Insect Science

Insect Science (2011) 18, 671–681, DOI 10.1111/j.1744-7917.2010.01400.x

ORIGINAL ARTICLE

Evaluation of differential antitermitic activities of *Lantana camara* oven-dried tissues against *Reticulitermes virginicus* (Isoptera: Rhinotermitidae)

Zhonglin Yuan[1,†] and Xing Ping Hu[2]

[1]*Qingdao Agricultural University, Qingdao, Shandong Province, China,* [2]*Department of Entomology and Plant Pathology, Auburn University, Auburn, Alabama, USA*

Abstract Chemical-treated soil or physical barriers have been the most commonly used approach for termite management. We hypothesized that a barrier of soil incorporated with oven-dried *Lantana camara* L. tissues could prevent termite infestation. We first examined the antitermitic effects of the dried tissues from two cultivars (‘Mozelle’ and ‘New Gold’) on the subterranean termite, *Reticulitermes virginicus* (Banks) (Isoptera: Rhinotermitidae). Results show that all of the tissues of Mozelle had greater antitermic activity than corresponding tissues of New Gold, and leaves had greater termiticidal effects than flowers and stems. When termites were exposed to the test materials in a no-choice bioassay, the 24-day test resulted in a significant reduction of survival (52.5%–88.6%), running speed (18.2%–37.3%), live weight (21.8%–53.5%) and body water content (33.2%–56.2%) compared to the control. The consumption of leaves and flowers was exiguous. When used as 25% tissue mulch-barrier, the oven-dried lantana tissues decreased termite tunneling and wood consumption and increased termite mortality. The decreased survival, vigor, and low consumption indicate a toxic and anti-feeding property of the materials tested. The results therefore support our hypothesis that the dried lantana tissues possess antitermitic activities.

Key words antitermitic activity, mulch barrier bioassay, no-choice bioassay, organic termite control, oven-dried plant tissues, subterranean termite, termiticidal toxicity

Introduction

Termites (Isoptera) are economically and ecologically important structural insect pests. When building repair cost is included, the economic impacts of termites may reach up to $11 billion annually in the United States (Su, 2002). Therefore, the control of subterranean termites is an important concern of homeowners and the pest control industry (Hu & Hickman, 2006). At the present, control of subterranean termites depends primarily on incorporation of synthetic residual termiticides into the soil surrounding a target structure (Forschler, 1998; Hu & Hickman, 2006). In recent years, there has been increasing public concern over the environmental fate of the large quantity of liquid insecticides being applied to the soil beneath and around homes. These concerns have evoked the desire to implement more eco-friendly and safer control strategies (Forschler & Jenkins, 2000). Searching for botanically based insecticides is an approach currently under investigation for pest management (EPA, 2000).

Plants contain a virtually untapped reservoir of natural insecticides (Duke, 1990). Many plants have insecticidal properties or act to alter behaviors, growth and development of a large variety of insects. A variety of

Correspondence: Xing Ping Hu, Department of Entomology and Plant Pathology, Auburn University, Auburn, AL 36849, USA. Tel: 334 844 6392; fax: 334 844 5002; email: huxingp@auburn.edu

†Visiting scholar at Auburn University 2009–2010.

essential oils have been evaluated for their use in controlling termites (review by Verma *et al.*, 2009). For example, essential oils from *Chrisopogon zizanioides* (vetiver grass), *Cymbopogon* spp. (lemongrass), *Eucalyptus* spp. (lemon scented gum), *Eugenia* spp. (euginia), *Tagetes erecta* (Mexican marigold), *Nepeta cataria* (catnip), *Lepidium meyenii* (maca), *Calocedrus formosana* (Taiwan incense-cedar), *Melaleuca cajuputi* (gelam), *caryophyllata* (clove bud) and *Allium sativum* (garlic) have shown biological activities as feeding deterrents, repellants, or toxicants against termites (Zhu *et al*., 2001; Tellez *et al*., 2002; Peterson & Ems-Wilson, 2003; Sakasegawa *et al*., 2003; Singh *et al*., 2003; Cheng *et al*., 2004; Park & Shine, 2005). Antitermitic properties are also associated with crude solvent extracts from different plant tissues, including leaves, roots, stems, fruits and seeds, of a number of plants (Lajide *et al*., 1995; Sharma *et al*., 1999; Ganapaty *et al*., 2004; Fokialakis *et al*., 2006). Additionally, some plant tissues have been used directly as a mulch barrier to subterranean termites by incorporating the plant tissues into soil. For example, Nix *et al*. (2006) reported that a dried vetiver roots mulch barrier effectively decreases the tunneling activity and wood consumption of Formosan subterranean termites, *Coptotermes formosnaus* Shiraki (Isoptera: Rhinotermitidae).

Lantana camara L. (Verbenaceae), commonly known as wide or red sage is the most widespread species in the genus *Lantana* and is regarded as a notorious weed in tropical regions and a popular ornamental garden plant in tropical, subtropical and temperate regions (Sharma *et al.*, 1988; Ghisalberti, 2000). It is also listed as one of the most important medicinal plants around the world (Ross, 1999). Additionally, *Lantana camara* contains many chemical compounds possessing insecticidal, antimicrobial, nematicidal activity, and allelopathic qualities (Sharma *et al.*, 1988; Verma *et al*., 1997; Begum *et al.*, 2000; Hernandez *et al*., 2005; Kong *et al.*, 2006; Sharma *et al.*, 2007). Its insecticidal activities include antifeeding, antioviposition, larvicide, repellency and toxicity toward bees, stored-product beetles, mosquitoes and cattle flies (Saxena *et al*., 1992; Dua *et al*., 1996; Ogendo *et al*., 2004; Abdel-Hady *et al*., 2005; Kumar & Maneemegalai, 2008). Using lantana, extracts or mulch-barriers, against termites has been a topic of great interest as alternatives to synthetic insecticides. Verma and Verma (2006) reported a mortality of 68.7% within 48 h in the termite *Microcerotermes beesoni* Snyder (Isoptera: Termitidae), feeding on filter paper treated with a 5% chloroform extract of *L. camara* leaves. An earlier study documented the use of fresh lantana leaf-mulch as a repellent barrier to termites (Ding & Hu, 2010). However, chemical compositions in plants often vary with seasonal plant status (fresh or dried) (Randrianalijaona *et al*., 2005; Okon *et al*., 2008).

Thus, the main objective of the present study was to determine the differential antitermitic activities of oven-dried aerial parts (flowers, leaves and stems) of two *L. camara* cultivars, 'Mozelle' and 'New Gold', on the subterranean termite, *R. virginicus* (Banks). In addition, the potential of dried lantana tissues as a mulch barrier to termites was evaluated using a laboratory bioassay.

Materials and methods

Plant samples

Leaves, stems and flowers of two *L. camara* cultivars, Mozelle and New Gold, were collected in November 2009, in Auburn, Alabama, USA. These tissues were each put into separate metal pans and dried in an oven (637G Isotemp Oven, Fisher Scientific, Waltham, MA, US) at 40°C for 3 days. Dried leaves and flowers were cut into small pieces and passed though a No. 5-mesh sieve (Hubbard Sci. Co., Chippewa Falls, WA, US). Dried stems were cut into approximately 0.5 cm pieces. The dried tissues were sealed in zip-plastic bags before testing. Dried southern yellow pine (SYP) wood cut into pieces (approximately $0.5 \times 0.5 \times 0.2$ cm) were used as control.

Subterranean termites

Workers of *Reticulitermes virginicus* (Banks) were collected from two colonies at locations > 800 m apart on the Auburn University campus at Auburn, Alabama, by using underground open-bottom bucket traps baited with moistened corrugated cardboard rolls (Hu & Appel, 2004). The cardboard rolls harboring *R. virginicus* were brought back to the laboratory and kept separately in plastic containers for 5 days before being subject to the laboratory bioassay. Species were identified using a key to soldier caste (Scheffrahn & Su, 1994) and confirmed with mitochondrial DNA (mtDNA) 16S analysis. When termites were needed, they were carefully knocked from the cardboard rolls into clean plastic trays ($30 \times 50 \times 2$ cm) and separated from debris by allowing them to cling to sheets of moistened paper towels. Only workers that were at the third instar or older were used for testing.

No-choice bioassay

The no-choice bioassay was conducted to determine the effects of dried lantana tissues on termite survival, running speed, body weight, body water content, as well as the consumption of test material. Experimental units consisted of 0.5 g of a test material added to a plastic Petri dish (50 × 13 mm) and moistened with 0.5 mL of distilled water. A group of 100 termite workers was introduced into the area not covered by the test material in the experimental unit. Seven treatments were tested: control (SYP), dried leaves of Mozelle, dried leaves of New Gold, dried stems of Mozelle, dried stems of New Gold, dried flowers of Mozelle and dried flowers of New Gold. Each treatment was replicated six times (three for each termite colony). Additionally, 28 surplus units (4 replicates of each treatment) were set up to obtain enough specimens for determinations of termite body water content. Experimental units were kept inside Plexiglas boxes (27 × 15 × 9 cm) containing small cups of water to maintain humidity. Boxes were covered with a lid and sealed with Parafilm (American Can Company, Dixie/Marathon, Greenwich, CT, USA), and placed in a dark incubator at 25 ± 1°C and 80%–90% RH. On days 2, 4, 8, 12, 16, 20 and 24, termite distribution within each experimental unit, survival rate, live weight and running speed were measured. Survival rate was obtained by counting the number of living workers in each unit. Dead bodies were removed at the time of inspection. Running speed was measured by timing a worker running a distance of 15.7 cm (a circle of 5-cm diameter) drawn on plain paper with a Papermate® ballpoint pen. Ballpoint pen ink contains a substance (2-phenozyethanol) that elicits termite trail-following (Becker, 1966; Chen *et al*., 1998). A stopwatch was used to record the time an individual termite completed the circle. Twelve workers selected haphazardly from each treatment were tested. Times were recorded only when workers completed the circle distance without stopping or reversing walking direction on or from the line. Live weight (± 0.01 mg) was determined by weighing six groups of five living workers selected haphazardly from each experimental unit on an electronic balance (M-220D, Denver Instruments, Arvada, CO, USA). Body water content was measured on days 8, 16 and 24. Six groups of five workers were pooled from surplus units of each treatment. Groups of termites were weighed (W1), oven-dried at 80°C for 48 h, and reweighed (W2) on the same electronic balance previously mentioned. Dried workers were held at room temperature in a desiccation chamber containing Drierite® (Xenia, OH, US) crystals for 5 min before being reweighed. Body water content (mg/worker) was determined by obtaining the difference between live and dry weighs (W1–W2), divided by the number of workers (5). Consumption of the tested materials was determined on day 24. For each experimental unit, termites were removed and the test material was dried at 40°C for 48 h and weighed to calculate the amount of materials consumed.

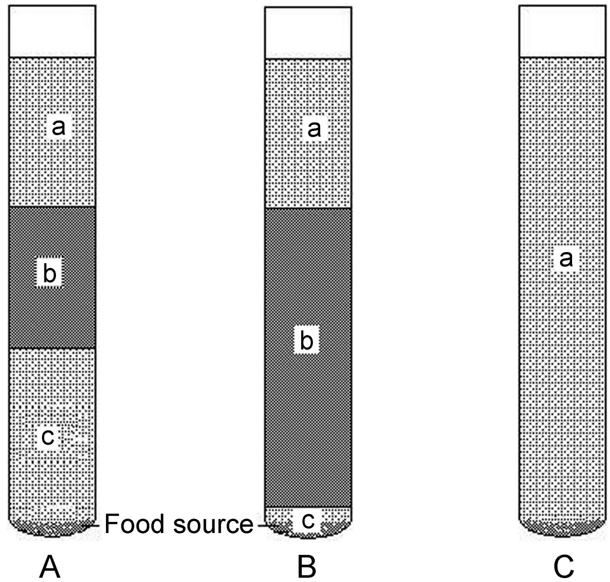

Fig. 1 Diagram of experimental unit used in mulch-barrier bioassay, noting the arrangement of sand layers, mulch-barrier and food source. Unit A: 5-cm mulch barrier (b) sandwiched by two layers of sand (a = 5cm, c = 6 cm). Unit B: 10-cm mulch barrier (b) sandwiched by two layers of sand (a = 5 cm, c = 1 cm). Unit C: control with only sand layer (a = 16 cm).

Mulch-barrier bioassay

The mulch-barrier bioassay was used to determine the effects of dried lantana tissues, when used as a mulch barrier, on termites penetrating through the barrier, mortality and consumption of wood (SYP). This study only tested Mozelle because its fresh tissues exhibited a stronger repellence against subterranean termites than New Gold (Ding & Hu, 2010). Modified experimental units designed by Hu (2005) were used. The experimental units (Fig. 1) consisted of a glass test tube (2.2 cm inner diameter by 20 cm in length) filled with, from bottom to top, a piece of moistened SYP (0.5 g dry weight), a layer of plain sand (6 or 1 cm), 5 or 10-cm sand-mulch barrier and a topping of plain sand (5 cm). Sand (Premium play sand, Short Mountain Silica, Mooresburg, TN, USA) was washed, oven-dried and remoistened with distilled water (12% w/w) before using. Dried lantana tissues (leaves, stems or flowers) were mixed with sands, respectively, at a ratio of 2 : 8 (w/w) and moistened with distilled water (12% w/w). The total length of the three layers and the food source at the bottom was 16 cm. A plastic stopper attached to a needle with a wood handle was used to slightly tamp and level the bottom sand layer before adding sand-mulch barrier, and the same was repeated for the sand-mulch barrier before adding the upper sand layer. A group of 100 workers were poured into the top of each experimental unit using a glass funnel. The experimental unit was sealed with a piece of Parafilm over the top of the glass test tube to keep the unit moist and to prevent termites from escaping. Five tiny holes were pierced in the Parafilm with a needle (0.3 mm diameter) for ventilation. Experimental units with plain sand replacing the mulch-barrier were used as control treatment. Six replicates were performed for each treatment. The test tubes were held vertically in Styrofoam racks with the termites at the top of the tube. To reach SYP (the food source) at the bottom, termites had to tunnel through the sand and the mulch-barrier. Tunneling depth was recorded at 12-h intervals for the first 2 day and then at 24-h intervals to record the days needed to penetrate through a mulch-barrier. Termite mortality and wood consumption were determined on day 24. At termination, the experimental units were carefully disassembled and the number of live termites was counted to determine mortality. The piece of SYP was cleaned, oven-dried at 40°C for 48 h, and weighed to determine the amount of SYP consumed.

Data analysis

Each of the response variables (live weight, running speed and body water content from the no-choice assay, and survival, consumption, and time of penetrating through mulch-barrier from the mulch-barrier bioassay) was subjected to an analysis of variance (ANOVA) (SigmaPlot® version 10, Systat Software Inc. 2007) to determine whether there was any significant difference in these responses attributable to the tested tissues. Specifically, the null hypothesis of no difference in mean values of the particular response variable associated with tissues at each inspection date was tested. Because no significant difference was detected between the two termite colonies, pooled means of each treatment from the same tissues and time were used for analysis. The means were separated using Tukey's highly significant difference (HSD) test at $\alpha = 0.05$. The survival responses in the no-choice bioassay were further regressed as a function of the exposure time (day) for each plant tissue by the polynomial equation for the best fit to the data. Although the survival rate and percent body water loss were transformed to the arcsine of the square root to ensure the data set was in normal distribution for data analysis, untransformed means are presented in figures and table. The actual lengths of tunneling are shown in figures.

Results

Antitermitic effects of lantana dried tissues on termites

Overall results from the no-choice bioassay show promising toxic activity of dried lantana aerial tissues. Rather than staying at the empty area where they were introduced, termites entered and clustered inside the test tissues. Cultivar Mozelle exhibited greater antitermitic property than New Gold, regardless of the tissues. Leaves exhibited higher antitermitic quality than flowers and stems, for both cultivars.

R. virginicus worker survival rates decreased over time. After 4 days exposure, the survivals were significantly lower in lantana treatments than control ($F = 8.77$; df = 6,35; $P < 0.05$) (Fig. 2). At the end of the bioassay, Mozelle leaves produced the lowest survival (10.8%), followed by Mozelle flowers, New Gold flowers, and New Gold leaves (22.8%, 26.2% and 35.8%, respectively, which did not vary significantly from each other), then Mozelle stems and New Gold stems (42.8% and 45.5%), and the highest in control (95.1%) ($F = 81.32$; df = 6,35; $P < 0.001$). Compared to the control, termite survival was reduced 88.6%, 76.0%, 72.5%, 62.4%, 55.0% and 52.2% by Mozelle leaves, Mozelle flowers, New Gold flowers, New Gold leaves, Mozelle stems and New Gold stems, respectively. Initial plotting of the survival data permitted evaluation of the various model equations for fit to the data. The equations selected were $Y = aX^2 + bX + c$, with $R^2 > 0.97$, Y = survival value and X = exposure day (Fig. 2). These equations demonstrated an important concept: with increasing exposure time, comes exponentially decrease of termite surviving rates. However, the rapid declines of mean survivals in the flower treatments were due to a fungal infection in two and three Mozelle and New Gold flower replicates, respectively. These replicates had higher mortality than other replicates of the same treatments that had greater standard errors (SE) than other treatments (Fig. 2). The fungal infection was observed on day 16; infected termites were covered with whitish mycelium and filamentous hyphae. Had we been aware of it, we should have had this pathogenic fungal species identified at that time.

Termite running speeds decreased gradually over time (Fig. 3). Beginning on day 12, lantana-exposed termites exhibited visible lethargic behavior and a tendency to aggregate together. Rather than avoiding, they clustered inside the tissues that were being tested and reduced locomotor activity. On day 24, the slowest running speed was observed in termites fed on leaves (27.57 cm/min and 29.81 cm/min for Mozelle and New Gold, respectively), followed by those fed on flowers and stems of the two

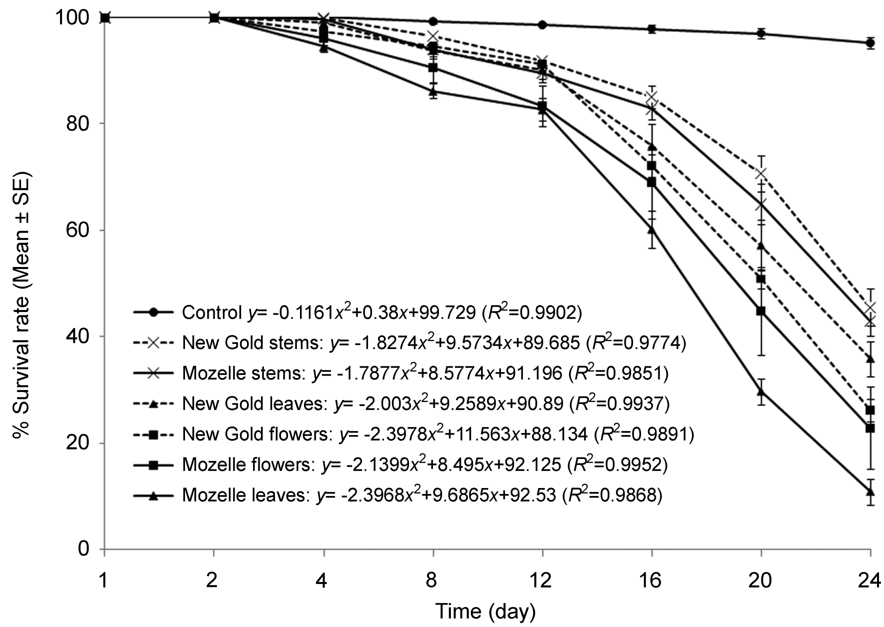

Fig. 2 Regression of the mean survival (± SE) as a function of the exposure time (day) of six dry lantana tissues. *R. viginicus* workers were exposed to lantana tissues in a no-choice bioassay.

cultivars (running speeds ranged between 34.2 cm/min and 36.0 cm/min), and the fastest (44.0 cm/min) was in the control ($F = 7.11$; df = 6,77; $P < 0.05$). The corresponding reduction of running speed on day 24, in comparison to control, was 37.3%, 32.2%, 21.6%, 22.3%, 20.5% and 18.2%, respectively.

Live termite weights stayed generally steady in controls across the sample dates, but decreased gradually in lantana treatments over time (Fig. 4). Beginning on day 4, control workers were significantly heavier ($F > 15.97$; df = 6,35; $P < 0.05$) than workers in lantana treatments. Visible difference in physical appearances was not observed until day 16 and thereafter. Termites in lantana treatments became whitish in color and their bodies became smaller and wrinkled. On day 24, live weight decreased to 0.79, 0.85, 0.93, 0.95, 1.09, 1.33 and 1.7 mg/termite in Mozelle leaves, New Gold leaves, New Gold flowers, Mozelle flowers, Mozelle stems, New Gold stems, and control, showing a 53.5%, 50%, 45.3%, 44.1%, 35.9% and 21.8% reduction in body mass, respectively, in comparison to control.

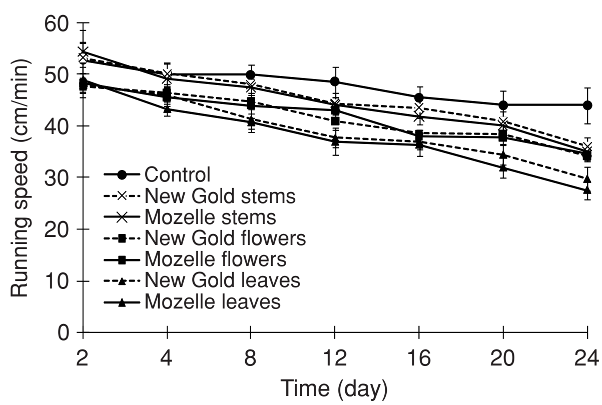

Fig. 3 Means (± SE) of running speed dynamic of *R. viginicus* workers in different treatments during the 24-day no-choice bioassay.

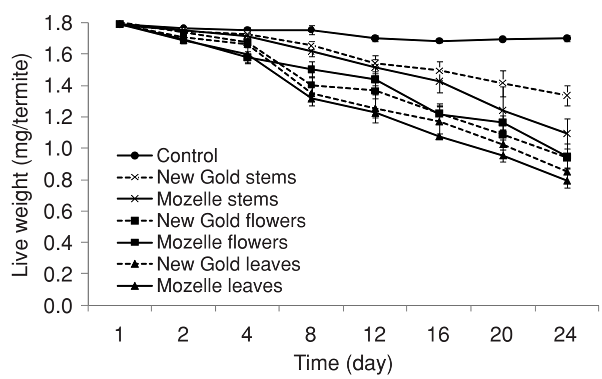

Fig. 4 Means (± SE) of *R. viginicus* worker live weight in different treatments during the 24-day no-choice bioassay.

Table 1 Mean ± SE (mg) of body water/termite and percent reductions from original weight on days 8, 16 and 24 in no-choice bioassay.

Treatment	8 days		16 days		24 days	
	Mean water/termite	Percent reduction	Mean water/termite	Percent reduction	Mean water/termite	Percent reduction
Control	1.45 ± 0.04 a	–	1.44 ± 0.02 a	–	1.40 ± 0.02 a	–
New Gold stems	1.28 ± 0.03 b	11.4 ± 2.4 b	1.09 ± 0.05 b	23.7 ± 2.4 c	0.94 ± 0.02 b	33.2 ± 1.5 b
Mozelle stems	1.27 ± 0.03 b	12.3 ± 2.1 b	1.06 ± 0.03 b	25.9 ± 2.1 c	0.87 ± 0.01 b	37.8 ± 0.9 b
New Gold leaves	1.24 ± 0.03 b	14.3 ± 2.3 b	0.84 ± 0.02 cd	41.6 ± 1.3 a	0.65 ± 0.02 c	53.5 ± 1.2 a
New Gold flowers	1.27 ± 0.02 b	12.2 ± 1.3 b	0.93 ± 0.03 c	35.1 ± 2.0 b	0.70 ± 0.06 c	50.0 ± 4.0 a
Mozelle flowers	1.26 ± 0.02 b	12.9 ± 1.3 b	0.95 ± 0.02 c	34.6 ± 1.5 b	0.72 ± 0.03 c	48.0 ± 1.8 a
Mozelle leaves	1.03 ± 0.04 c	28.8 ± 2.5 a	0.78 ± 0.06 d	45.5 ± 1.3 a	0.61 ± 0.02 c	56.2 ± 1.3 a

Means followed by different letters are significantly different (Tukey's honestly significant different test, $P < 0.05$).

Termite body water content and percent reduction data are presented in Table 1. The body water content as well as the live weight, regardless of treatment, showed an overall consistent declining pattern as the experiment progressed. The decrease of water content in lantana-treated termites was significant for all the dates ($F > 17.7$; df = 6,35; $P < 0.05$). Mozelle leaves caused the greatest water loss than any other tissue on days 8 and 16 ($F = 17.7$ and 58.6; df = 6,35; $P < 0.05$), with the exception on day 24 when leaf and flower treatments resulted in similar water reduction, which were higher than stem treatments ($F = 104.1$; df = 6,35; $P < 0.05$).

At the end of the bioassay, the average consumption of the examined tissues were significantly lower than in control ($F = 242.6$; df = 6, 30; $P < 0.05$) (Fig. 5). The consumption data exclude those from fungal-infected units because of the decomposition caused by the fungi. Among the treatments, significantly fewer leaves and flowers were consumed compared to stems, regardless of cultivars.

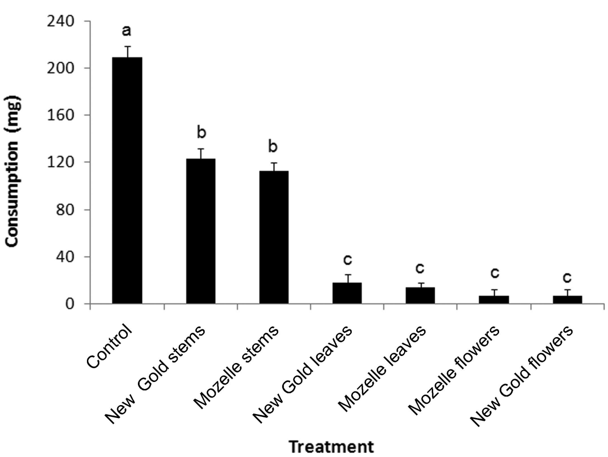

Fig. 5 Means (± SE) of consumption (mg) at 24 days after *R. viginicus* workers were exposed to the tested materials in a no-choice bioassay.

Antitermetic effects when dried lantana tissues were used as mulch barrier

The means of tunneling depth over time are presented in Figure 6. Lantana mulch-barriers significantly reduced workers' tunneling ability and increased the time for termites to reach the wood at the bottom of the experimental units ($P < 0.05$). It took 0.5 days for termites to tunnel through the 5-cm layer of sand, but 1.5, 5 and 10 days to penetrate through a 5-cm mulch-barrier of flowers, stems and leaves, respectively. When the mulch-barrier thickness doubled to 10-cm, the time to tunnel through was increased to 6.5, 11 and 13.5 days, correspondingly. Close examination revealed that the majority of the tunnels passed through the mulch-barriers along the glass-tube wall, thus minimized the direct contact of termites with the mulch. Behaviorally, termites in lantana mulch-barrier treatments acted sluggishly and literately remained clustered together with little foraging activity. As the result, the consumptions of wood (Fig. 7) were significantly less in mulch-barrier treatments than control ($F > 64.6$, df = 3,20, $P < 0.05$). The amount of wood consumed was significantly lower in 10-cm mulch treatments than 5-cm mulch treatments; the lowest was observed in leaf treatment, followed by stem and flower treatments, and the highest in control. Additionally, the 10-cm mulch treatments led to significantly higher termite mortality than the 5-cm mulch treatments, which were higher than control ($P < 0.05$) (Fig. 8).

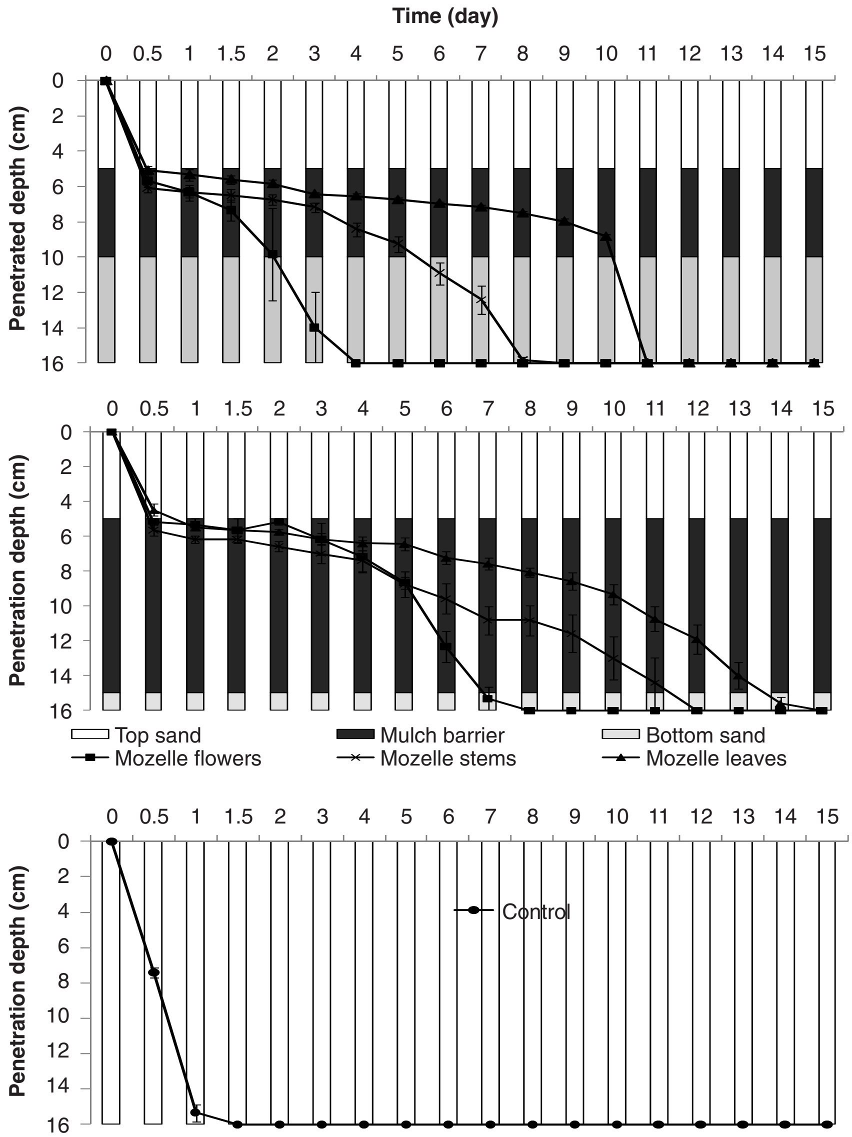

Fig. 6 Mean (± SE) penetration depth (cm) of *R.virginicus* workers in mulch-barrier bioassay. Top: 5-cm mulch-barrier sandwiched by 5 cm sand on the top and 6 cm sand at the bottom. Middle: 10-cm mulch-barrier sandwiched by 5 cm sand on the top and 1cm sand at the bottom. Bottom: 16-cm sand, control. Groups of 100 termites were introduced into the experimental units from the top.

Discussion

Promising antitermitic properties of *Lantana camara* dried tissues were indicated by the lower survival, running speed, live weight, body water content and wood consumption, in comparison to the control. The fact that termites clustered inside the tissues tested, rather than avoiding, seems to indicate a lack of repellency. However, confining termites in a no-choice condition is merely a short-term toxicological test to examine mortality and symptoms of intoxication, and was not designed to determine repellency of materials. To test for repellency, termites should be provided choices or at least with a niche isolated from contact with the test material. Termites gathering inside the moistened tissues could be due to a lack of repellency of the tissues or because the preference of termites to moisture and physical touching/harboring (Green *et al.*, 2005) had overridden the repellent effect of the tissues. Although the results from this study are not intended for determining the qualities of the

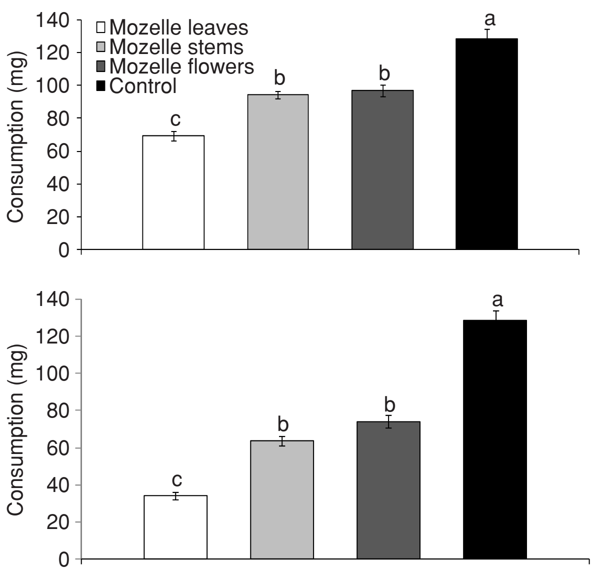

Fig. 7 Means (± SE) of wood consumption (mg) for *R. viginicus* workers after 24 days foraging in the 5 cm (Top) and 10 cm (Bottom) mulch-barrier experimental units. Means followed by different letters are significantly different ($P < 0.05$).

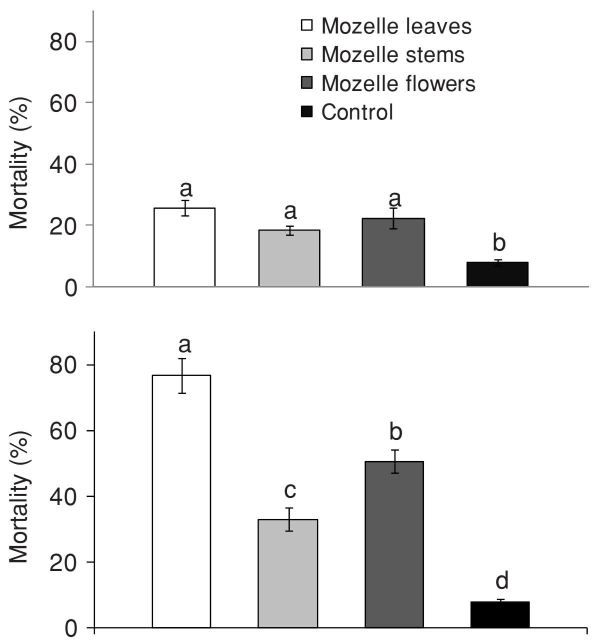

Fig. 8 Means (± SE) of mortality of *R. viginicus* workers after 24 days foraging in the 5 cm (Top) and 10 cm (Bottom) mulch-barrier experimental units. Means followed by different letters are significantly different ($P < 0.05$).

antitermitic activity, the measured mortality and physiological changes could be the reactions of termites to the toxic, antifeeding and/or repellent effects of lantana tissues. Hu *et al*. (2010) reported that 25-day starvation produced a mortality of ≈ 40%, which is lower than any of the mortality results from 24-day exposure to the test materials (leaves: 77.2%–89.2%; flowers: 65%–73.8%; stems: 55%–58%). The greater mortality of termites exposed to lantana tissues, in comparison with control, indicates the toxic property of both leaves and stems and the leaves are more toxic than stems. The lesser consumption of lantana tissues compared with SYP could result from their antifeeding and/or repellent activity, or cellulose preference of termites to SYP. The antitermitic activity in flowers is inconclusive because the high mortality after 16 days could be a result of fungal infection or toxic effect. Many previous reports have described insecticidal activities of *L. camara* extracts and essential oils, including termiticidal activity reported recently by Verma and Verma (2006). The only report on insectidical effect of *L. camara* plant parts was by Ogendo *et al*. (2004). It was reported that dried ground powders of lantana leaves and stems could significantly reduce insect damage to stored maize grains and such botanical treatment did not affect the grain color and odor during a 5-month testing period.

Lantana camara whole plant, plant parts and essential oils have been studied for their chemical compositions (Sharma & Sharma, 1989; Ghisalberti, 2000; Ganjewala *et al*., 2009). Chemical compositions are reported to vary in different *L. camara* varieties, cultivars and plant parts; they are also reported to be influenced by geographical and seasonal factors as well as the developmental stages of the concerned plant (Sharma & Sharma, 1989; Randrianalijaona *et al*., 2005; Ganjewala *et al*., 2009). The major chemical constituents of *L. camara* are in the groups of alkaloids, terpenoids, flavonoids and phenolics. Some of these compounds have been described as being responsible for biological activity (Verma & Verma, 2006; Kumar & Maneemegalai, 2008; Dua *et al*., 2010). Thus the different antitermitic activities between Mozelle and New Gold, as well as between lantana tissues, could be the result of their chemical composition differences.

Mulches are materials spread over the soil surface to provide insulation during extreme temperatures to inhibit weed growth, protect soil from erosion and improve soil hydraulic properties (Munir, 1996; Ghisalberti, 2000; Bhushan & Sharma, 2005). Organic mulches such as leaves, wood chips, pine bark and pine needles are the most widely used mulch to top soils previously treated with termiticides in landscaping and around homes, and as a result, providing a bridge for termites to cross over the treated soil and to infest residential homes (Long *et al.*, 2001). Such organic mulches are also at risk for attack by termites because they are mainly composited of cellulose and create a hospitable environment by conserving moisture. Being a popular fast-growing ornamental, *L. camara* planted around homes and in landscapes is frequently pruned. Due to its attractive appearance, homeowners who are aware of its antiteritic activities have had great interest to know if the lantana debris placed around the perimeter of a structure as mulch would provide a barrier to subterranean termites. Results of the 25% dried lantana tissue mulch treatments show decreased termite tunneling and wood consumption, increased termite mortality, and a delayed penetration through the mulch barriers (5-cm and 10-cm) as compared to control. Previous research reported that termites were not able to tunnel across a 5-cm mulch barrier of 25% fresh *L. camara* tissues in a 3-week test period (Ding & Hu, 2010). This could well be attributed to the differences in biochemical and chemical composition between the oven-dried and fresh plant tissues and/or between the plant collection seasons of the two studies. The current study collected and tested oven-dried tissues in November (winter); the previous work evaluated fresh tissues in June (summer). Chemical composition, in particular secondary metabolities, or allelochemicals, of plant tissues is known to vary between different environments, season, region and even time of day (Ralijerson *et al.*, 2005; Randrianalijaona *et al.*, 2005; Sousa *et al.*, 2010). The variation in chemical composition among the cultivars, and throughout a growing season, would affect biological activity. Furthermore, different experimental designs were used in our current and previously reported studies. The previous study provided a food substrate (SYP) in the arena where termites were introduced, so that termites did not have to penetrate the mulch-barrier to reach food. In particular, termites had to tunnel through the mulch barrier to reach a food source (SYP) in the current study. The current study showed that the thicker the mulch barrier, the slower the termite penetration and the higher the mortality.

In conclusion, the results support our hypothesis that dried lantana tissues possess promising antitermitic activities when used as a mulch barrier, which may be used as critical baseline information for further studies. Future studies will investigate the chemical composition differences between lantana cultivars and tissues, as well as between oven-dried and fresh tissues. Moreover, studies are needed to evaluate the antitermitic effects of the extracts and essential oils from different lantana tissues. However, conclusive recommendations on their use can only be made after the effects of the plants on the environmental and safety are ascertained.

Acknowledgments

We thank Lisha Li, Charles Hesselein, and Nancy Wagner for helpful comments and suggestions on early versions of this manuscript. We thank Lan Luo for technical support in laboratory experiments and Yuqing Fan for collecting lantana tissues. This research was jointly supported by the Urban Pest Management Program at Auburn University, USA, and the International Cooperation Program for Young Scientist, Shandong Province, China.

References

Abdel-Hady, N.M., Abdel-Halim, A.S. and Al-Ghadban, A.A. (2005) Chemical composition and insecticidal activity of the volatile oils of leaves and flowers of *Lantana camara* L. cultivated in Egypt. *Journal of Egypt Society of Parasitology*, 35, 687–698.

Becker, G. (1966) Spurfolge-Reaktion von Termiten auf Glycolverbindung. *Zeitschrift für Angewandte Zoologie*, 53, 495–498.

Begum, S., Wahab, A., Siddiqui, B.S. and Qamar, F. (2000) Nematicidal constituents of the aerial parts of *Lantana camara*. *Journal of Natural Products*, 63, 756–767.

Bhushan, L. and Sharma, P.K. (2005) Long-term effects of lantana residue additions on water retention and transmission properties of a medium-textured soil under rice-wheat cropping in northwest India. *Soil Use and Management*, 21, 32–37.

Chen, J., Henderson, G. and Laine, R.A. (1998) Isolation and identification of 2-phenoxyethanol from a ballpoint pen ink as a trail-following substance of *Coptotermes formosanus* Shiraki and *Reticulitermes* sp. *Journal of Entomological Science*, 33, 91–105.

Cheng, S.S., Wu, C.L., Chang, H.T., Kao, Y.T. and Chang, S.T. (2004) Antitermitic and antifungal activity of essential oil of *Calocedrus formosana* leaf and its composition. *Journal of Chemical Ecology*, 30, 1957–1967.

Ding, W. and Hu, X.P. (2010) Antitermitic effect of the *Lantana camara* plant on subterranean termites (Isoptera: Rhinotermitidae). *Insect Science*, 17, 427–433.

Dua, V.K., Gupta, N.C., Pandey, A.C. and Sharma, V.P. (1996) Repellency of *Lantana camara* flowers against *Aedes mosquitoes*. *Journal of the American Mosquito Control Association*, 12, 406–413.

Dua, V.K., Pandey, A.C. and Dash, A.P. (2010) Adulticidal activity of essential oil of *Lantana camara* leaves against mosquitoes. *Indian Journal of Medical Research*, 131, 434–439.

Duke, S.O. (1990) Natural pesticides from plants. *Advances in New Crops* (eds. J. Janick & J.E. Simon), pp. 511–517. Timber Press, Portland, Ore.

EPA (2000) *Pesticide Registration (PR) Notice 2000–6*. US Environmental Protection Agency, Washington, DC.

Fokialakis, N., Osbrink, W.L.A., Mamonov, L.K., Gemejieva, N.G., Mims, A.B., Skaltsounis, A.L., Lax, A.R. and Cantrell, C.L. (2006) Antifeedant and toxicity effects of thiophenes from four *Echinops* species against the Formosan subterranean termite, *Coptotermes formosnaus*. *Pest Management Science*, 62, 832–838.

Forschler, B.T. (1998) Subterranean termite biology in relation to prevention and removal of structural infestation. *NPMA Research Report on Subterranean Termites* (National Pest Management Association), pp. 31–52. Dunn Loring, VA.

Forschler, B.T. and Jenkins, T.M. (2000) Subterranean termites in the urban landscape: understanding their social structure is the key to successfully implementing population management using bait technology. *Urban Ecosystems*, 4, 231–251.

Ganapaty, S., Thomas, P.S., Fotso, S. and Laatsch, H. (2004) Antitermitic quinines from *Diospyros sylvatica*. *Phytochemistry*, 65, 1265–1271.

Ganjewala, D., Sam, S. and Khan, K.H. (2009) Biochemical compositions and antibacterial activities of *Lantana camara* plants with yellow, lavender, red and white flowers. *EurAsian Journal of BioSciences*, 3, 69–77.

Ghisalberti, E.L. (2000) *Lantana camara* L. (Verbenaceae). *Fitoterapia*, 71, 467–486.

Green, J.M., Scharf, M.E. and Bennett, G.W. (2005) Impacts of soil moisture level on consumption and movement of three sympatric subterranean termites (Isoptera: Rhinotermitidae) in a laboratory assay. *Journal of Economic Entomology*, 98, 933–937.

Hernández, T., Canales, M., Avila, J.G., García, A.M., Martínez, A., Caballero, J., de Vivar, A.R. and Lira, R. (2005) Composition and antibacterial activity of essential oil of *Lantana achyranthifolia* Desf. (Verbenaceae). *Journal of Ethnopharmacology*, 96, 551–554.

Hu, X.P. (2005) Evaluation of efficacy and nonrepellency of indoxacarb and fipronil treated soil at various concentration and thicknesses against two subterranean termites (Isoptera: Rhinotermitidae). *Journal of Economic Entomology*, 98, 509–517.

Hu, X.P. and Appel, A.G. (2004) Seasonal variation of critical thermal limits and temperature tolerance in Formosan and Eastern subterranean termites (Isoptera: Rhinotermitidae). *Environmental Entomology*, 33, 197–205.

Hu, X.P. and Hickman, B. (2006) Exterior perimeter plus limited interior treatments with fipronil as an IPM option for subterranean termite management. *International Pest Control*, 48, 200–203.

Hu, X.P., Song, D. and Gao, X. (2010) Biological changes in the Eastern subterranean termite, *Reticulitermes flavipes* (Isoptera: Rhinotermitidae) and its protozoa following starvation. *Insectes Sociaux*, DOI: 10.1007/s00040-010-0114-1.

Kong, C.H., Wang, P., Zhang, C.X., Zhang, M.X. and Hu, F. (2006) Herbicidal potential of allelochemicals from *Lantana camara* against *Eichhornia crassipes* and the alga *Microcystis aeruginosa*. *Weed Research*, 46, 290–295.

Kumar, M.S. and Maneemegalai, S. (2008) Evaluation of larvicidal effect of *Lantana camara* Linn against mosquito species *Aedes aegypti* and *Culex quinquefasciatus*. *Advances in Biological Research*, 2, 39–43.

Lajide, L., Escoubas, P. and Mizutani, J. (1995) Termite antifeedant activity in *Detarium microcarpum*. *Phytochemistry*, 40, 1101–1104.

Long, C.E., Thorne, B.L., Breisch, N.L. and Douglass, L.W. (2001) The effect of organic and inorganic landscape mulches on subterranean termite foraging activity. *Enviromental Entomology*, 30, 832–836.

Munir, A.A. (1996) A taxonomic review of *Lantana camara* L. and *L. montevidensis* (Spreng.) Briq. (Verbenaceae) in Australia. *Journal of the Adelaide Botanic Gardens*, 17, 1–27.

Nix, K.E., Henderson, G., Zhu, B.C.R. and Laine, R.A. (2006) Evaluation of vetiver grass root growth, oil distribution, and repellency against Fromosan subterranean termites. *HortScience*, 41, 167–171.

Okon, O.O., Sadimenki, A.P., Asekun, O.T. and Afolayan, A.J. (2008) The effects of drying on the chemical components of essential oils of *Calendula officinalis* L. *African Journal of Biotechnology*, 7, 1500–1502.

Ogendo, J.O., Deng, A.L., Belmain, S.R., Walker, D.J. and Musandu, A.A.O. (2004) Effect of insecticidal plant materials, *Lantana camara* L. and *Tephrosias vogelii* Hook on the quality parameters of stored maize grains. *The Journal of Food Technology in Africa*, 9, 29–35.

Park, I.K. and Shine, S.C. (2005) Fumigant activity of plant essential oils and components form garlic (*Allium sativum*) and clove bud (*Eugenia caryophyllata*) oils against the Japanese termite (*Reticulitermes speratus* Kolbe). *Journal of Agricultural and Food Chemistry*, 53, 4388–4392.

Peterson, C.J. and Ems-Wilson, J. (2003) Catnip essential oil as a barrier to subterranean termites (Isoptera: Rhinotermitidae) in the laboratory. *Journal of Economic Entomology*, 96, 1275–1282.

Ralijerson, L.B., Rabehaja, D.J.R., Rajaonarison, J.F., Urverg, S.R., Hérent, M.F., Mvar-Manga, H. and Tilquim, B. (2005) Comparison between the fresh and dry essential oil of *Helichrysum faradifani* Scott Elliot from Madagascar. *Journal of Essential Oil Research*, 17, 597–600.

Randrianalijaona, J.A., Ramanoelina, P.A.R., Rasoarahona, J.R.E. and Gaydou, E.M. (2005) Seasonal and chemotype influences on the chemical composition of *Lantana camara* L. essential oils from Madagascar. *Analytica Chimica Acta*, 545, 46–52.

Ross, I.A. (1999) *Medicinal Plants of the World. Chemical Constituents, Traditional and Modern Medical Uses*. Humana Press, New Jersey. 487 pp.

Sakasegawa, M., Hori, K. and Yatagai, M. (2003) Composition and antitermite activities of essential oil from *Melaleuca* species. *Journal of Wood Science*, 49, 181–187.

Saxena, R.C., Dixit, O.P. and Harshan, V. (1992) Insecticidal action of *Lantana camara* against *Callosobruchus chinensis* (Coleoptera: Bruchidae). *Journal of Stored Products Research*, 28, 279–281.

Scheffrahn, R.H. and Su, N.Y. (1994) Key to soldiers and winged adult termites (Isoptera) of Florida. *Florida Entomologist*, 77, 460–474.

Sharma, O.P., Makkar, H.P.S. and Dawra, R.K. (1988) A review of the noxious plant *Lantana camara*. *Toxicon*, 26, 975–987.

Sharma, O.P. and Sharma, P.D. (1989) Natural products of the lantana plant– the present and prospects. *Journal of Scientific and Industrial Research*, 48, 471–474.

Sharma, O.P., Sharma, S., Pattabhi, V., Mahato, S.B. and Sharma, P.D. (2007) A review of the hepatotoxic plant *Lantana camara*. *Pharmaceutical Science*, 37, 313–352.

Sharma, R.N., Tare, V. and Pawan, P. (1999) Toxic action of some plant extracts against selected insect pest and vectors. *Pestology*, 23, 30–37.

Singh, G., Singh, O.P., De Lampasona, M.P. and Catalán, C.A.N. (2003) Studies on essential oils. Part 35: Chemical and biocidal investigations on *Tagetes erecta* leaf volatile oil. *Favour and Fragrance Journal*, 18, 62–65.

Sousa, E.O., Colares, A.V., Rodrigues, F.F.G., Campos, A.R., Lima, S.G. and Costa, J.G.M. (2010) Effect of collection time on essential oil composition of *Lantana camara* Linn (Verbenaceae) growing in Brazil northeastern. *Records of Natural Products*, 4, 31–37.

Su, N.Y. (2002) Novel technologies for subterranean termite control. *Sociobiology*, 40, 95–101.

Systat Software Inc. (2007) *SigmaPlot® version 10 [computer program]*. Systat Software inc., Richmond, California.

Tellez, M.R., Khan, I.A., Kobaisy, M., Schrader, K.K., Dayan, F.E. and Osbrink, W. (2002) Composition of the essential oil of *Lepidium meyanii* (Walp.). *Phytochemistry*, 61, 149–155.

Verma, D.K., Singh, S.K., Nath, G. and Tripathi, V. (1997) Antimicrobially active triterpenoids from lantana species. *Indian Drugs*, 34, 390–392.

Verma, M., Sharma, S. and Prasads, R. (2009) Biological alternatives for termite control: a review. *International Biodeterioration & Biodegradation*, 63, 959–972.

Verma, R.K. and Verma, S.K. (2006) Phytochemical and termiticidal study of *Lantana camara* var. *aculeata* leaves. *Fitoterapia*, 77, 466–468.

Zhu, B.C.R., Henderson, G., Chen, F., Fei, H. and Laine, R.A. (2001) Evaluation of vetiver oil and seven insect-active essential oils against the Formosan subterranean termite. *Journal of Chemical Ecology*, 27, 1617–1625.

Accepted November 4, 2010