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Threat of Subterranean Termites Attack in the Asian Countries and their Control: A Review

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ABSTRACT
This review focuses on the study of subterranean termites as structural and building pests especially in Asia Tropical countries. Since wood is one of the oldest, most important and most versatile building materials and still widely utilized by home owners in the region. Subterranean termites have long been a serious pest of wooden construction and they are still causing an important problem in most of tropical and subtropical regions. This termite group is build shelter tubes and nest in the soil or on the sides of trees or building constructions and relies principally on soil for moisture. Subterranean termite damage on building and other wooden structure cause costs associated with the prevention and treatment of termite infestation. Termite control, thus, is a realistic problem not only for human life but also for conservation of natural environment. All countries especially Asian countries are now seeking for the safer chemicals or the more effective methods for termite control. A huge amount of research in recent years has been devoted to termite control technologies to reduce environmental contamination and the risk to human health.

Key words: Subterranean termite, asian tropical, termite infestation, termite control, coptotermes

INTRODUCTION
Termites play vital roles in tropical ecosystems. As ecosystem engineers, their mounds modify habitats in ways that can affect the survival of other species (Jouquet *et al*., 2006). They feed on a very wide variety of organic detritus like dry grass, decaying leaves, animal dung, humus and living or dead wood (Brossard *et al*., 2007). However, termite also becomes of considerable economic importance if introduced to man modified environments such as houses, buildings and cultivated crops (Gay, 1969) as termites continue the act of cycling as ecosystem engineer. Attacks on buildings are usually initiated from a nest in the ground. Termites build one or several galleries on trees or walls of the building to reach the cellulose, including wood, in a building. Once inside the building, termites will continue to maintain contact with the ground (for moisture) and the nest center (the center of the communication). In tropical regions, due to their high diversity of termites, they do a very serious damage (Ghaly and Edwards, 2011).

Facts on the field indicate that the subterranean termites attack against buildings mainly occur in areas formerly forested land or plantation (Mo *et al*., 2006). Land clearing of forest or plantation for the expansion of human settlements are often left stump and piles of litter scattered on or in the ground. In other words, the condition of the residential areas provide abundant food source for termites. Termites doing ecological adaptation and become serious menace to both plants and structures. They cause significant losses to annual and perennial crops and damage to wooden components in buildings (Verma *et al*., 2009).

Of the 2,700 termite species known in the world, 80 termite species were considered serious pests (Lee and Chung, 2003) and subterranean termites accounted for 38 species, with the genus *Coptotermes* containing the largest number of species followed by *Macrotermes*, *Reticulitermes* and *Odototermes* (Rust and Su, 2012). The global damage caused by termites was estimated at US $ 22 billion to US $ 40 billion worldwide (Su, 2002; Rust and Su, 2012) and in Southeast Asia alone, it was estimated to cost approximately US $ 400 million per year (Lee, 2007). Furthermore, Rust and Su (2012) reported that subterranean termite cause economic losses was estimated that $ 32 billion in 2010 worldwide for control and damage repairs. Subterranean termites attack accounted for 90% of the total economic loss and about 70% of damage of construction. The main species of subterranean termite *Coptotermes* sp., is the most aggressive one.

Unlike in the temperate countries, it is common in Tropical Asia countries to find several termite pest species co-existing and infesting the same buildings and worse, other termite species can re-infest building structures after previous termite treatments have been successfully carried out. This condition has made termite control in the areas rather complicated. It is understood that the success of the management and control of termites depends on the accuracy of the information taxonomy of the target species (Matthews and Matthews, 1978) so as to identify the types of termites are potentially beneficial or detrimental in direct interaction with humans. Pesticide use will drive development and implementation of acceptable control strategies for subterranean termites. The implementation strategies of termite control is correlation between killing termites in the landscape and understanding of termite biology (Forschler and Jenkins, 2000).

Thus, the present review gives an overview of the subterranean termite pests when they damage wooden structure or any wood products used by humans. Existings of subterranean termite control and their success is discussed.

SUBTERRANEAN TERMITE COLONY

The most familiar form of termite nest is termite mound, however, not all species live in this sort of environment. Some of termite species prefer build their nest within dead or living trees, even a completely underground existence. Other species prefer to attach their nests to in places that are not directly in contact with the ground (tree, building) but maintain connection with the soil via mud galleries running down the surface of the trunk and wall. The ability of a termite colony to construct complex architectures despite the simplicity of its individuals is a conundrum not completely solved. The steps contributing to construction of colony in social insects are explained extensively by Theraulaz *et al*. (2003).

A termite colony is highly structured and has castes that perform distinctly different duties. There are three different castes in form and function. Recent studies indicate the caste system in termite colonies is very dynamic (Theraulaz *et al*., 2003). The reproductives produce all other members of the colony and play an important part in dispersal and formation of new colonies. There are three types of reproductives in a termite colony: the primary, secondary and tertiary reproductives. Recently, Hayashi *et al*. (2013) found that the termite colony *Reticulitermes speratus* that lost the primary reproductive castes will form the secondary reproductive castes (neotenic reproductive) within four to seven days. In the colony there is a main colony, where the main queen lives and satellite units, in which secondary reproductive are laying eggs. In underground, they are connected by a network of tunnels. Over time, these units may become isolated from one another to the point where the termites no longer interact. Type of colony expansion is called "budding", in which a number of the secondary reproductive and workers may split and form a new colonies independently.

Because the reasons for its invasive success, the termite colony may have to do with the flexible social and spatial organization of colonies. Colonies formed begin from a simple families headed by two primary (alate-derived) reproductives who produced from pair alate during mating flights (Raina *et al*., 2003). According to Pickens (1934) the primary reproductive caste produce a specific chemical substance, which can inhibit the development of female nymphs become neotenics (Pickens and Light, 1934). This inhibitor chemicals by Castle (1934) called primer pheromones. Furthermore, in the final stage, the primary queen and/or king will be supplemented or replaced by neotenics (non-alate derived reproductives) from within the colony. As colonies grow, they expand their foraging range reaching up to 50 m or more from the main nest (Su and Tamashiro, 1987). This colony sometimes form buds in which they separated (physically) from the rest of the colony to become independent colonies. According to Husseneder and Grace (2001), the termite colonies consisted of genetically distinct family units. Vargo *et al*. (2003) observed 30 colonies and found that 27 colonies contained a single pair of reproductives, whereas the remaining three colonies contained multiple related reproductives. This behaviour in world has been the focus of an intensive recent study of population and colony structure and colony-colony dynamics (Messenger *et al*., 2005).

The caste proportions that are normal in colonies of different species of termites. However, the discovery that juvenile hormone analogs can cause the production of excess soldiers in termite colonies has recently created interest in the normal proportions of soldiers (Bollazzi and Roces, 2007). They consist of 10-20% of the total colony members but the caste proportion varies with time (Lee, 2002b). The optimal proportion of soldiers for a species has apparently evolved through selection of the mix of castes that will minimize the energy expended in producing the maximum number of virgin males and females while maintaining adequate defense of the colony (Wilson, 1971). Many studies on distribution and abundance of termites, such as Lee and Lee (2011) had been study to understand population size and caste composition. They found that workers constituted the largest proportion (44.77%) of the total number, followed by larvae (39.09%), soldiers (15.37%) and pre-soldier (0.77%). An excess number of soldiers would burden the colony because the soldiers must be fed by food producing members. Such a disruption might break down the social structure of a colony and could be used to control termite populations.

In a subterranean termite colony, the workers leave the nest and forage for food wood or other sources of cellulose. They may travel as far as 90 m underground in their search (Puche and Su, 2001). When they find wood, they chew it up and bring it back to the nest to feed the other termites in the colony: Soldiers and reproductive termites. When a worker termite discovers a food source, it leaves a scent trail as it returns to the colony, so other workers can also find their way to the food. The tunneling strategy termite made for lowers the energy expenditure. Campora and Grace (2001) and the chances to locate new food source (Swoboda and Miller, 2004). According to Puche and Su (2001) that when the tunneling system is larger or longer, the strength of the termite cohort will diminish thus less tunnels are formed as the distance from the nest increases. Further reported by Swoboda and Miller (2004), that galleries are combined when termites had locate major or new food source. Houseman and Gold (2003) have been studying the tunneling rates in *Reticulitermes flavipes*. Their study suggest that tunneling rates are strongly influenced by environment include texture of soil, humidity and tactile orienting stimuli.

SUBTERRANEAN TERMITES ATTACK

Due to their diversity, termites are serious structural pests of homes and wood structures in the tropical and subtropical countries. One unique aspect of subterranean termites is that they have to discover food in soil by constructing underground tunnels (Su *et al*., 1984). Its biology, aggressiveness and hidden, unpredictable invasiveness make this insect difficult to detect and control. Subterranean termites have a cryptobiotic or "hidden" lifestyle. This cryptobiotic nature contributes to their success in invading human structures.

The pest status of subterranean termite is based on the damages caused by the termites to buildings construction including residential buildings. Subterranean termites, especially those from the subfamily Macrotermitinae (*Odontotermes* spp. and *Macrotermes* spp.) and Rhinotermitinae (*Coptotermes* spp.) are found to be attacking buildings in urban area and buildings in rural or suburban areas (Sornnuwat *et al*., 1996; Kirton and Azmi, 2005). Apart from causing damages, subterranean termites, also has spread this species to countries beyond its native range via dispersal flights from shipboard infestations (Scheffrahn and Su, 2005).

The first known record of the presence of termites attack in the beginning of 20th century (Seabra, 1907). In the next period, the attacking-termites has been studied since the first half of the twentieth century. Starting in 1936, researchers have started to consider the subterranean termites are pests that cause severe damage in the region (Kirton and Azmi, 2005). Since then many records have been reported, however, with the data available so far, it is believed that their records are very important in knowing the economic loss due to termite attack. The history of research of the attack rate and the value of losses in buildings by several researchers are shown in Table 1.

Several reports among others by Nandika (2014), Sornnuwat *et al*. (1996), Lee (2004), Takahashi and Yoshimura (2002), Tai and Chen (2002) and Zhong and Liu (2002) the Asian subterranean termite attack on building have been shown not less than five species of subterranean termite (*Coptotermes* sp., *Macrotermes* sp., *Odontotermes*, *Schedorhinotermes* sp. and *Nasutitermes* sp.), with *Coptotermes* sp., was the most dominant pest species found infesting (Fig. 1).

Coptotermes gestroi is the most economically important species in the South East Asia (Kirton and Brown, 2003; Lee *et al*., 2003; Kirton and Azmi, 2005). In Peninsular Malaysia, 85% of buildings infested by termites in urban area were caused by *C. gestroi* (Kirton and Azmi, 2005).

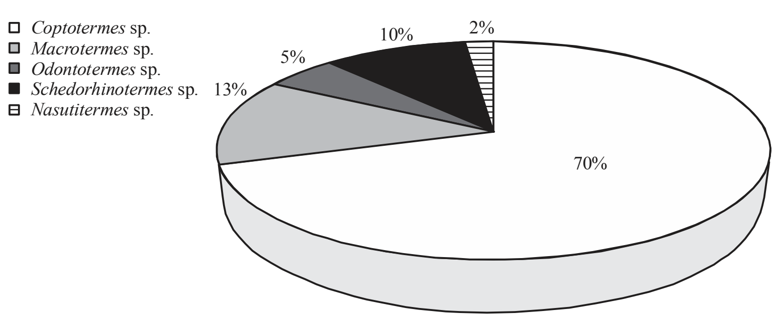

Fig. 1: Percentage of infestation of five termite species on wooden building

Table 1: Chronological order of events in the exploration of subterranean termite attack in Asian countries

Event	References
In Indonesia, economic impact of termites on building in big cities estimated over IDR 90 billion/year. The main species of termite in Indonesia are *Coptotermes* sp., *Macrotermes* sp., *Microtermes* sp., *Nasutitermes* sp., *Odontotermes* sp. and *Schedorhinotermes* sp.	Nandika (2014)
In Malaysia, subterranean termite control were spent USD 8-10 million in 2000 and 2003, the cost for termite control was at USD 10-12 million. The most important species are *Coptotermes travians*, *C. curvignathus*, *C. havilandi*, *C. kalshoveniand C. sepangensis*, *Macrotermes gilvus*, *M. carbonarius*, *Globitermes sulphureus*, *Microtermes pakistanicus*, *Microcerotermes* spp. and *Odontotermes* spp.	Lee (2002a, 2004) and Yeoh and Lee (2007)
Thailand recorded a total of 13 species belonging to the families Rhinotermitidae and Termitidae. The *Coptotermes gestroi* is most common infestation in the urban area, while houses in the rural area were predominantly infested by *Microcerotermes crassus*	Sornnuwat *et al.* (1996)
In Singapore include Malaysia found 7 genera of subterranean termites (*Coptotermes*, *Macrotermes*, *Microtermes*, *Globitermes*, *Odontotermes*, *Schedorhinotermes* and *Microcerotermes*). However, their economic loss no the data, but they can be readily found in and around buildings and structures, particularly in suburbia and rural settlements	Lee *et al.* (2007)
Two species of subterranean termites, *Coptotermes formosanus Shiraki* and *Reticulitermes speratus* (Kolbe), cause great economic losses in wooden constructions in Japan with estimated to be about US $ 1 billion per year	Takahashi and Yoshimura (2002)
In China about 80-90% of the buildings have been damaged or are being damaged by subterranean termite (*Coptotermes formosanus* Shiraki and *Reticulitermes flaviceps* Oshima). They have caused economic losses of RMB 1700-2000 million per year	Zhong and Liu (2002)
About 95% of the damage to buildings in Hong Kong has been caused by *Coptotermes formosanus*	Tai and Chen (2002)
India specialists consider loss by termites in the country as 280 millions rupee per year. The major subterranean termite species are *Heterotermes indicola*, *Coptotermes ceylonicus*, *C. heimi*, *Odontotermes horni*, *Microtermes obese*, *Trinervitermes biformis* and *Microcerotermes beesoni*. *Trinervitermes biformis*, *Coptotermes heimi* and *Neotermes assmuthi*	Rajagopal (2002) and Anantharaju *et al.* (2014)
Costs of repairs due to termite damage in the Philippines are estimated hundreds of millions of dollars annually	Yudin (2002) and Acda (2013)
Over 90% of historical buildings were heavily damaged by termites. *Coptotermes* spp. was responsible for >87% of termite infestation in urban area of Taiwan and termite control cost was estimated as 4 million US dollars annually and over 3 million US dollars is the annual cost for controlling *Coptotermes* spp. (*C. gestroi* and *C. formosanus*)	Li *et al.* (2011)
A total of sixteen species of termites were recorded damaging the log and structural wood in the building in Iran. *Anacanthotermes vagans* (Hagen) and *Microcerotermes diversus* (Silvestri) were more abundant in this country	Ravan (2010)

While in Thailand, 90% of termite infestations in urban area were also caused by *C. gestroi* (Sornnuwat *et al.*, 1996). Another *Coptotermes* species, *Coptotermes formosanus* Shiraki is the most serious structural pest in Japan, Taiwan (Su and Hsu, 2003) and China (Zhong and Liu, 2002). In Indonesia, *Coptotermes curvignathus* Holmgren is an economically important pest of structure timber (Dungani and Nandika, 1999). It is also a major pest in oil palm plantations (Nandika, 2014).

Like all foraging insects, termites (isoptera) follow a hierarchy of behaviors when searching for food (Matthews and Matthews, 1978). Initially, an termite searches the appropriate habitat in which to locate food. The termites search within it for potential resources. When a nutritional resource is located, it must be examined and recognized as potentially edible. Finally, the food must be accepted and consumed. Primary reproductives choose the initial nesting site at the culmination of the nuptial flight. The foraging area for the colony is established based on the nest location, although the search for food may extend out many meters from that center with made exploratory tunnels (Su *et al.*, 1993).

For subterranean termites, the second stage of foraging, the search for food within the patch consists of exploratory tunneling around foci of the nest complex (Reinhard *et al.*, 1997). Food resources, once located, then are examined (Hedlund and Henderson, 1999; Campora and Grace, 2001). If the food is accepted and consumed, the forager lays a pheromone trail back to the nest. A primary gallery then is constructed around this recruitment trail (Reinhard *et al.*, 1997). If food

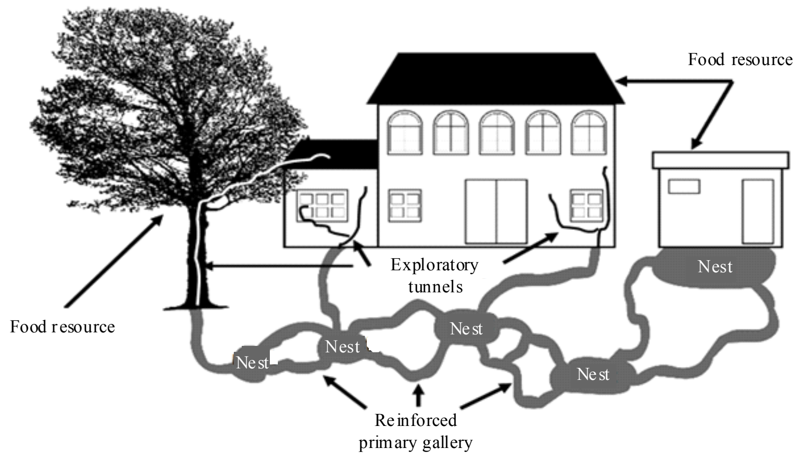

Fig. 2: Subterranean termite attacking strategy on buildings

is located an expanded gallery or 'primary tunnel' is constructed along the recruitment trail that called exploratory tunnels (Fig. 2). After the food is depleted, exploration of the environment begins again with the current food resource as the new center of activity (Reinhard *et al*., 1997; Campora and Grace, 2001; Puche and Su, 2001). Campora and Grace (2001) found that the likelihood of a food resource being discovered is a function of its proximity to previously exploited resources.

EXISTING OF SUBTERRANEAN TERMITES CONTROL

A number of control measures are used to prevent termite attack on buildings. These are physical, chemical and biological. The generally accepted method of termite control over the years has been chemical pesticides. Much of the research into the specifics to suppress termite populations with baits e.g., use of toxic baits (Su, 2002), barrier technology with inert gravel/granitegard (Su *et al*., 2004), stainless steel mesh (Termimesh) (Wege *et al*., 2003).

There are a number of alternatives to using chemical pesticides for termite control. Research on termiticides for termite control was reported by Scheffrahn and co-workers in the early 1950s (Scheffrahn *et al*., 1997). In their report mention that, these termiticides are typically applied to soil beneath or surrounding building foundations to protect structure from subterranean termites. However, nearly four decades, treatment of soil with termiticides has been the conventional technique for control of termites. Since 1952, the soil termiticide injection originally contain two cyclodienes (chlordane and heptachlor). According to Su and Scheffrahn (1990), the termiticides contain the active ingredients, such as bifenthrin, chlorfenapyr, permethrin, cypermethrin, imidacloprid and fipronil. The chemicals spinosad, Disodium Octaborate Tetrahydrate (DOT), calcium arsenate and chlorpyriphos, have been also used for this purpose. It will probably become less acceptable to spray a large quantity of insecticide in soil to protect a house from subterranean termites and need to use less pesticide for future technologies, no pesticide at all or controlled-release pesticide barriers (i.e., insecticide-impregnated polymer). Future trends of termite control technology is less pesticide and no pesticide.

Subterranean termite control by baiting system have recently gained popularity. The principle of termite baiting system is the active ingredient introduced into a station and termites locate a station and begin to feed. This efforts can reduce environmental contamination from pesticide exposure (Potter *et al*., 2001; Verkerk and Bravery, 2001). The active ingredient of chitin synthesis inhibitors causes metabolic disorders molting to termites, so it can not form a chitin and then death. The first formula used is diflubenzuron and triflumuron (Su *et al*., 1982, 1987). Subsequently, it was discovered a new formula is hexafumuron, which is a benzoylphenyl urea groups (Su, 1994; Su *et al*., 1998). Diba and Nandika (2009) states that the termite *Coptotermes curvignthus* who has eaten hexaflumuron for one week, experience morphological changes, especially in the integument. Integument pucker caused by dehydration in termites. However, the results of recent research shows that not all species of termites can be controlled by those active ingredients that has been commercially available, it is due to the different types of molting among species. Amran *et al*. (2014) suggest that the active ingredient fipronil can control the termites of family Termitidae effectively, the researchers tested it on *Macrotermes gilvus* Hagen.

The physical barriers can be used most effectively as continuous horizontal barriers during pre-construction installation. This method using the principle that termites cannot tunnel through a layer of moist or dry sand 1.2-1.7 mm in size (Ebeling and Forbes 1988). Su *et al*. (1992) found that single-sized particle barriers 2.00-2.80 mm effective in structure protection. Lenz and Runko (1994) found that a fine mesh of high-grade stainless steel, installed during construction as a continuous horizontal barrier, withstood foraging by several termite species. According to O'Toole *et al*. (2003), the Termi-Mesh (one type of physical barriers), is a fine stainless steel mesh (Termi-Mesh Australia Pty Ltd, Malaga, WA, Australia) with mesh holes 0.66×0.45 mm that are too small for termites to pass through.

The biological control have several potentials and distinct advantages over other forms of control in that high degree of safety among vertebrates and other non-target organisms and reduce or eliminate the use of chemicals around a structure that is needing treatment (Kaya and Gaugler, 1993). With the general public becoming increasingly concerned about pesticide usage, the use of bio-control for termite control is a potentially promising market. However, the control of termites with the entomopathogenic micro-organisms is not field proven, only based on laboratory studies with limited numbers of termites in a restrictive environment. Furthermore, Lacey *et al*. (2001) suggested that the termites species and the environment can significantly limit the success of pathogens.

Since known as very dangerous pest, an effort to control termites will always go on, especially using microbial insecticide. Neves and Alves (2004) stated that using microbial insecticide for controlling termites has several advantages such as has relative low cost, have many strains and can be germinate strain *in vitro*. Milner and Staples (1996) suggested that using microbial insecticide in controlling termites besides has relative low cost, those agents relative have no negative effect for human and environment. Currently, the microbial insecticide used for termites control in the world is primarily fungi.

The ability of fungi for controlling termites according by Grace *et al*. (1992) supported by the characteristics of fungi that have properties similar to a slow-acting chemicals. This is reinforced by the ability to replicate itself and fungal spores can be spread with the help of the social behavior of termites in the form of trophallaxis. Milner *et al*. (1996) review a wide variety of fungal pathogens that been reported as potential pathogens to termites. They reported several genera entomopathogenic fungi as potential pathogenic agents in controlling termites and among all of entomopathogenic genus, *Metarhizium* is one of entomopathogenic fungi that very potential in controlling termites especially *Metarhizium anisopliae* and *Metarhizium brunneum*. Desyanti *et al*. (2011) have collected the entomopathogenic fungus from varied source or host in

Indonesia, the result of screening test for termite control, eight species effective as candidate of bio-termiticides, namely *Metarhizium anisopliae* (Metsch), *Metarhizium* sp., *Myrothecium roridum*, *Beauveria bassiana* (Bals.), *Aspergillus flavus* (Link), *Aspergillus niger*, *Aspergillus* sp., *Rhizopus* sp., *Acremonium* sp. and *Penicillium* sp.

Nematodes are obligate insect parasites are widely used in bio-control for termite control besides the entomopathogenic fungus. Few researcher, such as Trudeau (1989), Mauldin and Beal (1989) and Lenz *et al*. (2000) reported that termite susceptibility to entomopathogenic nematodes in the families *Steinernematidae* and *Heterorhabditidae* varies and is influenced by nematode species. Gaugler (1988) reported the differences in efficacy between Steinernematid and Heterorhabditid nematodes depending on the host infected.

CONCLUSION

The subterranean termite, *Coptotermes* spp., is a pest of major economic importance in Asian countries (tropical and subtropical region). This subterranean termite colonies can cause hundred millions or even billions of dollars worth of damage each year. The extensive damage caused by *Coptotermes* sp., colonies cannot be attributed to individuals within the colony consuming a greater amount of wood than those of native subterranean termite species. This termite is a cryptic insects that resides underground, inside trees and remain hidden within walls of buildings. Efforts of prevention and control of subterranean termites (*Coptotermes* sp.) are generally performed using a liquid termiticide as chemical barriers in the soil, physical barriers and termite bait strategies. In general, control of subterranean termites in Asian countries rely heavily on the use of liquid termiticides. It is used in the soil both as repellent or non-repellent. The bio-control of termites with the fungi or nematodes are still tentative for application in the field. Successful control of subterranean termites starts with the detection, proper identification of species of termites and an understanding of the problem.

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REFERENCES

Acda, M.N., 2013. Geographical distribution of subterranean termites (Isoptera) in economically important regions of Luzon, Philippines. Philippine Agric. Scient., 96: 205-209.

Amran, I. Ahmad, R.E. Putra and E. Kuswanto, 2014. Effectiveness of fipronil bait to control *Macrotermes gilvus* (Isoptera: Termitidae) in Bandung. Jurnal Entomologi Indonesia, 11: 123-130.

Anantharaju, T., G. Kaur, S. Gajalakshmi and S.A. Abbasi, 2014. Sampling and identification of termites in Northeastern Puducherry. J. Entomol. Zool. Stud., 2: 225-230.

Bollazzi, M. and F. Roces, 2007. To build or not to build: Circulating dry air organizes collective building for climate control in the leaf-cutting ant *Acromyrmex ambiguus*. Anim. Behav., 74: 1349-1355.

Brossard, M., D. Lopez-Hernandez, M. Lepage and J.C. Leprun, 2007. Nutrient storage in soils and nests of mound-building *Trinervitermes* termites in Central Burkina Faso: Consequences for soil fertility. Biol. Fertil. Soils, 43: 437-447.

Campora, C.E. and J.K. Grace, 2001. Tunnel orientation and search pattern sequence of the formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol., 94: 1193-1199.

Castle, G.B., 1934. The Damp-Wood Termite of Western United State, Genus *Zootermopsis* (Formerly *Termopsis*). In: Termites and Termite Control, Kofoid, C.A. (Ed.). 2nd Edn., University of California Press, Berkeley, CA., USA., pp: 273-310.

Desyanti, Yumarni and Zulmardi, 2011. Pathogenicity of the entomopathogenic fungus *Myrothecium roridum* Tode Ex Steudel, *Beauveria bassiana* (Bals.) Vuill and *Metarhizium* sp. from natural in West Sumatera Indonesia against *Coptotermes gestroi* Wasmann (Blattodea: Rhinotermitidae). Proceedings of the 8th Conference of the Pacific Rim Termite Research Group, February 28-March 1, 2011, Bangkok, Thailand.

Diba, F. and D. Nandika, 2009. Hexaflumuron termite bait effectiveness against subterranean termites *Coptotermes curvignathus* Holmgren. Proceeding of the Annual Conference of Indonesian Wood of Researchers Society (IWORS), August 2009, Yogyakarta, pp: 2113-2120.

Dungani, R. and D. Nandika, 1999. Wood consumption and survival of subterranean termite *Coptotermes curvignathus* Holmgren (Isoptera: Rhinotermitidae) in laboratory test. J. Hayati, 6: 40-42.

Ebeling, W. and C.F. Forbes, 1988. Sand barriers for subterranean termite control. IPM Practitioner, 10: 1-6.

Forschler, B.T. and T.M. Jenkins, 2000. Subterranean termites in the urban landscape: Understanding their social structure is the key to successfully implementing population management using bait technology. Urban Ecosyst., 4: 231-251.

Gaugler, R., 1988. Ecological considerations in the biological control of soil-inhabiting insects with entomopathogenic nematodes. Agric. Ecosyst. Environ., 24: 351-360.

Gay, F.J., 1969. A new species of *Stolotermes* (Isoptera: Termopsidae, Stolotermitinae) from New Zealand. N. Z. J. Sci., 12: 748-753.

Ghaly, A. and S. Edwards, 2011. Termite damage to buildings: Nature of attacks and preventive construction methods. Am. J. Eng. Applied Sci., 4: 187-200.

Grace, J.K., R.T. Yamamoto and M. Tamashiro, 1992. Resistance of borate-treated Douglas-fir to the Formosan Subterranean termite. For. Prod. J., 42: 61-65.

Hayashi, Y., H. Miyata, O. Kitade and N. Lo, 2013. Neotenic reproductives influence worker caste differentiation in the termite *Reticulitermes speratus* (Isoptera; Rhinotermitidae). Sociobiology, 60: 446-452.

Hedlund, J.C. and G. Henderson, 1999. Effect of available food size on search tunnel formation by the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol., 92: 610-616.

Houseman, R.M. and R.E. Gold, 2003. Factors that influence tunneling in the Eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhintermitida). J. Agric. Urban Entomol., 20: 69-81.

Husseneder, C. and J.K. Grace, 2001. Similarity is relative: Hierarchy of genetic similarities in the Formosan subterranean termite (Isoptera: Rhinotermitidae) in Hawaii. Environ. Entomol., 30: 262-266.

Jouquet, P., J. Dauber, J. Lagerlof, P. Lavelle and M. Lepage, 2006. Soil invertebrates as ecosystem engineers: Intended and accidental effects on soil and feedback loops. Applied Soil Ecology, 32: 153-164.

Kaya, H.K. and R. Gaugler, 1993. Entomopathogenic nematodes. Annu. Rev. Entomol., 38: 181-206.

Kirton, L.G. and V.K. Brown, 2003. The taxonomic status of pest species of *Coptotermes* in Southeast Asia: Resolving the paradox in the pest status of the termites, *Coptotermes gestroi*, *C. havilandi* and *C. travians* (Isoptera: Rhinotermitidae). Sociobiology, 42: 43-63.

Kirton, L.G. and M. Azmi, 2005. Patterns in the relative incidence of subterranean termite species infesting buildings in Peninsular Malaysia. Sociobiology, 46: 1-15.

Lacey, L.A., R. Frutos, H.K. Kaya and P. Vail, 2001. Insect pathogens as biological control agents: Do they have a future? Biol. Control, 21: 230-248.

Lee, C.C. and C.Y. Lee, 2011. Population size and caste composition of a fungus-growing termite, *Macrotermes gilvus* (Blattodea: Termitidae). Proceedings of the 8th Conference of the Pacific Rim Termite Research Group, February 28-March 1, 2011, Bangkok, Thailand, pp: 78-82.

Lee, C.Y. and K.M. Chung, 2003. Termites. In: Urban Pest Control: A Malaysian Perspective, Lee, C.Y., J. Zairi, H.H. Yap and N.L. Chong (Eds.). 2nd Edn., Vector Control Research Unit, Universiti Sains Malaysia, Penang, Malaysia, ISBN-13: 9789832514398, pp: 99-111.

Lee, C.Y., 2002a. Subterranean termite pests and their control in the urban environment in Malaysia. Sociobiology, 40: 3-9.

Lee, C.Y., 2002b. Control of foraging colonies of subterranean termites, *Coptotermes travians* (lsoptera: Rhinotermitidae) in Malaysia using hexaflumuron baits. Sociobiology, 39: 411-416.

Lee, C.Y., 2004. Current termite management in Peninsular Malaysia. Proceedings of the First Pacific Rim Termite Research Group Meeting, March 8-9, 2004, Penang, Malaysia, pp: 37-42.

Lee, C.Y., 2007. Perspective in Urban Insect Pest Management in Malaysia. Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia, Malaysia, ISBN-13: 9789833986071, Pages: 104.

Lee, C.Y., J. Yap, P.S. Ngee and Z. Jaal, 2003. Foraging colonies of a higher mound-building subterranean termite, *Globitermes sulphureus* (Haviland) in Malaysia. Japanese J. Environ. Entomol. Zool., 14: 105-112.

Lee, C.Y., C. Vongkaluang and M. Lenz, 2007. Challenges to subterranean termite management for multi-genera faunas in Southeast Asia and Australia. Sociobiology, 50: 213-221.

Lenz, M. and S. Runko, 1994. Protection of buildings, other structures and materials in ground contact from attack by subterranean termites (Isoptera) with a physical barrier-a fine mesh of high grade stainless steel. Sociobiology, 24: 1-16.

Lenz, M., M.K. Kamath, S. Lal and E. Senivasa, 2000. Status of the tree-damaging *Neotermes* sp. in Fiji's American mahogany plantations and preliminary evaluation of the use of entomopathogens for their control. ACIAR Small Project No. FST/96/205, Australian Centre for International Agricultural Research, Australia.

Li, H.F., N.Y. Su, W.J. Wu and E.L. Hsu, 2011. Termite pests and their control in Taiwan. Sociobiology, 57: 575-586.

Matthews, R.W. and J.R. Matthews, 1978. Insect Behavior. John Wiley and Sons, New York, USA., Pages: 507.

Mauldin, J.K. and R.H. Beal, 1989. Entomogenous nematodes for control of subterranean termites, *Reticulitermes* spp. (Isoptera: Rhinotermitidae). J. Econ. Entomol., 82: 1638-1642.

Messenger, M.T., N.Y. Su, C. Husseneder and J.K. Grace, 2005. Elimination and reinvasion studies with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Louisiana. J. Econ. Entomol., 98: 916-929.

Milner, R.J. and J.A. Staples, 1996. Biological control of termites: Results and experiences within a CSIRO-project in Australia. Biocontrol Sci. Technol., 6: 3-9.

Milner, R.J., J.A. Staples and M. Lenz, 1996. Options for termite management using the insect pathogenic fungus *Metarhizium anisopliae*. IRG Document No. IRG/WP 96-10142. http://www.irg-wp.com/irgdocs/details.php?5e0d7df6-19fa-4a73-92e0-74564e047518.

Mo, J., Z. Wang, X. Song, J. Guo, X. Cao and J. Cheng, 2006. Effects of sublethal concentrations of ivermectin on behaviors of *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology, 47: 687-696.

Nandika, D., 2014. Termites: New pests on oil palm plantation. Southeast Asian Regional Center for Tropical Biology, Bogor, Indonesia, pp: 23.

Neves, P.M.O.J. and S.B. Alves, 2004. External events related to the infection process of *Cornitermes cumulans* (Kollar) (Isoptera: Termitidae) by the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae*. Neotrop. Entomol., 33: 51-56.

O'Toole, D.K., N.Y. Su, J.H. Zhong, S.K. Cheng and C.C. Ho *et al*., 2003. Termite Control Manual for Government Premises, Hong Kong. Architectural Services Department Press, Hong Kong.

Pickens, A.L. and S.F. Light, 1934. The Desert Subterranean Termite, *Heterotermes aureus*. In: Termites and Termite Control, Kofoid, C.A. (Ed.). 2nd Edn., University of California Press, Berkeley, CA., USA., pp: 196-198.

Pickens, A.L., 1934. The Barren-Lands Subterranean Termite, *Reticulitermes tibialis*. In: Termites and Termite Control, Kofoid, C.A. (Ed.). 2nd Edn., University of California Press, Berkeley, CA., USA., pp: 184-186.

Potter, M.F., E.A. Eliason, K. Davis and R.T. Bessin, 2001. Managing subterranean termites (Isoptera: Rhinotermitidae) in the Midwest with a hexaflumuron bait and placement considerations around structures. Sociobiology, 38: 565-577.

Puche, H and N.Y. Su, 2001. Application of fractal analysis for tunnel systems of subterranean termites (Isoptera: Rhinotermitidae) under laboratory conditions. Environ. Entomol., 30: 545-549.

Raina, A.K., Y.I. Park and C. Florane, 2003. Behavior and reproductive biology of the primary reproductives of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Sociobiology, 41: 37-48.

Rajagopal, D., 2002. Economically important termite species in India. Sociobiology, 40: 33-46.

Ravan, S., 2010. Ecological distribution and feeding preferences of Iran termites. Afr. J. Plant Sci., 4: 360-367.

Reinhard, J., H. Hertel and M. Kaib, 1997. Systematic search for food in the subterranean termite *Reticulitermes santonensis* De Feytaud (Isoptera, Rhinotermitidae). Insectes Sociaux, 44: 147-158.

Rust, M.K. and N.Y. Su, 2012. Managing social insects of urban importance. Annu. Rev. Entomol., 57: 355-375.

Scheffrahn, R.H. and N.Y. Su, 2005. Distribution of the termite genus Coptotermes (Isoptera: Rhinotermitidae) in Florida. Florida Entomol., 88: 201-203.

Scheffrahn, R.H., N.Y. Su and P. Busey, 1997. Laboratory and field evaluations of selected chemical treatments for control of drywood termites (Isoptera: Kalotermitidae). J. Econ. Entomol., 90: 492-502.

Seabra, A.F., 1907. Some observations on the *Calotermes flavicollis* (Fab.) and the *Termes lucifugus* Rossi. Bull. Portuguese Soc. Nat. Sci., 1: 122-123.

Sornnuwat, Y., C. Vongkaluang, M. Takahashi, K. Tsunoda and T. Yoshimura, 1996. Survey and observation on damaged houses and causal termite species in Thailand. Jpn. J. Entomol. Zool., 7: 191-200.

Su, N.Y. and E.L. Hsu, 2003. Managing subterranean termite populations for protection of the historic Tzu-Su temple of San-Shia, Taiwan (Isoptera: Rhinotermitidae). Sociobiology, 41: 529-545.

Su, N.Y. and M. Tamashiro, 1987. An Overview of the Formosan Subterranean Termite in the World. In: Biology and Control of the Formosan Subterranean Termite, Tamashiro, M. and N.Y. Su (Eds.). College of Tropical Agriculture and Human Resources, University of Hawaii, Honolulu, HI., USA., pp: 3-15.

Su, N.Y. and R.H. Scheffrahn, 1990. Economically important termites in the United States and their control. Sociobiology, 17: 77-92.

Su, N.Y., 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol., 87: 389-397.

Su, N.Y., 2002. Novel technologies for subterranean termite control. Sociobiology, 40: 95-102.

Su, N.Y., M. Tamashiro, J.R. Yatesand and M.I. Haverty, 1982. Effect of behavior on the evaluation of insecticides for prevention of or remedial control of the Formosan subterranean termite. J. Econ. Entomol., 75: 188-193.

Su, N.Y., M. Tamashiro, J.R. Yates, P.Y. Lai and M.I. Haverty, 1984. Foraging behavior of the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environ. Entomol., 13: 1466-1470.

Su, N.Y., M. Tamashiro and M.I. Haverty, 1987. Characterization of slow-acting insecticides for the remedial control of the Formosan subterranean termite (Isoptera: Rhinotermitidae). J. Econ. Entomol., 80: 1-4.

Su, N.Y., P.M. Ban and R.H. Scheffrahn, 1992. Penetration of sized-particle barriers by field populations of subterranean termites (Isoptera: Rhinotermitidae). J. Econ. Entomol., 85: 2275-2278.

Su, N.Y., P.M. Ban and R.H. Scheffrahn, 1993. Foraging populations and territories of the Eastern subterranean termite (Isoptera: Rhinotermitidae) in Southeastern Florida. Environ. Entomol., 22: 1113-1117.

Su, N.Y., J.D. Thomas and R.H. Scheffrahn, 1998. Elimination of subterranean termite populations from the Statue of Liberty National Monument using a bait matrix containing an insect growth regulator, hexaflumuron. J. Am Inst. Conserv., 37: 282-292.

Su, N.Y., P.M. Ban and R.H. Scheffrahn, 2004. Polyethylene barrier impregnated with lambda-cyhalothrin for exclusion of subterranean termites (Isoptera: Rhinotermitidae) from structures. J. Econ. Entomol., 97: 570-574.

Swoboda, L.E. and D.M. Miller, 2004. Laboratory assays evaluate the influence of physical guidelines on subterranean termite (Isoptera: Rhinotermitidae) tunneling, bait discovery and consumption. J. Econ. Entomol., 97: 1404-1412.

Tai, O.S. and F. Chen, 2002. A Course of Termite Control. Science Press, Guangdong, China.

Takahashi, M and T. Yoshimura, 2002. Recent development in the control of Japanese subterranean termites. Sociobiology, 40: 13-24.

Theraulaz, G., J. Gautrais, S. Camazine and J.L. Deneubourg, 2003. The formation of spatial patterns in social insects: From simple behaviours to complex structures. Philos. Trans. R. Soc. London A, 361: 1263-1282.

Trudeau, D., 1989. Selection of entomophilic nematodes for control of the eastern subterranean termite, *Reticulitermes flavipes* (Kollar) (Isoptera: Rhinotermitidae). Master's Thesis, University of Toronto, Toronto, Ontario, Canada.

Vargo, E.L., C. Husseneder and J.K. Grace, 2003. Colony and population genetic structure of the Formosan subterranean termite, *Coptotermes formosanus*, in Japan. Mol. Ecol., 12: 2599-2608.

Verkerk, R.H.J. and A.F. Bravery, 2001. The UK termite eradication programme: Justification and implementation. Sociobiology, 37: 351-360.

Verma, M., S. Sharma and R. Prasad, 2009. Biological alternatives for termite control: A review. Int. Biodeterior. Biodegrad., 63: 959-972.

Wege, P.J., W.D. McClellan, A.F. Bywater and M.A. Hoppe, 2003. IMPASSE termite barrier: New pre-construction termite barrier technology. Sociobiology, 41: 169-176.

Wilson, E.O., 1971. The Insect Societies. Belknap Press of Harvard University, Cambridge. ISBN: 9780674454958, Pages: 548.

Yeoh, B.H. and C.Y. Lee, 2007. Tunneling activity, wood consumption and survivorship of *Coptotermes gestroi*, *Coptotermes curvignathus* and *Coptotermes kalshoveni* (Isoptera: Rhinotermitidae) in the laboratory. Sociobiology, 50: 1087-1096.

Yudin, L., 2002. Termites of Mariana Islands and Philippines, their damage and control. Sociobiology, 40: 71-74.

Zhong, J.H and L.L. Liu, 2002. Termite fauna in China and their economic importance. Sociobiology, 40: 25-32.