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Foraging Populations and Control Strategies of Subterranean Termites in the Urban Environment, with Special Reference to Baiting

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This paper reviews the literature on foraging populations, and control of subterranean termites with special reference to baiting. Studies on foraging populations of subterranean termites generally involved population characterization and estimation of foraging territories. Population characterization was normally conducted using mark-recapture techniques (single or triple) by trapping subterranean termites in underground monitoring stations, followed by marking the insects using histological dyes. Methods of studying foraging territories of subterranean termites involved the use of radio isotopes, direct excavation, histological dyes, flourescent paints and conducting agonistic behavioral experiments. Subterranean termite control strategies included chemical, biological and physical control methods. The soil treatment and baiting methods were common chemical methods, while the use of specific sand or granite particles, and stainless steel mesh are recent advances in physical exclusion method. Baiting is a relatively popular method which takes the advantage of social nature and foraging behaviour of subterranean termites where food sharing among the workers and nestmates through trophallaxis could enable the transfer of slow-acting toxicant to the whole colony. Many potential active ingredients as bait toxicants had been evaluated including metabolic inhibitors, fungi (bioagents) and insect growth regulators (IGRs), but only the latter has been shown to give more promising results and could effect colony elimination.

Key words: Foraging populations, Control strategies, Baiting, Subterranean termites

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Introduction

Termites cause significant building and structural damages worldwide, especially in the tropical and sub-tropical regions (Pearce, 1997). It was estimated that a total of US $ 22 billion were spent each year for termite control and repair cost of damages caused by this group of pests world-wide (Su, 2003 a). In United States alone, the control and repair cost for the damages by subterranean termites reached a total of US $ 2 billion in the year 2000 (Culliney and Grace, 2000). In Malaysia, the cost of termite control was estimated at US $ 10-12 million for year 2003 (Su and Lee, 2003; Lee, 2004), and total repair cost was estimated to be 3-4 times higher.

Coptotermes formosanus Shiraki, *Reticulitermes hesperus* Banks and *R. flavipes* (Kollar) are the three most important subterranean termite species in the U. S. A. (Su and Scheffrahn, 1990). Among these termite species, *C. formosanus* is the predominant one (Culliney and Grace, 2000; Haagsma *et al.*, 1995; Grace and Yamamoto, 1994; Jones *et al.*, 1996; Yates and Tamashiro, 1999). Due to its ferocious feeding behaviour (Su and Tamashiro, 1987), *C. formosanus* is also an important termite pest species in Japan, Taiwan and China. In China, *C. formosanus* was found to attack antiques, furniture, clothing, boats, electrical wiring, forest trees, agricultural crops and water damps (Lin, 1987; Liu *et al.*, 1998). The situation was critical especially in areas which are located in potential earthquake regions. In Taiwan, in addition to causing severe damages to residential premises, this termite species also caused destruction to historical buildings and monuments. One good example is the historic Tzu-Su Temple, which was founded in 1769 in northern Taiwan and it had to be rebuilt in 1947 due to the damages by *C. formosanus* (Su and Hsu, 2003).

In Malaysia, damages caused by subterranean termites were encountered in forestry, agricultural and urban settings (Kirton *et al.* 2000; Kirton and Wong, 2001; Lee, 2002a; 2002b). *C. curvignathus* Holmgren and *Microcerotermes dubius* (Haviland) are known to have killed a variety of tree species in Malaysia (Kirton and Wong, 2001). On the other hand, several species of *Coptotermes* are important pest species in the urban environment to the pest control industry (Lee, 2002a), accounting to more than 90% of total infestation in buildings and structures in a survey conducted in central Peninsular Malaysia. The study also reported that 65 % of the pest control services were provided for infestations in residential premises, 20 % in industrial sectors, 10 % in commercial buildings and 5 % for other locations.

In this paper, we review the literature on foraging populations and various control strategies against subterranean termites in the urban environment, with special reference to baiting.

Foraging populations of subterranean termites

Ecological studies on subterranean termites generally involved three basic aspects: monitoring and trapping; population estimation; and foraging territory (Nutting and Jones, 1990). To achieve these goals, several initiatives can be adopted.

Toilet paper rolls were used as food baits for the trapping of *Gnathamitermes perplexus* (Banks) and *Heterotermes aureus* (Snyder) (Haverty, 1975; La Fage *et al.*, 1973), *H. ferox* (Froggatt), *C. acinaciformis* (Froggatt) and *C. frenchi* Hill (French and Robinson, 1981; Johnson and Whitford, 1975), *Microcerotermes* sp., *Microtermes* sp., *Amitermes* sp. and *Anacanthotermes ochraceus* Burm. (Badawi *et al.*, 1984). However, this method was less desirable for long-term monitoring process because the toilet paper rolls were too sensitive to the wet and dry weather and might be consumed by termites within a relatively short period (Su and Scheffrahn, 1986a). The toilet paper roll method was later modified by using corrugated fiberboard for the trapping of *C. lacteus* (Froggatt) (French and Robinson, 1985); *R. virginicus* (Banks) and *C. formosanus* (La Fage *et al.*, 1983).

Su and Scheffrahn (1986a) subsequently designed an underground trap as a modification from that described earlier by Tamashiro *et al.* (1973). This method had enabled several researches such as population dynamics (Lai, 1977) and foraging behaviour of subterranean termites (Su *et al.*, 1984). Grace (1989) and Grace *et al.* (1989) further modified this method to trap *R. flavipes.*

Foraging population of subterranean termites can be estimated using two methods, i.e. mark-recapture and direct counting. However, none of these methods were absolutely accurate, although mark- recapture is a generally more acceptable method because of its practicality (Nutting and Jones, 1990).

The use of mark-recapture requires the fulfilment of several assumptions (Begon, 1979) such as zero migration, zero mortality and birth and the marked insects must be able to continue to lead a normal life. Two mark-recapture methods have been used intensively to estimate the foraging population of subterranean termites, namely single mark-recapture, and triple mark-recapture techniques. Single mark recapture technique with Lincoln index (Begon, 1979) was used to estimate the foraging populations of *C. formosanus* (Lai, 1977; Su *et al.*, 1984), *Reticulitermes* spp. (Forscheler and Townsend, 1996a; Grace *et al.*, 1989; Thorne *et al.*, 1996), *C. lacteus* and *Nasutitermes exitiosus* (Hill) (Evans *et al.*, 1998), *C. acinaciformis* (Evans *et al.*, 1999) and *Globitermes sulphureus* (Haviland) (Ngee and Lee, 2002). The triple mark-recapture technique using weighted mean method (Begon, 1979) was used to estimate the populations of *C. formosanus* (Su and Scheffrahn, 1988a), *R. flavipes* (Forschler and Townsend, 1996a; Su *et al.*, 1993a), *R. speratus* (Kolbe) (Tsunoda *et al.*, 1999), *C. gestroi* (Wasmann) (Sornnuwat *et al.*, 1996), *C. travians* (Lee, 2002b), *C. curvignathus* (Sajap, 1999), *Microt. pakistanicus* Ahmad (Lee *et al.*, 2003a) and *G. sulphureus* (Haviland) (Lee *et al.*, 2003b).

In addition to foraging populations, it is also crucial to be able to estimate the foraging territories of the subterranean termites. Generally, several methods can be engaged: Lai (1977) pioneered the use of histological dyes to delineate foraging territory of subterranean termites. This method was subsequently adopted by many other researchers (Lai *et al.*, 1983; Su *et al.*, 1983a; 1983b; 1988; 1991a; Grace and Abdallay, 1990; Salih and Logan, 1990; Haagsma and Rust, 1993; Evans, 1997). Spragg and Paton (1980) used radio-isotope to trace the foraging territories of subterranean termites. Other attempts include the use of flourescent paint (Miller, 1993; Forschler, 1994), fumigant (Darlington, 1984), agonistic behaviour of subterranean termites (Jones, 1990a; Pearce *et al.*, 1990) and direct excavation (King and Spink, 1969; Howard *et al.*, 1982).

Subterranean termite control

Termite control often generally emphasized on the control of the subterranean termites because of its more destructive nature than other termite groups (Lee and Chung, 2003). Subterranean termite control involved both preventive as well as curative measures (Su and Tamashiro, 1987; Su and Scheffrahn, 1990).

The fundamental and conventional method of subterranean termite control is to create an impenetrable chemical or non-chemical barrier between soil and building or structure (Su and Scheffrahn, 1998). Soil treatment is referred as the application of a layer of chemical barrier preventing the termites from entering into the building. The withdrawal of chlorinated hydrocarbon soil termiticides (eg. chlordane) had led to numerous extensive research on other potential soil termiticides for subterranean termite control (Su and Scheffrahn, 1990; Smith and Rust, 1991; Grace *et al.*, 1993; Su *et al.*, 1993b; Rust and Smith, 1993; Smith and Rust, 1993a; Thomas *et al.*, 1993; Thomas and Robinson, 1994; Su *et al.*, 1995a; Robinson and Barlow, 1996; Forschler and Townsend, 1996b; Su *et al.*, 1999; Gahlhoff and Koehler, 2001).

Subsequent candidates of soil termiticides after chlorinated hydrocarbon compounds were organophosphates and pyrethroids. Organophophates such as chlorpyrifos generally kill termites quickly upon contact, resulting in a large number of corpses in a localized area. In comparison, pyrethroids are repellents which deter termites from penetrating through treated substrates. Although the mechanism of prevention by organophophates and pyrethroids may differ, both groups provide an effective protection of structures from subterranean termites when properly applied in soil.

A relatively new generation of soil-applied termiticide, imidacloprid posed lethal effects to subterranean termite *R. flavipes* in laboratory (Ramakrishnan *et al.*, 2000). Imidacloprid is an insecticide exhibiting low mammalian toxicity. It acts on the insect nervous system by binding to the acetylcholine binding sites, called nicotinergic receptors, on receiving nerve cells. This mode of action prevents transmission of information at these binding sites, resulting a lasting impairment of the nervous system and eventually, death of the insect. However, a recent study reported by Thorne and Breisch (2001) revealed that certain concentrations of imidacloprid may affect termite foraging behaviour, preventing treated termites from entering the treated area. Another relatively new soil termiticide is fipronil, which was known to allow longer toxicant transmission via allogrooming and termite-termite interaction (Cross *et al.*, 2002).

Su and Scheffrahn (1990) pointed out that the use of chemical for soil treatment around and beneath the buildings tend to kill only a small portion of the termites that get contacted with the termiticides. If the buildings are not properly treated, the remaining large portion of termites will continue to forage and attack the buildings. Besides that, the efficacy of the termiticides are very much affected by environmental factors such as the soil types and their various biotic components (Forschler and Townsend, 1996b; Smith and Rust, 1993a; 1993b; Tamashiro *et al.*, 1987) such as population density of subterranean termite colonies (Jones, 1990b) and the defensive mechanism of subterranean termites (Su, 1982; Grace, 1991). Other factors include types of termiticides used (Su *et al.*, 1993b) and the depth of treatments (Su *et al.*, 1995b).

In addition to chemical treatment, several physical preventive methods were also adopted for subterranean termite control. Ebeling and Pence (1957) first reported the use of selected uniform size sand particles as barrier that could act as physical exclusion device against subterranean termites. During a routine termiticide evaluation, Tamashiro *et al.* (1987) rediscovered the finding of Ebeling and Pence (1957). The use of these uniform sized particles is based on the fact that the particles were too large for termites to displace with their mandibles, yet were small enough to prevent termites from penetrating through the gaps between them (Smith and Rust, 1990; Su *et al.* 1991b; Su and Scheffrahn, 1992). A good example of this physical barrier is the 'Granitgard®' which is currently registered in

Australian market (French *et al.,* 2003). However, the effective particle size depended on the mandible and head capsule dimensions of the target termite species. Therefore, uniform sized particle barriers that successfully prevent one termite species may not prove to be effective against another termite species. Another physical termite exclusion devices involve the use of stainless steel mesh (eg. Termimesh®) (Grace *et al.,* 1996a).

Yamano (1987) demonstrated that alates of *C. formosanus* were attracted to the fluorescent light with wavelength between 400-420 nm. There-fore, light trap with blue fluorescent light is effective in trapping alates. However, this method will play very minimal role as a control measure since majority of alates generally die of natural causes.

For post-construction treatment against subterranean termites, corrective soil treatment and spot treatment by spraying and dusting could be carried out (Lee and Chung, 2003). The infested wooden structures, however will need to be replaced (Su and Scheffrahn, 1990). Arboreal nests and termite mounds could be manually removed, or by using the fumigants such as methyl bromide and sulfuryl flouride (Lin, 1987; Mori, 1987; Su and Scheffrahn, 1986b; Su and Tamashiro, 1987; Osbrink *et al.,* 1987). Thermal pest eradication was discussed by Woodrow and Grace (1998), where the intolerable temperatures of 47.9 ℃ to 51.3 ℃ resulted 99.5 % of termite mortality.

Many researchers also discussed other termite control strategies, but their usages are practically minimal. Culiney and Grace (2000) reviewed the prospect of biological control against subterranean termites. Hanel and Watson (1983) reported the potential use of the pathogenic fungus *Metarhizium anisopliae* (Metschnikoff) for the control of *N. exitiosus.* Fujii (1975) was the first to test on the use of nematode against termites, where he reported an evaluation of an entomogenous nematode, *Neoaplectana carpocapsae* Weiser against Formosan subterranean termites. Mauldin and Beal (1989) studied the potential use of entomogenous nematodes such as *Steinernema feltiae* Filipjev, in preventing or eliminating eastern subterranean termites *R. flavipes.* However, both laboratory and field results were not encouraging. Logan *et al.* (1990) reviewed several non-chemical methods for the control of subterranean termites in agriculture and forestry. These include the use of selected cultural methods, good quality seed, crop rotation, manipulating water stress and others.

Many natural compounds were found to have potential lethal effects on subterranean termites. Some extracted compounds from ants were found to repel subterranean termites (Cornelius and Grace, 1994a; 1994b; Cornelius *et al.,* 1995). Leaf extracts of *Azadirachta excelsa* (Jack) were found to reduce the wood consumption and survival of *C. curvignathus* (Sajap and Aloysius, 2000). Ohmura *et al.* (2000) reported the antifeedant activity of some flavonoids and related compounds against *C. formosanus.*

Subterranean termite control was revolutionized when Dow AgroSciences LLC (formerly known as DowElanco) registered the first termite bait product for subterranean termite control (Su, 1994). Su (1994) was the first to use hexaflumuron as baits in field trials, which lead to the development of Sentricon®. Termite baiting takes the advantage of social nature and foraging behaviour of subterranean termites where food sharing among the workers and nestmates via trophallaxis could enable the transfer of slow-acting toxicant to the whole colony (Lee and Chung, 2003).

Subterranean termite baiting

Subterranean termite control entered an

important turning point when necrophobic behaviour was found in subterranean termite *C. formosanus* in the termiticide treated areas (Su, 1982; Su *et al.*, 1982). The fatty acids from the decomposing subterranean termites were suspected to give cues to other nestmates from getting near the treated areas. In addition, if a soil treatment was not properly done, the remaining large portion of the colony population will continue to seek untreated gaps to enter the buildings. On the contrary, termite bait acts by eliminating or suppressing colony that infest the structures. This reduces the risk of termite re-infestation, unless it is caused by a new colony. Because of its ability to eliminate termite colonies, baiting technology can be a stand-alone measure for long-term protection of structures (Thorne and Forschler, 2000; Grace and Su, 2001).

Su (1982) stressed on the importance of using a slow-acting and non-repellent active ingredient in termite baiting. Basically, there are three groups that meet the requirements of being the appropriate bait toxicant: (i) the metabolic inhibitors, (ii) biological control agents, and (iii) insect growth regulators (IGRs). Su *et al.* (1982) revealed that the evaluation of bait toxicants could not be based on termite mortality alone; the behavioural responses of the termites to the insecticides also had to be considered. This is because termites can seal off, or avoid treated areas and effectively protect themselves.

i) **Metabolic inhibitors**

Su *et al.* (1982) tested the possibility of using hydramethylnon for the control of subterranean termites *C. formosanus* in the laboratory. Hydramethylnon was found to be slow acting and non-repellent to the termites. However, field trial with hydramethylnon failed to eliminate colonies of *C. formosanus* (Su, 1982). Recently, the use of 0.3 % hydramethylnon in termite bait (Subterfuge®) was reported to provide delayed mortality that allows transfer of lethal doses within the termite population, followed by a relatively rapid elimination of the termites (Klein, 2002).

Jones (1991) was the first to evaluate borate in baits for population control of field colonies of *H. aureus*. Subsequently, case studies by Forschler (1996) using abamectin and zinc borate-treated sawdust revealed the potential use of these toxicants against subterranean termites *Reticulitermes* sp. in the field. Results reported by Forschler, despite being inconsistent, showed changes of foraging behaviour of termites which indicated that borate-based toxicants had some impacts on the termite colonies.

Su and Scheffrahn (1991) and Su *et al.* (1995b) tested the sulfluramid (N-ethylperfluoro-octane-1-sulfonamide) (FirstLine® and Terminate®) and found that wooden boards impregnated with sulfluramid at higher concentration were initially accepted by termites, but were later avoided in the presence of untreated food sources. They also found that the termites' learning behaviour played an important role in bait evaluation studies. Subterranean termites that were initially exposed to sulfluramid at a higher concentration was later deterred from the food treated with lower concentration of sulfluramid. Grace *et al.* (2000) reported that sulfluramid at the concentration of less than 100 ppm may be desirable and effective against *C. formosanus*, but the time needed for termites to accumulate the lethal dose is crucial.

Other potential toxicants of this group include diiodomethyl para-toly sulfone (Su and Scheffrahn, 1988b) and boric acid (Mori, 1987).

ii) **Fungi (bioagent)**

The possible usage of pathogenic fungi in baits to control Formosan subterranean termite *C. formosanus* was pioneered by Lai (1977) and had been discussed by Delate *et al.* (1995) and Jones *et al.* (1996). However, the conidia of the fungus were found to have in dormant stage in field colonies which likely due to temperature, humidity, inhibition by soil microorganisms and fungistatic secretions produced by termites.

A more successful case of using pathogenic fungus in the termite baiting system was reported by Milner (2001) where the formulated *M. anisopliae* bait matrix caused *N. exitiosus* to loss their reproductives and brood and this caused gradual decline of the colony.

iii) Insect growth regulators (IGRs)

Insect growth regulators have attracted great attention as promising bait toxicants. These active ingredients were known to have interfered with the normal developmental processes of insect growth. They induced abnormal physiological development stages which led to defective larvae, pupae or adults either through molt inhibition or hormonal superimpositions of the normal endocrinal control of the development (Palleske, 1997).

Researchers have also taken advantage of several aspects of termite biology to control subterranean termites using various types of potential IGRs. There are generally two classes of IGRs, namely juvenoids (juvenile hormone analogues [JHA] and juvenile hormone mimics [JHM]) and chitin synthesis inhibitors (CSI) (Su and Scheffrahn, 2000).

Subterranean termite colonies are known to rely solely on the worker caste for food (Haverty, 1977) and the excessive production of dependent castes such as soldiers and pre-soldiers causes colony imbalance (Hrdy and Krecek, 1972; Okot-kotber, 1980). Also, the subterranean termites, especially those from the lower group are known to have pseudergates or false workers in their colony, which can readily moult to another caste (Miller, 1969). Consequently, specific IGRs were studied for the above mentioned aspects.

Hrdy and Krecek (1972) and Hrdy *et al.* (1978) reported that by exposing subterranean termites such as *R. lucifugus santonensis* Feyt. to three JHAs, trans,cis-methyl 10-epoxy-3,7,11-trimethyl-2,6 tridecadienoate, methyl 10-chloro-3,7,11-trimethyl-2 dodecenoate and 10-epoxy-3,7,11-trimethyl-2,6-dodecadienoate, these JHAs caused superfluous number of pre-soldiers and / or pseudergate-soldier intercastes from the differentiation of larvae and pseudergates. Such disturbance to the normal proportion of colony castes can lead to increased mortality. The effects of JHA (ethyl [2-(p-phenoxy phenoxy) ethyl carbamate) on developmental stages of workers and nymphs of Japanese *R. speratus* were also reported by Doki *et al.* (1984), and Tsunoda *et al.* (1986).

Effects of methoprene were studied by Haverty and Howard (1979), Howard (1983), Su *et al.* (1985) and Haverty *et al.* (1989) against subterranean termite species *C. formosanus* and *Reticulitermes* spp. This JHA was found to induce large numbers of pre-soldiers and soldiers. This compound was also found to cause significant mortality to the termites by eliminating their symbiotic protozoan or causing ecdysis failure. However, the efficacy of methoprene was influenced by its concentration used and probably, the termite species as well. Another IGR that induced the formation of pre-soldiers and had lethal properties is pyriproxyfen or 2-[1-methyl-2(4-phen-oxyphenoxy) ethoxy] pyri-dine (Su and Scheffrahn, 1989).

Fenoxycarb impregnated in bait blocks was found to cause significant superfluous intercaste production without affecting the feeding behaviour of *C. formosanus* and *R. virginicus* (Jones, 1984). This compound also caused the larvae, workers, nymphs and alates of *R. virginicus* of this termite species to develop morphological abnormalities. However, differences in food substrate altered the development of *C. formosanus* intercaste.

Besides JHA, CSIs are also known to cause an impact on insect developmental processes. The family of benzoyl urea insecticides acts on the chitin synthesis, which is restricted to arthropods (Pallaske, 1997); in another words, as moulting inhibitors or more specifically, disrupt the synthesis and deposit of chitin. This was achieved by inhibiting the function of the moulting enzyme called UDP-N-AG-Polymerase (chitin polymerase or chitin synthetase) or chitin-matrix for deposition. Examples of CSIs include diflubenzuron, lufenuron and hexaflumuron (Su and Scheffrahn, 1993; 1996). Hexaflumuron at the concentration of 0.5 % (w / w) is currently a registered active ingredient in a bait product for subterranean termite control in many parts of the world.

Field performance of hexaflumuron bait against subterranean termites, particularly *Coptotermes* and *Reticulitermes*, had been studied and reported by many researchers world-wide (Su, 1994; Grace *et al.*, 1996b; Su *et al.*, 1997; Tsunoda *et al.*, 1998; Demark and Thomas, 2000; Yates and Grace, 2000 ; Getty *et al.*, 2000; Sajap *et al.*, 2000; Potter *et al.*, 2001; Kistner and Sbragia, 2001; Lee, 2002a; 2002b ; Su and Hsu, 2003). Almost all researchers reported elimination of termite colonies by hexaflumuron baits which can be achieved at a minimum of 25 days in the tropics. For a more complete list of the effects of hexaflumuron against subterranean termites, readers are urged to refer to Su (2003b).

Recently, a new chitin synthesis inhibitor, noviflumuron, [N{((3,5-dichloro-2-fluoro-4 (1,1,2, 3,3,3-hexafluoropropoxy)phenyl)amino)carbonyl}-2,6-difluorobenzamide] has been tested for its potential as a bait toxicant (Smith *et al.*, 2002). This CSI was found to show faster activity than that of hexaflumuron and with a broader spectrum of control particularly against cockroaches, fleas, ants, drywood and subterranean termites and houseflies (Ameen *et al.*, 2002; DeMark, 2002; Suiter, 2002).

The increasing availability of bait systems for the control of active termite infestations is already significantly affecting termite management practices in many parts of the world (Lenz and Evans, 2002). Therefore, more changes to existing termite bait technology are anticipated in future.

Two considerations should be given priority when designing a bait matrix i. e. the quality and the quantity of matrix (Lenz and Evans, 2002). Smythe and Carter (1970) and Morales-Ramos and Rojas (2001) also pointed out the important of relationship between wood species and termite wood preference. Subterranean termites show different feeding responses when exposed to various types of wood and wood extractives within the wood (Carter, 1979; Carter and Beal, 1982; Carter *et al.*, 1983; Su and Tamashiro, 1986; Waller, 1989; Sornnuwat *et al.*, 1995; Ngee *et al.*, 2004). Smythe *et al.* (1971) showed that *R. flavipes* attacked two times more on the wood decayed by fungus. When presented with choice, subterranean termites readily attack certain wood more than others (Edwards and Mill, 1986). The applicability of stream-treated larch wood (*Larix leptolepis*) as bait matrix against two Japanese subterranean termites has also been explored (Doi *et al.*, 1998; 1999) and is now commercialized in a bait system in Japan.

The general objective of the termite bait matrix, in addition to consideration of huge production and cost reduction, is to formulate a bait matrix that is effective against all termite species (Lenz and Evans, 2002). However, this is always difficult to achieve due to biological variations with different termite species. For example, Lee (2002a; 2002b) reported the poor response of several secondary termite pest species (eg. *Macrotermes gilvus* Hagen, *G. sulphureus, Microt. pakistanicus*) to paper-based termite bait matrix in Malaysia. Therefore, there have been some efforts to enhance the palatability and attractiveness of bait matrix by adding in the phagostimulants or nutritional supplements (Henderson *et al.,* 1994; Reinhard *et al.,* 2002).

Waller and La Fage (1987) reported that in the presence of rich food supply, termite food consumption was found to increase in comparison with normal situations. However, the food quantity may not necessary reflect the bait system (Lenz and Evans, 2002). An alternative way of doing this is to use more bait stations, instead of using one that contains large volume or capacity of matrix. Furthermore, the degree of influences resulted from either the quality or quantity of the bait matrix on bait acceptance need to be determined, as well as the suitability and ease in handling the system in real situations.

Future research directions

There has been extremely limited biological information on the foraging populations and territories of many termite pest species, particularly peridomestic species from lower (*Schedorhinotermes*) and higher termite groups from the tropics such as *Macrotermes, Microtermes, Microcerotermes, Odontotermes* and *Globitermes.* Numerous opportunity lies ahead for termite researchers to explore these aspects of termite biology. Foraging population and territory of introduced species such as *C. formosanus* was often thought to be larger than those in their native land; however, no information is available to-date. Newer control strategies against subterranean termites have been relatively promising than before; however, there is a serious need to address the issue of lack of palatability of bait matrices against many higher termite species. It was also thought that chitin synthesis inhibitor could not possibly eliminate higher termite colonies due to the large number of true (adult) workers; however, this was yet to be proven and thus promises a great opportunity for research.

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