Sensitivity of *Bemisia tabaci* (Hemiptera: Aleyrodidae) and the Generalist Predator *Orius albidipennis* (Hemiptera: Anthocoridae) to Vapors of Essential Oils[1]

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Abstract In recent years, plant derivatives such as essential oils have been one of the most promising sources for the substitution of chemical insecticides for pest management. A laboratory assessment was conducted to find the fumigant toxicity of *Artemisia sieberi* Besser, *Pelargonium roseum* Andrews, and *Ferula gummosa* Boiss essential oils against the sweetpotato whitefly *Bemisia tabaci* Gennadius and its predator, *Orius albidipennis* Reuter. The responses varied depending on oil type and insect species. Based on 24-h median lethal concentration (LC_{50}) values, all the essential oils showed similar toxicity to *B. tabaci*. *Ferula gummosa* essential oil had lesser toxicity (LC_{50}, 3.46 $\mu l l^{-1}$ air) than *P. roseum* (LC_{50}, 0.95 $\mu l l^{-1}$ air) and *A. sieberi* (LC_{50}, 0.62 $\mu l l^{-1}$ air) against *O. albidipennis*. The toxicity of the oils increased for both insects by increasing the exposure time from 3 h to 48 h. A comparison of the essential oils' toxicity on the two insects showed a lower susceptibility of *O. albidipennis* to the tested essential oils, which is a promising result for the control of *B. tabaci* in integrated pest management programs.

Key Words whitefly, fumigant toxicity, *Orius* sp., botanical insecticide

The sweetpotato whitefly *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae) is one of the most serious pests in greenhouses and cropping systems throughout the world (Oliveira et al. 2001, Yang et al. 2010). Whitefly nymphs (which are sessile) and adults feed on phloem, causing chlorosis of infested leaves (Yang et al. 2010). The production of honeydew by nymphs and development of sooty molds reduce crop yield (Schuster et al. 1996). The use of insecticides has been the common technique for the control of *B. tabaci*. However, the pest continues to show resistance to a range of chemical insecticides, including imidacloprid, pyrethroid, acetamiprid, and nitenpyram (Li et al. 2011) The extremely rapid rate of population increase and the protected location of this species on the lower surfaces of the leaves, in addition to the development of resistance to chemical insecticides, have prompted the search for alternative control measures such as biological agents (Zandi-Sohani et al. 2009).

Generalist arthropod predators are famous for their capability to control phytophagous insects and mites in various cultivated crops (Symondson et al.

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2002). Most species of the family Anthocoridae are polyphagous predators and play an important role in the management of several pests such as mites, aphids, whiteflies, and moths in greenhouses and fields (Biondi et al. 2012). *Orius albidipennis* Reuter (Hemiptera: Anthocoridae) has been reported as a widely distributed species in the Mediterranean basin, Western Europe, Israel, and Canary Islands (Carnero et al. 1993, Chyzik et al. 1995, Pericart 1972). It is also distributed in different parts of Iran (Erfan and Ostovan 2005). Nymphs and adults of this species can attack eggs and immature stages of various arthropods, including whiteflies (Sobhy et al. 2010). Mass rearing and release of *Orius* spp. predators for use against horticultural and greenhouse crop pests have been reported from Eurasia and North America (Bosco et al. 2008, Weintraub et al. 2011).

Although biological control agents are potentially effective against crop pests, chemical insecticides are usually required to manage unexpected outbreaks. These chemical pesticides, which are usually toxic to beneficial organisms, also affect agricultural sustainability (Desneux et al. 2007, Wilson and Tisdell 2001) and are not compatible with biological control. In recent years, there have been some activities to develop pesticides of natural origin, which are more environmentally friendly than chemical pesticides (Isman 2000). Essential oils, which are obtained by steam distillation of aerial plant parts, are one of the promising alternative sources for pest control. These potential compounds can be applied to the resting and hiding sites of *B. tabaci* in the same manner as conventional insecticides (Chae et al. 2014). They exhibit several modes of action and can affect pests as repellents, antifeedants, fumigants, and contact toxins as a disruptor of the cuticle. They can also reduce growth and fecundity (Akhtar and Isman 2004, Isman 2000, Isman 2006, Sertkaya et al. 2010). They are often biodegradable into nontoxic products and have few or no harmful effects on no-target organisms and the environment. They are also widely available, and some of them are relatively inexpensive (Isman 2000).

Several laboratory studies have evaluated the toxic effects of essential oils on *B. tabaci* and different species of genus *Orius*. Some of these studies have focused on the fumigant toxicity of essential oils on *B. tabaci* adults (Chae et al. 2014, Liu et al. 2014, Zandi-Sohani 2011). However, other investigations have focused on the contact toxicity of essential oils against adults (Kim et al. 2011, Yarahmadi et al. 2013) and immatures (Yang et al. 2010). Fumigant and contact toxicity properties of various plant essential oils have been assessed against *Orius strigicollis* (Poppius) (Kim et al. 2014, Yi et al. 2006), *Orius insidiosus* (Say) (Bostanian et al. 2005), and *O. albidipennis* (Faraji et al. 2016). The objective of this work was to assess the fumigant toxicity of essential oils extracted from *Artemisia sieberi* Besser, *Pelargonium roseum* Andrews, and *Ferula gummosa* Boiss against *B. tabaci* and its predator *O. albidipennis*.

Materials and Methods

Essential oils and insect colonies. Essential oils of *A. sieberi*, *P. roseum*, and *F. gummosa* were purchased from Barij Essence Pharmaceutical Co. (Kashan, Iran) and maintained in a refrigerator at 4°C until used in the experiments.

Cucumber (*Cucumis sativus* L. "Superdominus") was grown in plastic pots (15-cm diameter) filled with soil, one seedling to a pot, under laboratory conditions (25 ± 3°C, 40–50% relative humidity (RH), 14:10-h light:dark [L:D] photoperiod). Pots were watered every other day. Plants 4 to 5 weeks old with 3 or 4 true leaves were used for *B. tabaci* rearing and bioassays.

Colonies of *B. tabaci* and *O. albidipennis* were established in the Entomology Laboratory of the Plant Protection Department of Ramin Agriculture and Natural Resources University (Khuzestan, Iran). The *B. tabaci* colony was initiated by collecting individuals from a cucumber field on a university farm. The colony was maintained on the foliage of cucumber plants in the laboratory. Infested plants were kept in rearing cages (120 × 60 × 60 cm) covered with 210-μm mesh of white nylon and maintained under conditions similar to those previously described. Plants were replaced as needed.

The *O. albidipennis* colony was initiated with insects collected from sunflower, *Helianthus annuus* L., plants growing on the university campus. The insects were reared at 25 ± 2°C, 65 ± 5% RH, and 16:10-h (L:D) photoperiod. Transparent plexiglass cylindrical containers (7.5-cm diameter by 18-cm height) were used as rearing containers for *O. albidipennis*. Two holes of 2-cm diameter were made on the wall of the containers for ventilation that were covered with fine-mesh gauze. Adults and nymphs of *O. albidipennis* were fed with a mixture of sterile eggs of *Ephestia kuehniella* Zeller and dry date palm, *Phoenix dactylifera* L., pollen. A bean, *Phaseolus vulgaris* L., pod was placed in each container to provide moisture and a substrate for female oviposition and was replaced every day.

Bioassay of fumigant toxicity against *B. tabaci*. All bioassays were conducted in an environmental chamber maintained at 25 ± 2°C, 65 ± 5% RH, and 16:10-h L:D photoperiod. Bioassays with adults were performed in 4-L desiccators. Preliminary testing indicated that concentrations of 0.05, 0.07, 0.12, 0.19, and 0.33 $\mu l l^{-1}$ air of *F. gummosa* essential oils; concentrations of 0.03, 0.05, 0.08, 0.14, and 0.25 $\mu l l^{-1}$ air of *A. sieberi* essential oils; and concentrations of 0.01, 0.03, 0.06, 0.10, and 0.17 $\mu l l^{-1}$ air of *P. roseum* essential oils were appropriate for the determination of concentration–mortality responses.

The concentrations of essential oils were prepared using acetone as the solvent. Ten microliters of each concentration was applied by micropipette to a filter paper disc placed on the bottom of the desiccator, after which a leaf infested with 10 *B. tabaci* adults was placed on the perforated surface above the treated filter disc, and the desiccator was covered with a lid. To maintain the turgor of the leaves during the bioassays, the petiole was covered with a piece of wet cotton. Ten microliters of pure acetone was used as controls. Each concentration and the control were replicated three times. After 24 h, the insects were inspected for survival. If there was no movement after prodding with a fine brush, the insects were considered dead.

An additional bioassay was conducted to determine the fumigant effects against adults over different exposure times. For each essential oil, 10 adults were exposed to concentrations of 0.03, 0.06, 0.12, 0.24, and 0.30 $\mu l l^{-1}$ air for 3, 6, 9, 12, 24, and 48 h. The bioassay was conducted as previously described, with the exception that survival was determined at the end of each specified exposure duration.

Bioassay of fumigant toxicity against *O. albidipennis*. Plastic vials (50 ml) with screw caps were used as bioassay containers to determine the concentration–

Table 1. Concentration–mortality response, expressed as μl per liter, of *B. tabaci* adults to essential oils extracted from *A. sieberi*, *F. gummosa*, and *P. roseum* used as fumigants.

Essential Oils	LC_{50} (95% FL)	LC_{95} (95% FL)	Slope ± SE	Degrees of Freedom	Chi Square (χ^2)
A. sieberi	0.059 (0.048–0.070)	0.215 (0.164–0.329)	2.29 ± 0.30	3	2.42
F. gummosa	0.076 (0.065–0.086)	0.18 (0.151–0.232)	3.39 ± 0.41	3	1.76
P. roseum	0.040 (0.015–0.080)	0.204 (0.095–4.422)	1.81 ± 0.379	3	8.57

mortality response of *O. albidipennis* to the essential oils. Twenty adults (both sexes, 1 to 4 days after emergence) were placed in each vial. Dry date palm pollen and sterile eggs of *E. kuehniella* were added to each vial as food for the insects. Appropriate concentrations of each essential oil were established in preliminary tests. Those were 1.4, 2.39, 4.17, 7.12, and 12 $\mu l l^{-1}$ of air for *F. gummosa*; 0.15, 0.31, 1.32, 1.48, and 3.00 $\mu l l^{-1}$ of air for *A. sieberi*; and 0.20, 0.40, 0.70, 1.30, and 2.60 $\mu l l^{-1}$ of air for *P. roseum*. One μL of each concentration was deposited on an individual filter paper disk (1-cm diameter, Whatman No. 2) which was placed in the appropriate bioassay vial. The control was acetone. Treatments were replicated three times in under the same conditions described in the *B. tabaci* bioassays. After 24 h, the insects were inspected for survival and considered dead if no movement was observed after being probed with a fine brush.

The fumigant toxicity of the essential oils against *O. albidipennis* adults over time was investigated. The concentrations of the essential oils were 0.20, 1.00, 2.00, 6.00, and 12.00 $\mu l l^{-1}$ air with an acetone-only control. Exposure times were 3, 6, 9, 12, 24, and 48 h for each concentration. Twenty adults, along with the food and the treated filter paper discs, were placed in the 50-ml vials. Treatments were replicated three times, and survival was determined at the end of each exposure time as previously described.

Data analysis. Mortality was corrected using the Abbott (1925) formula. Data were subjected to probit analysis (Finney 1971) to estimate the concentration–mortality response for each essential oil within each bioassay with SAS software version 6.12 (SAS Institute 1997). Mortality data for different exposure times were subjected to analysis of variance (ANOVA), and Tukey's least significant difference was used to compare significantly different treatment means by using SPSS version 11.5.

Results

Fumigant toxicity against *B. tabaci*. The concentration–mortality response, expressed with lethal concentration values, for each essential oil is in Table 1. The estimated LC_{50}s of the essential oils against *B. tabaci* adults were 0.076 $\mu l l^{-1}$for *A.*

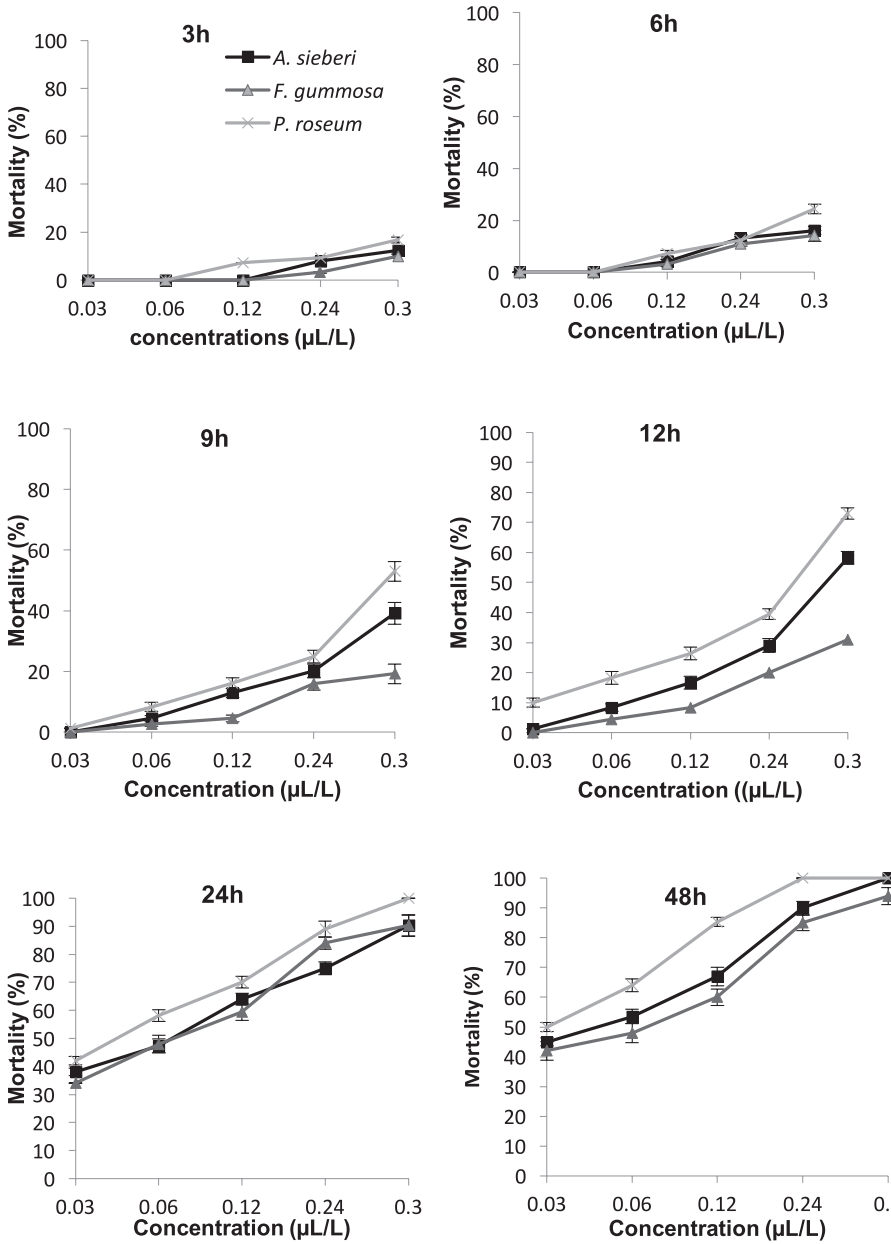

Fig. 1. Percent mortality of *B. tabaci* adults at various concentrations of *A. sieberi*, *F. gummosa*, and *P. roseum* essential oils over exposure time.

Table 2. Concentration–mortality response, expressed in ul per liter, of *O. albidipennis* adults to essential oils extracted from *A. sieberi*, *F. gummosa*, and *P. roseum* used as fumigants.

Essential Oils	LC_{50} (95% FL)	LC_{95} (95% FL)	Slope ± SE	Degrees of Freedom	Chi Square (χ^2)
A. sieberi	0.621 (0.462–0.823)	8.671 (4.755–23.94)	1.437 ± 0.20	3	1.43
F. gummosa	3.467 (2.645–4.391)	34.599 (19.714–99.726)	1.64 ± 0.27	3	1.41
P. roseum	0.954 (0.760–1.231)	8.010 (4.678–20.096)	1.77 ± 0.25	3	0.43

sieberi, 0.059 $\mu l l^{-1}$for *F. gummosa*, and 0.040 $\mu l l^{-1}$ for *P. roseum*. Based on overlapping 95% fiducial limits of each of these estimated values, there was no significant difference in the lethal activity against *B. tabaci* for these three essential oils.

Adult mortality increased with increased duration of exposure to the oils. Fig. 1 shows the mortality of *B. tabaci* adults exposed to various concentrations of essential oils at different exposure times. At the highest concentration tested (0.3 $\mu l l^{-1}$ air), 100% mortality was observed after 24 h of exposure to *P. roseum* oil and after 48 h of exposure to *F. gummosa* oil. Adult mortality was 94% after 24 h of exposure to *A. sieberi* oil.

Fumigant toxicity against *O. albidipennis*. The concentration–mortality responses of *O. albidipennis* to the oils of *A. sieberi*, *F. gummosa*, and *P. roseum* were 0.62, 3.46, and 0.95 $\mu l l^{-1}$ air, respectively (Table 2). Based on the 95% fiducial limits, there were no significant differences between the toxicity of *A. sieberi* and *P. roseum* essential oils against *O. albidipennis,* whereas the toxicity of the *F. gummosa* oil was significantly lower. The mortality of *O. albidipennis* adults also increased as exposure time increased (Fig. 2).

Discussion

In our study, the essential oils of *A. sieberi*, *F. gummosa*, and *P. roseum* showed insecticidal activity against adult *B. tabaci* when used as fumigants. All three essential oils showed the same insecticidal effect on *B. tabaci*. On the other hand, *O. albidipennis* was more susceptible to the oils of *A. sieberi* and *P. roseum* than *F. gummosa*. Comparing the effects of the essential oils on *O. albidipennis* and *B. tabaci* demonstrated a lower susceptibility of *O. albidipennis* to the three tested oils. This difference may be related to several physiological characteristics, such as the difference in detoxifying enzymes in the two species and the susceptibility of target sites to toxic lesions (Hollingworth 1976, Terriere 1984).

The concurrent use of insecticides and alternative control agents is common in integrated pest management (IPM) programs. However, these two practices are not

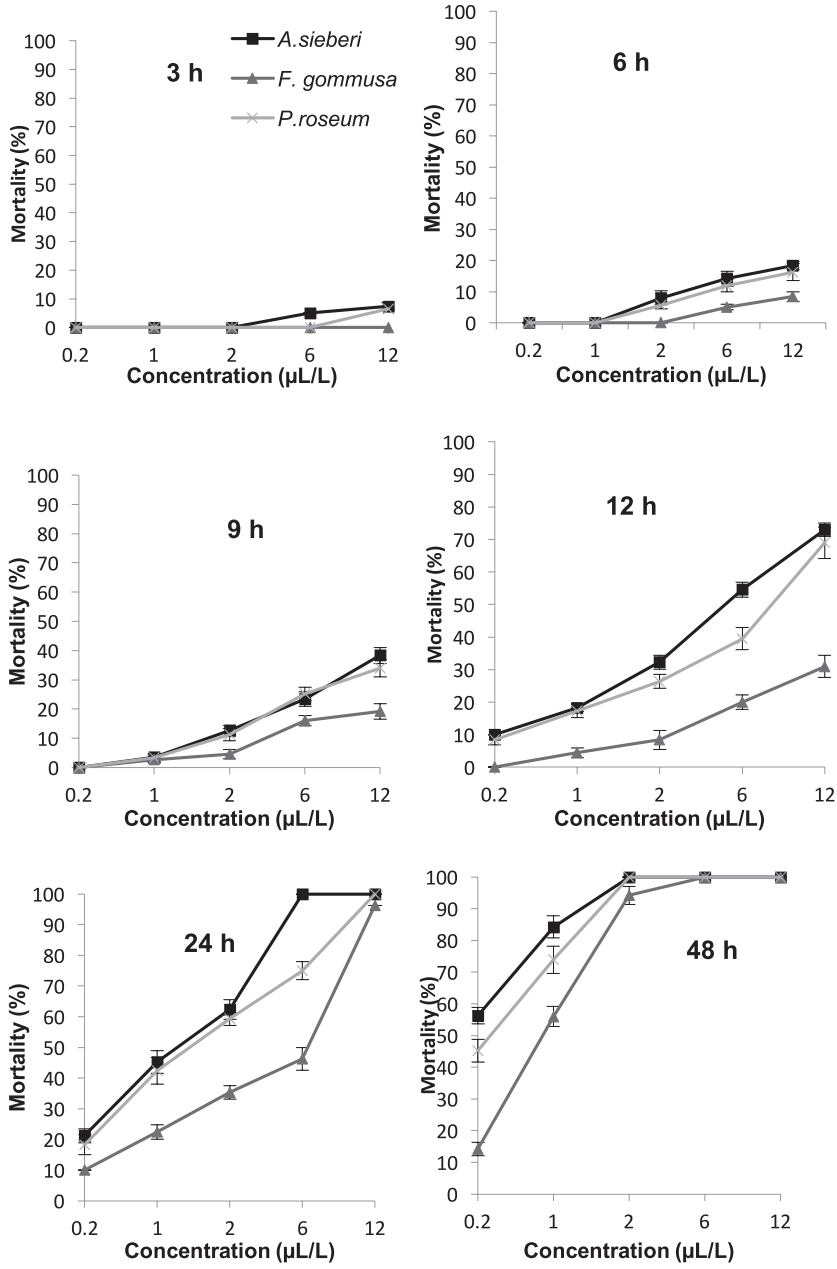

Fig. 2. Percent mortality of *O. albidipennis* adults at various concentrations of *A. sieberi*, *F. gummosa*, and *P. roseum* essential oils over exposure time.

always compatible, with some previous studies demonstrating that predatory insects are often more susceptible to chemical insecticides than their prey (Ahn et al. 2001, Choi et al. 2004, Yi et al. 2006). Among different groups of insecticides, plant derivatives, including essential oils, are proven to be safer for the environment and for human safety, so they might be used as replacements for chemical insecticides in IPM programs, especially if they are compatible with natural enemies.

Our results add to the accumulating body of knowledge on the impact of essential oils on *B. tabaci* and *Orius* spp. (Bostanian et al. 2005, Chae et al. 2014, Kim et al. 2011, Kim et al. 2014, Yi et al. 2006, Zandi-Sohani 2011). Effectiveness in controlling *B. tabaci* adults has been reported with essential oils extracted from *Allium vineale* L. and *Origanum vulgare* L. (Kim et al. 2011, Liu et al. 2014), *Mentha pulegium* L. and *M. viridis* L. (Zandi-Sohani 2011), *Satureja hortensis* L. (Aslan et al. 2004), *Micromeria fruticosa* L., *Nepeta racemosa* L., and *Origanum vulgar* L. (Calmasur et al. 2006). Yi et al. (2006) also tested 92 plant essential oils against *Thrips palmi* Karny and its predator *O. strigicollis* Poppius, demonstrating that *O. strigicollis* was less susceptible to some of the oils than *T. palmi* adults. Similarly, Kim et al. (2014) demonstrated less susceptibility of *O. strigicollis* than *T. palmi* to different compounds of oil from basil, *Ocimum basilicum* L., whereas Faraji et al. (2016) reported lower contact and fumigant toxicity of *Foeniculum vulgare* Mill and *Citrus lemon* L. essential oils against *O. albidipennis* than its prey *Tetranychus turkestani* Ugarov & Nikolski.

Our findings have practical implications in IPM programs for the management of *B. tabaci*. The difference in toxicity of essential oils for this insect pest and its predator is promising for the use of essential oils for pest control as fumigants without seriously impacting its predator *O. albidipennis*. On the other hand, in spite of the same toxicity of three tested essential oils against *B. tabaci*, *F. gummosa* essential oil showed less toxicity against *O. albidipennis*. This makes it an ideal choice for further studies for implication of its use in IPM programs with *B. tabaci*.

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