Timing Spring Insecticide Applications to Target both *Amyelois transitella* (Lepidoptera: Pyralidae) and *Anarsia lineatella* (Lepidoptera: Gelechiidae) in Almond Orchards

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ABSTRACT *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae) and *Anarsia lineatella* Zeller (Lepidoptera: Gelechiidae) are key Lepidoptera pests of almonds in California. Spring insecticide applications (early to mid-May) targeting either insect were not usually recommended because of the potential to disrupt natural enemies when broad-spectrum organophosphates and pyrethroids were applied. The registration of reduced risk compounds such as chlorantraniliprole, methoxyfenozide, and spinetoram, which have a higher margin of safety for natural enemies, makes spring (early to mid-May) application an acceptable control approach. We examined the efficacy of methoxyfenozide, spinetoram, and chlorantraniliprole at three spring application timings including the optimum spring timing for both *A. lineatella* and *A. transitella* in California almonds. Our study also examined the possibility of reducing larval populations of *A. lineatella* and *A. transitella* simultaneously with a single spring insecticide application. There were no significant differences in the field efficacy of insecticides targeting either *A. lineatella* or *A. transitella*, depending on application timing for the three spring timings examined in this study. In most years (2009–2011), all three timings for each compound resulted in significantly less *A. transitella* and *A. lineatella* damage when compared with an untreated control, though there was some variation in efficacy between the two species. Early to mid-May applications of the reduced-risk insecticides chlorantraniliprole and spinetoram can be used to simultaneously target *A. transitella* and *A. lineatella* with similar results across the potential timings.

KEY WORDS chlorantraniliprole, methoxyfenozide, spinetoram, navel orangeworm, peach twig borer

Navel orangeworm, *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae), and peach twig borer, *Anarsia lineatella* Zeller (Lepidoptera: Gelechiidae), are key Lepidoptera pests of almonds, *Prunus dulcis* (Miller) Webb, in California. *A. transitella* cause direct larval feeding damage to almond kernels that are approaching maturity (hull split) or have been injured (Wade 1961). *A. transitella* is considered to be the most important pest of almonds in California, and since 2002, the damage goal for *A. transitella* has been reduced to $\leq 2\%$ damage because of the high value of the commodity and more stringent food quality standards (Higbee and Siegel 2009). *A. transitella* infestation has been correlated to infections of the nutmeat by *Aspergillus* spp. fungi and contamination of nuts by fungal toxins that are a food quality concern. In fact, to obtain a 95% acceptance rate, aflatoxin B_1 levels must be between 0.12 and 0.22 ng/g, which corresponds to between 1.2 and 3.8% insect (mostly *A. transitella*) damage (Schatzki and Ong 2001). *A. lineatella* larvae bore into shoots, and can deform small trees. Of greater concern are the larvae feeding on new crop nuts after hull split (Strand 2002, Zalom et al. 2002). *A. transitella* are attracted to and may invade nuts previously damaged by *A. lineatella,* masking *A. lineatella* damage (Zalom et al. 2002, Higbee and Siegel 2012).

Historically, organophosphates (e.g., chlorpyrifos, diazinon, azinphosmethyl, methidathion, and phosmet) were the most common chemicals used to control both *A. lineatella* and *A. transitella* (Summers et al. 1959, Zalom et al. 2002). Pyrethroids (e.g., bifenthrin, esfenvalerate, fenpropathrin, and lambda cyhalothrin) have since replaced the organophosphates as the dominant insecticides applied for their control (Higbee and Siegel 2012). Cultural controls for *A. transitella* such as orchard sanitation (removing unharvested almonds from the previous year ["mummy" nuts] to reduce overwintering population; Zalom et al. 1984) and early and rapid harvest (shortens the exposure period for infestation; Curtis et al. 1984) are major components of the management program in California. If these do not sufficiently reduce damage, insecticides are applied. The recommended treatment timing for *A. transitella* is at hull split of the 'Nonpareil' variety when the new crop nuts become susceptible to infestation (Curtis and

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Barnes 1977). An additional treatment may be applied post hull split to protect pollinator varieties from *A. transitella* damage (Zalom and Nicola 2014). For many years, the recommended timing of an insecticide application to control *A. lineatella* was during orchard dormancy when control of San Jose scale *Quadraspidiotus perniciosus* Comstock (Hemiptera: Diaspididae), if present, could also be achieved (Rice and Jones 1988, Zalom et al. 2002). However, environmental concerns such as pesticide run-off into waterways associated with dormant sprays of organophosphates encouraged the development of alternative compounds and spray timings for *A. lineatella* pest management (Epstein et al. 2001).

Spring applications targeting *A. transitella* applied at 55.6 *A. transitella* degree–days (DD) centigrade may be used when winter mummy removal was not adequate and mummy counts are high to reduce damage risk to the new crop from this overwintering source (Strand 2002). Similarly, post-bloom sprays usually applied in early to mid-May at 222.2 *A. lineatella* DD are an alternative to *A. lineatella* dormant sprays (Rice and Jones 1988, Strand 2002). However, spring sprays (early to mid-May) with organophosphate or pyrethroid insecticides have not been encouraged because of potential disruption of natural enemies present in the orchards (Bentley et al. 1987, Zalom et al. 2001, Hamby et al. 2013).

After the Food Quality Protection Act initiated a search for pest management alternatives to organophosphate insecticides (Van Steenwyk and Zalom 2005), novel classes of insecticides have been developed and registered that are less active against humans and less likely to harm natural enemies in comparison to broad-spectrum organophosphate, carbamate, neonicotinoid, and pyrethroid insecticides (Grafton-Cardwell et al. 2005). "Reduced risk" compounds such as chlorantraniliprole, methoxyfenozide, and spinetoram are effective on Lepidoptera and have been found to provide control of *A. transitella* that is comparable to some organophosphate and pyrethroid insecticides (Higbee and Siegel 2012, Zalom and Nicola 2014). Given the higher margin of safety for natural enemies for these products, a spring (early to mid-May) application could be used. This is particularly advantageous for control of *A. lineatella*, as dormant applications may result in water quality issues (Epstein et al. 2001), bloom time sprays put pollinators at risk (though use of the selective microbial insecticide *Bacillus thuringiensis kurstaki* at bloom is an option; Barnett et al. 1993, Epstein et al. 2001), and hull split sprays for this species are difficult to time and not very effective (Reil et al. 1981, Strand 2002).

Each of these newer insecticide classes has a novel mode of action where contact toxicity is secondary (Suh et al. 2000, Sparks et al. 2008, Brugger et al. 2010), therefore, spray timing may need to be adjusted to ensure efficacy. We examined the efficacy of methoxyfenozide, spinetoram, and chlorantraniliprole at three spring application timings including the optimum spring timing for both *A. lineatella* and *A. transitella* in California almonds. Our study also examined the possibility of reducing larval populations of *A. lineatella* and *A. transitella* simultaneously with a single spring insecticide application. To best evaluate the efficacy of these products against both the target organisms, we used sites with known pest pressure. Sutter and Colusa County field sites were used to evaluate efficacy against *A. lineatella* because *A. lineatella* is regularly a problem in this area. However, *A. transitella* pressure in the region is less predictable. Therefore, a separate San Joaquin County site was used to evaluate efficacy against *A. transitella.* Because of differences in pest biology and to facilitate evaluation of insecticide efficacy, application methods varied for each target organism. Because *A. lineatella* are feeding on the apex of shoots at the timings used in this study, insecticides were applied with a sprayer to whole trees and shoot damage was used to evaluate efficacy. *A. transitella* adults would oviposit directly upon the nuts; therefore, sentinel nut strands were used to determine efficacy against *A. transitella.*

Materials and Methods

A. lineatella and _A. transitella_ Spring Phenology at the San Joaquin County Field Site. From 2009 through 2011, spray timing experiments were conducted in a mature 8.1-ha almond orchard (mixed 'Nonpareil' and 'Fritz' varieties) in San Joaquin County near Ripon, CA, with known *A. transitella* pressure that was not treated during the dormant period or the spring timing when our experiments were conducted. One to four pheromone-baited PHEROCON IC wing traps (Trécé Inc., Adair, OK) were placed ~30.5 m from the edge of the orchard in a central row of trees and ~18.2 m apart to measure *A. lineatella* adult populations, either within the trial orchard or in nearby almond orchards (<1.6 km from the trial orchard). Ten PHEROCON IV *A. transitella* egg traps (Trécé Inc., Adair, OK) baited with PHEROCON IV *A. transitella* almond meal bait (Trécé Inc., Adair, OK) were deployed to establish biofix, then six traps were removed to reduce sampling labor on 15 May 2009, 14 May 2010, and May 19, 2011. *A. transitella* egg traps were deployed ~6 m apart (distance between almond trees) within the area intended for the experiment and at least five rows from the orchard border. We began to accumulate *A. transitella* degree–days once eggs were recorded for two consecutive sampling periods on the egg traps, starting biofix at the second date with eggs, and unless sampling periods were ≥7 d apart, we would set biofix 3–4 d earlier than that date. *A. lineatella* biofix was established either after two consecutive sampling periods caught moths or after a single date if all traps were capturing moths. Temperature data were collected by the California Irrigation Management Information System (CIMIS) station number 70 in Manteca, CA, and DD°C for *A. transitella* (lower threshold 12.8°C/ upper threshold 34.4°C) and *A. lineatella* (lower threshold 10.0°C/upper threshold 31.1°C) were calculated using the single sine upper cutoff methods on the University of California Integrated

Table 1. Mean percentage of nuts infested with *A. transitella* per strand (*n* strands) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2009

Treatment	Date	Timing	*N*	Infestation mean ± SE	*P* value[a]
Control	6 May 2009	0.0 *A. transitella* DD	20	14.7 ± 2.7	NA
Chlorantraniliprole[b]	6 May 2009	0.0 *A. transitella* DD	10	0.6 ± 0.6	0.0230
Chlorantraniliprole[b]	14 May 2009	55.6 *A. transitella* DD	10	0.5 ± 0.5	0.0188
Chlorantraniliprole[b]	20 May 2009	254.4 *A. lineatella* DD	9	0.7 ± 0.7	0.0232
Methoxyfenozide[c]	6 May 2009	0.0 *A. transitella* DD	10	2.5 ± 1.7	0.0169
Methoxyfenozide[c]	14 May 2009	55.6 *A. transitella* DD	10	2.3 ± 1.3	0.0185
Methoxyfenozide[c]	20 May 2009	254.4 *A. lineatella* DD	10	1.7 ± 0.9	0.0116
Spinetoram[d]	6 May 2009	0.0 *A. transitella* DD	10	2.7 ± 1.2	0.0319
Spinetoram[d]	14 May 2009	55.6 *A. transitella* DD	9	4.2 ± 1.8	0.1132
Spinetoram[d]	20 May 2009	254.4 *A. lineatella* DD	10	3.0 ± 1.3	0.0321

[a] Logistic generalized linear model $F_{9,98} = 5.12$, $P < 0.0001$, *P* values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b] Altacor 35WG, DuPont, Wilmington, DE, at 111.0 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[c] Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1}.
[d] Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 122.6 g AI ha^{-1}.

Pest Management Program Web site (UC IPM Online (http://ipm.ucdavis.edu/WEATHER/index.html) accessed 31 August 2014).

Efficacy of Spring Applications Targeting *A. transitella* at the San Joaquin County Field Site. 'Nonpareil' mummy nuts saved from the almond harvest previously (nuts with intact hulls were preferred but some nuts lacked hulls) were shaken, as kernels with frass and *A. transitella* webbing do not move freely within the shell, and inspected to determine that they were uninfested. Twenty of these unshelled, uninfested nuts were hot glued (10 on each side) to unopened 30.5-cm mesh Vexar bags (Eagle-Bag.net, Medford, NY) to create sentinel strands of almonds. Five central rows were chosen within the almond orchard, and all 121 strands were deployed in 11 central trees within these rows at the *A. transitella* biofix, as determined by egg trap captures. Strands were hung at a height of ~3 to 4 m, which placed them approximately one-third of the total height of the canopy, with up to four strands per tree on the north side of the tree within the tree canopy. Strands were deployed immediately following *A. transitella* biofix, as indicated by the egg traps previously described.

Chlorantraniliprole (Altacor 35WG, DuPont, Wilmington, DE), methoxyfenozide (Intrepid 2 F, Dow AgroSciences LLC, Indianapolis, IN), and spinetoram (Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN) solutions for all years were made at field-relevant concentrations if a label rate application was made using a 378.5-liter treatment volume (Tables 1–3).

No more than 24 h prior to deployment of the sentinel strands, the strands representing a treatment timed to 0.0 *A. transitella* DD°C (the *A. transitella* biofix) were dipped in 500 ml of insecticide solution to thoroughly coat the nuts and then shaken to remove excess solution to ensure that an even coat was applied. All remaining strands were left untreated. Additional insecticide treatments were made by removing and similarly treating remaining untreated strands as close as possible to 55.6 *A. transitella* DD°C (optimal insecticide timing for spring control of *A. transitella*; Strand 2002) and 222.2 *A. lineatella* DD°C (optimal insecticide timing for spring control of *A. lineatella*; Rice and Jones 1988; Tables 1–3), then rehanging the strands. Strands to be treated with each insecticide and timing were randomly selected using a random number generator. Each row had at least one replicate of each treatment. More replicate control strands (20–26) were deployed than insecticide-treated strands (10–11) because of the increased variability in *A. transitella* infestation anticipated in control strands. In total, ~121 strands were hung each year. Although this application approach produces coverage that is unattainable in the field with commercial equipment, it provides an accurate measure of efficacy at insecticide concentrations applied by growers.

Strands were removed before the predicted start of the subsequent *A. transitella* flight and just before hull split (when the new crop nuts become susceptible to *A. transitella* and the field site is sprayed with an insecticide to target *A. transitella*) on 29 June 2009 (456.5 *A. transitella* DD°C), 16 July 2010 (542.2 *A. transitella* DD°C), and 11 July 2011 (424.3 *A. transitella* DD°C) and held at room temperature for 2 wk to allow all freshly laid eggs to hatch. Infestation was then assessed by cracking the remaining nuts (some were lost during the time in the field) and any evidence of *A. transitella* presence (eggs, frass, webbing, larvae, pupae, and pupal cases) was considered infested. The sentinel nuts were exposed, in effect, to *A. transitella* oviposition of first flight females from biofix until the predicted start of the subsequent generation.

A logistic generalized linear model was used to analyze each insecticide (across years) using PROC GLIMMIX (specifying a binomial distribution and including a random statement to adjust for overdispersion where necessary) in SAS 9.3 (SAS Institute Inc., Cary, NC) with the response variable number of infested nuts on the strand/number of nuts remaining on the strand and timing as a fixed effect. In addition, a logistic generalized linear model was performed for each year using PROC GLIMMIX (specifying a binomial distribution and including a random statement to adjust for

Table 2. Mean percentage of nuts infested with *A. transitella* per strand (*n* strands) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2010

Treatment	Date	Timing	*N*	Infestation Mean ± SE	*P* value[a]
Control	30 Apr. 2010	0.0 *A. transitella* DD	26	14.1 ± 2.3	NA
Chlorantraniliprole[b]	30 Apr. 2010	0.0 *A. transitella* DD	10	0.0 ± 0.0	–
Chlorantraniliprole[b]	13 May 2010	55.0 *A. transitella* DD	11	1.7 ± 1.1	0.0181
Chlorantraniliprole[b]	31 May 2010	245.6 *A. lineatella* DD	10	2.3 ± 1.6	0.0290
Methoxyfenozide[c]	30 Apr. 2010	0.0 *A. transitella* DD	10	0.0 ± 0.0	–
Methoxyfenozide[c]	13 May 2010	55.0 *A. transitella* DD	11	2.6 ± 1.8	0.0091
Methoxyfenozide[c]	31 May 2010	245.6 *A. lineatella* DD	10	1.5 ± 1.0	0.0224
Spinetoram[d]	30 Apr. 2010	0.0 *A. transitella* DD	10	0.6 ± 0.6	0.0460
Spinetoram[d]	13 May 2010	55.0 *A. transitella* DD	11	1.3 ± 0.9	0.0138
Spinetoram[d]	31 May 2010	245.6 *A. lineatella* DD	9	1.4 ± 0.9	0.0290

[a] Logistic generalized linear model $F_{9,108} = 6.09$, $P < 0.0001$, P values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b] Altacor 35WG, DuPont, Wilmington, DE, at 98.6 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[c] Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[d] Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 112.1 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.

Table 3. Mean proportion of nuts infested with *A. transitella* per strand (*n* strands) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2011

Treatment	Date	Timing	*N*	Infestation Mean ± SE	*P* value[a]
Control	10 May 2011	0.0 *A. transitella* DD	19	16.0 ± 5.0	NA
Chlorantraniliprole[b]	10 May 2011	0.0 *A. transitella* DD	10	1.7 ± 1.1	0.0556
Chlorantraniliprole[b]	25 May 2011	53.3 *A. transitella* DD	10	3.9 ± 2.2	0.1118
Chlorantraniliprole[b]	27 May 2011	200 *A. lineatella* DD	11	0.0 ± 0.0	–
Methoxyfenozide[c]	10 May 2011	0.0 *A. transitella* DD	10	1.7 ± 1.2	0.0487
Methoxyfenozide[c]	25 May 2011	53.3 *A. transitella* DD	10	1.5 ± 1.0	0.0353
Methoxyfenozide[c]	27 May 2011	200 *A. lineatella* DD	10	2.2 ± 1.5	0.0872
Spinetoram[d]	10 May 2011	0.0 *A. transitella* DD	11	11.6 ± 9.0	0.1161
Spinetoram[d]	25 May 2011	53.3 *A. transitella* DD	9	3.2 ± 1.6	0.0972
Spinetoram[d]	27 May 2011	200 *A. lineatella* DD	10	0.7 ± 0.7	0.0522

[a] Logistic generalized linear model $F_{9,100} = 4.09$, $P = 0.0002$, P values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b] Altacor 35WG, DuPont, Wilmington, DE, at 98.6 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.
[c] Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.
[d] Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 112.1 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.

overdispersion where necessary) in SAS 9.3 (SAS Institute Inc., Cary, NC) with the response variable number of infested nuts on the strand/number of nuts remaining on the strand and treatment (insecticide and timing combined) as a fixed effect. The treatments were compared with the control using Dunnett's multiple comparison procedure.

***A. lineatella* and *A. transitella* Spring Phenology at Sutter and Colusa County Sites.** The location of field sites for this study were ~190 km north of the San Joaquin County site. *A. lineatella* field sites were chosen for expected *A. lineatella* pressure and for ease of detecting *A. lineatella* shoot strikes (wilted shoot tips resulting from larval feeding). Shoot strikes are easier to detect on young trees; therefore, orchards that were in their second or third growing season with adjacent mature (at least 10 yr old) orchards that would provide a source of adult *A. lineatella* migrants were chosen for treatment. Treatment blocks were placed toward the edges of the treatment orchard nearest the mature orchards because *A. lineatella* damage tends to be greater at these locations (Weakley et al. 1990). Two to three pheromone-baited PHEROCON IC wing traps (Trécé Inc., Adair, OK) were hung mid-canopy on the north side of the trees in the mature almond orchard near the orchard edge closest to the adjacent trial orchard to determine biofix and monitor *A. lineatella* populations. Three to 11 PHEROCON IV *A. transitella* egg traps (Trécé Inc., Adair, OK) baited with PHEROCON IV *A. transitella* almond meal bait (Trécé Inc., Adair, OK) were deployed to determine biofix and monitor *A. transitella* biofix. Traps were hung mid-canopy on the north side of the trees toward the edges of mature almond orchards within 8.0 km of the trial orchard. We began to accumulate *A. transitella* DD once eggs were recorded for two consecutive sampling periods on the egg traps. *A. lineatella* biofix was established either after two consecutive sampling periods caught moths using the second date of capture, though in 2010, biofix was established after a single capture event because the trap captures had increased so dramatically between the two sampling periods. Temperature data were collected by the CIMIS weather station nearest the orchard; CIMIS station number 30 in Nicolaus, CA, for 2010, and station number 32 in Colusa, CA, for 2009 and 2011. DD°C for *A. transitella* (lower

Table 4. Mean *A. lineatella* shoot strikes per tree (*n* trees) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2009

Treatment	Date	Timing	*N*	Shoot strikes	*P* value[a]
Control	NA	NA	12	10.67 ± 2.01	NA
Chlorantraniliprole[b]	28 April 2009	12.6 *A. transitella* DD	6	1.00 ± 0.68	0.0004
Chlorantraniliprole[b]	11 May 2009	72.6 *A. transitella* DD	6	0.83 ± 0.65	0.0002
Chlorantraniliprole[b]	19 May 2009	287.0 *A. lineatella* DD	6	6.83 ± 3.66	0.7444
Methoxyfenozide[c]	28 April 2009	12.6 *A. transitella* DD	6	4.17 ± 2.06	0.0294
Methoxyfenozide[c]	11 May 2009	72.6 *A. transitella* DD	6	8.17 ± 1.72	0.9068
Methoxyfenozide[c]	19 May 2009	287.0 *A. lineatella* DD	5	8.00 ± 2.79	0.8264
Spinetoram[d]	28 April 2009	12.6 *A. transitella* DD	6	1.67 ± 1.09	0.0026
Spinetoram[d]	11 May 2009	72.6 *A. transitella* DD	6	3.00 ± 1.75	0.0099
Spinetoram[d]	19 May 2009	287.0 *A. lineatella* DD	6	6.00 ± 2.22	0.2576

[a] Model: $F_{14,50} = 7.21$, $P < 0.0001$; Treatment $F_{9,50} = 6.10$, $P < 0.0001$, Block $F_{5,50} = 9.20$, $P < 0.0001$; *P* values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b] Altacor 35WG, DuPont, Wilmington, DE, at 111.0 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[c] Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1}.
[d] Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 122.6 g AI ha^{-1}.

threshold 12.8°C / upper threshold 34.4°C) and *A. lineatella* (lower threshold 10.0°C / upper threshold 31.1°C) were calculated using the single sine upper cutoff methods on the UC IPM Web site (http://ipm.ucdavis.edu/WEATHER/index.html, accessed 31 August 2014).

Efficacy of Spring Applications Targeting *A. lineatella*. In 2009, a 24.3-ha orchard in its third growing season near Yuba City, CA, with a mixed variety composition of 25% 'Winters,' 25% 'Monterey,' and 50% 'Nonpareil' was used. No insecticides had been applied to the trees used for this study prior to the study period. Treatments were applied to 'Nonpareil' trees in a randomized complete block design and one tree per row (block) was treated with each treatment and timing combination in six rows using the trees closest to the adjacent mature orchard for six replicate trees per treatment and timing combination. The control treatment was represented twice in each randomized block, whereas other treatments were not repeated within the block. The 2010 orchard was a 2.8-ha orchard in its third growing season near Yuba City, CA, with a mixed variety composition of 33% 'Sonora,' 33% 'Price,' and 33% 'Peerless.' No insecticides had been applied prior to our study. Two trees of each variety were treated with each treatment and timing combination in six rows (blocks) using the trees closest to the adjacent mature orchard for 6 replicate trees per treatment, and timing combination and two control trees per block were left unsprayed for 12 control trees. In 2011, a 20.2-ha orchard in its second growing season near Colusa, CA, with a variety composition of 25% 'Wood Colony,' 25% 'Monterey', and 50% 'Nonpareil' was chosen, and no insecticides targeting *A. lineatella* or *A. transitella* were applied the year prior. Treatments were applied to 'Nonpareil' trees in a randomized complete block design with two trees (each tree in a separate block) per orchard row treated with each treatment and timing combination for six replicate trees in three rows. Two control trees per block were left unsprayed for 12 trees. In this year, orchard rows were bounded on both sides by mature trees.

Treatments in all years were applied with field-relevant concentrations (Tables 4–6) using an Echo Duster-Mister Air Assist sprayer (Echo Inc., Lake Zurich, IL) with an unsprayed tree between each treated tree (including the untreated control). Chlorantraniliprole (Altacor 35WG, DuPont, Wilmington, DE), methoxyfenozide (Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN), and spinetoram (Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN) were applied each year at the same concentrations, and timings described earlier were used in the *A. transitella* efficacy experiment (Tables 4–6).

Treatment effects were assessed by counting the number of *A. lineatella* shoot strikes found on each treated and control tree used in the study during a 3 min timed search conducted at ~475 *A. lineatella* DD°C after biofix.

An ANOVA was performed for each insecticide (across years) using the Fit Model platform of JMP 9.0.0 (SAS Institute Inc., Cary, NC) with number of *A. lineatella* shoot strikes as the response variable and block and timing as fixed effects. Log (X+0.5) transformations were performed if the data did not meet the assumption of normality of residual errors assed using a Shapiro-Wilk test. Weighted least squares methods [weighting factor: (treatment or block residual variance)$^{-1}$] were performed as necessary for whichever fixed effect did not meet the assumption of homoscedasticity as assessed using a Levene's test. In addition, an ANOVA was performed for each year using the Fit Model platform of JMP 9.0.0 (SAS Institute Inc., Cary, NC) with number of *A. lineatella* shoot strikes as the response variable and block and treatment (treatment and timing combination) as fixed effects. Because each block only contained one replicate of treatment the block*treatment effect could not be assessed. Log (X+0.5) transformations were performed if the data did not meet the assumption of normality of residual errors assessed using a Shapiro-Wilk test. Weighted least squares methods [weighting factor: (treatment or block residual variance)$^{-1}$] were performed as necessary for whichever fixed effect did not meet the assumption of homoscedasticity as assessed using a Levene's test. Treatment means were compared with the untreated control using Dunnett's multiple comparison procedure.

Table 5. Mean *A. lineatella* shoot strikes per tree (*n* trees) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2010

Treatment	Date	Timing	*N*	Shoot strikes	*P* value[a]
Control	NA	NA	12	10.41 ± 0.73	NA
Chlorantraniliprole[b]	12 May 2010	57.7 *A. transitella* DD	6	2.00 ± 0.45	<0.0001
Chlorantraniliprole[b]	28 May 2010	116.8 *A. transitella* DD	6	1.67 ± 0.76	<0.0001
Chlorantraniliprole[b]	4 June 2010	281.8 *A. lineatella* DD	6	1.33 ± 0.56	<0.0001
Methoxyfenozide[c]	12 May 2010	57.7 *A. transitella* DD	6	8.83 ± 1.56	0.8694
Methoxyfenozide[c]	28 May 2010	116.8 *A. transitella* DD	6	8.67 ± 2.09	0.9489
Methoxyfenozide[c]	4 June 2010	281.8 *A. lineatella* DD	6	6.83 ± 1.74	0.2834
Spinetoram[d]	12 May 2010	57.7 *A. transitella* DD	6	1.50 ± 0.56	<0.0001
Spinetoram[d]	28 May 2010	116.8 *A. transitella* DD	6	1.67 ± 0.92	<0.0001
Spinetoram[d]	4 June 2010	281.8 *A. lineatella* DD	6	1.17 ± 0.40	<0.0001

[a]Model: $F_{14,51} = 13.54$, $P < 0.0001$; Treatment $F_{9,51} = 20.12$, $P < 0.0001$, Block $F_{5,51} = 1.71$, $P = 0.1500$; *P* values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b]Altacor 35WG, DuPont, Wilmington, DE, at 98.6 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[c]Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.
[d]Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 112.1 g AI ha^{-1} with a nonionic surfactant at 1.0% v/v.

Table 6. Mean *A. lineatella* shoot strikes per tree (*n* trees) for each treatment and timing (*A. transitella* and *A. lineatella* DD°C) in 2011

Treatment	Date	Timing	*N*	Shoot strikes	*P* value[a]
Control	NA	NA	12	5.42 ± 1.39	NA
Chlorantraniliprole[b]	13 May 2011	6.3 *A. transitella* DD	6	0.17 ± 0.17	<0.0001
Chlorantraniliprole[b]	24 May 2011	46.2 *A. transitella* DD	6	0.33 ± 0.21	<0.0001
Chlorantraniliprole[b]	26 May 2011	209.1 *A. lineatella* DD	6	0.17 ± 0.17	<0.0001
Methoxyfenozide[c]	13 May 2011	6.3 *A. transitella* DD	6	2.50 ± 0.81	0.3313
Methoxyfenozide[c]	24 May 2011	46.2 *A. transitella* DD	6	2.33 ± 0.71	0.2414
Methoxyfenozide[c]	26 May 2011	209.1 *A. lineatella* DD	6	2.00 ± 0.63	0.2220
Spinetoram[d]	13 May 2011	6.3 *A. transitella* DD	6	0.33 ± 0.21	<0.0001
Spinetoram[d]	24 May 2011	46.2 *A. transitella* DD	6	0.50 ± 0.22	<0.0001
Spinetoram[d]	26 May 2011	209.1 *A. lineatella* DD	6	0.33 ± 0.21	<0.0001

[a]Model: $F_{14,51} = 6.50$, $P < 0.0001$; Treatment $F_{9,51} = 9.82$, $P < 0.0001$, Block $F_{5,51} = 0.51$, $P = 0.7641$; *P* values reported for means comparisons with Dunnett's adjustment to compare against a control.
[b]Altacor 35WG, DuPont, Wilmington, DE, at 98.6 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.
[c]Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN, at 280.2 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.
[d]Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN, at 112.1 g AI ha^{-1} with a nonionic surfactant at 0.25% v/v.

Results

***A. lineatella* and *A. transitella* Spring Phenology.** At both sites *A. lineatella* biofix consistently occurred two to three weeks earlier than *A. transitella* biofix (Figs. 1 and 2). At the San Joaquin County site, in 2009, *A. lineatella* biofix conditions were met on 20 April, when all three *A. lineatella* pheromone traps captured moths, and *A. transitella* biofix was on 6 May, after oviposition on the 2 and 7 May sampling dates (Fig. 1A). In 2010, *A. lineatella* biofix conditions were met on 19 April, after moth captures in one of the four *A. lineatella* pheromone traps on consecutive (April 16 and 20) sampling dates, and *A. transitella* biofix was on May 1, after eggs were recorded on the 24, 27, and 28 April sampling dates (Fig. 1B). In 2011, *A. lineatella* biofix was 22 April after trap captures on the 19 April and 22 April sampling dates, and *A. transitella* biofix was 10 May after eggs were recorded on the 2 and 6 May sampling dates (Fig. 1C). *A. lineatella* spring adult captures in pheromone traps were bimodal, with high captures in early May and mid-June for all years and *A. transitella* oviposition was detected at low levels throughout the spring (Fig. 1).

At the Colusa and Sutter County sites, *A. transitella* oviposition was very low in all years, while *A. lineatella* moth captures were slightly greater than those observed at the San Joaquin County site in 2009 and 2011 (Fig. 2). In 2009, *A. lineatella* biofix conditions were met on 13 April, when *A. lineatella* pheromone traps captured moths on two consecutive sampling dates (April), and *A. transitella* biofix was 24 April after oviposition of 1.42 eggs per trap per day at the treatment orchard on that date (Fig. 2A). In 2010, *A. lineatella* biofix was on 19 April after moth captures on 22 April and *A. transitella* biofix was 26 April after oviposition on both the 22 and 26 April sampling dates (Fig. 2B). In 2011, *A. lineatella* biofix was on 23 April after trap captures on the 19 and 24 April sampling dates, and *A. transitella* biofix was on 13 May after oviposition was recorded on the 10 May sampling date (Fig. 2C).

Efficacy of Spring Applications of Chlorantraniliprole Targeting *A. transitella* and *A. lineatella*. Across years (2009–2011), chlorantraniliprole-treated nut infestation was 0.8 ± 0.4% (mean ± SE; $N = 30$ strands) at the 0.0 *A. transitella* DD°C treatment timing, 2.0 ± 0.8% ($N = 31$ strands) at the 55.6 *A. transitella* DD°C treatment

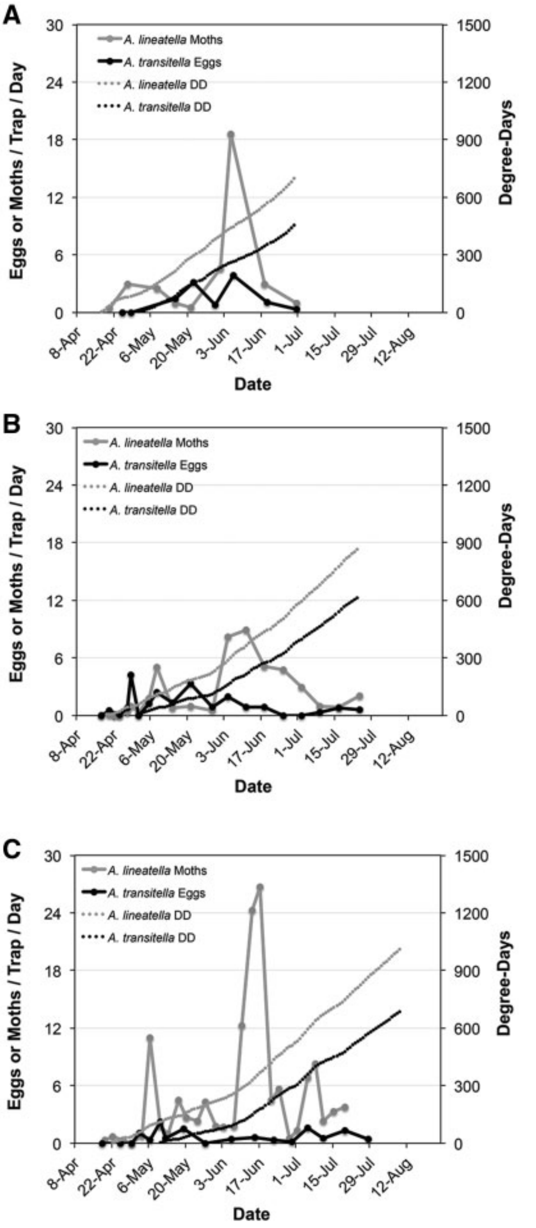

Fig. 1. Accumulated *A. transitella* and *A. lineatella* DD°C, mean *A. transitella* egg captures per trap per day, and mean *A. lineatella* moth captures per trap per day at the San Joaquin County site for (A) 2009, (B) 2010, and (C) 2011.

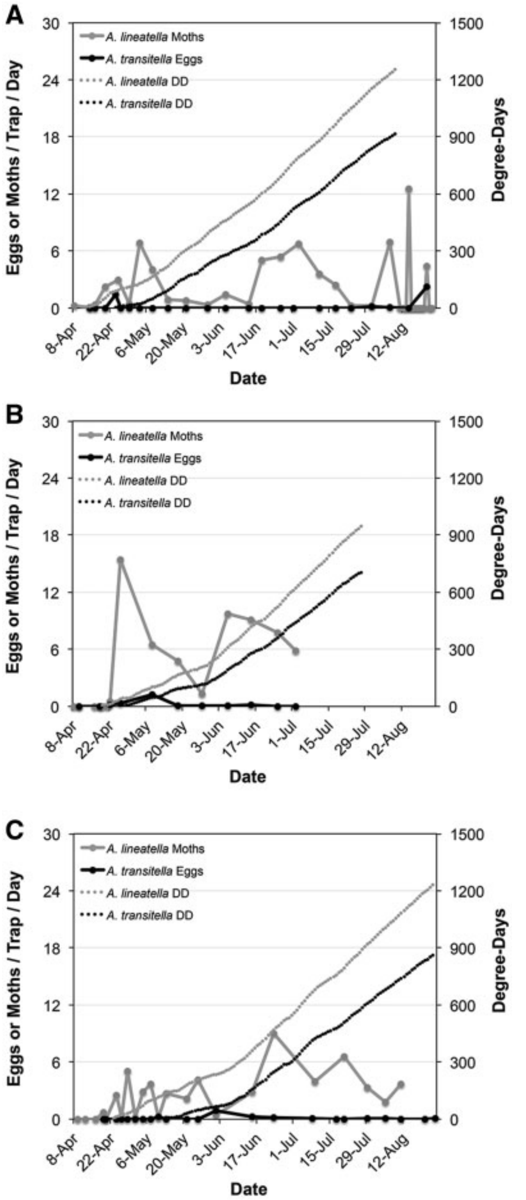

Fig. 2. Accumulated *A. transitella* and *A. lineatella* DD°C, mean *A. lineatella* egg captures per trap per day, and mean *A. lineatella* moth captures per trap per day at the Sutter and Colusa County sites for (A) 2009, (B) 2010, and (C) 2011.

timing, and 1.0 ± 0.6% ($N = 30$ strands) at the 222.2 *A. lineatella* DD°C treatment timing. The logistic generalized linear model of infestation against timing for chlorantraniliprole was not significant ($F_{2,29} = 0.69$; $P = 0.5076$) and there were no significant differences in infestation at the different chlorantraniliprole treatment timings. In 2009, the chlorantraniliprole-treated strands all exhibited infestation, with 0.5–0.7% of the nuts damaged by *A. transitella*, and all treatment timings showed significantly lower infestation relative to the 14.7 ± 2.7% infestation on the control strands (Table 1). As no nuts or replicate strands were infested at the first spray timing (0.0 *A. transitella* DD°C) in 2010, this timing could not be compared with the control. The other two timings exhibited significantly lower infestation (1.7 and 2.3% infestation) than the control (14.1 ± 2.3% infestation; Table 2). The 2011 control strands were 16.0 ± 5.0% infested, and no nuts on the replicate strands were infested on the 199.9 *A. lineatella* DD°C treatment timing for chlorantraniliprole;

therefore, no statistical comparison was made between the two (Table 3). Nut infestations at the other two chlorantraniliprole treatment timings were 1.7 and 3.9% and were not significantly different from the control (Table 3).

Across all years, the 0.0 (approximately) *A. transitella* DD°C ($N = 18$) treatment timing exhibited 1.05 ± 0.32 (mean ± SE) *A. lineatella* shoot strikes per tree, the 55.6 (approximately) *A. transitella* DD°C ($N = 18$) timing exhibited 0.94 ± 0.35 *A. lineatella* shoot strikes per tree, and the 222.2 (approximately) *A. lineatella* DD°C ($N = 18$) timing exhibited 2.78 ± 1.36 *A. lineatella* shoot strikes per tree on chlorantraniliprole-treated trees. Indeed, there was no significant difference (Model: $F_{7,46} = 3.24$, $P = 0.0070$; Block: $F_{5,46} = 4.36$, $P = 0.0025$; Timing: $F_{2,46} = 0.4513$, $P = 0.6396$) in *A. lineatella* shoot strikes depending on treatment timing for chlorantraniliprole. In 2009, both early timings of chlorantraniliprole resulted in significantly fewer *A. lineatella* shoot strikes per tree (0.83–1.00 strikes) than the control (10.67 ± 2.01), but the latest timing (6.83 ± 3.66 strikes; 287.0 *A. lineatella* DD°C) was not significantly different from the control (Table 4). However, in 2010 and 2011, all timings of chlorantraniliprole (1.33–2.00 and 0.17–0.33 strikes per tree, respectively) exhibited significantly fewer shoot strikes per tree than the control (10.41 ± 0.73 and 5.42 ± 1.39 strikes, respectively; Tables 5 and 6).

Efficacy of Spring Applications of Methoxyfenozide Targeting *A. transitella* and *A. lineatella*. There was no significant difference in *A. transitella* nut infestation between treatment timings for methoxyfenozide across years ($F_{2,28} = 0.09$; $P = 0.9135$), and methoxyfenozide-treated strands exhibited $1.4 \pm 0.7\%$ infestation ($N = 30$ strands) at the 0.0 *A. transitella* DD°C treatment timing, $2.2 \pm 0.8\%$ infestation ($N = 31$ strands) at the 55.6 *A. transitella* DD°C treatment timing, and $1.8 \pm 0.7\%$ infestation ($N = 30$ strands) at the 222.2 *A. lineatella* DD°C treatment timing. In 2009, nut infestation for the different methoxyfenozide treatment timings ranged from 1.7 to 2.5%, and all were significantly lower than the control (Table 1). In 2010, no infestation occurred at the 0.0 *A. transitella* DD°C treatment timing for methoxyfenozide and no statistical comparison was made. The other two treatment timings had significantly lower infestation than the control, ranging from 1.5 to 2.6% (Table 2). Nuts exposed at the first two methoxyfenozide treatment timings had significantly less infestation than the control in 2011, and infestation in methoxyfenozide-treated nuts ranged from 1.5 to 2.2% (Table 3).

There were 5.17 ± 1.07 *A. lineatella* shoot strikes per tree when methoxyfenozide was applied at 0.0 *A. transitella* DD°C ($N = 18$), 6.39 ± 1.12 shoot strikes per tree at 55.6 *A. transitella* DD°C ($N = 18$), and 5.47 ± 1.17 shoot strikes per tree at 222.2 *A. lineatella* DD°C ($N = 17$). There was no significant difference (Model: $F_{7,45} = 3.15$, $P = 0.0085$; Block: $F_{5,45} = 4.23$, $P = 0.0031$; Timing: $F_{2,45} = 0.5084$, $P = 0.6049$) in *A. lineatella* shoot strikes for the different treatment timings. Methoxyfenozide typically exhibited poorer *A. lineatella* control than the other insecticides used in this study, and only the first timing (4.17 ± 2.06, 12.6 *A. transitella* DD°C) of methoxyfenozide was significantly different than the control in 2009 (Table 4). In 2010 and 2011, no methoxyfenozide application was significantly different than the control (Tables 5 and 6).

Efficacy of Spring Applications of Spinetoram Targeting *A. transitella* and *A. lineatella*. There was no significant difference in *A. transitella* damage between spinetoram treatments at different timings across years ($F_{2,29} = 0.38$; $P = 0.6843$). At the first treatment timing (0.0 *A. transitella* DD°C), $5.2 \pm 3.3\%$ of nuts were damaged ($N = 31$ strands), $2.8 \pm 0.8\%$ ($N = 29$) at the second timing (55.6 *A. transitella* DD°C), and $1.7 \pm 0.6\%$ of the nuts were damaged at the latest treatment timing (222.2 *A. lineatella* DD°C). Spinetoram treatments varied from 2.7 to 4.2% infestation in 2009 and the first and last timings were significantly lower than the control (Table 1). In 2010, spinetoram-treated strands varied from 0.6 to 1.4% damage, depending on timing, and all timings exhibited significantly less damage than the control (Table 2). Spinetoram showed more variation between treatment timings in 2011, with a range of 0.7 to 11.6% damage, and no timings were significantly different than the control (Table 3).

For *A. lineatella*, a 0.0 *A. transitella* DD°C ($N = 18$) application of spinetoram resulted in 1.17 ± 0.41 shoot strikes, a 55.6 *A. transitella* DD°C ($N = 18$) timing resulted in 1.72 ± 0.67 shoot strikes and a 222.2 *A. lineatella* DD°C ($N = 18$) timing resulted in 2.50 ± 0.93 *A. lineatella* shoot strikes. Timing did not significantly impact *A. lineatella* shoot strike damage when spinetoram was used (Model: $F_{7,46} = 2.91$, $P = 0.0133$; Block: $F_{5,46} = 4.23$, $P = 0.0072$; Timing: $F_{2,46} = 1.022$, $P = 0.3678$). In 2009, both early timings of spinetoram resulted in significantly fewer *A. lineatella* shoot strikes than the control, but the latest timing (6.00 ± 2.22, 287.0 *A. lineatella* DD°C) was not significantly different from the control (Table 4). In 2010 (1.17–1.67 strikes) and 2011 (0.33–0.50 strikes), all timings of spinetoram resulted in significantly less damage than the control (Tables 5 and 6).

Discussion

As anticipated, *A. transitella* oviposition was greater in the San Joaquin County field site that was selected for historical *A. transitella* pressure, and *A. transitella* oviposition was much lower at the Colusa and Sutter County sites that were used to assess *A. lineatella* infestation. *A. transitella* egg traps have been the primary monitoring tactic used in almonds since the mid-1970s (Rice et al. 1976, Van Steenwyk and Barnett 1985), and DD models for timing insecticide treatments using the egg traps have been available since the late 1980s (Sanderson et al. 1989, Zalom et al. 1998). Sex pheromone baited traps developed as an *A. transitella*-monitoring tool for adult males (Burks et al. 2011) and became commercially available in 2013, and research to develop specific DD guidelines for their use in timing spring insecticide treatments is currently underway.

In fact, recent work by Higbee et al. (2014) has described a pheromone lure that correlates well with female moth baited traps. Male moth captures in *A. transitella* pheromone traps are much greater than the number of eggs in corresponding egg traps, but the proportion of egg traps with eggs present correlates with *A. transitella* male moth captures in pheromone traps (Burks et al. 2011). Proportion of *A. transitella* egg traps with eggs is also correlated with mean eggs per trap (Burks et al. 2011). *A. lineatella* captures in pheromone traps were relatively similar between the two sites, and tended towards bimodal flights similar to that reported in previous work (Zalom et al. 1992). Except in 2009, *A. transitella* biofix conditions were met within a week of one another for both sites, and *A. lineatella* biofix conditions were met within a week of one another at both sites in all years. In addition, *A. lineatella* biofix typically occurred 2–3 wk earlier than *A. transitella* biofix. This could be because of the difference in biology between the moths or because of differences in the trapping methods used to measure biofix. Although both traps measure adult activity in the field, *A. lineatella* pheromone traps are capturing mate-seeking male moths, whereas *A. transitella* egg traps are detecting egg-laying females. Applications approximating 0.0 *A. transitella* DD°C, 55.6 *A. transitella* DD°C, and 222.2 *A. lineatella* DD°C resulted in a 2–3 wk spread between the first application and the last (Tables 1–6).

Methoxyfenozide (Intrepid 2F, Dow AgroSciences LLC, Indianapolis, IN) was registered in California in May 2003 (www.cdpr.ca.gov accessed 31 August 2014), and was the first of a series of products registered on almonds that are active against Lepidoptera and considered to be more compatible with IPM programs because of an improved margin of safety to nontarget organisms including nontarget and beneficial insects (Carlson et al. 2001). Indeed, methoxyfenozide was found to be inactive against the beneficial egg parasitoid *Trichogramma* nr. *brassicae* (Hymenoptera: Trichogrammatidae) adults and larvae at field rate (Hewa-Kapuge et al. 2003), and *Trichogramma exiguum* Pinto exhibited no adverse effects on preimaginal development and adult survival after exposure to methoxyfenozide (Suh et al. 2000). Methoxyfenozide is a diacylhydrazine insecticide that is a potent agonist of the insect molting hormone 20-hydroxyecdsone, which is most efficacious when ingested but also has some topical and ovicidal properties (Carlson et al. 2001). One to three methoxyfenozide applications provide control of *A. transitella* when applied at hull split or post hull split timings that is comparable with some organophosphate and pyrethroid insecticides (Higbee and Siegel 2012), and our results suggest that methoxyfenozide is also efficacious against *A. transitella* at spring timings (Tables 1–3). However, our study found methoxyfenozide to be less efficacious against *A. lineatella* shoot strikes, and it was only significantly different from the control on one instance (Tables 4–6).

Chlorantraniliprole (Altacor 35WG, DuPont, Wilmington, DE) was registered in California in May 2008 (www.cdpr.ca.gov accessed 31 August 2014). It is an anthranilic diamide that activates ryanodine receptors and is primarily active via ingestion with secondary contact activity (Brugger et al. 2010). Demonstrating good ovilarvicidal and larvicidal activity, it has low mammalian toxicity and preserves beneficial species (Brugger et al. 2010). Indeed, no significant mortality was observed to seven species of beneficial parasitic wasp including species from the genera *Aphidius*, *Trichogramma*, and *Diadegma* (Brugger et al. 2010). Chlorantraniliprole has been found to provide control of *A. transitella* that is comparable with some organophosphate and pyrethroid insecticides (Zalom and Nicola 2014), and our study indicates that it is effective in reducing *A. lineatella* shoot strikes, an indicator of its efficacy (Tables 3–6).

Spinetoram (Delegate 25WG, Dow AgroSciences LLC, Indianapolis, IN) was registered in California in November 2007 (www.cdpr.ca.gov accessed 31 August 2014), and like other spinosyns, it has broad-spectrum activity causing hyperexcitation of the nervous system by activating the Dα6 subunit of the nicotinic acetylcholine receptor while maintaining a safe environmental and toxicological profile (Sparks et al. 2008, Besard et al. 2011). Spinosad exhibits low to moderate toxicity to many species of predatory insects and mites (Williams et al. 2003). In addition, spinetoram wet residues are $\sim 52\times$ less active than spinosad to the beneficial pollinator *Bombus terrestris* L. (Hymenoptera: Apidae) workers, though spinosyns more broadly are not recommended for application during crop flowering (Besard et al. 2011). Spinetoram is effective on Lepidoptera and has previously been found to provide control of *A. transitella* that is comparable with some organophosphate and pyrethroid insecticides (Zalom and Nicola 2014). Our study found spinetoram to be effective in controlling *A. lineatella* at the spring treatment timings (Tables 4–6), although it was less consistent in its performance against *A. transitella* with significant control in 56% of the trials (Tables 1–3).

Despite differences in seasonal phenology between *A. transitella* and *A. lineatella*, there were no significant differences in efficacy of the insecticides for the different application timings for either species. Indeed, in most years, all three timings for chlorantraniliprole and spinetoram resulted in significantly fewer *A. transitella* infested "mummy" nuts and *A. lineatella* shoot strikes than the control (Tables 1–6). However, methoxyfenozide did not perform as well against *A. lineatella*, and spinetoram did not perform as well against *A. transitella*.

Our results indicate that a single spring treatment with a reduced-risk insecticide such as chlorantraniliprole can be used to simultaneously target *A. transitella* and *A. lineatella* with similar results across the potential timings. They also suggest that timing a treatment with the insecticides used in our study requires somewhat less precision than was recommended in earlier studies by Rice and Jones (1988) that were conducted with organophosphates. Almond orchards near external *A. transitella* sources may be subject to infestation by migrating adult females at hull split that will require insecticide treatment at that time. Reducing larval infestation of remaining mummy nuts that represent the resident orchard population can be expected to provide additional reduction of new crop damage and allow growers to meet more stringent food-quality standards. Concurrent control of *A. lineatella* with a reduced-risk insecticide application at the spring treatment timing provides an alternative to a dormant season spray targeting this insect, thereby addressing environmental concerns associated with that timing such as pesticide run-off into waterways.

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References Cited

Barnett, W. W., J. Edstrom, R. L. Coviello, and F. G. Zalom. 1993. Insect pathogen "Bt" controls peach twig borer on fruits and almonds. Calif. Agric. 47: 4–6.

Bentley, W., F. G. Zalom, W. W. Barnett, and J. P. Sanderson. 1987. Population densities of *Tetranychus* spp. (Acari: Tetranychidae) after treatment with insecticides for *Amyelois transitella* (Lepidoptera: Pyralidae). J. Econ. Entomol. 80: 193–200.

Besard, L., V. Mommaerts, G. Abdu-Alla, and G. Smagge. 2011. Lethal and sublethal side-effect assessment supports a more benign profile of spinetoram compared with spinosad in the bumblebee *Bombus terrestris*. Pest Manage. Sci. 67: 541–547.

Brugger, K. E., P. G. Cole, I. C. Newman, N. Parker, B. Scholz, P. Suvagia, G. Walker, and T. G. Hammond. 2010. Selectivity of chlorantraniliprole to parasitoid wasps. Pest Manage. Sci. 66: 1075–1081.

Burks, C. S., B. S. Higbee, J. P. Siegel, and D. G. Brandl. 2011. Comparison of trapping for eggs, females, and males of the navel orangeworm (Lepidoptera: Pyralidae) in almonds. Environ. Entomol. 40: 706–713.

Carlson, G. R., T. S. Dhadialla, R. Hunter, R. K. Jansson, C. S. Jany, Z. Lidert, and R. A. Slawecki. 2001. The chemical and biological properties of methoxyfenozide, a new insecticidal ecdysteroid agonist. Pest Manage. Sci. 57: 115–119.

Curtis, R. K., and M. M. Barnes. 1977. Oviposition and development of navel orangeworm (Lepidoptera: Pyralidae) in relation to almond maturation. J. Econ. Entomol. 70: 395–398.

Curtis, C. E., R. K. Curtis, and K. L. Andrews. 1984. Progression of navel orangeworm (Lepidoptera: Pyralidae) infestation and damage of almonds on the ground and on the tree during harvest. Environ. Entomol. 13: 146–149.

Epstein, L., S. Bassein, F. G. Zalom, and L. R. Wilhoit. 2001. Changes in pest management practices in almond orchards during the rainy season in California, USA. Agric. Ecosyst. Environ. 83: 111–120.

Grafton-Cardwell, E. E., L. D. Godfrey, W. E. Chaney, and W. J. Bentley. 2005. Various novel insecticides are less toxic to humans, more specific to key pests. Calif. Agric. 59: 29–34.

Hamby, K. A., J. A. Alifano, and F. G. Zalom. 2013. Total effects of contact and residual exposure of bifenthrin and λ-cyhalothrin on the predatory mite *Galendromus occidentalis* (Acari: Phytoseiidae). Exp. Appl. Acarol. 61: 183–193.

Hewa-Kapuge, S., S. McDougall, and A. A. Hoffmann. 2003. Effects of methoxyfenozide, indoxacarb, and other insecticides on the beneficial egg parasitoid *Trichogramma* nr. *brassicae* (Hymenoptera: Trichogrammatidae) under laboratory and field conditions. J. Econ. Entomol. 96: 1083–1090.

Higbee, B. S., C. S. Burks, and T. E. Larsen. 2014. Demonstration and characterization of a persistent pheromone lure for the navel orangeworm, *Amyelois transitella* (Lepidoptera: Pyralidae). Insects 5: 596–608.

Higbee, B. S., and J. P. Siegel. 2009. New navel orangeworm sanitation standards could reduce almond damage. Calif. Agric. 63: 24–28.

Higbee, B. S., and J. P. Siegel. 2012. Field efficacy and application timing of methoxyfenozide, a reduced-risk treatment for control of navel orangeworm (Lepidoptera: Pyralidae) in almond. J. Econ. Entomol. 105: 1702–1711.

Reil, W. O., T. W. Johnson, J. C. Profita, C. S. Davis, L. C. Hendricks, and D. Rough. 1981. Monitoring peach twig borer in almonds with sex pheromone traps. Calif. Agric. 35: 19–20.

Rice, R. E., and R. A. Jones. 1988. Timing post-bloom sprays for peach twig borer (Lepidoptera: Gelichiidae) and San Jose scale (Homoptera: Diaspididae). J. Econ. Entomol. 81: 293–299.

Rice, R.E., L.L. Sadler, M.L. Hoffmann, and R.A. Jones. 1976. Egg traps for the navel orangeworm, *Paramyelois transitella* (Walker). Environ. Entomol. 5: 697–700.

Sanderson, J. P., M. M. Barnes, and W. S. Seaman. 1989. Synthesis and validation of a degree-day model for navel orangeworm (Lepidoptera: Pyralidae) development in California almond orchards. Environ. Entomol. 18: 612–617.

Schatzki, T. F., and M. S. Ong. 2001. Dependence of aflatoxin in almonds on the type and amount of insect damage. J. Agric. Food Chem. 49: 4513–4519.

Sparks, T. C., G. D. Crouse, J. E. Dripps, P. Anzeveno, J. Martynow, C. V. DeAmicis, and J. Gifford. 2008. Neural network-based QSAR and insecticide discovery: spinetoram. J. Comput. Aided Mol. Des. 22: 393–401.

Strand, L. L. 2002. Integrated pest management for almonds, pp. 61–78, 2nd ed Publication 3308. University of California Division of Agriculture and Natural Resources, Oakland, CA.

Suh, C.P.C., D. B. Orr, and J. W. Van Duyn. 2000. Effect of insecticides on *Trichogramma exiguum* (Trichogrammatidae: Hymenoptera) preimaginal development and adult survival. J. Econ. Entomol. 93: 577–583.

Summers, F. M., D. Donaldson, and S. Togashi. 1959. Control of peach twig borer on almonds and peaches in California. J. Econ. Entomol. 52: 637–639.

Van Steenwyk, R. A., and W. W. Barnett. 1985. Improvement of navel orangeworm (Lepidoptera: Pyralidae) egg traps. J. Econ. Entomol. 78: 282–286.

Van Steenwyk, R. A., and F. G. Zalom. 2005. Food Quality Protection Act launches search for pest management alternatives. Calif. Agric. 59: 7–10.

Wade, W. H. 1961. Biology of the navel orangeworm, *Paramyelois transitella* (Walker), on almonds and walnuts in northern California. Hilgardia 31: 129–171.

Weakley, C. V., P. A. Kirsch, and F. G. Zalom. 1990. Within-orchard and within-tree distributions of peach twig borer (Lepidoptera: Gelechiidae) damage to peaches. J. Econ. Entomol. 83: 505–510.

Williams, T., J. Valle, and E. Vinuela. 2003. Is the naturally derived insecticide Spinosad® compatible with insect natural enemies? Biocontrol Science and Technology 13: 459–475.

Zalom, F. G., W. W. Barnett, and C. V. Weakley. 1984. Efficacy of winter sanitation for managing the navel orangeworm *Paramyelois transitella* (Walker), in California almond orchards. Prot. Ecol. 7: 37–41.

Zalom, F. G., W. W. Barnett, R. E. Rice, and C. V. Weakley. 1992. Factors associated with flight patterns of the peach twig borer (Lepidoptera: Gelichiidae) observed using pheromone traps. J. Econ. Entomol. 85: 1904–1909.

Zalom, F. G., J. H. Connell, and W. J. Bentley. 1998. Validation of phenology models for predicting development of the navel orangeworm *Ameylois transitella* (Walker) in California almond orchards. Acta Hortic. 470: 525–533.

Zalom, F. G., and N. L. Nicola. 2014. Controlling the first generation of navel orangeworm in almonds. Acta Hortic. 1028: 185–190.

Zalom, F. G., M. W. Stimmann, T. S. Arndt, D. B. Walsh, C. Pickel, and W. H. Krueger. 2001. Analysis of permethris (*cis*- and *trans*- isomers) and esfenvalerate on almond twigs and effects of residues on the predator mite *Galendromus occidentalis* (Acari: Phytoseiidae). Environ. Entomol. 30: 70–75.

Zalom, F. G., D. B. Walsh, W. Krueger, and J. Connell. 2002. Tolerance of peach twig borer, *Anarsia lineatella* Zeller, to organophosphate and pyrethroid insecticides. Acta Hortic. 591: 585–591.

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