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ORIGINAL ARTICLE

Yuliati Indrayani · Tsuyoshi Yoshimura · Yuji Imamura

A novel control strategy for dry-wood termite *Incisitermes minor* infestation using a bait system

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Abstract Three types of experiments were designed to evaluate the performance of a bait system intended to control *Incisitermes minor* (Hagen). In the first type of experiment, Type I, the effectiveness of the bait in a small wood specimen was evaluated. In the second type, Type II, the bait effectiveness was evaluated in a larger wood specimen. Feeding arena lumber with artificial galleries was prepared for the Type III experiment so that the response of the insects to the gel could be observed. In general, the average percentage of termites that died after being exposed to the gel formulation in all three types of experiment was more than 60%, and in the gel control the average percentage of live termites was more than 95% in Types I and III, and more than 75% in Type II. These results suggest that the gel bait system used in this study has the potential to eliminate *I. minor* colonies. Further investigation will be necessary to increase the reliability of the bait system as a control measure against dry-wood termites.

Key words Control strategy · Bait system · Dry-wood termite · *Incisitermes minor* (Hagen)

Introduction

Dry-wood termites establish their colonies in nondecayed wood that contains little moisture, and, unlike subterranean termites, they never need contact with the ground. The first evidence of dry-wood termite infestations is usually piles of fecal pellets below "kickout" holes in the infested wood. Infestation by dry-wood termites is difficult to detect, because the termites usually leave a thin layer under the surface of the attacked wood.

Y. Indrayani (✉) · T. Yoshimura · Y. Imamura
Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
Tel. +81-774-38-3663; Fax +81-0774-38-3664
e-mail: mandaupermai@yahoo.com

Chemical treatment with a liquid formulation has been widely used to prevent the infestation of dry-wood termites in buildings. However, such chemical treatments are problematic due to health and environmental considerations. Therefore, it is important to develop remedial treatments that do not pose environmental hazards. Whole-structure treatments such as heat treatment, and local remedial treatments such as use of microwaves, electrocution, screening, caulking, and painting have been developed as dry-wood termite control measures that use fewer or no chemicals.[1,2]

In recent years, the introduction of bait systems that use fewer chemicals to the methods of subterranean termite control have helped us to develop new strategies for eliminating colonies of dry-wood termites.[3–10] *Incisitermes minor* (Hagen), which is known as the western dry-wood termite, is a serious pest in the United States.[11] A colony of *I. minor* may contain 2000 termites and may live entirely within sound dry wood.[12] The development of such colonies is slow, and they are found in both natural and artificial environments.[11] This study was conducted to develop a control strategy for dry-wood termite *I. minor* infestation using a bait system.

Materials and methods

Termites

As test organisms, pseudergates of *Incisitermes minor* were collected from infested timbers in Yokohama City, Kanagawa Prefecture, Japan. The termites were than extracted from the timbers and kept in plastic containers with lids containing small wood blocks of Douglas fir (*Pseudotsuga menzietti* Franco) as both a food source and harborage. The containers with the termites were kept in a termite culturing room of the Research Institute for Sustainable Humanosphere (RISH), Kyoto University, at 28° ± 2°C with relative humidity (RH) greater than 85% in darkness for at least 1 week before testing to ensure that only healthy termites would be used in the experiment.

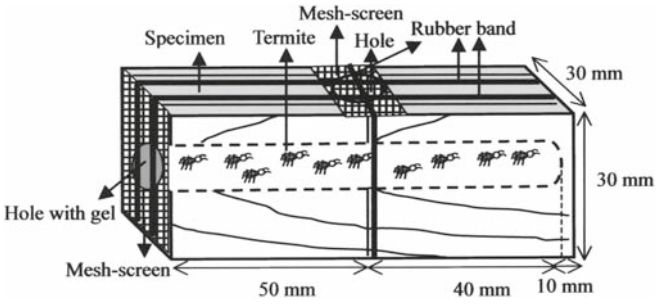

Fig. 1. Type I test apparatus for the testing of a bait system against *Incisitermes minor*

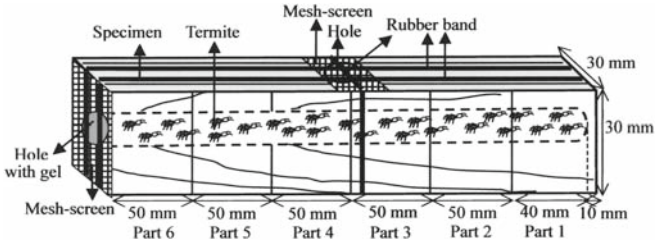

Fig. 2. Type II test apparatus for the testing of a bait system against *I. minor*

Sample preparation

Three types of experiments were carried out in the current investigation. In the first type, known as Type I, a pair of air-dried sapwood specimens of spruce (*Picea abies* Karst.), measuring 30 (R) × 30 (T) × 50 mm (L), were used. In our previous wood-feeding preference study, spruce sapwood was the most preferred species among the ten wood species investigated.[13] A hole, measuring 50 mm deep and 10 mm in diameter, was drilled in the center of a specimen to accommodate the termites. Another hole, measuring 40 mm deep and 10 mm in diameter, was also drilled in the center of the other specimen. These two specimens were glued together, and a hole, measuring 15 mm deep and 10 mm in diameter, was then drilled in the center of the top surface of the combined specimen for the termites to be placed inside (Fig. 1).

In the second type of experiment, known as Type II, the sample preparation was similar to that described for Type I except for the number of specimens for each set (six specimens) (Fig. 2). In the third type of experiment, known as Type III, a feeding arena was prepared with spruce sapwood lumber [200 (R) × 20 (T) × 300 mm (L)]. Artificial galleries were then drilled as shown in Fig. 3. The width and depth of the galleries were 10 mm and 5 mm, respectively.

Gel formulation

A gel formulation with an active ingredient (2.15% hydromethylon) and food attractants was used for the testing (Types I, II, and III). For the control in Type I, we used a commercial gel product for horticultural plantations. The gel control was dipped in distilled water for approximately 4 h before the experiment. Gels without an active ingredient were employed as the controls in Type II and III tests.

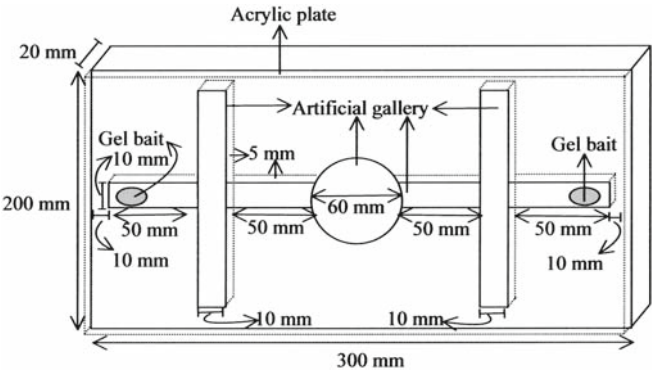

Fig. 3. Type III test apparatus for the testing of a bait system against *I. minor*

Bioassays

A gel formulation (0.4 g) was put into the hole drilled in the side of the specimen for the Type I and Type II experiments. The hole was covered with a fine mesh screen that was tightly attached using two rubber bands to prevent the termites from coming out of the hole.

For the Type I and II experiments, 10 and 30 pseudergates, respectively, of *I. minor* without external evidence of wing buds or eyes were put into the center holes of the top surfaces of the wood specimens and the holes were then covered with a fine mesh screen that was attached tightly with a rubber band (Figs. 1 and 2). A similar control experimental setup was employed, except that a much greater amount of gel (2 g) was used in the Type I control. For the control in the Type II experiments, the experimental procedure and the amount of gel were the same as described above except that the gel used had no active ingredient.

On the other hand, 1 g of the gel formulation was placed at the center of one of the 300-mm sides of the specimen for the Type III experiments (Fig. 3). For the control in the Type III experiments, the same experimental procedure as that described above was used.

Forty pseudergates of *I. minor* for Type III experiments were put in the center of the artificial gallery. The assembled arena was then covered with an acrylic plate (2 mm thick), which was fastened by four paperclips.

All the experiment units (Types I, II, and III) were kept in a termite culturing room of the Research Institute for Sustainable Humanosphere (RISH), Kyoto University, for 2 weeks. Three replicates were used for each type. The mortalities of the termites were evaluated for all types after 2 weeks. For Type II, the test setup was disassembled and the location of the test insects was observed at the end of the experiment. On the other hand, for Type III, the location of the termites inside the test arena was observed daily.

Table 1. Response of pseudergates of *Incisitermes minor* exposed to the gel formulation after 2 weeks (Type I)

Treatment	Replication	Condition of termites		
		Live (%)	Moribund (%)	Dead (%)
Gel formulation	1	0.0	0.0	100.0
	2	0.0	40.0	60.0
	3	60.0	20.0	20.0
	Average	20.0	20.0	60.0
Gel control	1	100.0	0.0	0.0
	2	90.0	0.0	10.0
	3	100.0	0.0	0.0
	Average	96.7	0.0	3.3

Table 2. Response of *I. minor* pseudergates exposed to the gel formulation after 2 weeks (Type II)

Treatment	Replication	Condition of termites		
		Live (%)	Moribund (%)	Dead (%)
Gel formulation	1	0.0	0.0	100.0
	2	0.0	0.0	100.0
	3	33.3	6.7	60.0
	Average	11.1	2.2	86.7
Gel control	1	73.3	0.0	26.7
	2	96.7	0.0	3.3
	3	60.0	0.0	40.0
	Average	76.7	0.0	23.3

Results

Mortality of termites

The percentages of live, moribund, and dead pseudergates of *Incisitermes minor* after being exposed to the gel formulation in Types I, II, and III for 2 weeks are shown in Tables 1, 2, and 3, respectively. As shown in Table 1, the percentages of live, moribund, and dead termites after 2 weeks of exposure to the gel formulation in the Type I experiment were 20.0%, 20.0%, and 60.0% on average, respectively, with a high variation in replicates, for example 100%, 60%, and 20% for dead termites. When the gel control was used, the average percentages of live and dead test insects after 2 weeks were 96.7% and 3.3%, respectively (Table 1).

In the bigger test setup, Type II, the average percentages of live, moribund, and dead termites after 2 weeks of exposure to the gel formulation were 11.1%, 2.2%, and 86.7%, respectively, with variation in replicates being 0.0%, 0.0%, and 33.3% for live termites, and 100.0%, 100.0%, and 60.0% for dead termites (Table 2). The percentages of live, moribund, and dead termites in the gel control of Type II were 76.7%, 0.0%, and 23.3% on average, respectively, with the variation in replicates being 73.3%, 96.7%, and 60.0% for live termites and 26.7%, 3.3%, and 40.0% for dead termites (Table 2).

For the Type III experiment, the average percentages of live, moribund, and dead termites after 2 weeks of exposure to the gel formulation were 32.5%, 0.8%, and 66.7%, with the variation in replicates being 0.0%. 97.5%, and 0.0% for live termites and 97.5%, 2.5%, and 100% for dead termites (Table 3). The average percentages of live, moribund, and dead termites were 97.5%, 0.0%, and 2.5%, respectively, in the Type III control (Table 3).

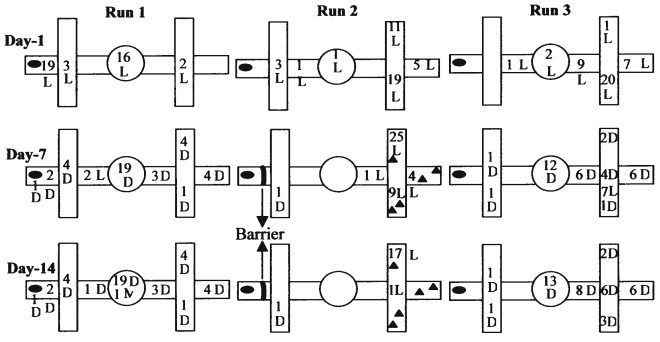

Fig. 4. Locations of termites in the test arena exposed to the gel formulation in Type III tests after 1, 7, and 14 days. *Numbers* in the galleries represent numbers of termites. *Filled circles*, gel; *filled triangles*, perforations by termite; *D*, dead; *L*, live; *M*, moribund

Location of termites

The location of the termites in the Type II and III tests are shown in Table 4 and in Figs. 4 and 5, respectively. As shown

Table 3. Response of pseudergates of *I. minor* exposed to the gel formulation after 2 weeks (Type III)

Treatment	Replication	Condition of termites		
		Live (%)	Moribund (%)	Dead (%)
Gel formulation	1	0.0	2.5	97.5
	2	97.5	0.0	2.5
	3	0.0	0.0	100.0
	Average	32.5	0.8	66.7
Gel control	1	100.0	0.0	0.0
	2	92.5	0.0	7.5
	3	100.0	0.0	0.0
	Average	97.5	0.0	2.5

Table 4. Location of termites after 2 weeks in test apparatus in Type II tests

Replication	Part of sample[a]					
	1	2	3	4	5	6[b]
Gel formulation						
1	3 D	5 D	7 D	11 D	1 D	3 D
2	7 D	2 D	6 D	2 D	5 D	8 D
3	2 L, 2 M, 2 D	6 L, 1 D	2 D	6 D	2 L, 5 D	2 D
Gel control						
1	21 L, 3 D	2 D	1 L, 1 D	1 D	–	1 D
2	4 L	2 L	11 L	7 L, 1 D	5 L	–
3	2 D	4 D	2 D	6 L	2 L, 3 D	10 L, 1 D

D, dead termite; L, live termite; M, moribund termite
[a] See Fig. 2 for explanation of sample parts
[b] Part in which the gel was applied

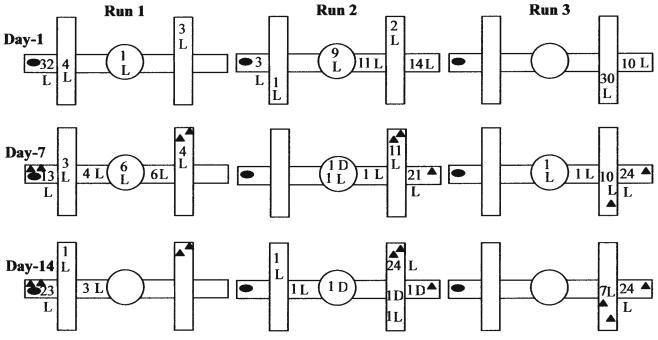

Fig. 5. Locations of termites in the test arena exposed to the gel control in Type III tests after 1, 7, and 14 days. *Numbers* in the galleries represent numbers of termites

in Table 4, the termites were spread evenly in all parts of the sample when exposed to the gel formulation in all replications after 2 weeks. A similar result was observed in the gel control, except for the fifth and the sixth parts of the samples for replications one and two, respectively.

The termites exposed to the gel formulation were spread evenly in almost all of the galleries of the test arena in replications 1 and 3 after 1, 7, and 14 days. In replication 2, the total spread of the termites in all of the galleries of the test arena was observed only after 1 day (Fig. 4). In contrast, after 7 and 14 days, the majority of termites in replication 2 were present on the side opposite to that of the gel (Fig. 4). Interestingly, the termites built a barrier using their fecal pellets and wet feces near the gel formulation in replication 2 after 7 days (Figs. 4 and 6). In addition, five perforations appeared in the test arena in replication 2 after 7 and 14 days (Fig. 4), and at the end of the experiment only 19 termites in the test arena were observed (Fig. 4).

Most termites were located near the gel control in replication 1 throughout the experiment (Fig. 5). For both replications 2 and 3, the majority of termites were seen on the side opposite to that of the gel control (Fig. 5). The number of termites observed was less than 40 individuals (the initial number) after 7 and 14 days in all replications in which many perforations appeared (Fig. 5).

Discussion

The average percentages of dead termites after 2 weeks of exposure to the gel formulation were more than 60% for Types I and III, and more than 85% for Type II. On the other hand, the average percentages of dead termites in the gel control were less than 4% for Types I and III, and less than 25% for Type II in the same period. These results suggest that the present test methods are suitable for evaluating the performance of the bait system against *Incisitermes minor*, and that the gel formulation used in this study has considerable potential as a control measure for drywood termites.

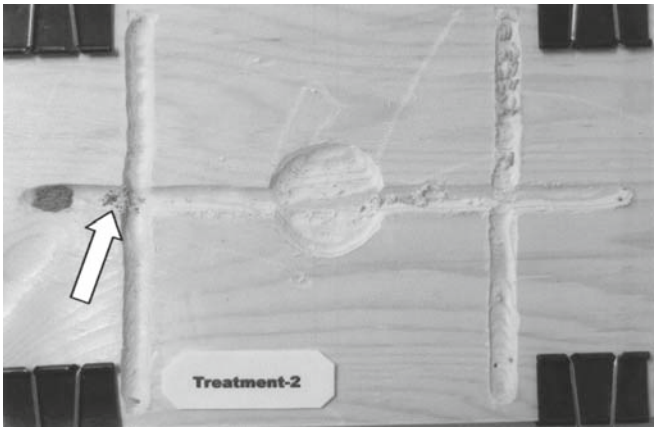

Fig. 6. Barrier built by termites using their fecal pellets and wet feces (*arrow*)

In Type III experiments, the percentage of live termites in replication 2 was 97.5% at the end of the experiment (Table 3), while replications 1 and 3 did not show any sound termites after 2 weeks (Table 3). The fact that the termites in replication 2 of the Type III experiment built a barrier using their fecal pellets and wet feces (Fig. 6) near the gel might explain this phenomenon. The insects could not come into contact with the gel through the barrier.

Concerning the location of the termites, when exposed to the gel formulation, the insects were spread evenly in all parts of the sample at the end of the Type II experiment (Table 4). Although the termites were not accumulated in the bait, the mortality of these test insects was 86.7% on average (Table 2). This clearly indicates that the gel formulation does not have any special attraction or repellent effect on *I. minor*, and that trophallaxis activity, one of the characteristic behaviors of termites and other social insects, may contribute to the high mortality.[14,15]

In the test arena for the Type III experiment, in replication 2, the gel formulation resulted in very low mortality among the termites (2.5%) after 2 weeks (Table 3). The termites avoided the bait and built a barrier using their fecal pellets and wet feces in this case (Fig. 6). But in replications 1 and 3, in which the mortalities were 97.5% and 100%, respectively (Table 3), the termites were spread evenly in all parts of the test arena (Fig. 5). They were also spread evenly in the Type II experiment (Table 4). These varied results support the assumption mentioned above that the gel formulation does not have any special attraction or repellent effect on *I. minor*.

From the present investigation, it can be concluded that the gel bait has the potential to be used as a remedial control measure against *I. minor*, and that consideration of its varied performance will be a key factor in constructing a reliable bait system. The search for special attractants such as trail-following substances that are spread into the entire attacked area should be the next step in this research. In Type III tests, some replications showed numbers of test insects that were smaller than the initial numbers (40 individuals) with many perforations. This behavior also indicates the need for attractants.

Recently, the development of control treatments for termites that use fewer chemicals than in the past or no chemicals at all has been a subject of attention. The application of the gel formulation will be one of the alternative strategies for controlling dry-wood termite infestations with fewer chemicals.

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