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IMPROVED MANAGEMENT OF TERMITES TO PROTECT JAPANESE HOMES

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Abstract Termites are considered to be urban pests in Japan, which has a long history of combating the two most economically important subterranean termites [*Reticulitermes speratus* (Kolbe) and *Coptotermes formosanus* Shiraki], since Japanese houses are made principally of wood. Approximately half of new homes are still being built using wood-frame construction. Apart from treatment of the soil and lumber with more environmentally benign termiticides, information on the ecology of Japanese termites, coupled with experience, may be helpful for the development of a new termite management technology. Recent experimental studies by Japanese scientists have produced some interesting evidence: (1) the population size of *R. speratus* is much larger than previous estimates, (2) intestinal protozoa play specific roles in the supply of nutrition to *C. formosanus*, (3) cellulase excreted by termites themselves participates in wood decomposition, (4) colony recognition mediated by intestinal bacteria and colony fusion may occur in *R. speratus*, (5) a symbiotic sclerotium-forming fungus helps to protect termite eggs from natural enemies, (6) *C. formosanus* and *R. speratus* differ with regard to their requirements for water, (7) a baiting system may be useful for controlling infestations of both *C. formosanus* and *R. speratus*, (8) termites show higher penetrating activity in soil rich in available phosphate, organic matter and humic substances, and (9) timber that is categorized as durable (resistant against termites), is not as durable if it was grown on a plantation. These findings may be linked to the development of an integrated termite management (ITM) approach. For example, protozoicides and bactericides may be useful for controlling termite infestations if the termites could be induced to ingest them and deliver them to their nestmates through grooming and trophallaxis. A bating system can contribute to the reduced use of chemicals when used consistent with the characteristic foraging dynamics of the target termite species, which results in less environmental impact. This review describes the possibility of new approaches to termite prevention and control with an emphasis on the situation in Japan.
Key Words Termite management, grooming, trophallaxis, baiting system, *Coptotermes formosanus*, *Reticulitermes speratus*

INTRODUCTION

A survey of the literature showed that termites were first described in Japan in the 9th century (JTCA, 1998). Twenty-one species are currently distributed in Japan (Morimoto, 2000; Takematsu, 2000). With an increase in the urban population, termites have become a serious threat to wooden houses and structures, and cause considerable economic damage. It is estimated that roughly US$0.8-1.0 billion per year is used to prevent and control termite infestations, based on the sales of termiticides in 1996 (Fushiki, 1998; Tsunoda, 2003). The two most economically important subterranean termites, *Reticulitermes speratus* and *Coptotermes formosanus*, are thought to account for almost all of these costs in Japan. Other Japanese termites are not considered to be economically important as either urban or forest/ agricultural pests.

Conventional preventive and control methods are heavily dependent on the use of chemicals. Chlordane, which was once the most widely applied persistent organic pesticide for termite management in the world, was actually banned in Japan in 1986. Alternative termiticides have appeared in the market, and presently imidacloprid, bifenthrin, permethrin, fenobucarb, chlorfenapyr and others account for about half of market share. Termite-proof plastic sheeting is used to prevent subterranean termites from invading the crawlspace of houses. Recently, a physical barrier system was introduced and commercialized. In addition, the concept of integrated termite management (ITM) has gradually been catching the interest of termite professionals. However, as in other countries, it has not been well accepted in Japan.

The purpose of this paper is to review the results of recent research in Japan and to discuss their applicability to the development of a new termite management technology.

New and Environmentally Benign Approaches to Termite Management

Limited ecological and physiological information has contributed to the recent development of new, environmentally sound termite management technology (Table 1). Baiting systems and physical barriers are widely accepted in some countries and are thought to form the foundation for ITM. This is also true in Japan. Although the entomogenous fungus *Beauveria brongniartii* (Saccardo) Petch was shown to kill individual *C. formosanus* termites in the laboratory (Yoshimura and Takahashi, 1998), biological control is not widely commercialized in Japan because its termiticidal efficacy has not yet been demonstrated in the field. I will now briefly discuss the potential of recent scientific findings in Japan to lead new approaches to termite management.

Table 1. Application of scientific information to the development of new termite management technologies

Ecological/physiological characteristics	Application	Commer-cialization
Trophallaxis	Bait system	**
Grooming	Treatment of soil with non-repellent insecticides Biological control by pathogens	**
Symbiotic intestinal microorganisms	Protozoicides and bactericides	X
Cellulase excretion	Chemical disturbance of enzyme activity	X
Caste differentiation	Disturbance of caste system by JHA’s	X
Colony protection mechanism	Biological control by pathogens and chemical control	X
Colony and nestmate recognition mechanism	Biological and/or chemical disturbance of communication signals among termite individuals	X
Colony fusion	Disturbance of caste system by chemicals such as JHA’s	X
Difference in water requirement among termite species	Construction design to regulate the conditions of access pathways	X
Foraging dynamics (colony mobility)	Physical barriers using stainless steel, gravel, etc.	*
Symbiotic microorganisms (termite ball) other than those in the termite gut	Chemical and/or biological control to circulate toxins among colony members	X

** widely commercialized, * partly commercialized, **X** : not commercialized

Bait System

The success of baiting is strongly dependent on how many termite foragers visit the monitoring station where they are supposed to take bait when food in the monitoring station is replaced by bait containing a slow-acting toxin. Since this system has been shown to be effective at suppressing the foraging population of *C. formosanus*, bait systems have been widely commercialized in southern parts of Japan. Nest excavation also supports the applicability of a bait program to the elimination of colonies of this termite species (Yamauchi et al., 1997, 1998; Tsunoda et al., 2001). However, unsatisfactory results are seen with *Reticulitermes speratus*, possibly because they differ from *C. formosanus* with regard to foraging aggressiveness and dynamics. The foraging behavior of *R. speratus* is so complicated that it is not easy to determine their foraging territory and to estimate the size of the population (Wang et al., 2000). Apparently, it takes a while for *R. speratus* to return to monitoring stations (traps) once they are disturbed, such as by removing wood bait stakes, replacing them or moving an entire assembled monitoring station (Tsunoda et al., 1998, 1999; Wang et al., 2000). These findings suggest that careful attention is needed for the successful suppression of foraging activity and elimination of colonies of *R. speratus*.

Colony Recognition in *R. speratus*

Although the mechanism of colony and nestmate recognition in termites is not fully understood, it is now believed that colony odor is the key factor because of its colony specificity. However, no single hypothesis can account for the ability of termites to distinguish nestmates and colony from others (Matsuura, 1999). Since it is thought that the composition of intestinal bacteria in *R. speratus* varies among colonies due to differences in environmental factors, it is possible that the composition of intestinal bacteria is at least a partial cue for nestmate recognition in this species. In addition, termite feces contain bacterial products that reflect the composition of intestinal bacteria, and these substances certainly spread among nestmates through body-body contact. Experiments were conducted to explore the above possibilities. Ten bacteria were isolated from 9 colonies of *R. speratus* based on color, shape and size. The composition of intestinal bacteria was so highly colony-specific that termite individuals treated with an unfamiliar water-soluble odor prepared from bacteria of another colony were strongly attacked by their nestmates. Furthermore, when the composition of intestinal bacteria was artificially modified with antibiotics, nestmate recognition behavior was changed. These results indicate that the composition of intestinal bacteria is an important factor in nestmate recognition (Matsuura, 2001), and also suggest that bacterial odor infection may be useful for suppressing a target colony. Further investigations are needed to elucidate the practical application of this idea to termite management.

Symbiotic Fungal Mimic in *R. speratus*

Matsuura et al. (2000) found small brown balls (termite balls) in the piles of eggs of *R. speratus*, and subsequent rDNA analysis revealed that these were sclerotia of the fungus *Fibularhizoctonia* sp. The sclerotia were similar in size but different in shape and color from eggs. Interestingly, termites had carried these termite balls, which had diameters similar to the short diameter of eggs, to the piles of eggs. These phenomena may be useful in termite management because termites may carry dummy eggs that have been surface-treated with chemicals originating from termite eggs and bioactive chemicals toxic to termites, and thus toxins could be subsequently transferred to uninfected nestmates. A patent on the use of dummy eggs as a pest control measure is currently pending (Matsuura, 2000a). Since sclerotium-forming fungi are present in termite colonies throughout Japan (Matsuura, 2000b), this method is worth evaluating in the field.

Disturbance of Intestinal Symbiotic Microbiota in *C. formosanus*

The different parts of termite digestive tract including the foregut, midgut and hindgut, have different roles, and the hindgut is thought to play the most important role in wood decomposition by workers of *C. formosanus* (Yoshimura et al., 1995). Yoshimura et al. (1996) also demonstrated that three kinds of protozoa in the hindgut play different roles in the ingestion and decomposition of cellulose materials as evidenced by microscopic observations. Two larger protozoa (*Pseudotrichonympha grassi* Koidzumi and *Hodomastigotoides hartmanni* Koidzumi) ingest most of the wood and cellulose fragments, and cellulose is decomposed into water-soluble materials by the enzymatic function of protozoan fauna. These findings clearly support the significance of protozoan symbionts in the decomposition of wood by workers of *C. formosanus*. Thus, it is reasonable to suggest that the elimination of protozoan fauna in the hindgut could cause termites to die, since they cannot use wood as a food source without the aid of protozoa. *P. grassi*-defaunated termite workers do not consume as much wood as normal workers. However, the wood-attacking activity of defaunated workers quickly recovered upon co-feeding with freshly collected workers. Wood-attacking activity did not recover upon co-feeding in workers that were subjected to complete defaunation (Yoshimura et al., 1993/1994). Although the application of protozoicides might be an option for termite management, there are as yet no commercial applications. The use of bactericides for *R. speratus* has also not yet been commercialized. There are several reasons why these chemicals are not used more widely: the lack of a method to efficiently treat sound termite individuals with protozoicides or bactericides, the lack of knowledge about the possibility of secondary and tertiary effects after the initial application of the chemicals, side-effects of such chemical treatment on other organisms, and so on.

Water Dependence

The water dependence (defined as the tolerance to desiccation) of the two major Japanese subterranean termites, *R. speratus* and *C. formosanus*, was examined. When the body water contents fell to half of the original (normal) level, workers from both species died. However, under conditions of 25ºC and 70% RH, *C. formosanus* survived twice as longer as *R. speratus* (Nakayama et al., 2004a). Subsequent experiments at 9 temperature-RH combinations showed a similar difference in water dependence between the two termite species (Nakayama et al., 2004c). Based on the recovery from desiccation, a longer treatment resulted in the serious decrease in the survival rates of both termite species. *C. formosanus* was more tolerant to desiccation than *R. speratus* when test termites were returned to a container with a water supply before they sustained serious damage (Nakayama et al., 2004b). These findings suggest that regulation of the ambient environment might be more effective against *R. speratus*, and that controlling the relative humidity in the crawlspace of a Japanese house may be useful for suppressing access by these termite species. This approach should also help to suppress decay in Japanese houses. Damp-proofing and -regulating materials in the crawlspace are well accepted in modern Japanese houses.

Contact Poisoning With Non-Repellent Termiticides

Non-repellent termiticides such as imidacloprid, silafluofen, chlorfenapyr and fipronil have been commercialized in some countries because of their relatively low impact on the environment and mammals. In most cases, these replace conventional organophosphates and synthetic pyrethroids. When they are used in a traditional manner, such as soil-poisoning agents, no additional beneficial effects are expected. As with a bait program, small amounts of termiticides should be used and residual termiticides must be recovered and recycled after the termination of termite management. We might be able to apply termite ecological behavior, e.g., grooming instead of trophallaxis in a bait system, in the next generation of termite management. An example of such an application is shown below (Figure 1).

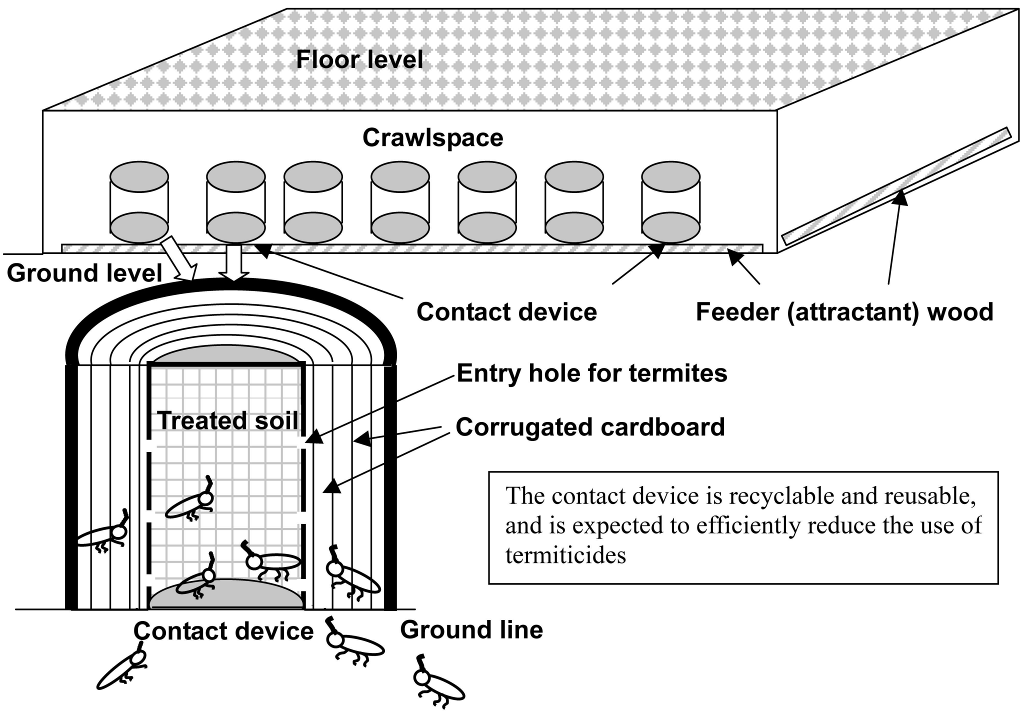

Figure 1. Potential application of non-repellent termiticides

Construction Design to Improve Conditions in the Crawlspace

Since this subject has already been reviewed elsewhere (Tsunoda 2003; Tsunoda and Yoshimura 2004), a detailed description is omitted here. An on-ground 15 cm-thick concrete slab under the floor, damp-proof plastic sheeting with or without termiticide(s) and heat insulation materials are commonly used in modern Japanese houses to protect them from biological attack and to reduce energy consumption, especially during the winter months in northern regions.

CONCLUSION

Current termite management throughout most of the world, including Japan, is heavily dependent on the use of termiticides. There has been some interest in Japan in the use of stainless steel mesh as a physical measure, in addition to the application of termite-proof devices, such as plastic and metal floor posts, metal termite shields, etc. Since the lumber components of houses are exposed to the risk of termite infestation, it is also important to consider protecting the lumber itself. Most of lumber components are situated above ground (not in direct contact with soil) and protected from the weather, and both fixed and unfixed wood preservatives can be used in the preservative impregnation treatment of housing lumber. In conclusion, combined approaches (ITM) are strongly recommended to achieve termite management in the urban environment.

REFERENCES CITED

Fushiki, S. 1998. Report of the inquiry on termite preventive treatment. Shiroari (Termite) 112: 32-38 (in Japanese).

Japanese Termite Control Association. 1998. Memorial publication for the celebration of the 40th anniversary of establishment of the association. 239 pp., JTCA (Tokyo) (in Japanese).

Matsuura, K. 1999. A review of studies on the mechanism of nest-mate recognition in termites. Jpn. J. Ecology 49: 175-182 (in Japanese).

Matsuura, K. 2000a. Pest control using mimic eggs to be carried by target pests. Tokkai (Patent open to the public) 2000-342149.

Matsuura, K. 2000b. Symbiosis between the Japanese subterranean termite *Reticulitermes speratus* and the sclerotium-forming fungus *Fibularhizoctonia* sp. nov. Insectarium 37: 264-269.

Matsuura, K. 2001. Nestmate recognition mediated by intestinal bacteria in a termite. *Reticulitermes speratus*. Oikos 92: 20-26.

Matsuura, K., Tananka, C. and Nishida, T. 2000. Symbiosis of a termite and a sclerotium-forming fungus: Sclerotia mimic termite eggs. Ecological Research 15: 405-414.

Morimoto, K. 2000. Ecology of termites and damage caused by termites, In: Fundamental Knowledge on Decay and Termite Control Executions, JTCA (Tokyo) (in Japanese), pp 11-34.

Nakayama, T., Yoshimura, T. and Imamura, Y. 2004a. Effects of desiccation treatment on Japanese subterranean termites, *Reticulitermes speratus* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae), from desiccation treatment. Sociobiology 43: 477-487.

Nakayama, T., Yoshimura, T. and Imamura, Y. 2004b. Recovery of Japanese subterranean termites, *Reticulitermes speratus* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology 43: 489-499.

Nakayama, T., Yoshimura, T. and Imamura, Y. 2004c. Effects of desiccation process on survival and food consumption of Japanese subterranean termites, *Reticulitermes speratus* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology 44: 127-138.

Takematsu, Y. 2000. Termites in the world and Japan. In, Imamura, Y., K. Tsunoda and T. Yoshimura (eds.). Housing and Termites, Kaiseisha (Ohtsu, Shiga, Japan), pp 57-66 (in Japanese).

Tsunoda, K. 2003. Economic importance of Formosan termite and control practices in Japan. Sociobiology 41: 27-36.

Tsunoda, K., Hikawa, Y. and Yoshimura, T. 2001. Efficacy of hexaflumuron as a bait-toxicant in the field using a transferred nest of *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology 37: 261-263.

Tsunoda, K., Matsuoka, H. and Yoshimura, T. 1998. Colony elimination of *Reticulitermes speratus* (Isoptera: Rhinotermitidae) by bait application and the effect on foraging territory. J. Econ. Entomol. 91: 1383-1386.

Tsunoda, K., Matsuoka, H., Yoshimura, T. and Tokoro, M. 1999. Foraging populations and territories of *Reticulitermes speratus* (Isoptera: Rhinotermitidae). J. Econ. Entomol. 92: 604-609.

Tsunoda, K. and Yoshimura, T. 2004. Current termite management in Japan. Proc. 1st Conference of Pacific Rim Termite Research Group, March 8-9, 2004, Penang, Malaysia, pp 1-5.

Wang, J., Ohtani, Y. and Sameshima, K. 2000. Study on basic biology of *Reticulitermes speratus* (Kolbe) with both field and laboratory trials in Kochi. Proc. 3rd International Wood Science Symposium, November 1-2, 2000, Uji, Kyoto, Japan, pp167-172.

Yamauchi, K., Ishikura, H., Otake, J. Maeda, I. Kashihara, A. and Uechi, K. 1997. Field evaluation of the Sentricon system – Confirmation of colony elimination. Shiroari (Termite) 110: 2-7 (in Japanese).

Yamauchi, K., Otake, J. and Ishikura, H. 1998. Termite control technology in the new era – Termite colony elimination by the Sentricon system. House and Household Insect Pests 20: 17-24 (in Japanese).

Yoshimura, T., Azuma, J., Tsunoda, K. and Takahashi, M. 1993/1994. Changes of wood-attacking activity of the lower termite, *Coptotermes formosanus* Shiraki in defaunation-refaunation process of the intestinal protozoa. Material und Organismen 28: 153-164.

Yoshimura, T., Fujino, T, Ito, T., Tsunoda, K. and Takahashi, M. 1996. Ingestion and decomposition of wood and cellulose by the protozoa in the hindgut of *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae) as evidenced bipolarizing and transmission electron microscopy. Holzforschung 50: 99-104.

Yoshimura, T., Imamura, Y., Tsunoda, K. and Takahashi, M. 1995. Biodegradation of wood fragments in the digestive tube of *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). Holzforschung 49: 385-388.

Yoshimura, T. and Takahashi, M. 1998. Termiticidal performance of an entomogenous fungus, *Beauveria brongniartii* (Saccardo) Petch. Jpn. J. Environ. Entomol. Zool. 9: 16-22.