Effect of Methyl Salicylate-Based Lures on Beneficial and Pest Arthropods in Strawberry

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ABSTRACT Methyl salicylate (MeSA) is a common herbivore-induced plant volatile that, when applied to crops, has the potential to enhance natural enemy abundance and pest control. The impacts of MeSA in strawberry were unknown and examined in the spring and midsummer period. Strawberry plots contained no lures (control) or two 30-d MeSA lures (Predalure) in the center: one lure 0.61 m aboveground over a sticky trap, and one lure on a plant near the ground. Arthropod abundance was monitored at the point source, 5 m and 10 m away from lures over 31 d with white sticky traps, pitfall traps, and leaf inspection. Twenty-seven and nine comparisons were made among beneficial and pest arthropods, respectively. Overall positive responses were found among Chrysopidae in July–August 2008 and *Orius tristicolor* (White) in May–June 2009 to MeSA based on sticky traps. Chrysopidae showed attraction to the point source, but not at 5 m and 10 m. Ground-dwelling predators collected in pitfall traps such as Araneae, the carabid beetles, *Pterostichus melanarius* (Illiger), and *Nebria brevicollis* (Fabricius) did not respond. Increased abundance of six natural enemy groups appeared on various dates between 3 and 24 d after placement of lures in the field based on leaf inspection and sticky traps. Conversely, fewer Coccinellidae were captured on sticky traps on days 0–3, and fewer natural enemies were observed on leaves on day 28 in MeSA plots. MeSA did not increase nor decrease pest abundance.

KEY WORDS Carabidae, green lacewing, herbivore-induced plant volatiles, HIPV, lady beetles

Plants produce volatile organic compounds during and after herbivore attack for defense and signaling. During the past 30 yr, a variety of predators and parasitoids has been found to locate pests via these herbivore-induced plant volatiles (HIPV) in laboratory and field experiments (reviewed by Dicke et al. 1998 and Khan et al. 2008). Recently, field applications of various synthetic HIPVs have enhanced natural enemy abundance in vineyards and hops (James and Price 2004), parasitism rates in cotton (Williams et al. 2008), and predation rates in the desert plant *Nicotiana attenuata* Torr. ex S. Watson (Kessler and Baldwin 2001). In addition, synthetic HIPVs may induce crop plants to produce a blend of defensive volatiles that may render it more attractive to natural enemies (Khan et al. 2008), or prime neighboring plants for future production of defensive volatiles (Engelberth et al. 2004).

Of the various HIPVs, methyl salicylate (MeSA) is commonly emitted by plants, is attractive to natural enemies, and is readily available to growers. Release of MeSA has been documented in herbivore-infested lima bean, tomato, cucumber, cabbage, pear, hops, bird cherry, potato, *N. attenuata, Lotus japonicus* (Regel) K. Larsen (reviewed by James 2003a), kidney bean (Maeda and Liu 2006), spring onion (Tatemoto and Shimoda 2008), Norway spruce (Kannaste et al. 2008), soybean (Zhu and Park 2005), and strawberry (Himanen et al. 2005). MeSA is also directly attractive to natural enemies even when other semiochemical cues are present at close spatial range. Twelve natural enemy species or families were attracted to traps individually baited with a MeSA lure compared with the control when set 10–15 m apart from unbaited and other HIPV-baited traps (James 2003a, 2005). For grower applications, MeSA is available as a slow-release dispenser Predalure for 30 or 90 d (AgBio, Westminster, CO), as a component in the botanical insecticide Ecotrol (Ecosmart Technologies, Alpharetta, GA), or for mixing with pesticides to mask unpleasant odors, Odor-Mask (Monterey AgResources, Fresno, CA).

Practical considerations for using MeSA or other HIPVs include the optimal spacing and dosage of lures, and whether the volatiles are attractive to pests and interfere with the searching ability of natural enemies. Khan et al. (2008) found that MeSA at 447–642 lures/ha were less effective than 180/ha. Besides direct attraction to the lure, the synthetic HIPVs should augment natural enemies in the general vicinity to

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benefit pest control. This has been demonstrated with higher natural enemy abundance in MeSA-baited vineyards and hop yards than unbaited yards (James and Grasswitz 2005, James and Price 2004). Abundance was monitored with shake samples taken randomly in the yard and sticky traps in the center of the yard that were not necessarily next to the lure. A second consideration is that the volatile may also attract pests if pests prefer plants weakened by prior feeding. For instance, the apple fruit moth, *Argyresthia conjugella* Zeller, was attracted to MeSA in field tests (Bengtsson et al. 2006). Alternatively, MeSA may repel pests; for example, it reduced the aphid *Phorodon humili* Schrank in hop yards (Losel et al. 1996), and delayed the establishment of bird cherry-oat aphid, *Rhopalosiphum padi* (L.), in barley (Ninkovic et al. 2003). Lastly, synthetic HIPVs may affect the natural enemy's ability to search for pests. Using a deterministic model, a parasitoid attacked three times as many pests if they searched mainly for volatile-producing plants under ideal conditions (Puente et al. 2008). However, if a field becomes saturated with volatiles, the proportion of volatile-producing plants with suitable pests decreases, thereby lowering the success of parasitoids. Conversely, laboratory studies by Ozawa et al. (2004) suggest that volatile manipulation may not necessarily interfere with a parasitoid's ability to locate pests at close range. Parasitoids preferred jasmonic acid-induced plants infested with armyworms more than just infested plants or induced plants.

This study evaluated the impacts of MeSA in strawberry fields by: 1) monitoring the abundance of natural enemies, including ground-dwelling predators; 2) abundance of pests; 3) determining the temporal trends with a 30-d lure; and 4) the attractiveness of MeSA over several short-range distances. Studies were conducted in strawberry, where the field efficacy of MeSA is unknown, and the benefits appeared promising. First, MeSA is a relevant HIPV in strawberries. Plants infested with cyclamen mite (Himanen et al. 2005) and strawberry blossom weevil (Bichao et al. 2005) emitted higher levels of MeSA compared with undamaged plants. Secondly, natural enemies of major strawberry pests respond to MeSA in the laboratory, including *Anaphes iole* Girault, an egg parasitoid of *Lygus hesperus* Knight (Williams et al. 2008), and *Phytoselius persimilis* Athias-Henriot, a predator mass released for control of twospotted spider mite, *Tetranychus urticae* Koch (De Boer and Dicke 2004). Although not examined in this study, MeSA may have a beneficial effect of inhibiting development of gray mold, *Botrytis cinerea* Pers. ex Pers, on the strawberry fruit (Archbold et al. 1997).

Materials and Methods

In 2008–2009, four control and four MeSA plots were arranged in a randomized complete block design within a large commercial strawberry field in Linn County, Oregon. The field was managed to meet sustainable guidelines and received minimal pesticide input (Food Alliance 2009). Plots were spaced at least 100 m apart to minimize volatile overlap from the two MeSA lures (2 g load/lure) positioned at the center of the plot. A previous test with various volatiles including MeSA (5 g load/lure, 14 lures in 8 by 30 m) had reported differences from unbaited plots when plots were at least 100 m apart (James 2006). The field contained several varieties of strawberries comprising 20–80 rows, with some varieties repeating. To adequately space plots apart from each other, blocks were set up among different varieties. In 2008, two blocks were set up in Tillamook, one in Totem, and one in Shuskan. In 2009, one block was placed in Tillamook, two in Totem, and one in Shuksan. Plots were situated in different parts of the field each year.

At the center of each MeSA plot, one 2-g, 30-d Predalure lure was staked 0.61 m aboveground over a sticky trap, and another lure was placed on a strawberry plant and in contact with the ground. The high-hanging lure enabled testing the attraction of flying insects, whereas the low-hanging lure enabled testing of ground-dwelling predators. Ground-dwelling predators were monitored by pitfall traps using 32-ounce plastic cups. Foliar insects were monitored by folded white sticky traps (20 × 28 cm) and nondestructive visual inspection of the upper and lower sides of three leaflets (one leaf) on random strawberry plants. All pests and natural enemies observed on the leaves with the aid of Magni-focusers (BioQuip, Rancho Dominguez, CA) were recorded. To determine spatial trends, nine pitfall and nine sticky traps were set up per plot with positions at the center, and at 5 m and 10 m from the center in the north, south, east, and west directions. The arrangement of traps followed a '+' shape. Thirty leaves were randomly sampled per plot with 10 leaves examined next to center, and at 5 m and 10 m radius. MeSA lures were placed 25 July 2008 and 9 May 2009, and six sample collections were taken until 25 August 2008 and 9 June 2009.

Common predators from traps were identified to species or genus, and parasitoids to super/family level. Most Chrysopidae adults could not be identified to species in 2008 because of deterioration of samples. When abundance of insects was low, related taxa were combined into larger groups such as by family for sticky cards, or by natural enemies and pests for leaf counts. Before analyses, count data were tested for homogeneity of variance, and arthropods captured from pitfall and sticky trap samples were divided by the number of days elapsing between placement and collection. In tables and figures, mean arthropod counts are presented as 7-d counts, except for Thripidae, which is presented as daily counts. For statistical analyses, all major arthropod groups were tested for response to MeSA with a repeated measures split-plot model including block, treatment, distance from the point source (center, 5 m, 10 m), time, and interaction terms (SAS Institute 2007). Treatment was the whole factor, distance was the split factor, and the number of subsamples taken at each distance within a plot was weighted in the analyses. Nonsignificant treatment × time, distance × time, and treatment × distance interaction terms ($P > 0.1$) were eliminated from the

Table 1. Counts from leaf, pitfall, and sticky traps in control and MeSA plots and *P* values from repeated measures analysis

Sampling method	Response variable, year	Mean ± SE		Treatment	Distance	Time	Block	Interaction terms
		Control	MeSA	df[a] = 1, 3	2, 14	5, 115	3, 3	if used
Leaf (per 10 leaves)	Natural enemies 2008	0.67 ± 0.1	0.72 ± 0.1	0.630	0.431	0.013	0.120	Treatment × time **0.038**
	Natural enemies 2009	1.53 ± 0.29	1.67 ± 0.28	0.847	0.554	<0.001	0.393	
	Pests 2008	1.58 ± 0.27	1.25 ± 0.16	0.425	0.099	0.010	0.343	
	T. urticae 2009[b]	13.7 ± 2.5	5.2 ± 1.5	0.443	0.577	0.005	0.456	
	Aphididae 2009	3.3 ± 0.66	5.9 ± 1.4	0.516	0.253	<0.001	0.229	
Pitfall (per trap per week)	*P. melanarius* 2008	123 ± 7.2	122 ± 8.0	0.957	0.216	<0.001	0.788	
	P. melanarius 2009	5.0 ± 1.0	4.7 ± 1.1	0.972	0.065	<0.001	0.041	
	N. brevicollis 2009	1.1 ± 0.2	1.5 ± 0.3	0.423	0.402	0.045	0.052	
	Araneae 2008	2.3 ± 0.3	2.2 ± 0.3	0.988	0.457	<0.001	0.452	
	Araneae 2009	1.3 ± 0.3	1.4 ± 0.2	0.253	0.302	<0.001	0.068	
	Opiliones 2008	1.5 ± 0.2	1.8 ± 0.2	0.085	0.247	<0.001	0.138	
	Opiliones 2009	2.8 ± 0.3	3.4 ± 0.5	0.325	0.390	<0.001	0.048	
	Chilopoda 2009	5.0 ± 1.1	4.4 ± 0.9	0.896	0.198	<0.001	0.608	
White sticky trap (per trap per week)	Chalcidoidea 2008	6.1 ± 0.45	9.0 ± 0.76	0.063	**0.019**	<0.001	0.186	Treatment × time **0.011**, distance × time **0.046**
	Chalcidoidea 2009	1.9 ± 0.16	2.2 ± 0.18	0.107	0.247	<0.001	0.303	
	Other parasitoids 2008	2.2 ± 0.19	2.3 ± 0.19	0.894	0.364	<0.001	0.793	
	Other parasitoids 2009[c]	4.7 ± 0.39	4.1 ± 0.30	0.469	0.241	<0.001	0.273	
	Braconidae 2009	0.25 ± 0.021	0.18 ± 0.02	0.138	0.999	<0.001	0.287	
	O. tristicolor 2008	15.9 ± 1.8	16.2 ± 1.5	0.945	**<0.001**	<0.001	0.497	Treatment × time **0.015**
	O. tristicolor 2009	2.5 ± 0.60	3.2 ± 0.69	**0.045**	0.621	<0.001	0.008	
	Coccinellidae 2008	2.5 ± 0.21	3.3 ± 0.27	0.170	**0.008**	<0.001	0.171	
	Coccinellidae 2009[d]	1.2 ± 0.13	1.2 ± 0.13	0.890	0.661	<0.001	0.106	Treatment × distance **0.043**, treatment × time **0.030**
	Stethorus 2009	0.05 ± 0.012	0.05 ± 0.009	0.775	0.440	<0.001	0.653	
	Chrysopidae 2008	0.92 ± 0.12	1.5 ± 0.26	**<0.001**	**0.005**	0.003	0.056	Treatment × distance **0.007**
	C. plorubunda 2009	1.6 ± 0.24	1.8 ± 0.30	0.500	0.568	<0.001	0.286	
	Hemerobius sp. 2009	1.3 ± 0.15	1.8 ± 0.18	0.140	**0.001**	0.031	0.278	
	Aeolothrips 2008[d]	27.3 ± 2.2	31.2 ± 2.7	0.221	0.605	<0.001	0.092	Treatment × time 0.053
	Aeolothrips 2009	4.9 ± 0.66	4.7 ± 0.66	0.571	0.473	<0.001	0.012	
	Staphylinidae 2009	2.5 ± 0.30	2.0 ± 0.21	0.450	0.951	<0.001	0.078	
	Araneae 2009	6.4 ± 0.42	8.0 ± 0.68	0.227	0.207	<0.001	0.770	Treatment × time **<0.001**
	Cicadellidae 2008	3.2 ± 0.36	2.7 ± 0.33	0.097	0.822	<0.001	0.039	
	Cicadellidae 2009	0.85 ± 0.11	0.76 ± 0.12	0.817	0.592	<0.001	0.057	
	D. undecimpunctata 2008	12.6 ± 0.91	11.2 ± 0.82	0.579	**0.029**	<0.001	0.359	
	D. undecimpunctata 2008	0.63 ± 0.08	0.80 ± 0.14	0.760	0.193	<0.001	0.129	
(Per trap per day)	Thripidae 2008[d]	94.1 ± 8.9	83.5 ± 8.1	0.392	**<0.001**	<0.001	0.314	
	Thripidae 2009	81.0 ± 13.1	76.5 ± 10.9	0.703	0.724	<0.001	0.430	

Significant *P* values are in bold.
[a] Df for standard analyses without interaction terms in the model and an equal weight of subsamples taken at each distance.
[b] Pests on leaves in 2009 were separated into the two main taxonomic groups for analyses, but pooled together in Fig. 1a.
[c] Other parasitoids include counts of Braconidae; Coccinellidae includes counts of *Stethorus.*
[d] *Aeolothrips* was not included in the count of Thripidae.

model in a stepwise approach. Each year was tested separately because the first experiment occurred in summer, the second experiment occurred in spring, and the impacts of MeSA could vary by season. When treatment or treatment × time effects were significant, comparisons of MeSA and control plots for each date were tested by Student's *t* test. When distance or treatment × distance effects were significant, means were compared by Tukey honestly significant difference.

Results and Discussion

Natural Enemy Attraction. In 2008, Opiliones had a marginal increase of 20% in MeSA versus control plots when pooling pitfall traps from all distances within a plot ($P = 0.085$, Table 1). In both years, the generalist carabid *Pterostichus melanarius* did not respond to the presence of MeSA in spring or summer. When the newly detected exotic carabid *Nebria brevicollis* (Kavanaugh and LaBonte 2008) appeared more frequently in the spring of 2009, it also did not respond to MeSA. Whereas no published studies have documented the response of carabids to MeSA, carabids have aggregated near dimethyl disulfide, a major volatile released by damaged brassica, in field traps (Ferry et al. 2007). Additionally, *P. melanarius* adults were responsive to aphid alarm pheromone (E)-β-farnesene in an olfactometer (Kielty et al. 1996). Orientation to MeSA may not be advantageous for some carabids because they are generalist predators opportunistically eating prey at the ground level, and the common prey may not induce plants to emit MeSA. Potentially, carabids may be responsive to other plant volatiles induced by root feeders. Volatiles induced by root herbivory have been shown to attract soil-dwelling parasitic nematodes (van Tol et al. 2001).

On sticky traps, mean capture rate of green lacewings (Chrysopidae) was 1.5 ± 0.26 per sticky trap per

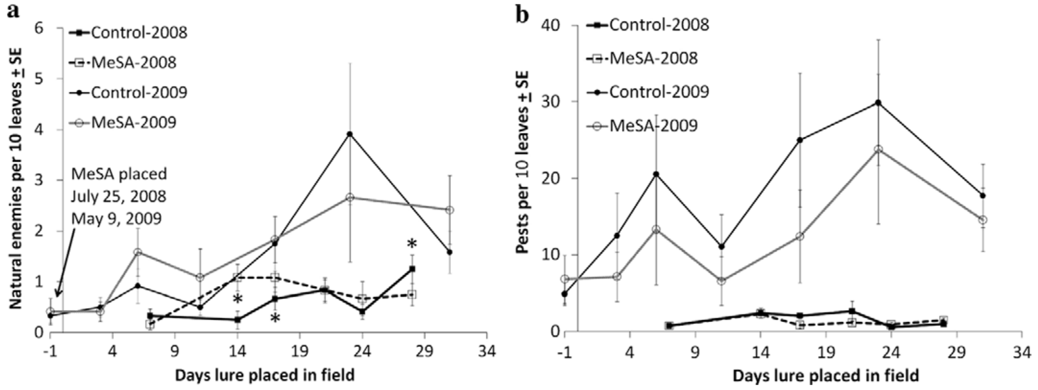

Fig. 1. Abundance of total natural enemies (a) and pests (b) on strawberry leaves in 2008–2009. In 2009, a pretrial observation occurred 1 d before MeSA placement in the field. Asterisks indicate significant difference between natural enemies found in control and MeSA plots on a given date with Student's t test, $P < 0.05$.

week in MeSA plots, 63% greater than control plots in 2008. Mean capture rate of *Orius tristicolor* was 2.5 ± 0.6 per trap in MeSA plots, 28% greater than controls in 2009 (Table 1). A statistically marginal increase ($P = 0.063$) of 48% was observed for parasitic wasps of the superfamily Chalcidoidea in MeSA plots in 2008. The green lacewing, *Chrysoperla plorubunda* (Fitch), did not respond to MeSA in 2009 (Table 1). A similar lack of response was also observed in grape and hop yards in which James (2003a, 2006) suggested that this may result from the noncarnivorous feeding behavior of adults of this species. In other studies, *Chrysopa nigricornis* Burmeister, *Hemerobius* sp., *Stethorus punctum picipes* (Casey), *O. tristicolor*, *Geocoris pallens* Stal., *Deraeocoris brevis* (Uhler), syrphids, empidids, parasitic braconids, and micro-hymenoptera were frequently attracted to MeSA in Washington vineyards and hop yards (James 2003a, 2003b, 2005; James and Price 2004); *Orius similis* Zheng and the spider, *Erigonidium graminicolum* Sundevall, were attracted to MeSA-baited traps in cotton (Yu et al. 2008); and syrphids and *Coccinella septempunctata* Linnaeus were attracted to MeSA-baited traps in soybean (Zhu and Park 2005). The current study shows some similar trends with *O. tristicolor* and micro-hymenoptera such as the Chalcidoidea, but not with *Hemerobius* sp., *Stethorus* sp., and braconids (Table 1). Sample sizes of the other insect groups found in strawberries were too small for meaningful comparisons. Differences in results from this experiment and others could occur as a result of different responses from strawberries to MeSA. MeSA induces hop plants to produce a blend of HIPVs (Khan et al. 2008); whether such an induction occurs in strawberries is unknown. Another difference is that this study applied MeSA at a single point source in the center of the experimental plot, whereas in other systems, multiple MeSA and other HIPV lures were distributed over a larger area. A higher overall dosage of MeSA or other semiochemical lures distributed over an area may be necessary to attract more natural enemies.

Temporal Trends. The effectiveness of 30-d lures was monitored during the time that they were expected to be actively emitting volatiles. Direct observations of natural enemies on strawberry leaves, which were comprised mostly of Coccinellidae, Araneae, and green lacewing eggs, revealed a treatment × time interaction in 2008 (Table 1). Combined leaf data from the center, 5 m and 10 m, showed more natural enemies in MeSA plots than control plots on days 14 and 17, but the reverse trend occurred on day 28 (Fig. 1a). In 2009, strawberry leaves did not differ in the abundance of natural enemies, which were comprised mostly of predatory mites, adult Syrphidae, and eggs from *Hemerobius* or Syrphidae (Fig. 1a). Additionally, several natural enemy groups captured in sticky traps responded variably to treatment at different dates (Table 1). Chrysopidae captures were higher in MeSA plots 3–7, and 21–24 d after lure placement in 2008 (Fig. 2a). *O. tristicolor* captures were higher in MeSA plots on days 11–17 in 2008 (Fig. 2b). Coccinellidae captures were lower in MeSA plots on days 0–3 in 2009, but higher in MeSA plots on days 3–7 in 2008 (Fig. 2c). Chalcidoidea were higher in MeSA plots on days 3–21 in 2008 (Fig. 2d). Araneae were higher on days 3–9 in 2009 (Fig. 2e). The predatory thrips, *Aeolothrips* sp., were marginally affected by treatment × time interactions in 2008 (Table 1), and captures were higher on days 3–7 (Fig. 2e). Positive responses to MeSA were generally observed among several natural enemy groups from days 3–24, but a negative response appeared on days 0–3 for Coccinellidae in sticky traps, and a negative response appeared on day 28 for natural enemies found on leaves. In other studies in which many MeSA lures were dispersed over an area, higher natural enemy abundance appeared in MeSA versus control vineyard blocks 2–3 mo later using 90-day 5-g load lures at 2297 lures/ha (James and Price 2004) and 586 lures/ha (James and Grasswitz 2005).

Spatial Trends. Arthropods were sometimes observed with a trend toward higher captures at 10 m away than the center regardless of treatment (Table 1) among Thripidae, *O. tristicolor*, and *Diabrotica undecimpunctata* in 2008 and *Hemerobius* sp. in 2009 (Fig. 3). Reasons for this are unknown. An edge effect might be suspected to influence trap captures if plots were

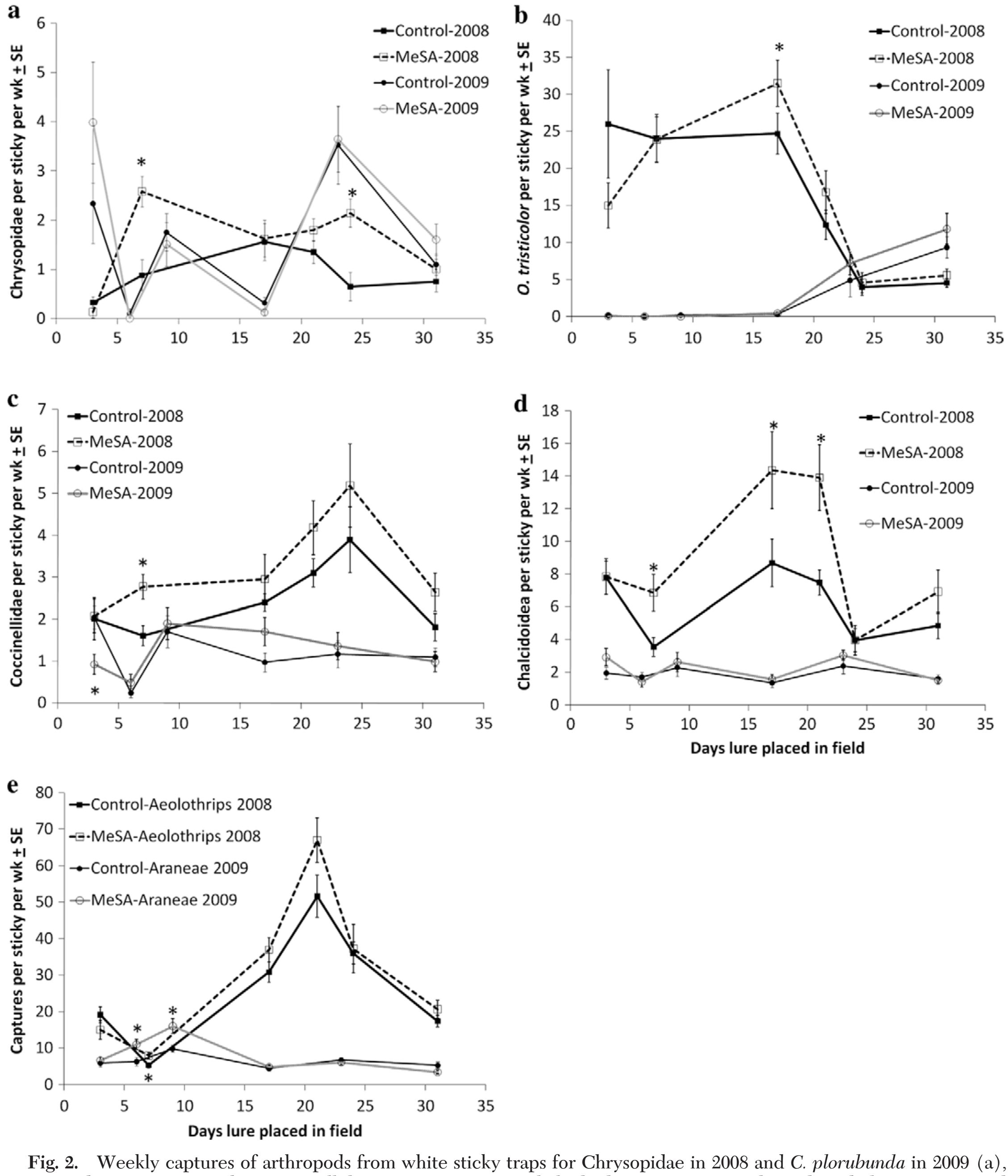

Fig. 2. Weekly captures of arthropods from white sticky traps for Chrysopidae in 2008 and *C. plorubunda* in 2009 (a), *O. tristicolor* in 2008–2009 (b), Coccinellidae in 2008–2009 (c), Chalcidoidea in 2008–2009 (d), and *Aeolothrips* in 2008 and Araneae in 2009 (e). Traps were placed on day 0, collected on day 3, and represented as data points on day 3. Asterisks indicate significant difference between control and MeSA plots in a given time with Student's t test, $P < 0.05$.

individual strawberry plantings. However, all plots were embedded in a large strawberry field, and some plots were distant from the edge. Rather, insect trends may reflect a difference in trap densities. At 10 m, there were fewer traps per unit area, and each trap would catch more insects. In contrast, the center trap was more closely surrounded by traps at the 5-m distance, which were also capturing a share of the insects in the area. Given the potential trap density bias, opposite trends still appeared among Coccinellidae and Chalcidoidea in 2008, with higher catches at the center versus 5 or 10 m away regardless of treatment (Fig. 3a). In both cases, captures visually appeared higher among the center of the MeSA plot than control plot, but this could not be substantiated because treatment × distance effects were nonsignificant (Table 1).

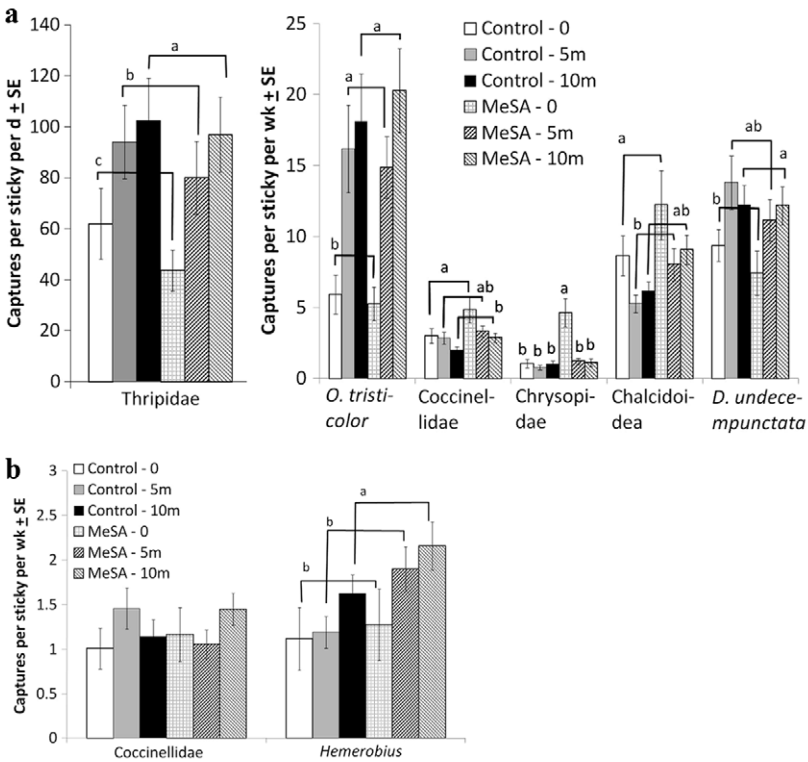

Fig. 3. Captures of arthropods from white sticky traps grouped by treatment × distance combinations in 2008 (a) and 2009 (b). Letters indicate significant differences with Tukey honestly significant difference, $P < 0.05$.

Chrysopidae in 2008 and Coccinellidae in 2009 responded to treatment × distance interactions (Table 1). No trends were apparent for Coccinellidae among the six treatment × distance combinations (Fig. 3b). Chrysopidae, however, responded 4.5-fold more to the center trap baited with MeSA than the center of the control plot and other distances in either MeSA or control plots (Fig. 3a). This suggests that these lacewings were responding to the point source of MeSA directly, but abundance was not enhanced in the immediate vicinity. Although the species of Chrysopidae were unknown, I have captured mostly *C. plorubunda* and some *Chrysopa oculata* Say in nearby areas (personal observation). In other studies, Chrysopidae such as *C. nigricornis* and *C. oculata* were directly attracted to MeSA-baited traps in hop yards and vineyards (James 2003a, 2006). Moreover, more *C. oculata* were caught at the 99% MeSA lure than the 10% or 1% lures, suggesting attraction to high dosages (James 2006). In the opposite case, the parasitoids *Metaphycus* sp. and *Anagrus* sp. were not attracted to sticky cards baited with MeSA, methyl jasmonate, or hexenyl acetate (James 2003a, 2005), but were collected more often in vineyard blocks baited with those volatiles than unbaited blocks (James and Grasswitz 2005). Those authors suggested that parasitoids may have been repelled by higher doses of HIPVs and were thus found in the baited block, but less frequently at the point source. Similarly, *Phytoselius persimilis* appeared repelled by high levels of MeSA in the laboratory (De Boer and Dicke 2004), and *C. septempunctata* were trapped more at 300 mg than 1-g MeSA lures in a soybean field (Zhu and Park 2005). In these latter cases, application of MeSA or other HIPV lures may be effective in enhancing natural enemies in the general vicinity, provided the lure dosages are not repellent.

Effect on Pests. Although pest abundance appeared lower on leaves within MeSA plots, there was no significant effect on Aphididae, Thripidae, and Cicadellidae in 2008, nor were there effects on twospotted spider mite *Tetranychus urticae* Koch and Aphididae in 2009 (Fig. 1b). On sticky traps, a marginal decrease of 19% was observed for leafhoppers in MeSA plots in 2008 (Table 1). All other common pests captured on sticky traps, including Thripidae and cucumber beetles *D. undecimpunctata* Mannerheim, were not significantly different among plots. Other field studies have reported increased pest control after inducing plants or applying HIPV components. Among tomato plants induced by foliar sprays of jasmonic acid, parasitism of sentinel caterpillars placed in the field was 37% higher in induced versus control plots (≈1.05 versus 0.77 parasitized caterpillars per plot) (Thaler 1999). On *Nicotiana* plants, the application of commonly emitted HIPVs, including *cis*-3-hexen-1-ol, linalool, and *cis*-α-bergamotene at the stems, increased mortality on sentinel *Manduca sexta* L. eggs by *G. pallens* Stäl (33–38% versus 17% in control) (Kessler and Baldwin 2001). In cotton, application of (Z)-3-hexenyl acetate and α-farnesene, but not MeSA, elevated parasitism of sentinel *Lygus lineolaris* (Palisot de Beauvois) eggs from ≈0.7% to 2–2.5% (Williams et al. 2008).

In summary, the effects of MeSA on natural enemies and pests were assessed in 27 and 9 statistical comparisons, respectively (Table 1). MeSA had an overall beneficial impact on Chrysopidae in 2008 and *O. tristicolor* in 2009. For MeSA application to be useful to growers, it must reduce pest abundance and/or increase yield. MeSA applied at a point source did not decrease local pest abundance, and the impacts on strawberry yield were not monitored in the commercial field. Elevated biological control has been demonstrated in other systems with sentinel prey (Kessler and Baldwin 2001, Thaler 1999, Williams et al. 2008) in which natural enemies drawn in by the HIPVs receive an immediate reward. However, elevated biological control needs to be demonstrated with naturally occurring pest populations in which predators and parasitoids must search the crop area for prey. How elevated HIPVs may affect the natural enemy's ability to search for pests in the field requires examination; this has been addressed in a deterministic model (Puente et al. 2008) and in the laboratory (Owaza et al. 2004). To improve efficacy, other strategies might be combined, such as pairing HIPV applications with floral resources to attract and reward natural enemies in the area with supplemental food (Khan et al. 2008).

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