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*Research Article*

# Observations of the Biology and Ecology of the Black-Winged Termite, *Odontotermes formosanus* Shiraki (Termitidae: Isoptera), in Camphor, *Cinnamomum camphora* (L.) (Lauraceae)

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Aspects of the biology and ecology of the black-winged termite, *Odontotermes formosanus* Shiraki, were examined in a grove of camphor trees, *Cinnamomum camphora* (L.), located at the Fruit and Tea Institute, Wuhan, China. Of the 90 trees examined, 91.1% had evidence of termite activity in the form of exposed mud tubes on the bark. There was no relationship between tree diameter and mud tube length. Mud tubes faced all cardinal directions; most (60%) trees had multiple tubes at all directions. However, if a tree only had one tube, 22.2% of those tubes faced the south. The majority (>99%) of mud tubes were found on the trunk of the tree. Approximately 35% of all mud tubes had termite activity. Spatial distribution of termite activity was estimated using camphor and fir stakes installed throughout the grove. Camphor stakes were preferred. Kriging revealed a clumped distribution of termite activity.

## 1. Introduction

The black-winged termite, *Odontotermes formosanus* Shiraki, is distributed throughout Southeast Asia including Burma, China, India, Japan, Thailand, and Vietnam where it is an economically important pest of crops, forests, and various wooden structures [1]. Although this species consumes wood and other cellulosic material, it does not directly use these for food. Rather, masticated cellulosic material is used to grow fungus gardens which are the termite food. Termite infestation may result in weakened trees and reduction of yield in fruit trees, or even death of tress, without proper prevention and management [1]. Foraging areas of this species range from 4.2 to 35 m; foraging territories are 13–367.9 $m^2$ [2]. Damage to camphor trees appears as areas of removed bark that may extend from the soil line and roots to the tree crown. These termites move up the tree by building mud tubes along the trunk and removing the bark beneath. In severe infestations, these termites can infest and hollow out branches resulting in severe limb drop especially during windy or icy weather. The mud tubes are thought to provide protection from predators such as ants and from the environment by allowing the creation of a dark and humid microclimate.

Camphor, *Cinnamomum camphora* (L.), is an aromatic tree in the laurel family (Lauraceae) that is native to Southeast Asia including southern China. It is an economically important species because it is used for construction and furniture making, as a spice in cooking, as incense, as a medicine, as an ornamental plant (pers. comm.), and as a repellent for several insect pests [3]. Extracts of camphor trees include several essential oils including camphor, linalool, and 1–8 cineole [4]. The latter two essential oils have toxic and repellent properties to a number of insects

Figure 1: Satellite image of Fruit and Tea Institute, Wuhan, Hubei, China. Top of the image is the north (Google Earth, version 6.0.3.2197, 2011).

including cockroaches [5, 6]. Interestingly, even with its toxic and repellent characteristics, camphor is a preferred indirect food plant of the black-winged termite [1].

The objectives of this study were to examine the distribution of black-winged termites in camphor groves and on camphor trees, determine if there is a relationship between tree size and the length of termite tubes, measure feeding preferences, and observe various aspects of termite tubing behavior.

## 2. Materials and Methods

This study was conducted at the Fruit and Tea Institute of the Hubei Academy of Agricultural Sciences, at Jin Shui Zha, Jiang Xia District, Wuhan, China, the Institute is situated on approximately 2.3 $km^2$ (230 hectares) at 30°17′53.74′′N 114°08′29.76′′E and an elevation of 55 m above sea level. It is located in a relatively rural area about 38 km from the urban areas of Wuhan. There are a number of brick and cement buildings, fields of tea, and orchards of kiwis, oranges, and pears. There are also several groves of camphor trees, *Cinnamomum camphora* (L.), situated between buildings (Figure 1). The camphor trees were planted in a regular grid pattern with almost equal distance between individual trees. A cursory inspection of the groves and nearby (ca. 100 m) wooden structures for the presence of tunnels and live termites and pieces of wood was conducted. Observations were made on 25-26 October 2009 with subsequent visits in March 2010 and July 2011.

Approximately one month before our observations (24–29 August 2009), pairs of fir, *Cunninghamia lanceolata* (Lambert) Hooker, and camphor wood stakes (5 by 3 by 40 cm) were installed 20 cm deep into the soil in the camphor groves (Figure 2). Fir was selected because it is a common wood species in the test area and stakes were readily available. Stakes were installed at 5 m intervals forming a uniform sampling grid. There were a total of 85 pairs of camphor-fir stakes installed in two groves (east and west). The percentage of stake locations with termite feeding, preferences in feeding between the types of wood, and the distribution of termite activity were recorded.

Measurements of termite infestations included visual inspection of 90 camphor trees located in the two adjacent groves of 45 trees each. Each tree was inspected for termite tubes and the location (trunk, roots, leaves, etc.), length (from the ground to the highest point on the trunk or branch), direction (cardinal direction), and presence of termites in each tube were recorded. The size of each tree was also estimated by measuring the circumference of the trunk 1.5 m above the ground with a tape measure. Presence of termites was determined by manually removing 5–10 cm section of each tube at several heights above the ground and noting the presence of termites.

The bark on a number of trees along the northernmost edge of each grove was covered with moss. When the moss-covered bark was removed it was evident that termites had formed a ca. 0.5 cm foraging space under the bark. There were no mud tubes; the moss-covered bark likely served the same protective functions as tubes. To determine the behaviors of these termites, sections of moss-covered bark (and active mud tubes) were removed and the areas were observed over a 2–4 h period.

Data are expressed as means ± standard errors, and differences were considered at $P \leq 0.05$. Regression and correlation analysis was used to determine the relationship between tree trunk diameters and termite tunnel length, analysis of variance (ANOVA) was used to determine differences in the orientation of termite tunnels on tree trunks, *t*-tests were used to compare wood preference, the length and areas of mud and moss-covered sections and repair times, and Kriging was used to estimate the distribution of termite activity in camphor groves. SigmaPlot 12.1 [7] was used for ANOVA, correlation, regression, and *t*-test analyses, and Surfer 10.0 [8] was used for Kriging.

## 3. Results

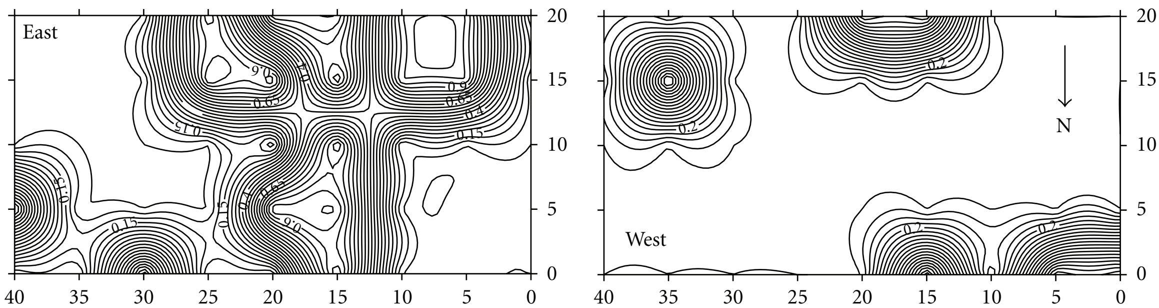
Of the 85 pairs of monitoring stakes, only 10 (11.8%) were infested by termites. There was no significant preference between the camphor (13.3%) and fir (8.9%) stakes (*t*-test; $P > 0.05$). The distribution of termite activity in each of the two camphor groves is illustrated in Figure 3. There are several concentrated areas of activity, but most stakes were not attacked. Termite activity was concentrated at both the northern and southern portions of both the eastern and western groves with relatively little activity in the center of the western grove and the southeaster and northwestern portions of the eastern grove. In contrast, virtually every tree (93.3%) had termite tubes indicating that the entire area of both groves was foraging territory of one or more termite colonies.

Camphor trunk circumference ranged from 42 to 183 cm with a mean of 109.73 ± 3.05 cm. Termite tube length ranged from 0 to 6 m with a mean of 3.31 ± 0.20 m. There was no significant relationship between camphor tree trunk circumference and the length (height) of termite tubes (regression; $P > 0.05$) (Figure 4).

Over 90% (91.1%) of the 90 camphor trees examined showed signs of current or prior infestation as determined by the presence of mud tubes. There was no obvious directional preference by these termites for the location of their tubes on tree trunks. Mud tubes were found facing all four cardinal

(a) (b)

Figure 2: Grove of camphor trees with pairs of sampling stakes: (left) pair of sampling stakes.




(a) (b)

Figure 3: Distribution of termite activity as measured by attacked stakes. (a) The eastern grove, (b) western grove. Increasing contour values indicate increasing probability of termite activity.

directions on 60% of the infested trees. Of those trees having only one tube, 11.1% of the tubes were formed on the north facing side of a tree compared with 22.2% formed on the south facing side (Figure 5), these proportions were not significantly different (ANOVA; $P > 0.05$). All mud tubes were broken open to determine termite activity. Only 34.4% of tubes were active, and there was no significant directional preference of the active tubes (ANOVA; $P > 0.05$).

A total of four mud tubes and four moss-covered areas were selected and the mud or moss removed to reveal active termites. There was no difference in the mean length of the areas removed (ca. 5.6 cm); however, the moss-covered areas ($2.25 \pm 0.26$ cm) were significantly wider (ca. 2.2 times) than mud tubes ($1.18 \pm 0.10$ cm) ($t$-test; $t = 3.3806$, df = 6; $P = 0.0089$). All exposed areas were repaired by the termites within 1 h. Mud tubes ($18.23 \pm 3.40$ min) were repaired significantly faster than moss-covered areas ($41.30 \pm 5.51$ min) ($t$-test; $t = 3.5656$, df = 6; $P = 0.0118$).

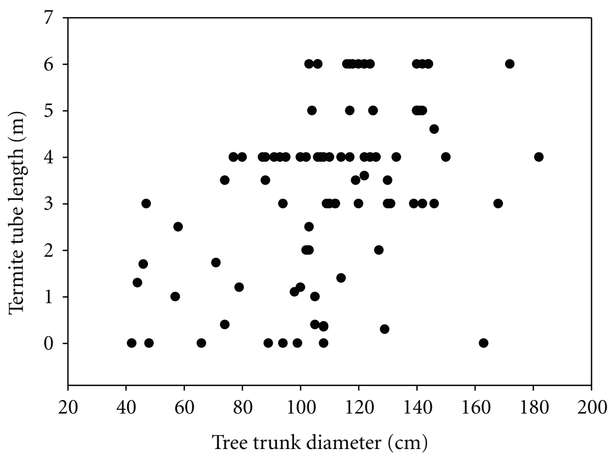



Figure 4: Relationship between tree trunk diameter measured 1.5 m above the ground and maximum termite tube length on the tree trunk.

## 4. Discussion

Black-winged termites were distributed throughout both adjacent groves of camphor trees. Inspection of nearby (within 100 m) trees, small wooden structures, and even relatively small (<2 cm diameter) sticks revealed the presence of these termites. Nearly all camphor trees (93.3%) in both groves had been attacked by termites as evidenced by the presence of mud tubes on the bark. The size and therefore age [3] of camphor trees were not related to termite attack. A variety of studies have shown that the concentration and composition of protective compounds, such as essential oils, in plants change with age. Also, as trees age and grow, they increase in height and circumference. There was no relationship between tree size and length of termite tubes

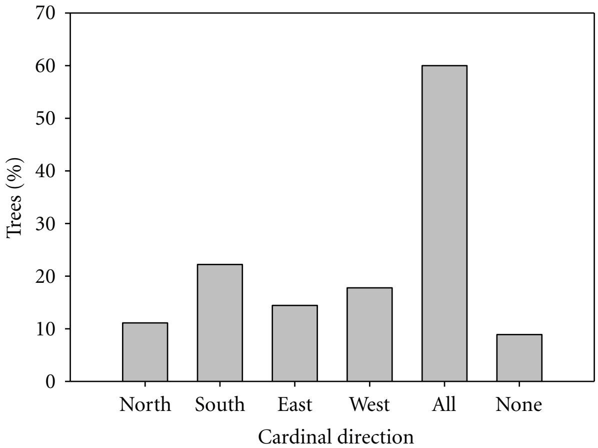



Figure 5: Percentage of trees with termite tubes oriented in each direction. All indicate that termite tubes were present in all four directions.

(Figure 4) indicating a probable lack of effective change in protective compounds with camphor tree age, or black-winged termites are not affected by these compounds.

Even though there was evidence of almost complete infestation of trees, only 11.8% of the pairs of monitoring stakes were infested. It is possible that the approximately one-month period between installation of the stakes and inspection was not sufficient for the termites to locate the stakes. It is more likely, however, that the termites had sufficient wood on the camphor trees and only attacked the stakes if a subterranean foraging tunnel directly contacted them. The condition of the wood stakes may also affect feeding activity and it is possible that the stakes had to age and decay to become as attractive as bark. Decomposing wood has greater concentrations of sucrose and more associated yeasts than sound wood [9]. In addition, fungi that are associated with wood decay are often consumed by termites [10], and these fungi are rich in urea [11]. Laboratory feeding preference studies that compare black-wing termite feeding on camphor and fir are clearly indicated. Many factors including wood density, presence of protective compounds, and concentration of glucose affect black-winged termite feeding preferences [12]. In a recent study with the black-winged termite, Kasseney et al. [12] found that solid wood consumption was inversely correlated with wood density and positively correlated with glucose concentration. Although camphor had moderately dense wood, it also had the greatest concentration of glucose among the wood species tested [12]. Perhaps feeding on bark allows these termites to avoid the dense solid wood while feeding on more glucose-rich cellulose. Unfortunately, the Kasseney et al. [12] study did not use fir as one of the wood choices. Interestingly, there was no preference between camphor and fir wood stakes in this study. However, in a similar field study about 0.5 km from the camphor groves, black-winged termites showed a decided (2 : 1) preference for camphor over fir wood stakes when the stakes were installed in a kiwi field (unpublished). Camphor is probably a preferred wood, and there is sufficient camphor in the camphor groves to interfere with relatively small camphor stakes.

The spatial analysis of the termite activity (Figure 3) indicated several areas of greater activity in both the east and west camphor groves. These areas of greater activity tended to be nearer to the northern and southern borders of the groves rather than in the center of the groves. Since many termites, and other insects, are known to follow structural guidelines in their foraging patterns [13, 14], it is possible that the greater activity along the northern and southern borders is due to the presence of cement sidewalks and brick walls that enclose the camphor groves. It is also possible that the greater activity in certain areas is a result of greater termite density in those areas or closer proximity to a primary nest. There was no correlation between termite activity in stakes and activity on trees.

The majority (60%) of trees had termite tubes facing all cardinal directions (Figure 5). If trees had only one termite tube, there was no preference for direction. Cardinal direction and therefore light and temperature exposure could affect the distribution of termite mud tubes on trees. Exposure to increased temperature could cause the conditions in tubes on one side of a tree, such as the side facing south, to become too hot for foraging workers. Increasing heat could cause an increase in desiccation or reach the critical thermal maximum. Water and temperature relations have not been studied in this species, but information on these aspects of termite physiology could help explain their micro- and macrodistribution patterns.

Black-winged termites usually construct mud or soil tubes when they are foraging above ground and exposed to the environment. Hundreds of meters of mud and soil tubes were observed in this study, most on camphor tree trunks and branches. These termites will also forage in other protected structures such as moss- and bark-covered voids. These voids ranged in size from 1 cm in width to >10 cm and could extend >1 m in length and were about 0.5 cm in height. The surfaces of these voids were very smooth and did not contain mud or soil. When a section of moss-covered bark was removed to expose the void, termite workers immediately began to seal the exposed areas by bringing soil and mud and depositing it along the exposed area. Rather than resealing the entire exposed area, the termites rapidly constructed a mud tube that provided an enclosed foraging corridor. Termites required about twice the time to repair exposed moss-covered bark foraging areas as they did to repair similar sized damage to mud tubes. It is likely that mud tubes could be repaired more quickly because there were mud tubes close to the broken area and termites removed some of this mud to repair the break. Termites foraging under moss-covered bark probably did not have ready access to mud or soil and had to transport it from the ground up to the broken area. The rapid repair of all broken foraging tubes and areas indicates the importance of these structures to the biology of the black-winged termite and the size of their colonies.

In conclusion, the black-winged termite is an important pest of camphor trees particularly in dense groves. Most trees in an area will be attacked, but sampling studies that rely on wooden stakes may require extended periods to yield results. This termite builds mud tubes on all age and size trees and shows no preference for the direction of these tubes. Further studies on the physiological ecology of this species will provide insight into foraging and above-ground tubing activities. Additional studies on the distribution patterns of this species will aid control strategies by accurately providing locations for insecticidal bait placements.

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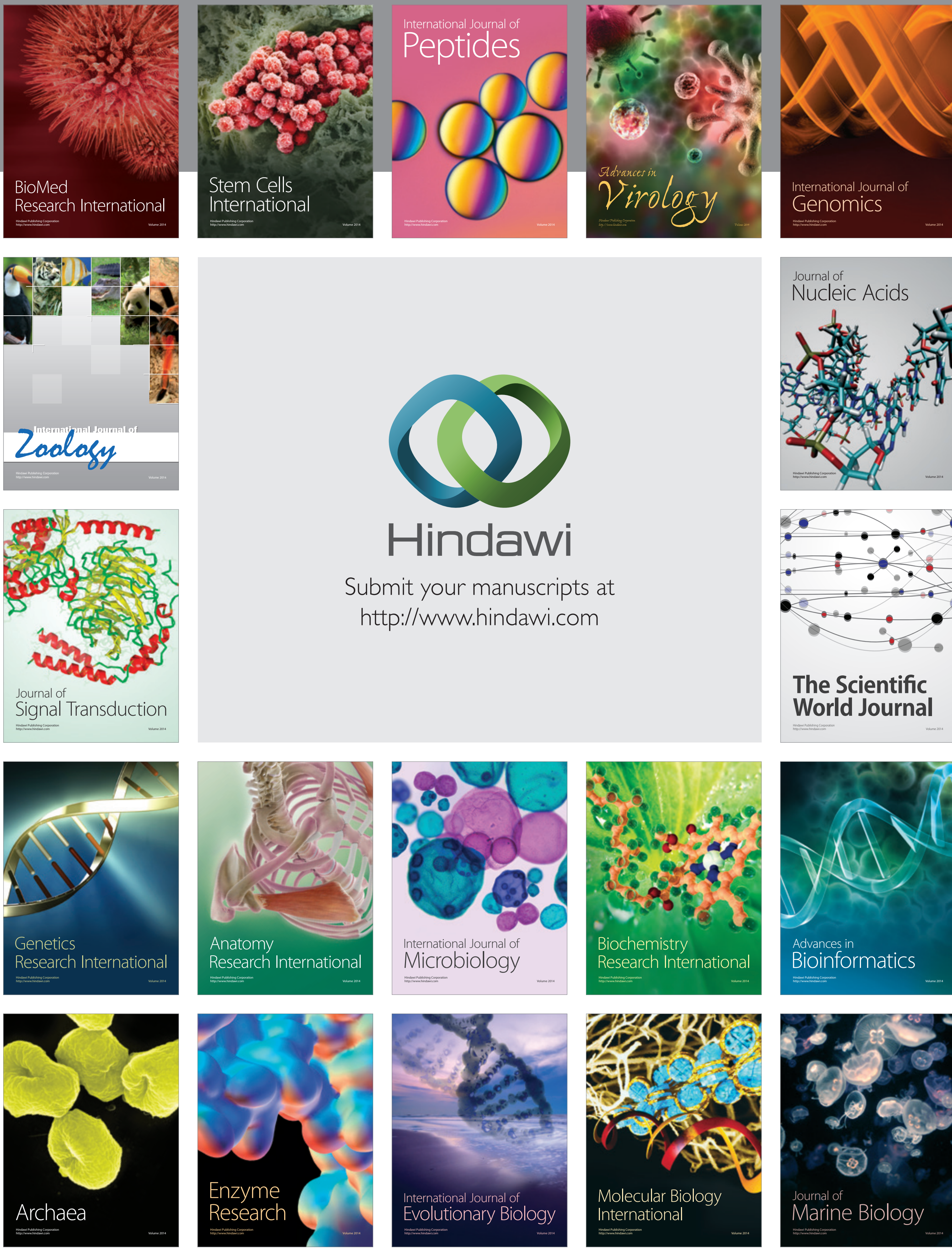
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