuk menghapuskan sesebuah koloni anai-anai. Apabila anai-anai didedahkan dengan racun dalam nisbah yang berlainan, terdapat perbezaan dalam kadar kematian yang diperhatikan dalam experimen pemilihan. Nisbah 50 anai-anai pekerja kepada 2 anai-anai askar mempunyai kadar kematian yang paling tinggi. Walaubagaimanapun, apabila anai-anai tidak diberi pilihan dalam eksperimen tiada pilihan, nisbah 50 anai-anai pekerja kepada tiada anai-anai askar adalah yang paling tinggi ($p<0.05$).

ECOLOGICAL FACTORS AFFECTING TERMITE INFESTATION AND DISTRIBUTION AND POPULATION MANAGEMENT OF *Coptotermes* spp (BLATTODEA: RHINOTERMITIDAE) USING CHLORFLUAZURON BAIT

ABSTRACT

In a natural ecosystem, termites play an important role as a decomposer since termite can digest cellulose. However, termites will be considered as pests once they had exerted substancial economical damages. The subterranean termites from the genus *Coptotermes* spp are known as the major termite pests. Type of buildings have no significant impact on the infestation level of termites as they can infest all types of building structures as long as there is cellulose, their main source of food. In this study, type of building; flat from government premises made up of 47.4% from the total buildings sample for termite infestation followed by single house, single-storey terrace house, and double-storey terrace house. Regardless of type of buildings, termite can be found attacking some common places in the buildings. Termites prefer to attack window frames (18.9%), followed by doors (13.5%) and cabinets (13.5%). From 21 surveyed sites, there are a total of 6 genera of termites (*Coptotermes*, *Microtermes*, *Hospitalitermes*, *Globitermes*, *Macrotermes* and *Microcerotermes*) of termites which include 7 termites species (*Coptotermes gestroi*, *Coptotermes curvignathus*, *Macrotermes gilvus*, *Microcerotermes* sp, *Microtermes* sp, *Hospitalitermes* sp, and *Globitermes sulphureus)*. In this study, the most common species found infesting building area are from the species *Coptotermes gestroi* and *Coptotermes curvignathus*. Many factors affecting the activity of termite to forage for food and each kind of species react differently towards the ecological factors. During foraging activity, number of termite workers and number of

termite soldiers do have a correlation which are affecting to each other (r=-1.000) Besides, humidity plays a role in affecting total wood consumption (r=-.814). Humidity has an impact towards the total number of termite workers (r=-7.92) and total number of termite soldiers (r=.792). In addition, temperature has an impact towards total number of termite workers (r=.718) and total number of termite soldiers (r=-.718). Thus, temperature and humidity have an effect towards total number of termite ratio during foraging activity while soil pH and soil moisture have no significant impact. Termites colonies in all sites have been successfully controlled by using bait matrix containing chlorfluazuron as the active ingredients. Generally, less than 300g baits matrix are needed to control termite population within 4-8.6 weeks. When termites were exposed to baits in different sets of ratio, there are difference in the mortality rate observed. In a choice bio-assays, termite ratio of 50 workers to 2 soldiers recorded the highest rate of mortality. However , when termites are left with no choice of foods, higher mortality rate were observed in ratio set of 50 workers to 0 soldiers ($p<0.05$).

CHAPTER 1

INTRODUCTION

Termites are major pests in the well develop area and categorized as social insects (Rust and Su, 2012). Termites are belongs to Blattodea order and also known as eusocial cockroaches (Inward et al., 2007). They serve a vital role in nutrient recycling (Gosling et al., 2012). Termites also act as beneficial decomposer of organic matters (Bignell and Eggleton, 2000). Termites are regarded as pest when they infest buildings, houses and crops (Evans et al., 2013). Some termites species are able to destroy living plants in a short period of time in which, their hard and soothed jaws are capable to chop off wood despite having weak and vulnerable body (Mueller and Gerardo, 2002). They are distributed mostly in tropical and tropical forests having the highest species richness of termites (Eggleton, 2000). Genus of *Coptotermes* distibuted broadly in tropical and subtropical region of the world while *Globitermes sulphureus* (Haviland) is abundance in Indo-Malayan region (Ab Majid et al, 2007). *Coptotermes gestroi* (Wasmann) and *G. sulphureus* are among the most common species of termites that can be found in Malaysia (Lee et al., 2007). Meanwhile, *Coptotermes formosanus* (Shiraki) and *C. gestroi* are the most verocious subterranean termites that can exert a significant economic loss as up to $32 billion in the world (Rust and Su, 2012).

Termites have the ability to control the environment inside their nest such as temperature and humidity (Korb and Linsenmair, 2000). Some social insects (invertebrates) can produce their favorable body temperature metabolically (Heinrich, 1993). However, many invertebrates regulates their internal body temperature by manipulating the temperature of their inhabited habitat (Korb and Linsenmair, 2000). The metabolism of the termites and their cultivated fungi farm generates heat that enough to maintain their nest temperature at a plateau high level approximately about 30ºC eventhough during periods with chilling cool environmental temperatures (Korb and Linsenmair, 2000). Besides temperature, relative humidity also play an important role in termite biology and behavior (Harahap et al., 2005). Colonies of *Reticulitermes flavipes* (Kollar) and *Reticulitermes virginicus* (Banks) were active at 80% relative humidity of higher however there were also *R. virginicus* colonies that are active 30% relative humidity during winter months (Harahap et al., 2005). Different species of subterranean termites have different microclimatic needs thus they will react differently towards soil moisture and temperature during foraging activites (Cornelius and Osbrink, 2011).

Dusting, soil treatments and baiting have been applied oftenly to eradicate termites (Lee et al., 2003). Southeast Asian countries including Malaysia depends heavily on the application of soil insecticides in the urban area (Chung and Lee, 1999). There are two type of soil insecticides; pre-construction and post-construction (Lee, 2002). Despite the effectiveness of chemical insecticides, they are not environmentally friendly (Wako, 2015). Baiting is a desired method to control termite populations by manipulating the foraging behaviour and social nature of subterranean termites where food transfer among the termite workers and other nestmates through a process known as trophallaxis which provides a medium for the distribution of slow-acting toxicant throughout the whole termite colonies (Ngee et al., 2004). In October 2000, pest control operators in Malaysia had started to use hexaflumuron baits to control subterranean termites (Lee, 2002). According to Su (1994), only a few grams of hexaflumuron needed to eliminate a whole colony containing several hundred thousand to millions of termites. In addition, total consumption of one to three baits (<35-105g of bait matrix or <175-525mg of hexaflumuron) was lethal to eliminate colonies of subterranean termites (Su, 2014). In comparison to other active ingredient, after 12 week application of chlorfluazuron baits, colony of *Coptotermes acinaformis* (Frogatt) shows a declination and total colony annihilation was confirmed 5 weeks later by destructive sampling of the mound (Peters and Fitzgerald, 2003).

The followings are the objectives of this study.

Study 1 (Chapter 3): Survey on infestation levels of subterranean termite, type of building designs, location of infestation and species of termite infesting the buildings in North Peninsular Malaysia.

Aim:

1. To investigate status of termite infestation in different type of buildings.
2. To discover the preferences of termite attack locations in the infested buildings.
3. To study the association between preferences of termite attack location in different type of buildings.
4. To determine the diversity of termites species found in the targeted infested buildings.

Study 2 (Chapter 4): Ecological factors affecting subterranean termite abundance during the foraging activity.

Aim:

1. To study the correlation between temperature with total number of termite ratio and total wood consumption.
2. To study the correlation between relative humidity with total number of termite ratio and total wood consumption.
3. To study the correlation between soil pH with total number of termite ratio and total wood consumption.
4. To study the correlation between soil moisture with total number of termite ratio and total wood consumption.

Study 3 (Chapter 5): Evaluation of chlorfluazuron in controlling the subterranean termite *Coptotermes* spp (Rhinotermitidae) in North Peninsular Malaysia.

Aim:

1. To evaluate the effectiveness of chlorfluazuron in controlling subterranean termite populations in targeted infested buildings in north Peninsular Malaysia.
2. To discover the effect of termite ratio on the mortality rate of subterranean termite when exposed to chlorfluazuron bait in laboratory setting.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to termites

Termites are hemimetabolous, eusocial insects that relate to the infraorder-Isoptera and order Blattodea (Saha et al., 2016). They are also known as social cockroaches and due to the similarity of phylogenetic relationship between termites and *Cryptocercus*, thus the order Isoptera should no longer be used and all species placed in Isoptera should be classified within the family Termitidae as part of the order Blattodea under the superorder Dictyoptera (Inward et al., 2007). Estimately, termites made up about 3105 species in the world and 185 from identified species of termites are pests (Krishna et al., 2013). Due to their role in biodegradation of plant material and nutrient cycling, subterranean termite have an impact on ecological and economical in urban and agricultural area (Husseneder, 2010). Subterranean termites can produce their own cellulases however it is not enough to support their nutritional needs (Inoue et al, 1997). Therefore, subterranean termites have a symbiosis relationship with a rich and variety flora of microorganisms in the hindguts of the termite workers that can help to digests lignocellulosic substance and to absorb important nutritions (Brune, 2006). Their diets mainly comes from various organic detritus like rotting leaves, humus, dry grasses, animal dungs, living woods and dead woods (Brossard et al., 2007). Ants, earthworms and termites are the three main agents of soil ecosystem engineers (Lavelle et al., 2006). In many area, specifically in the tropics region, termites are the major macrobiota that have a role to play in the ecological processes (Bonachela et al., 2015). The major ecosystem services provides by termites are the breakdown and recycling of organic matter, removal of dung, soil loosening and soil formation, soil fertility, helps in releasing green-house gas and pollination (Govorushko, 2018).

2.2 Biology of termites

There are three significant types of termites, which separated based on their habitats: (i) drywood termites, which prefer to eat dry wood and do not need to be near the soil to survive; (ii) dampwood termites, which live in a very moist wood; and (iii) subterranean termites which prefer to eat soft woods and live underground (Govorushko, 2018). According to Ghaly and Edwards (2011), termites are living in a large colonies inside a variety type of nests. There are three categories of termite nests: Epigeal (sticking out above the soil surface), Arboreal (nest above the ground with shelter tubes connecting to the ground tunnels) and Subterranean (completely deep into the ground) (Noirot et al., 2000). Due to their ecological behaviour such as feeding habits and their nesting habits, termites are grouped into two life types; the first one is the one-piece nesting termite or also known as wood-dwellers while another one is the multiple locations nesting termites (Choudhury et al., 2017). Termites can also be identified into further four feeding criteria: soil-eaters, wood-eaters, fungus-farmers and grass-eaters (Brauman et al., 2015).

Termites are soft, pale in colour and having a mouth part capable for biting, chewing and consuming cellulose as their main food source (Verma et al., 2009). Termite anatomy were built with thorax which joined broadly to the abdomen with wide waist (Grimaldi and Engel, 2005). Termite workers and termite soldiers have no wings and short of eyes (Lee and Neoh, 2014). Termite workers are small with averagely 6 mm in long and soldiers have bigger head when compare to the workers with jaws that can shoot liquids (Verma et al., 2009; Prahlad and Chimkod, 2012). With their mandibles, termites can mechanically chop up plant materials and grind it inside their gizzard (Choudhury et al., 2017).

Termites are very small in size with a perplexing nature and the total numbers of individual for a single colony can reach up to millions (Ab Majid and Ahmad, 2008). The termite colonies are usually begins when a single domain king and queen paring up during their nuptial flight, mate and eventually produce other colony members (Vargo et al., 2011). According to Lee and Neoh (2014), nuptial flight can reach a height about 15 m and can covered a distance of 200-300 m. Once the pair found a suitable place to establish their colony, they form the royal chamber and seal it (Phrahlad and Chimkod, 2012). Then, the queen starts laying yellowish eggs and eggs will hatch within the period of 50 to 60 days (Wako, 2015). In case of *Reticulitermes speratus*, when the female unable to find suitable male to mate during nuptial flight, they will join another female to start a colony or sometimes by herself through pathenogenetically process to start the colony (Matsuura, 2014).

In a single colony, there are neuter castes (workers and soldiers) and reproductive castes (alates, nymphoids and ergatoids) (Choudhury et al., 2017). Typically, in a single colony of termite colony, it consists of nymph, alates, workers, soldiers and reproductive individuals from both sexes (Wako, 2015). The life cycle of termites are incomplete in which the process of metamorphosis starts with egg, nymph and end at adult stages without undergo the pupae stage (Prahlad and Chimkod, 2012). A queen have extremely enlarged abdomen and can lay about 3000 eggs per day (Thompson, 2000). A queen can undergo two type of reproductions: (i) sexual reproduction is used to produce workers, soldiers and alates while (ii) asexual reproduction is used to produce their own successors which parthenogenetically producing the daughters of the queen (Matsuura et al., 2009). When the king or queen dies, they will be replaced by neotenics that develops from nymphoids (nymph) or workers (ergatoids) that arise from the same colony (Vargo et al., 2009).

The larvae (hatched from eggs) of termites will grows without any significant changes in their morphological appearance (Wako, 2015). King and queen will tend to their larvae as they need to be fed due to their soft and incomplete shape mouthpart until they are mature enough to take care of themselves (Lee and Neoh, 2014). Larvae will develop into workers or nymph after several molting or ecydysis (Ghaly and Edwards, 2011). Termite workers will help the royals (king and queen) by forage for their own food, feeding the other castes, care the eggs and young larvae, grooming the royals, making tunnels and expanding the nest (Lee and Neoh, 2014) while termite soldiers will keep the colony and its occupants from any disturbances (Ghaly and Edwards, 2011). *Heterotermes tenuis* soldiers involve in the expedition of new food sources (Casarin et al., 2008). Termite soldier is the only caste of termite which have no ability to molt (Lee and Neoh, 2014).

The production of nymph occurred when the colony is mature enough and there is abundance of food reserve (Lee and Neoh, 2014). Nymphs will grow either into alates or neotenic reproductive (Vargo and Husseneder, 2009). Alates have testes and ovaries, able to swarm and also derive from nymphal stage (Watanabe et al., 2014). The colony of termites have optimum set of ratio in terms of soldiers to workers and nymphs (Wako, 2015). The production of soldiers need to be regulated as any extra number of soldiers will burden the colony since they must be fed by termite workers (Kuswanto et al., 2015).

Nymphs will keep the balance ratio of the caste and number of termite individuals if any caste depletes below the optimum ratio (Wako, 2015). Workers (44.77%) are the largest population inside a colony, followed by larvae (39.09%), soldiers (15.37%) and pre-soldier (0.77%) (Lee and Lee, 2011).

2.3 Classification of termites

Termites have seven important families, which one of the families was placed under higher group termites and six others families were belongs to lower group termites (Ottesen and Leadbetter, 2011). Termitidae is the name of termite family under higher group termites which dominating 80% of the genera (Rahman and Tawatao, 2003). While lower group termite consists *Hodotermitidae*, *Kalotermitidae*, *Mastotermitidae*, *Rhinotermitidae*, *Serritermitidae*, and *Termopsidae* (Aanen et al., 2002). Family of *Kalotermitidae* are drywood termite species which nesting in the woods and can be found infesting inside structural timber of buildings (Verma et al., 2009). *Incisitermes minor* (Hagen), *Cryptotermes brevis* (Walker), *Marginitermes bubbardi* (Banks) and *Glyptotermes brevicaudarus* (Haviland) are the examples of drywood species (Rust and Su, 2012). The major termite pest species under *Kalotermitidae* family belong to the genus of *Cryptotermes* (Rust and Su, 2012). Moisture and soil do not affecting the survival of drywood termites as compared to the other groups who depends on moisture and soil to survive. The presence of fecal pellets around the timber are sign of timber damaged by drywood termite species (Lee and Neoh, 2014). When a single piece of wood has been colonized by drywood termites, thousands of individuals could be found living inside that wood (Rust and Su, 2012). The other group, the dampwood termites feed on decaying rotten woods, wet, buried timbers and old tree stumps (Lacey et al., 2010). *Hodotermitidae* are the example of dampwood termites which nesting inside moist wood and no contact with soil surface (Verma et al., 2009). *Termitidae* family such as *Macrotermes* spp (Verma et al., 2009), *Nasutitermes* spp. and *Odontotermes* spp. are the examples of higher group termite (Rust and Su, 2012). The nest of subterranean termite located under the ground as soil moisture is vital for their survival. (Lee and Neoh, 2014). *Coptotermes* spp, *Reticulitermes* spp. and *Heterotermes* spp. are Rhinotermitids that build nest in the soil (Rust and Su, 2012).

Termites and cockroaches shares the same order of Blattodea as phylogenetic studies suggest that both termites and cockroaches have evolutionary track originated back to the same ancestor (Choudhury et al., 2017). Evolution had separated termites into two major groups; lower and higher group termites which differs in the composition of the symbiont microbiota in their gut (Rahman and Tawatao, 2003). The hindgut of lower group termites support a diverse populations of flagellated protist (eukaryotes with a single cell), archaea and bacteria (Peterson and Scharf, 2016). In contrast, higher group termites were lack of symbiotic protozoa and they have to depend on the combination action of enzymes from bacteria and symbiotic fungus to digest food (Wood and Thomas, 1989). Lower group termites feed on wood or grass (Ottesen and Leadbetter, 2011) and their symbiotic intestinal protozoa will help to digest the cellulose materials (Lee et al., 2014). In contrast, higher group termites feed on wide type range of foods; wood, soil nutrition and cellulytic fungi (Ohkuma, 2003). Higher termite group is abundance in tropical forest as litter, wood and soil feeders whereas lower termite groups are generally wood eaters which commonly found outside forests (Rahman and Tawatao, 2003).

However, a mound-building species, *Macrotermes gilvus* (Hagen) (Isoptera: Termitidae: Macrotermitinae) can be found along the perimeters of structures and buildings (Lee et al., 2014). Aanen and Eggleton, (2005) reports that subfamily Macrotermitinae were actually comes from African rain forest and later expand into South and Southeastern Asia region. The response of lower group termites and higher group termites towards bait treatment also differ. According to Lee et al. (2007), after elimination of *Coptotermes* spp. (Rhinotermitidae) with application of termite baits, the frequency of *M. gilvus* infestations became increasingly significant. In contrast to rhinotermitids, *M. gilvus* do not react effectively to termite baits (Lee et al., 2007). Thus, to control higher group termites, pest control professionals use the combination of chemical spraying and physically removes the termite mounds (Lee et al., 2014). Molting process in lower group termites and higher group termites are different. Rhinotermitid workers have many stage of molting and several stage of worker instars can exist inside the colony (Roisin, 2000). However, only a single stage of worker caste exists inside the colony of macrotermitines since their worker caste is in the end-stage which unable to undergo another molting stage (Neoh and Lee, 2009).

2.4 Ecology of termite

In order to achieve effective termite control, it is vital to know the foraging and population territory (Ab Majid and Ahmad, 2015). The foraging population can be estimated by using two methods such as mark recapture technique and direct counting however mark recapture is more popular to be used in the field study (Nutting and Jones, 1990). Mark recapture technique are divided into two type: single mark recapture and triple mark recapture methods. However, triple mark recapture technique can increase the chance to recaptured termites in the population as compared to single mark recapture (Begon, 1979). Beside mark-recapture method, direct counts of fumigated mounts (Darlington, 1984), the reaction of subterranean termite (agonistic behavior) (Pearce, 1997) and direct excavation by Howard et al (1982) has been used to determine termite foraging territories.

In their study, Ab Majid and Ahmad (2015) used nile blue A to determine termite foraging arena in the field. Based on a study by Ngee and Lee (2002), stained *Globitermes sulphureus* can last as long as 60 days in the laboratory. In contrast, Ab Majid et al (2007) discovered that stained *G. sulphureus* can last for 90 days in the field. In Malaysia, extensive studies on foraging termite territories has been done as Ab Majid et al. (2007), Lee (2001), Lee et al. (2003b) and Sajap et al. (2000) had used Nile Blue A to study termite foraging population of *Coptotermes gestroi*, *Coptotermes curvignathus* and *G. sulphureus*. Population of *C. gestroi* in Penang, Malaysia were estimated to be ranging from 56, 127±11925 to 4, 185, 000±2, 127, 328 individuals (Ab Majid and Ahmad, 2015). In contrast, foraging population of *C. curvignathus* is 1.6 to 7.1 x 10^5 which covered the area of 15 and 50 m^2 (Sajap et al, 2000). The termite foraging population are different based on type of termite specie (Ab Majid and Ahmad, 2015).

There are few factors can affluence the foraging population and foraging territories of termite. Environmental factors of soils such as pH, moisture level, temperature, the content of organic materials and presence of microorganism (Felsot, 1989) and also type of soils (Forschler and Townsend, 1996a; 1996b). Small foraging population of termite in housing area in Ab Majid and Ahmad (2015) suggest that human activities could have an impact on termite foraging (Vasconcellos et al., 2010). According to Husseneder et al.,

(2005) and Vasconcellos et al., (2010) newly established colonies have smaller foraging size while larger colony is large because they has been there for a long period of time.

During termite foraging activity, termites use chemical substance to communicate to each other while searching for food (Reinhard et al., 1997). Foraging gallery is being constructed during the food searching activity (Reinhard et al., 1997). According to Campora and Grace (2001), termite foraging activities in the soil are in need of suitable moisture and optimum temperatures. In addition, environmental climate and temperature are believed to have a major role in affecting termite foraging looking for food (Campora and Grace, 2001). Based on research done by Ab Majid (2014), subterranean termite; *Reticulitermes flavipes* fed vigorously at 15-25ºC and the highest feeding rate occurred at 20ºC with mean consumption rate of 0.34 g while the lowest occurred at 15ºC. However there is no significant difference in terms of feeding factors at temperature of 15, 20, 23, 25 and 30ºC (Ab Majid, 2014).

Biology process of termite such as feeding are depends on temperature and relative humidity (Indrayani et al., 2007). However, due to termite always moving periodically to underground to restore their hydration thus diminish the importance of relative humidity and moisture content of their food sources (Rudolph et al., 1990). However, according to Appel et al. (1983), the ability of poikilothermic organisms to survive and utilize their habitat is depends on the abiotic factor (temperature). Woodrow and Grace (1998) suggests that there is potential to modified temperature factor to manipulate termite as a medium of control treatment. The overall performance, agility, and survival of termites is affected by environmental temperatures that can affect their susceptibility towards insecticides (Quarcoo et al., 2019). During cold winter, termite will tunnels deeper into the soil might influence the effectiveness of liquid termiticide (Hu, 2014). The rate of uptake and transfer effect of fipronil (Campbell et al., 2009), noviflumuron (Spomer and Kamble, 2006), and other active ingredients will increase as the temperature increase thus reducing the termite survivorship (Spomer and Kamble, 2005).

2.5 Economic important of termite infestations

Termites will cause a serious problem when the infestation occurred in urban areas as they give negative economic effects, reducing the value esthetic of the buildings, damaging crops and causing household repair due to termite damages (Ghaly and Edwards, 2011). Termites are polyphagous insect pest and can be very devastative that can cause damage to plants and agricultural crops (Govorushko, 2018). From the seed to the matured plants, termites are able to attack plants at any developmental stages (Govorushko, 2018). The main agricultural crops are cereals: maize; sorghum; rice; barley; wheat and millet, legumes: beans; pigeon pea; cowpea and chickpea, oil crops: soybean; groundnut; sunflower and sesame, vegetables: eggplant; pepper; okra and tomato, root crops: cassava; yam and potato, fruit plants: plum; litchi; almond; pineaple; mulberry; grapes; papaya; mango; banana; citrus; coffee and guava, and also including sugar cane, tobacco, cotton and tea (Qasim et al., 2015).

Termites leave a scar in crop tubers of groundnuts, reduce their markert value and increase the toxin level in groundnuts (Jouquet et al., 2018). Negassa and Sileshi (2018), stated that *Microtermes* is the most important genus in Africa that become pests of agricultural plants in Africa. In Zimbabwe, termites eat at the base of the stem or root system of maize, in results, the plants dies and the yield have been reduced due to altercation of water and nutrients movements. Thus, the delayed in harvesting the plants had increased the yield losses (Mutsamba et al., 2016). The two main palm oil exporters in the world, Malaysia and Indonesia have a serious problem in their agricultural industries. *Coptotermes curvignathus* (Holmgren) usually causing damage to the oil palm and in the long term, this will result in a clear loss in palm yield (Yii et al., 2015).

Coptotermitinae, *Termitogetoninae*, *Rhinotermitinae*, *Heterotermitinae*, *Macrotermitinae*, *Termitinae* and *Nasutitermitinae* are the seven subfamilies that can be found in oil palm planted in tropical peat soil environment in Malaysia (Ali et al, 2018). In addition, *Globitermes sulphureus* (Haviland) can be a major pest in coconut and oil palm industries (Lee and Neoh, 2014). Some of the termite species are able to trigger the death of a healthy trees (Rao et al., 2012).

Termites harm many structures includings homes (terrace, bungalow and traditional house), mosque and greenhouse (Ab Majid and Ahmad, 2015). In Nebraska of USA, termites were estimated to infest 17-20% of homes and caused damages to wood products. composite siding, stone panels and other building materials inside the house (Govorushko, 2018). 89% of infestation of historical buildings and 62% of housing buildings in Brazil were caused by *Kalotermitidae*, *Rhinotermitidae* and *Termitidae* (Mello et al., 2014). *Coptotermes acinaformis* (Froggatt, 1898) is the main reason behind the 80% of all damage to buildings in Sydney, Australia (Govorushko, 2018). Buildings in the southern part of China were infested by three type of most important termite pest species; *Coptotermes, Cryptotermes* and *Reticulitermes* (Li et al., 2013). *Coptotermes* sp comprised 85% of premises infestation in Northern Peninsular region of Malaysia (Lee et al., 2007).

Termites enter the buildings or structures usually begins from a nest in the soil through multiple tunnel galleries on trees or walls of the structures until they found cellulose materials (Kuswanto et al., 2015). The network of these tunnel galleries are connected to each other and connected to the multiple feeding sites which can extend from tens to hundreds metre in length (Arab et al., 2012). When the food source is located, trail pheromones will be secreted from termite sternal gland on substrate which later aided the orientation and movements of workers and soldiers towards the food sources (Arab and Costa-Leonardo, 2005). However, when they are foraging inside the infested buildings, they will continuously moving back and forth to the ground and nest center to retain their moisture and communication with other nestmates (Kuswanto et al., 2015). Deforestration and clearing plantation area usually will left a pile of tree stump and a lot of litter distributed on or in the ground (Kuswanto et al., 2015). Thus, subterranean termites infestation usually occurred in high frequency among the structures or buildings that were built on area previously forest or plantation farm (Mo et al., 2006).

Building damages are often cause by pest activities and usually causing a high cost in application of termite prevention methods which can reach upon billions (Ahmed and French, 2005). Annually, over $3 million were spent to control *Coptotermes* sp in Taiwan (Li, 2014). While in Vietnam, $1.7 million were spent to control termite and repair the damages caused by termites involving private houses (Yen et al., 2016). In Archipelago, it is reported that the cost of treatment for all infested buildings is $51 million and the cost to rebuilt the damage buildings involved $175 million (Guerreiro et al., 2014). According to Rust and Su (2012), the total damage caused by termite worldwide were estimated at US $ 22 billion to US $ 40 billion. In Malaysia, 50% of the total business revenue of the

Malaysian pest control industry in the year 2000 were comes from subterranean termite control in which US $ 8-10 million has been spent (Lee, 2002). According to Evans et al. (2013), Formosan subterranean termite *Coptotermes formosanus* (Shiraki) and the Asian subterranean termite *Coptotermes gestroi* were the most economically termite species that can have a broad distribution in nature.

2.6 Termite control and managements

The sole objective for the application of termite control measures is to protect a structure and its contents (Su and Scheffrahn, 1998). There are two general methods to control subterranean termite: (i) application of liquid termiticides into soils in order to create a chemical barrier and (ii) application of termite baits for controlling the colony of subterranean termites in the perimeter of a structure (Su, 2011). There are multiple choices of control measures that can be used to control termite infestation such as biological, physical and chemical control. However, chemical control has been widely used to control termite problems (Kuswanto et al., 2015).

For a physical control, uniform-sized particles and stainless steel screening have been used as non-chemical approach to control termites (Lax and Osbrink, 2003). Besides, wire mesh barrier like woven stainless steel mesh and application of particles barrier such as gravel, granite, basalt, quartz, coral sand, glas shards and silica sand can helps to prevent termite invasion (Verma et al., 2009). Humidity and temperature inside foraging galleries of subterranean termites are very favorable for the growth of biological agents. Biological approach to control termite includes the usage of fungi *Metarhizium anisopliae* Sorokin, *Beauveria bassiana* (Balsamo) Vullemin and releasing entomophatogenic nematode, *Neoaplectana carpocapsae* Weiser ((Su & Scheffrahn, 1998).

Since 1900s, soil treatments have been widely practised by pest control profesionals to combat subterranean termite infestations (Su, 2011). Chlordane, heptachlor, aldrin and dieldrin are registered to be used as soil termiticides and were dominating the termite control industry (Su and Scheffrahn, 1998) until they were stopped in the mid-1980s (Su, 2011) due to the concerns of various environmental aspects and health factors with respect to their active ingredients used as the soil termiticides (Lax and Osbrink, 2003). The success of these cyclodienes are due to their highly effective chemical characteristics, persistent in the soils for more than 25 years, and high vapour pressures that helps the termiticides to distribute thoroughly in the soils even under than less ideal application conditions (Lax and Osbrink, 2003).

There are two type of soil treatments; non-repellent termiticides (fipronil, chlorfenapyr, imidacloprid, chlorantraniliprole) or repellent termiticides (bifenthrin, permethrin and cypermethrin) (Su, 2011). Soil termiticides contributed 90% of the subterranean control with 65% of the soil termiticides are bifenthrin and imidacloprid (Koehler et al., 2011). The termiticides involved in the study of degradation rate and half-life of termiticides in Malaysian sandy loam soil by Mohd Rashid and Ab Majid (2018) are imidacloprid, fipronil and bifenthrin. The purpose of soil treatment is to create a layer of insecticide between the buildings and soil surface, around building perimeters in order to protect them from incoming termites (Buczkowski et al., 2012). Soil treatment relies on physical contacts between termites and insecticide substances to be successfull (Scharf, 2015). Thus, non-repellent liquid termiticides were used in the soil treatment that can delayed termite mortality (Baker and Miguelena, 2014).

Slow acting termiticides will given termites an adequate of time to penetrate the treated soils until they becomes immobilized due to intoxification and eventually died (Saran and Rust, 2007). Slow acting termiticides also will enable the toxicant termites to interact with their non-toxicant termite nestmates thus contiminate the areas beyond the application termiticids applied (Baker and Miguelena, 2014). According to Saran and Kamble (2008), termite control industry oftenly used fipronil as non-repellent liquid termiticide for soil treatment. Soil insecticide treatment can be separated into two methods such as pre-construction and post-construction (Lee, 2002). During pre-construction soil treatment, a layer of termiticide was applied to the soil during the construction phase of the buildings (Lee et al., 2014) while for post-contruction, dusting, trenching and corrective soil treatments were applied (Lee, 2002). In addition, dusting is the process when insecticidal dust is inserted into the foraging tube of termites (Lee et al., 2014).

Pest control operators in Malaysia started to use hexaflumuron baits to control subterranean termites back in October 2000 (Lee, 2002). Usage of baits in termite colony elimination gains more popularity in the recent years (Lee et al., 2014). These termite monitoring and baiting systems are focusing on eradication of termite colonies when compared to traditional barrier treatment which have no significant impact on termite populations (Lax and Osbrink, 2003). To ensure bait treatment achieve its purpose, baits must be found by termites, eaten and horizontally transfer the residual insecticide deposits among the colony members (Scharf, 2015).

Termite baiting can be applied in two methods: through in-ground (IG) and above-ground (AG) bait system. IG bait system is installed in the soil along the perimeter of the infested building in order to intercept foraging termites while AG bait sytem (bait box with one open side) is installed on a wall of a building that has been infested by termites (Su, 2015). Baiting method is very specific to targeted pest and have low impact on mammalian. To achieve its efficiency, baits required a small amount of toxicant when compared to soil treatment (barrier treatment) (Broadbent, 2011). The toxicant in bait targeting the immature castes such as larvae, nymph and workers in which, chitin synthesis inhibitor (CSIs) disrupt the chitin formation during the molting process (Neoh et al., 2011). However, higher group termite like *G. sulphureus* takes 4 times longer that the time taken needed to control lower group termite (Neoh et al, 2011).

2.7 Areawide pest management

Areawide pest management was basically the systematic reduction of a target pest(s), to tolerance levels by applying mandatory pest mitigation procedures uniformly over geographical areas which defined by biologically based criteria of target pest (Faust, 2008). There are four foundations of areawide management of pests: 1) it should be done in large geographic area; 2) it should be monitored by organizations rather than individuals; 3) it should be done with the intention to reduce and manage the density of pest at tolerance level; and 4) it should be include as regulatory component to ensure full cooperation in the program (Kogan, 1998). The implementation of areawide termite control strategy is considered to be successful if it can reduces the impact of termite activity in areas where struture and tree has serious termite infestation (Su, 2002; Lax and Osbrink, 2003; Su and Lees, 2009; Guillot et al., 2010).

The difference between areawide termite management and individual protection of a structure or a tree is it aiming to reduce termite populations in areas removed from the structures and with the objective to prevent reinvasion (Osbrink et al., 2011). According to Su and Lees (2009), if termite populations has been suppressed around the perimeter and in a structure, this can reduce the chance for a termite to attack over certain period of time as compared to soil barrier termiticide treatment. When there is large area left untreated, the termite populations will easily found new source of food and this includes untreated home and tress thus with the advance of newer termiticides that can achieve termite population eradication make areawide termite pest management become possible (Lax et al., 2007).

The benefit of areawide pest management is that it can offer a long-term solution to pest problem when the approach was implemented properly and perhaps it can prevent any major pest outbreaks (Faust, 2008). However, the tools used in areawide management must be able to manage the target pest, have a minimum impact on the environment (environmental friendly) and do not form any residues on the food product which can be dangerous to the health of customers (Faust, 2008). Application of baits treatment containing chitin synthsis inhibitors (CSIs) are able to control termite populations in areas adjacent to the area of treatments (Su and Lees, 2009).

The three most commonly used CSIs are chlorfluazuron, diflubenzuron and hexaflumuron (Osbrink et al., 2011). Slow acting, non-repellent, and dose-indepedents are what makes the CSIs become desirable for termite baits (Su, 2003) and this bait are able to eradicate colonies of termites one by one (Su and Lees, 2009). Bistrifluron bait (trade name Xterm) were evaluated for its efficacy against *Nasutitermes exitiosus* (Hill) which considered dead after 26 weeks and consume on average 39.1% from total bait offered (60g) (Webb and McClintock, 2015).

However, if targeted treatment area has been freed from termite, but surrounded by high population pressure of termites and no continuos control measure taken, that area can be re-populated by termites in 53 months (Su et al., 2016). To maintain the area freed from termite activities, continued baiting program must be sustained and the placement of baits can be expanded further outward from the target area to reduce the risk for reinvasion by alates or by existing colonies nearby the target area (Su et al., 2016).

2.8 Bioassay: no-choice and choice bioassay

No-choice or choice-bioassay is an assay used to study the test substances with the control variable or with other desired test substance (Lewis and Emdan, 2013). In no-choice bioassay, as the name suggest, the insects tested are not given any choices and only one treatment is applied (Drijfhout and Morgan, 2010). In contrast, choice-bioassay is used to study termite preferences between two subjects tested (control or desired substance) or between two different desired substance (Drijfhout and Morgan, 2010). The physiological changes of the treated subject is observed in separated arena of control and treated treatments (Muir et al., 2012). No-choice treatment is the standard laboratory method used to study the effect of insecticides (Rutledge and Gupta, 2006).

The effectiveness of chemical insecticides were evaluate through no-choice bioassay by recording the termite mortality, data consumption and behavior changes (Spomer and Kamble, 2005; Acda, 2007; Iqbal and Saeed, 2013; Eger et al., 2014; Gautam and Henderson, 2014). While in choice-bioassay, many experiments have been carried out by using natural insecticides to record termite mortality rate, preferences or repellency characteristics, attractant cue, consumption data and also physical behaviour changes (Bläske and Hertel, 2001; Boué and Raina, 2003; Onyilagha et al., 2004; Manzoor et al., 2012; Roszaini et al., 2013).

CHAPTER THREE

SURVEY ON INFESTATION STATUS OF SUBTERRANEAN TERMITE; TYPE OF BUILDING DESIGNS, LOCATIONS OF INFESTATION AND SPECIES OF TERMITE IN THE INFESTED BUILDINGS

3.1 Introduction

Malaysia is rich in biodiversity of termite species. There is 175 species recorded in Peninsular Malaysia from 42 genera (Tho, 1992) while Sabah alone have 103 species of termites (Zulkefli et al., 2012). Due to their ability to digest cellulose, termites play an important role as decomposers in the natural ecological system (Collins 1981, Genet et al., 2001), but they are labeled as pests when they consume structurally lumbers and directly causing economic damage (Acda, 2004). In the genus *Coptotermes* (Rhinotermitidae) alone, there are 23 species which are well known as the most significant termite pests worldwide for man-made structures. *Coptotermes formosanus* (Shiraki) and *Coptotermes gestroi* (Wasmann) are the example of damaging termite species that can affect the economy (Rust and Su, 2012) due to their ecological adaptability and invasive ability (Evans et al., 2013). Subterranean termites, *C. fomosanus* and *C. gestroi* are the major pest insects that can cause clear economic loss as high as up to $32 billion in the world (Rust and Su, 2012). Around the globe, the damage caused by termites was estimated at US $ 22 billion to US $ 40 billion (Rust and Su, 2012). Lee et al. (2007) stated that the loss of damage in Southeast Asia caused by termites was estimated at US $ 200 million per year.