IPM Solutions for Insect Pests in California Strawberries: Efficacy of Botanical, Chemical, Mechanical, and Microbial Options

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Western tarnished plant bug (*Lygus hesperus*), which is generally referred to as lygus bug, is a major pest of strawberries on the California Central Coast. Lygus bug, feeding on developing berries, causes fruit deformity. Deformed or "cat-faced" berries are not desirable for fresh market and lygus bug damage results in significant yield losses. Lygus bugs typically move into strawberry fields in early to mid-spring and thrive in fall-planted and summer-planted fields with multiple bug generations occurring during the following months. Degree-day calculations and timing of treatments are difficult for lygus bug management in strawberries due to multiple sources (from wild and cultivated hosts) and continuous movement of populations among different hosts. Conventional growers typically rely on pesticide applications and use of bug vacuums, which is gaining popularity in recent years. Lygus bug management continues to be a challenge with these tools and emphasizes the need for IPM strategies that use several control options. The greenhouse whitefly, *Trialeurodes vaporariorum*, and the western flower thrips, *Frankliniella occidentalis*, are other important insect pests that cause both direct damage and vector viruses that cause the virus decline of strawberries.

Studies conducted in 2012, 2013, and 2014 in commercial Santa Maria strawberry fields showed that non-chemical alternatives such as azadirachtin, entomopathogenic fungi, and bacteria-based pesticides can play an important role in managing lygus bug and other insect pests. Such botanical and microbial alternatives were also critical in managing twospotted spider mite, another major strawberry pest. An IPM approach beyond rotating chemicals among different modes of action groups is necessary for obtaining effective control, maintaining environmental sustainability, and reducing the risk of pesticide resistance.

An IPM study was conducted in 2015 at Sundance Berry Farms in the Santa Maria area using almost all available IPM tools (Table 1). The following groups of options were used in different combinations and rotations and evaluated for their efficacy against lygus bug, western flower thrips, and greenhouse whitefly.

Chemical pesticides:

- Pyrethrins: bifenthrin 10%, Insecticide Resistance Action Committee (IRAC) mode-of-action group 3A – sodium channel modulators
- Neonicotinoids: acetamiprid 70%, IRAC group 4A;

Table 1. List of treatments and IRAC mode-of-action (MOA) groups.

Treatment	1st Application (Rate/acre), MOA	2nd Application (Rate/acre), MOA	3rd Application (Rate/acre), MOA
1	Untreated	Untreated	Untreated
2	Acetamiprid (3 oz), **4A**	Acetamiprid (3 oz), **4A**	Acetamiprid (3 oz), **4A**
3	Vacuum	Vacuum	Vacuum
4	Novaluron (12 fl oz), **15** + Bifenthrin (16 oz), **3A**	*Metarhizium brunneum* (16 fl oz) + Oils margosa with azadirachtin 0.7% (104 fl oz)	*M. brunneum* (16 fl oz) + Azadirachtin 3% (16 fl oz)
5	Sulfoxaflor (4.5 oz), **4C**	Sulfoxaflor (4.5 oz), **4C**	Vacuum
6	*Isaria fumosorosea* (2 lb) + Azadirachtin 4.5% (9 fl oz)	*I. fumosorosea* (2 lb) + Azadirachtin 4.5% (9 fl oz)	Vacuum
7	Vacuum	Flupyradifurone (14 fl oz), **4D** + Oils margosa with azadirachtin 0.7% (104 fl oz)	Novaluron (12 fl oz), **15** + Bifenthrin (16 oz), **3A**
8	Flupyradifurone (14 fl oz), **4D**	Flupyradifurone (14 fl oz), **4D**	Vacuum
9	Sulfoxaflor (4.5 oz), **4C**	Flupyradifurone (14 fl oz), **4D**	Flonicamid (2.8 oz), **9C**
10	*Beauveria bassiana* + neem 75 ppm (1 qt)	*B. bassiana* + pyrethrum 0.5%, **3A** + neem 37.5 ppm (1 qt)	*B. bassiana* + pyrethrum 0.75%, **3A** (1 qt)
11	*B. bassiana* + pyrethrum 0.75%, **3A** (1 qt)	*B. bassiana* + neem 75 ppm (1 qt)	Flonicamid (2.8 oz), **9C**
12	*B. bassiana* + pyrethrum, **3A** (1 qt)	Vacuum	Novaluron (12 fl oz), 15 + Bifenthrin (16 oz), **3A**

Table 2. Number of lygus nymphs (young and old) and adults per 20 plants before and after each treatment.

Treat-ment	Pretreatment				Post I Spray				Post II Spray				Post III Spray				Post-treatment Average			
	1–3 Instar	4–5 Instar	Adult	All Stages	1–3 Instar	4–5 Instar	Adult	All Stages	1–3 Instar	4–5 Instar	Adult	All Stages	1–3 Instar	4–5 Instar	Adult	All Stages	1–3 Instar	4–5 Instar	Adult	All Stages
1	18.50	2.50	2.00	23.00	25.50	5.75	2.50	33.75	24.00	6.75	6.75	37.50	33.50	6.25	12.00	51.75	27.67	6.25a*	7.08	41.00
2	20.75	3.75	2.50	27.00	21.00	4.00	1.50	26.50	22.00	5.50	4.75	32.25	20.00	2.25	6.50	28.75	21.00	3.92ab	4.25	29.17
3	21.25	2.50	2.25	26.00	15.50	3.75	1.50	20.75	22.75	6.25	4.25	33.25	25.25	3.25	4.50	33.00	21.17	4.42ab	3.42	29.00
4	20.75	2.50	1.25	24.50	14.25	2.50	2.25	19.00	16.25	1.25	5.25	22.75	30.25	1.00	6.25	37.50	20.25	1.58b	4.58	26.42
5	11.50	1.75	0.75	14.00	11.50	2.25	3.25	17.00	13.25	2.75	4.00	20.00	26.50	0.50	7.75	34.75	17.08	1.83b	5.00	23.92
6	21.25	2.00	1.50	24.75	19.75	4.75	1.75	26.25	21.00	3.50	6.00	30.50	32.50	2.00	7.25	41.75	24.42	3.42ab	5.00	32.83
7	17.25	1.00	1.00	19.25	21.00	3.25	2.50	26.75	18.75	3.25	2.50	24.50	15.25	1.75	5.25	22.25	18.33	2.75ab	3.42	24.50
8	30.00	2.00	1.75	33.75	23.75	4.00	2.75	30.50	16.75	6.25	5.25	28.25	21.50	3.50	5.25	30.25	20.67	4.58ab	4.42	29.67
9	31.50	3.50	0.75	35.75	12.50	4.50	1.75	18.75	23.25	4.75	7.50	35.50	15.25	1.50	5.25	22.00	17.00	3.58ab	4.83	25.42
10	15.00	1.25	1.25	17.50	22.00	4.00	2.25	28.25	24.00	5.00	3.00	32.00	29.00	2.25	6.00	37.25	25.00	3.75ab	3.75	32.50
11	17.00	1.50	0.75	19.25	20.75	3.75	1.75	26.25	24.50	5.75	5.50	35.75	16.25	2.00	4.50	22.75	20.50	3.83ab	3.92	28.25
12	32.50	3.50	1.50	37.50	31.00	7.00	4.00	42.00	26.00	7.25	7.00	40.25	18.00	3.00	9.25	30.25	25.00	5.75ab	6.75	37.50

*Means followed by the same or no letter are not significantly different, Tukey's HSD ($P > 0.05$).

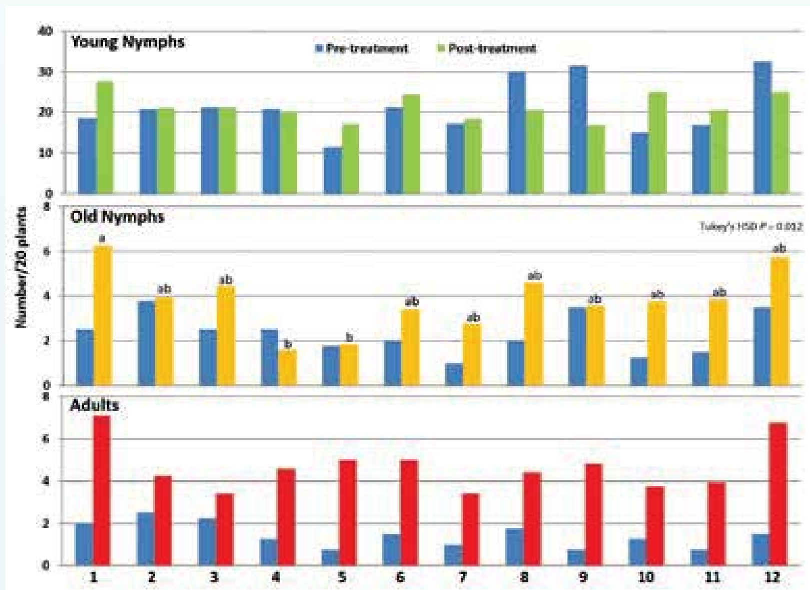

Figure 1. Pre- and post-treatment numbers of young and old nymphs and adult lygus bugs in different treatments. Bars followed by the same or no letter are not statistically significant, Tukey's HSD ($P > 0.05$).

sulfoximines (sulfoxaflor 21.8%, IRAC group 4C); and butenolides (flupyradifurone 17.09%, IRAC group 4D) – all of them are nicotinic acetylcholine receptor competitive modulators

- Flonicamid: flonicamid 50%, IRAC group 9C – modulators of chordotonal organs
- Benzoylureas: novaluron 9.3%, IRAC group 15 – inhibitors of chitin biosynthesis

Botanical pesticides: Three neem-based formulations were used in the study. Azadirachtin in neem products acts as an insecticide, insect growth regulator, antifeedant, and a repellent. The main active ingredient in two of these formulations was 3% or 4.5% of azadirachtin. The third one has 65.8% of oils margosa and 0.7% azadirachtin as active ingredients. Three new formulations of the entomopathogenic fungus, *Beauveria bassiana* used in this study included cold pressed neem (at 37.5 or 75 ppm) and/or natural pyrethrum (0.5 or 0.75%).

Entomopathogenic fungi: Fungi used in the study included *Beauveria bassiana* (strain GHA, 1X109 conidia/ml), *Isaria fumosorosea* (strain 97, 20%), and *Metarhizium brunneum* (strain 52, 11%). The three B. bassiana formulations used in the study had pyrethrum, cold pressed neem, or both.

Mechanical: Vacuuming twice a week with one pass each time at a speed of 2 miles per hour.

The study had 12 treatments that included an untreated control, acetamiprid alone and vacuuming alone as grower standards. Treatments were administered on 26 August, 2 September, and 9 September, 2015 using a tractor-mounted sprayer. A spray volume of 100 gallons per acre was used for pesticide treatments. Each treatment had six (4-row) beds that were 75 feet long, and four replications distributed in a randomized complete block design. Before the first treatment and six days after each treatment, 20 random plants from the middle two beds in each treatment were sampled for insect pests and beneficial arthropods. The number of young nymphs, old nymphs, and adult lygus bugs were counted. Thrips, adult whiteflies, and natural enemies that included bigeyed bugs, minute pirate bugs, lacewings, damsel bugs, ladybeetles, parasitic wasps, predatory thrips, predatory midge larvae, and spiders were also counted from each sample plant. Data were subjected to ANOVA and significant means were separated using Tukey's HSD test.

Lygus bug: Lygus bug populations were very high during the study period compared to the treatment threshold of 1 nymph/20 plants, and control was difficult in general (Table 2 and Fig. 1). The sulfoxaflor/

flupyradifurone/flonicamid rotation provided the highest control where there was a 29% reduction in all life stages compared to pretreatment numbers. The flupyradifurone/flupyradifurone/vacuum treatment was the only other treatment that provided control with a 12% reduction. The *B. bassiana* plus pyrethrum/vacuum/novaluron plus bifenthrin treatment prevented population buildup. Lygus numbers increased in all other treatments. The popular practice of vacuuming was ranked sixth among the treatment rotations. Having two passes instead of one pass might increase the efficacy of vacuuming, but results emphasize that multiple tools need to be considered for managing lygus bugs in strawberries.

While the treatment rotations compare the final results after three weeks, data were summarized in a different manner to compare the efficacy of individual products or options. Percent change in lygus numbers after applying each product or vacuuming twice during a week was calculated. The number of times each product was applied or vacuuming was done per week varied from one to eight. The average percent change where they were used more than one time were included in the comparison (Table 3). Flonicamid appeared to be the best option for controlling both lygus nymphs and adults, followed by novaluron plus bifenthrin (29% reduction), sulfoxaflor (10%), flupyradifurone plus oils margosa with azadirachtin (9%), and acetamiprid (2%) in controlling nymphs. None of the products reduced adult lygus numbers except that flupyradifurone plus oils margosa with azadirachtin stopped the population

Table 3. Mean percent change in lygus nymphs (young and old) and adults after applying a particular product or vacuuming.

Treatment/Vacuum	Number times administered	Mean % Change Compared to the Previous Counts				
		1–3 Nymphs	4–5 Nymphs	Adults	All Nymphs	All Stages
Untreated	3	23.85	46.66	90.93	25.49	31.95
Acetamiprid	3	-1.04	-4.97	71.17	-2.35	3.00
Vacuum	8	27.43	16.07	61.93	21.08	23.98
Novaluron + Bifenthrin	3	-26.92	-34.92	74.05	-29.18	-18.83
Sulfoxaflor	3	-15.03	26.46	163.25	-10.43	-2.83
Flupyradifurone	3	11.90	53.94	158.87	11.44	24.11
Flonicamid	2	-34.04	-66.82	-24.09	-39.92	-37.20
I. fumosorosea + Azadirachtin 4.5%	2	-0.36	55.59	129.76	2.69	11.13
B. bassiana + Neem	2	32.37	136.67	147.14	41.73	48.81
B. bassiana + Pyrethrum	3	12.76	65.00	133.33	15.25	21.59
M. brunneum + Oils margosa with Azadirachtin 0.7%	1	14.04	-50.00	133.33	4.48	19.74
M. brunneum + Azadirachtin 3%	1	86.15	-20.00	19.05	78.57	64.84
Flupyradifurone + Oils margosa with Azadirachtin 0.7%	1	-10.71	0.00	0.00	-9.28	-8.41
B. bassiana + Pyrethrum + Neem	1	9.09	25.00	33.33	11.54	13.27

Table 4. Mean number of western flower thrips, greenhouse whiteflies, and various natural enemies before and after each treatment. Perc

Treatment	Western Flower Thrips							
	Pre-treat.	Post I Treat.	Post II Treat.	Post III Treat.	Post-treat. Avg.	% Change	Pre-treat.	Post I Treat.
1	7.00	15.75	13.25	12.25	13.75	96.43	0.25	1.00
2	9.00	21.00	13.25	13.50	15.92	76.85	0.25	0.25
3	4.75	20.50	15.50	15.75	17.25	263.16	0.75	1.25
4	18.25	12.25	8.25	11.50	10.67	-41.55	0.50	0.25
5	5.50	17.75	14.75	18.25	16.92	207.58	0.00	0.25
6	13.25	18.50	15.25	13.50	15.75	18.87	0.00	1.00
7	5.50	14.25	11.75	6.25	10.75	95.45	0.75	0.00
8	9.75	12.50	11.75	10.50	11.58	18.80	0.25	0.00
9	7.25	14.50	13.75	16.75	15.00	106.90	0.25	1.00
10	16.50	16.50	10.25	11.75	12.83	-22.22	0.25	1.25
11	6.00	17.00	8.75	10.25	12.00	100.00	0.00	1.25
12	9.75	18.00	9.00	14.50	13.83	41.88	0.00	0.25

ent change as a result of three weekly treatments was also included.

Greenhouse Whiteflies				Natural Enemy Complex					
Post II Treat.	Post III Treat.	Post-treat. Avg.	% Change	Pre-treat.	Post I Treat.	Post II Treat.	Post III Treat.	Post-treat. Avg.	% Change
0.25	1.75	1.00	300.00	1.25	2.25	4.75	2.25	3.08	146.67
1.25	0.50	0.67	166.67	2.25	5.25	3.75	2.00	3.67	62.96
0.75	0.75	0.92	22.22	2.00	3.00	3.00	1.00	2.33	16.67
0.25	0.50	0.33	-33.33	2.00	3.50	1.75	2.00	2.42	20.83
0.00	0.50	0.25	-	0.75	3.00	3.00	2.75	2.92	288.89
0.25	1.00	0.75	-	0.25	2.50	2.25	2.50	2.42	866.67
0.00	0.00	0.00	-100.00	1.00	2.25	2.25	2.25	2.25	125.00
0.00	0.25	0.08	-66.67	2.75	3.50	5.25	3.00	3.92	42.42
0.00	0.25	0.42	66.67	1.00	6.75	1.25	5.50	4.50	350.00
0.00	0.25	0.50	100.00	0.75	3.50	2.00	3.25	2.92	288.89
0.50	0.75	0.83	-	2.50	3.75	1.75	2.00	2.50	0.00
0.00	1.00	0.42	-	1.75	5.75	4.25	2.75	4.25	142.86

increase. The highest increase in adult lygus was seen from sulfoxaflor (163%) followed by flupyradifurone (159%). Although populations were not reduced, some of the entomopathogenic fungi combinations limited the buildup and were better than some chemical pesticides or vacuuming. Among the 14 options, vacuuming was ranked eleventh against nymphs, fifth against adults, and tenth overall.

Western flower thrips: Post-treatment counts showed that thrips populations were reduced only in novaluron plus bifenthrin/*M. brunneum* plus oils margosa with azadirachin 0.7%/*M. brunneum* plus azadirachtin 3% and *B. bassiana* plus neem/*B. bassiana* plus pyrethrum plus neem/*B. bassiana* plus pyrethrum treatments (Table 4).

Greenhouse whitefly: Adult whiteflies occurred at very low numbers during the study and population reduction from post-treatment counts was seen only in vacuum/flupyradifurone plus oils margosa with azadirachin 0.7%/novaluron plus bifenthrin, flupyradifurone/flupyradifurone/vacuum, and novaluron plus bifenthrin/*M. brunneum* plus oils margosa with azadirachin 0.7%/*M. brunneum* plus azadirachtin 3% treatments (Table 4).

Natural enemies: Percent change post-treatment indicated that natural enemy populations were relatively higher in *I. fumosorosea* plus azadirachtin 4.5%/*I. fumosorosea* plus azadirachtin 4.5%/vacuum, followed by sulfoxaflor/flupyradifurone/flonicamid, sulfoxaflor/sulfoxaflor/vacuum, and *B. bassiana* plus neem/*B. bassiana* plus pyrethrum plus neem/*B. bassiana* plus pyrethrum (Table 4).

This study demonstrates the efficacy of various chemical and nonchemical tools in different combinations against lygus bug, western flower thrips, and greenhouse whitefly. Results reiterate that efficacy can vary both for chemical and biopesticides and emphasize the importance of rotating and combining different options and continuously evaluating their performance.

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