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Acaricidal and oviposition deterring effects of santalol identified in sandalwood oil against two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae)

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Abstract Thirty-four plant essential oils were screened for their acaricidal and oviposition deterrent activities against two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), in the laboratory using a leaf-dip bioassay. From initial trials, sandalwood and common thyme oils were observed to be the most effective against TSSM adult females. Subsequent trials confirmed that only sandalwood oil was significantly active (87.2 ± 2.9% mortality) against TSSM adult females. Sandalwood oil also demonstrated oviposition deterring effects based on a 89.3% reduction of the total number of eggs on leaf disks treated with the oil. GC–MS analysis revealed that the main components of the sandalwood oil were α-santalol (45.8%), β-santalol (20.6%), β-sinensal (9.4%), and *epi*-β-santalol (3.3%). A mixture of α- and β-santalol (51.0:22.9, respectively) produced significantly higher mortality (85.5 ± 2.9%) and oviposition deterrent effects (94.7% reduction in the number of eggs) than the control. Phytotoxicity was not shown on rose shoots to which a 0.1% solution of sandalwood oil was applied.

Keywords *Tetranychus urticae* · Essential oil · Natural acaricide · Sandalwood · Santalol · Common thyme

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Introduction

The two-spotted spider mite (TSSM), *Tetranychus urticae* (Acari: Tetranychidae), is a serious pest on various greenhouse vegetables and food crops (Lee et al. 2003b; Song et al. 1995; Takafuji et al. 2000). Damage by TSSM can cause direct effects including small spots on the leaf due to chlorophyll depletion, webbing, defoliation, necrosis in young leaves and stems; indirect effects including decreased photosynthesis and transpiration, and finally death of the whole plant (Badawy et al. 2010).

Control of the TSSM with conventional (chemical or non-chemical) acaricides is difficult due to its ability to rapidly develop resistance to the acaricides used (Cho et al. 1995; Song et al. 1995; Stavrinides and Hadjistylli 2009; Badawy et al. 2010). TSSM has evolved resistance to an estimated 80 or more acaricides to date (Van Pottelberge et al. 2009). Continuation of conventional acaricide use against TSSM can cause serious adverse effects against humans, the environment, and non-target organisms, including insects and predatory mites such as *Phytoseiulus persimilis* (Acari: Phytoseiidae) (Kumral et al. 2010). However, control of TSSM depends largely on the use of conventional acaricides. Therefore, new control technologies and relevant tactics to reduce the use of conventional pesticides are needed to achieve sustainable management of TSSM (Isman 2001; Lee et al. 2003a).

Semiochemicals are promising candidates to achieve environmentally friendly pest management. Several essential oils have toxic activities against various pests including TSSM. Many plant-derived secondary metabolites are toxic to different species of spider mites, including TSSM (Choi et al. 2004; Miresmailli et al. 2006). For example, extracts of *Capparis aegyptia* (Capparaceae) was toxic to TSSM females (Hussein et al. 2006). Crude extracts from

Capsicum (Solanaceae) fruits and from subfamilies *Ajugoideae*, *Scutellarioideae*, *Chloanthoideae*, *Viticoideae*, and *Nepetoideae* (Lamiaceae) were repellent and toxic to TSSM (Antonious et al. 2006; Rasikari et al. 2005). Extracts of *Ailanthus altissima* L. leaves and *Convolvulus krauseanus* Regel and Schmalh roots were also found to be active against TSSM (Chermenskaya et al. 2010), while leaf and seed extracts from *Datura stramonium* had demonstrated acaricidal, repellent, and oviposition deterrent activities against the spider mite (Kumral et al. 2010).

The goal of this study was to find new materials for potential use in controlling TSSM. Thus, 34 commercially available plant essential oils were screened against TSSM adult female. GC–MS analysis was used to identify the main constituents of sandalwood oil, and then a mixture of two main constituents, α- and β-santalol, was tested for its acaricidal and oviposition deterring effects in the laboratory.

Materials and methods

Mites and plants

Acaricide-susceptible TSSM, *T. urticae*, was obtained from Gyeongnam Agricultural Research & Extension Services in 2007. They were maintained in the absence of acaricides at 25 ± 2°C, 60 ± 10% RH, and 16L:8D on kidney bean (*Phaseolus vulgaris* var. *humilis*) plants in the insectary at the Insect Chemical Ecology Laboratory, Gyeongsang National University, Korea. Adult females (2-3-day old) were used in laboratory bioassays to assess the adulticidal effects of the essential oils and santalol. To obtain vigorous *T. urticae*, fresh kidney bean plants bearing 3-4 leaves were placed between the bean plants infested with *T. urticae* for 24–48 h. The TSSM adult females moved onto the fresh leaves and sucked plenty of fresh juice were used for experiments.

Essential oils and compounds

Thirty-four commercial plant essential oils were purchased from HerbMall Co. Ltd., (Seoul, Korea). Table 1 shows names of the essential oils used in these experiments, their extraction methods, and plant parts extracted. Santalol (a mixture of α- and β-santalol at 51:23 ratio) was purchased from MP Bio Inc. (Thuringer, Germany).

Laboratory bioassay of essential oils and santalol

200 µl of each essential oil or santalol was dissolved in 20 ml ethanol (97%, Burdik and Jackson, USA), and then mixed with 180 ml distilled water to give a 0.1% essential oil solution. Triton X-100 (0.009%) was added to the diluted solution. A mixture of ethanol (20 ml), Triton

Table 1 List of commercial essential oils, their scientific name, what plant part they originated from and the method used to extract them

Essential oil	Scientific name	Plant part used	Extraction method
Bergamot	*Citrus bergamia*	Zest	P
Bitter orange	*Citrus aurantium* var. *armara*	Bud	S
Black pepper	*Piper nigrum*	Fruit	S
Blue gum	*Eucalyptus globulus*	Leaf	S
Cajeput tree	*Melaleuca leucadendron*	Leaf	S
Cedarwood	*Cedrus atlantica*	Wood	S
Cinnamon	*Cinnamomum zeylandicum*	Bark	S
Citronella	*Cymbopogon winterianus*	Grass in flower	S
Clary sage	*Salvia sclarea*	Leaf	P
Clove bud	*Syzygium aromaticum*	Bud	S
Common thyme	*Thymus vulgaris*	Flower	S
Cypress	*Cupressus sempervirens*	Branch	S
Eucalyptus	*Eucalyptus radiate*	Leaf	S
Frankincense	*Boswellia carterii*	Sap	S
Geranium	*Pelargonium roseum*	Aerial part	S
Ginger	*Zingiber officinale*	Rhizome	S
Grapefruit	*Citrus paradisi*	Zest	P
Hyssop	*Hyssopus officinalis*	Leaf	S
Juniper	*Juniperus communis*	Fruit	S
Lemon peel	*Citrus limon*	Zest	P
Lemongrass	*Cymbopogon citratus*	Plant	S
Myrrh	*Commiphora myrrha*	Flower & wood	S
Niaouli	*Melaleuca viridiflora*	Leaf	P
Patchouli	*Pogostemon cablin*	Leaf	S
Peppermint	*Mentha piperita*	Leaf	S
Rosemary	*Rosmarinus officinalis*	Leaf and flower	S
Sandalwood	*Santalum austrocaledonicum*	Wood	S
Scotch pine	*Pinus sylvestris*	Needle	S
Sweet basil	*Ocimum basilicum*	Flower and leaf	S
Sweet marjoram	*Origanum majorana*	Flower and leaf	S
Sweet orange	*Citrus sinensis*	Zest	P
Tea-tree	*Melaleuca alternifolia*	Leaf	S
True lavender	*Lavandula vera*	Leading flower	S
Ylang-ylang	*Cananga odorata*	Flower	S

P pressure extraction, *S* steam distillation

X-100 (0.009%), and distilled water (180 ml) was used as a negative control.

A leaf-dip method was used for bioassays with the 34 essential oils. Each experimental unit was kept in a plastic Petri dish (60 × 15 mm) and consisted of a treated kidney bean leaf disk (30-mm diameter) placed on cotton pads that had been soaked in distilled water. Thirty adult females were placed on the lower surface of a bean leaf disk with a fine brush. The mites were allowed to acclimate for 30 min. The bean leaf disks were dipped individually in the 0.1% essential oil treatment for 5 s and dried at ambient temperature in the laboratory for 20 min, then placed upside down on the cotton pad in the Petri dish. Petri dishes were maintained at 24 ± 2°C, 40–80% RH, and 16L:8D. Numbers of live and dead TSSM adults were counted at 24 h post-treatment. TSSM adults were considered dead if no movement was apparent after probing with the tip of a fine brush. The number of TSSM eggs was counted under a dissecting microscope (Stemi 2000, Carl Zeiss, Germany). Each treatment was replicated three times. Given that the major compounds in sandalwood oil were identified as α- and β-santalol, santalol (a mixture of α- and β-santalol) was tested for its acaricidal activity against *T. urticae* using the same leaf-dip method described above.

Phytotoxicity test

The phytotoxicity of sandalwood oil was tested on rose shoots (*Rosa hybrida*, L. cv. "Peace One") using a 0.1% solution (sandalwood oil 200 µl + ethanol 20 ml + distilled water 180 ml, and Triton X-100). Rose shoots bearing flowers, leaves, and buds were obtained from the Department of Horticulture, Gyeongsang National University, Korea. The sandalwood oil solution was sprayed on rose shoots in a triangle flask (500 ml) using a 500 ml hand sprayer until run off. Each rose shoot was sprayed with approximately 30 ml of solution. Control rose shoots were sprayed with 10% ethanol solution (ethanol 20 ml + distilled water 180 ml + Triton X-100). A negative control was also included in which rose shoots were not sprayed. Rose shoots were then arranged in a 500 ml triangle flask filled with tap water in a laboratory maintained at 26 ± 2°C, 16L:8D. Phytotoxicity was evaluated 24 h after treatment and categorized from grade 0 (no damage) to grade 4 (brown spots on whole leaves) (Miresmailli and Isman 2006). Each treatment was replicated three times.

Chemical analysis of sandalwood oil

As sandalwood oil demonstrated the highest acaricidal activity against *T. urticae* adults, it was subjected to gas chromatography/mass spectrometry (GC–MS) to identify major constituents in the oil. This was conducted using a QP2010 plus GC–MS, (Shimadzu, Japan) using a 30 m × 0.25 mm i.d. × 0.25 µm DB-WAX capillary column (J & W Scientific Co., USA). The temperature program started at 40°C and increased to 200°C at 2°C/min. Split injection (1:10 ratio) was performed with 1 µl sample volume using an auto-sampler. The temperature was 220°C at the injection site, and helium was used as a carrier gas at a flow rate of 1 ml/min. The mass detector was fitted with an Electron Ionization source operated at 70 eV with a source temperature of 180°C, and mass spectra were recorded in the range of m/z 38–300 at 1 scan/0.75 s. Essential oils diluted in diethyl ether (0.5% v/v) were used for chemical analysis. Identification of compounds in sandalwood oil was based on the mass spectral information in a mass spectra library (Wiley Registry of Mass Spectra Data, 2000), and peaks of the samples were further confirmed by comparison with mass spectra of standards.

Statistical analysis

Corrected mortality (%) of adult female transformed by Abbott's formula and the number of eggs laid by adult females were subjected to analysis of variance (ANOVA), and the differences among treatment means were compared using a Tukey's studentized range test ($P < 0.05$). All statistical analyses were conducted using SAS (SAS Institute 1999)

Results

Acaricidal activity of essential oils

Mortality due to treatment with 34 essential oils and the number of eggs laid by the females treated with those oils did not differ significantly ($P < 0.05$) from the control (2.9%), although it approached significance ($P = 0.0588$) (Table 2). However, the mortality caused by treatment with sandalwood oil (89.4%) was highest, followed by that from common thyme oil (62.8%). In addition, the total number of eggs laid was lowest on the leaf disk dipped in the sandalwood oil solution. The number of eggs per live adult did not differ between oil treatments.

Because sandalwood and common thyme oil produced higher TSSM mortality compared with other oils, the acaricidal activities of the two oils were retested. Sandalwood oil was significantly more effective than common thyme oil and the two controls (0.0 and 1.1%) (Table 3). Mortality of the sandalwood oil treatment was higher and total number of eggs of the treatment was lower than that of common thyme oil. Mortality and the total number of eggs laid by TSSM adults treated with sandalwood oil in the 2nd trial were similar to those of

Table 2 Acaricidal activity of essential oils against *Tetranychus urticae* adult females at 0.1% concentration 24 h after treatment (Mean ± SD)

Essential oils	Corrected mortality (%)	Total no. of eggs	No. of eggs per live adult
Bergamot	11.0 ± 6.0	225.0 ± 24.1	10.2 ± 0.9
Bitter orange	21.4 ± 21.5	205.3 ± 58.1	10.1 ± 0.8
Black pepper	22.8 ± 20.0	239.0 ± 76.7	12.0 ± 1.2
Blue gum	19.7 ± 22.5	209.7 ± 50.9	9.6 ± 1.9
Cajeput tree	23.5 ± 11.4	201.3 ± 13.3	9.5 ± 1.4
Cedar wood	12.4 ± 6.7	224.0 ± 63.0	9.5 ± 3.2
Cinnamon	23.6 ± 20.6	211.0 ± 51.6	10.8 ± 1.6
Citronella	27.6 ± 20.7	192.3 ± 48.0	8.6 ± 1.7
Clary sage	7.1 ± 0.2	214.7 ± 77.5	8.7 ± 3.2
Clove bud	41.3 ± 36.3	174.3 ± 118.3	10.2 ± 0.9
Common thyme	62.2 ± 42.0	131.7 ± 151.4	17.3 ± 9.4
Cypress	28.9 ± 18.4	198.7 ± 55.5	10.7 ± 1.5
Eucalyptus	27.9 ± 21.7	201.0 ± 36.4	9.9 ± 2.2
Frankincense	24.8 ± 27.7	219.0 ± 98.3	10.3 ± 2.4
Geranium	30.0 ± 15.7	193.3 ± 13.1	10.6 ± 3.1
Ginger	11.9 ± 13.0	242.0 ± 41.1	10.2 ± 0.2
Grapefruit	30.6 ± 35.2	188.7 ± 70.8	11.7 ± 3.6
Hyssop	28.1 ± 22.3	196.7 ± 55.8	9.5 ± 1.7
Juniper	42.6 ± 21.8	128.0 ± 82.0	7.9 ± 3.4
Lemon peel	34.9 ± 37.9	129.3 ± 68.7	8.5 ± 1.7
Lemongrass	17.8 ± 9.5	210.3 ± 48.4	10.0 ± 4.0
Myrrh	22.8 ± 17.8	189.7 ± 70.2	8.9 ± 2.0
Niaouli	26.8 ± 30.7	213.0 ± 85.0	10.8 ± 0.4
Patchouli	20.3 ± 20.4	243.3 ± 86.0	10.9 ± 1.6
Peppermint	23.7 ± 18.2	215.7 ± 52.3	10.5 ± 1.8
Rosemary	11.7 ± 22.0	212.3 ± 33.3	9.3 ± 2.3
Sandalwood	89.2 ± 8.5	28.0 ± 10.0	13.2 ± 5.2
Scotch pine	50.4 ± 18.5	159.7 ± 53.5	14.6 ± 11.1
Sweet basil	21.0 ± 17.9	209.3 ± 62.4	10.5 ± 1.9
Sweet marjoram	7.1 ± 0.2	236.7 ± 18.6	9.5 ± 0.5
Sweet orange	45.6 ± 37.4	123.0 ± 51.9	9.4 ± 2.9
Tea-tree	28.6 ± 33.5	142.7 ± 70.5	7.7 ± 2.3
True lavender	26.1 ± 21.2	226.3 ± 85.7	11.0 ± 1.3
Ylang–Ylang	24.2 ± 14.9	221.7 ± 111.3	10.2 ± 4.2
EtOH + Triton-X + water	10.9 ± 4.4	227.0 ± 27.1	10.8 ± 1.3
Control	0.0	323.7 ± 52.0	13.1 ± 3.6
Statistics	$F = 1.46$	$F = 1.56$	$F = 0.89$
at $df = 35, 72$	$P = 0.0588$	$P = 0.0576$	$P = 0.6423$

the 1st trial. However, the effectiveness of common thyme oil decreased dramatically between the first and second experiments and did not cause any substantial mortality relative to the two controls.

Phytotoxicity

There was no evidence of phytotoxicity found on the flowers, foliage, buds, or stems of roses in response to the sandalwood oil treatment.

Chemical composition of sandalwood oil

Table 4 shows the GC–MS analysis of sandalwood oil. The GC–MS analysis revealed that the main constituents identified from sandalwood oil were α-santalol (45.8%), β-santalol (20.6%), β-sinensal (9.4%), and *epi*-β-santalol (3.3%).

Acaricidal activity of santalol

The effect of santalol against TSSM adult females is shown in Table 5. Mortality caused by dipping the leaf disks and

Table 3 Acaricidal activity of selected essential oils against *Tetranychus urticae* adult females at 0.1% concentration 24 h after treatment (Mean ± SD)

Treatment	Corrected mortality (%)	Total no. of eggs	No. of eggs per live adult
Sandalwood	87.0 ± 3.2 a[a]	33.3 ± 15.0 b	9.7 ± 2.8 a
Common thyme	4.5 ± 5.3 b	228.0 ± 62.5 ab	10.8 ± 1.0 a
EtOH + Triton-X + Water	0.0 ± 0.0 b	242.7 ± 76.0 a	8.6 ± 2.4 a
Control	0.0 b	311.3 ± 68.2 a	10.6 ± 2.1 a
Statistics	$F = 109.62$	$F = 11.74$	$F = 0.61$
at $df = 3, 8$	$P \leq 0.0001$	$P = 0.0027$	$P = 0.6249$

[a] Values followed by the same letter within a column are not significantly different at $P = 0.05$ (Tukey's HSD test)

Table 4 Chemical composition of sandalwood oil

Compound	Mass spectral data of sandalwood oil[a]	Retention time (min)		Composition (%)[b]	
		Sandalwood	Authentic sample	Sandalwood oil	Authentic sample
α-santalol	220, 202, 187, 147, 133, 122, 107, 94, 79, 77, 67, 55, 43	44.172	44.141	45.8	51.0
β-sinensal	220, 202, 147, 93, 79, 67, 55	44.624	44.609	9.4	9.9
Epi-β-santalol	202, 187, 161, 134, 122, 107, 94, 79, 77, 67, 55	46.619	46.597	3.3	3.1
β-santalol	220, 202, 189, 161, 147, 133, 122, 107, 94, 79, 77, 67, 55, 43	47.162	47.148	20.6	22.9

[a] Major fragments (EI mode)

[b] Data based on chromatogram peak areas

Table 5 Acaricidal activities of the main constituents of sandalwood oil against *Tetranychus urticae* adult females at 0.1% concentration 24 h after treatment (Mean ± SD)

Treatment	Corrected mortality (%)	Total no. of eggs	No. of eggs per live adult
Santalol[a]	85.5 ± 2.9 a[b]	18.3 ± 3.5 c	4.6 ± 0.3 c
EtOH + Triton-X + Water	0.0 ± 0.0 b	213.3 ± 10.1 b	8.7 ± 0.6 b
Control	0.0 b	348.0 ± 16.1 a	14.2 ± 1.0 a
Statistics	$F = 9121.2$	$F = 289.38$	$F = 149.35$
at $df = 3, 8$	$P \leq 0.0001$	$P \leq 0.0001$	$P \leq 0.0001$

[a] Santalol is a mixture of α- and β-santalol in the ratio of 51:23%

[b] Values followed by the same letter within a column are not significantly different at $P = 0.05$ (Tukey's HSD test)

spider mites in the santalol solution was significantly higher than those of the two controls (0.0%). The total number of eggs and the number of eggs laid by live females were significantly reduced by the santalol treatment.

Discussion

Much effort has been focused on plant essential oils as potential sources of insect control agents. Sandalwood (*Santalum album* L.) is one of the most valuable trees in the world (Fox 2000). It occurs naturally or may be cultivated in India (FAO 1995). The essential oil derived from sandalwood is typically used as a flavor component in many food products, including alcoholic and non-alcoholic beverages (Burdock and Carabin 2008).

The sandalwood oil tested in this study (0.1% solution) caused significant mortality (87.2%) in TSSM adults and significantly decreased the total number of eggs, proportionally according to the number of live versus dead females (Table 3). Lethality of sandalwood oil of the 2nd trial was similar to that of the 1st one. However, the lethality of common thyme oil in the 1st trial was much higher than in the 2nd one, possibly because of high variation among replications in the 1st trial (Tables 2, 3). Even though Miresmailli and Isman (2006) found that rosemary oil was toxic to TSSM with an LC_{50} of 13 ml/l (1.3% solution), our rosemary oil was not effective against TSSM

in this study. This result suggests that the essential oil of sandalwood trees may be used for effective management of TSSM. There are some other reports that plant-derived essential oils are effective to spider mites. Essential oils extracted from *Cuminum cyminum* L. and *Origanum syriacum* var *bevanii* (Holmes) Ietswaart have been demonstrated to be effective as greenhouse fumigants for the control of the carmine spider mite and the melon/cotton aphid (Tuni and Sahinkaya 1998). Essential oils obtained from some other aromatic plants showed toxic effects on insects and mites (Choi et al. 2004; Tripathi et al. 2000).

GC–MS analysis revealed that sandalwood oil primarily consisted of α-santalol (45.8%) and β-santalol (20.6%) (Table 4). The composition of α- and β-santalol in our sample oil was not different from the analyses of other researchers who reported that α-santalol (~46%) was more abundant than β-santalol (~20%) in sandalwood oil (Anonis 1998). Previous research has also shown that sandalwood oil consists almost exclusively of closely related sesquiterpenoids, in addition to the main constituents of α-santalol (≥43%) and β-santalol (≥18%), supporting the results observed here (Burdock and Carabin 2008).

The santalol solution demonstrated significant toxicity at 0.1% and significantly decreased the number of eggs laid by live TSSM adults (Table 5). Some previous studies reported that the acaricidal and/or insecticidal effects of plant essential oils were related to their chemical compositions (Pascual-Villalobus and Ballesta-Acosta 2003). The major constituents of essential oils have been effective in controlling various pests including TSSM. For example, thymol and carvacrol, the major compounds in thyme (*Thymus vulgaris* L.) and oregano (*Origanum vulgare* L.) essential oils, have been identified as potential insect antifeedants and oviposition deterrents against TSSM (El-Gengaihi et al. 1996) and tobacco cut-worm (*Spodoptera litura* Fabricius) (Isman et al. 2001). Several laboratory studies have described the acaricidal activity of essential oils and their major constituents (Basta and Spooner-Hart 2002; Cetin et al. 2009). However, no research has been reported on the effect of sandalwood oil and its major constituents against TSSM.

Jiang et al. (2009) indicates that the inactive constituents from *Litsea pungens* Hemsl. and *L. cubeba* (Lour.) Pers. (Lauraceae) have some synergistic effect on the active constituents and that, although not active individually, their presence is necessary to achieve full toxicity by contact against third-instar *Trichoplusia ni* larvae (Lepidoptera: Noctuidae). Also, Miresmailli et al. (2006) reported the acaricidal activity of *Rosmarinus officinalis* L. essential oil and blends of selected constituents indicated a synergistic effect among the active and inactive constituents against TSSM. In this study, we did not test the synergistic effects on TSSM of minor constituents in sandalwood oil which will possibly be valuable to be studied to get sufficient control efficacy.

Although plant-derived essential oils may be active against certain pests, one concern associated with their use is the possibility of plant injury or phytotoxicity (Arnason et al. 1993). In fact, many plant-derived essential oils are phytotoxic to vegetables and herbaceous and foliar plant material (Isman 1999). However, the extent of plant injury may be dependent on numerous factors, including the concentration of the compound, the rate at which it is applied, plant type, and which plant parts (e.g., leaves or flowers) are exposed during spray applications (Cloyd et al. 2009). In our test, sandalwood oil was not phytotoxic to flowers, foliage, buds, or stems of rose plant at a concentration of 0.1%.

In conclusion, this is the first study demonstrating that sandalwood oil and its constituents have acaricidal activities to TSSM, and decreased the number of eggs on treated leaves. Thus, sandalwood oil and santalol can likely be used for the sustainable management of TSSM on roses and possibly for susceptible greenhouse crops. However, this study only screened the essential oil and its constituents in the laboratory. Further studies are needed to further evaluate the acaricidal effects of the santalol in the field. It would also be valuable to test the efficacy of santalol against small and soft-bodied insect pests such as the western flower thrips, *Frankliniella occidentalis* Pergande, the cotton aphid, *Aphis gossypii* Glover, and the green peach aphid, *Myzus persicae* Sulzer, which are also major pests in many greenhouse crops.

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