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# Relationship of Almond Kernel Damage Occurrence to Navel Orangeworm (Lepidoptera: Pyralidae) Success

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**ABSTRACT** Laboratory and field studies are reported that assess navel orangeworm (*Amyelois transitella* (Walker)) development and damage on 11 almond varieties that represent both expected and outlying hull split and shell seal *A. transitella* damage. Twenty neonate larvae were introduced to almonds of three treatments for each variety: scratched (1 mm scratch through the pellicle), shelled (shell removed but pellicle intact), and unshelled (shell intact and exhibiting the tightest shell seal for the variety). Success was evaluated as moth emergence and degree-days (DD) to emergence. In 2010–2011 and 2011–2012, 10 replicate rows containing randomized strands of 20 unshelled, uninfested almonds from each variety were placed in the field for both the fall and spring *A. transitella* flight. The almonds were returned to the lab before the initiation of the second spring *A. transitella* flight and categorized by presumed cause of damage (bird damage, *A. transitella* damage, or both types of damage). Damage, variety, and their interaction significantly impacted *A. transitella* survival and DDs to emergence in male moths. Female moth DDs to emergence were significantly impacted by damage alone. Damage from birds and *A. transitella* damage were positively correlated, and *A. transitella* damage associated with bird damage was more common than *A. transitella* damage alone. Noncon-specific damage may have a significant impact on *A. transitella* populations in the field, and bird damage may have repercussions beyond its direct impact on marketable yield.

**KEY WORDS** *Prunus dulcis*, degree-days, survivorship, Corvidae, bird damage, *Amyelois transitella*

Although there are ≈30 almond varieties (*Prunus dulcis* L.) produced in commercial orchards in California, five varieties (Nonpareil, Monterey, Carmel, Butte, and Padre) represent over 80% of production. Few almonds are self-fertile, so orchards are usually planted as a mix of at least two varieties for pollination purposes. Critical factors that influence the selection of varieties that comprise a given orchard include: bloom time, pollen compatibility, yield, ease of nut removal, ease of shelling, disease susceptibility, and (perhaps the strongest selector) marketability (Asai et al. 1996).

Navel orangeworm, *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae), larvae feed directly on the nutmeat of almonds making them unmarketable (Phillips et al. 1980, Doster et al. 1996, Campbell et al. 2003, Niu et al. 2009). In addition, *A. transitella* infestations are correlated with infections of the nutmeat by *Aspergillus* spp. fungi and with contamination of nuts by fungal aflatoxins and ochratoxins. Damage costs because of these mycotoxins vary based on almond market value; however, over a 6 yr period direct market value losses because of inedible almonds ranged between US\$23 million and US\$47 million annually (Robens and Cardwell 2003). Damage tolerance is pres-

ently very low because of reduced safety thresholds for aflatoxin and almond industry price structures (Higbee and Siegel 2009). Thus, the pest status of *A. transitella* in almonds is even greater.

Shell hardness and seal have often been implicated in varietal resistance to *A. transitella* damage with the assumption that harder, more tightly sealed almonds suffer reduced infestation, thereby incurring less damage (Crane and Summers 1971, Soderstrom 1977, Hamby et al. 2011). Another varietal characteristic influencing *A. transitella* damage is nut phenology relative to moth flights as peak almond susceptibility to infestation begins at or near hull split (Curtis and Barnes 1977). The risk of *A. transitella* infestation has been reported to increase significantly after hull split (Soderstrom 1977).

Hamby et al. (2011) found a significant relationship between a variety's hull split date and infestation, with increased *A. transitella* damage in varieties undergoing hull split closer to the initiation of *A. transitella* flights. Greater percent shell seal correlated with lower infestation levels (Hamby et al. 2011). Despite the trends in percent *A. transitella* damage related to hull split date and percent shell seal, some varieties appeared to be outliers suggesting that other nut characteristics could influence *A. transitella* infestation. Eleven varieties were selected for the current study:

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Aldrich, Carmel, Johlyn, Livingston, Monterey, Nonpareil, Padre, Plateau, Price, Sonora, and Wood Colony. These varieties were chosen as a representative subset of those used by Hamby et al. (2011).

As *A. transitella* have previously been shown to have variable development rates and survival when reared on a variety of diets, including different almond varieties (Wade 1961, Finney and Brinkman 1967, Seaman and Barnes 1984, Tzanakakis and Barnes 1988, Sanderson et al. 1989, Siegel et al. 2010, Siegel and Kuenen 2011), we tested the development rate and survival on the 11 varieties of almonds. Statistically outlying varieties are presumed to possess some other qualities, such as variation in chemical constituents or shape of the nut, which affect their suitability for *A. transitella*. To resolve impact of shell seal on survival and development rate, three damage categories were compared for each variety; an unshelled nut with the tightest shell seal possible for the variety, a shelled nut (to simulate better access to a nut either via shell damage or poor seal), and a shelled nut with a scratch (to provide an access point to the nut meat without pellicle). Unshelled, uninfested nuts were hung on strands within the same orchard and subjected to the fall and spring *A. transitella* flights so as to measure the field infestation of each variety (a combined measure of survivability and attractiveness as an oviposition substrate) in a situation where background volatiles would be similar for all varieties.

### Materials and Methods

**Almond Varieties.** Almonds of each variety (Aldrich, Carmel, Johlyn, Livingston, Monterey, Nonpareil, Padre, Plateau, Price, Sonora, and Wood Colony) were collected from the San Joaquin Delta College almond Regional Almond Variety Trial (RAVT). The trees were not treated with insecticides. The RAVT almonds were planted in 1993 on Nemaguard peach rootstock with two standard commercial varieties (Nonpareil for early–mid blooming varieties and Mission for late blooming varieties) planted 1:1 as pollinators with the other varieties in full rows of 29–38 trees. To ensure uniform nut maturity at harvest, almonds were shaken from the trees when at least 95% of the almond hulls had split.

**Laboratory Damage Treatments.** Almonds of each variety were collected from the RAVT at their respective harvest timing in late summer 2009 and immediately placed in a 4°C cooler until January 2010. Damage treatments consisted of intact nutmeats with undamaged pellicles, nutmeats with undamaged pellicles that were artificially damaged with a paper clip (dipped in 95% ethanol and wiped off between varieties) to create a 1 mm scratch, and unshelled nuts that were externally undamaged and had the tightest shell seal possible for the variety (representing a best case scenario for excluding *A. transitella*).

Unused Ball (Ball Corporation, Broomfield, CO) wide mouth tapered 473 ml canning jars were washed with soap and warm water, rinsed with deionized water, and allowed to dry. The canning lids were

removed and replaced with 8.25 cm stainless steel wire of diameter 0.035 cm, and 9.45 mesh/cm discs with standard square weave (TWP Inc., Berkeley, CA). Whatman 90 mm qualitative circle filter papers (Whatman, Inc., Piscataway, NJ) were used under the mesh to help prevent introduction of pathogens and fungal spores. Ten nuts were placed in all the jars, with two replicate jars per treatment and variety combination. Twenty newly eclosed *A. transitella* larvae were loaded directly onto nuts in each jar using a fine-haired paintbrush. Larvae were collected within 24 h of hatching from eggs provided by the U.S. Department of Agriculture–Agriculture Research Service (USDA–ARS) lab in Parlier, CA, on 12 January 2010 from the UC Berkeley 1966 colony (SPIRL-1966) (Siegel et al. 2010).

Jars were maintained in an incubator (Percival model I-35L, Percival Scientific, Inc., Perry, IA) at a photoperiod of 16:8 (L:D) h,  $25 \pm 0.5^\circ\text{C}$ , relative humidity (RH)  $65 \pm 15\%$ . A single 20-Watt fluorescent light bulb (GE Cool White 2F20T12-CW, General Electric Company, Fairfield, CN) was placed 40.64 cm above each shelf. Jar locations in the incubator were rerandomized after being examined each day to eliminate positional effects. Once pupae were observed (larvae generally feed within the nuts and development can only be determined destructively), jars were examined at  $\approx 1:00$  p.m. daily and any emerged adult moths were collected. Sex was determined by visual inspection, and emergence dates were recorded. Time to emergence was expressed as Centigrade degree-days (DD) (Lower threshold  $12.8^\circ\text{C}$ /upper threshold  $34.4^\circ\text{C}$ ) and as they were kept at constant  $25^\circ\text{C}$  they accrued  $12.2$  DD  $^\circ\text{C}$  per day (University of California Division of Agriculture and Natural Resources State-wide Integrated Pest Management Program 2010). The experiment was considered complete after 14 successive days with no moth emergence.

**Variety Field Infestation.** A 2 yr field variety trial (2010 and 2011) was performed at a conventional Fritz and Nonpareil mixed almond orchard in Ripon, CA. Insecticide untreated almonds of each variety were collected from the RAVT at the time of their respective harvests in 2010 and 2011, and placed directly in a 4°C cooler. Unopened 12" mesh Vexar bags (Eagle-Bag.net, Medford, NY) were used as a substrate for attaching almonds to create an almond strand. Ten unshelled almonds were hot glued down the length of the strand on each side, to create a total of 20 almonds per strand. Almonds with the tightest shell seal possible for each variety were chosen from among those harvested, and were shaken (kernels with frass and *A. transitella* webbing do not move freely within the shell) and inspected to ensure that no *A. transitella* infestation had occurred before strand construction. Strands were knotted at the end and metal hooks were placed through the knot for hanging.

Almond strands were hung mid canopy on the north side of the Fritz and Nonpareil trees such that each row (alternating Fritz and Nonpareil trees) contained all 11 varieties in a random distribution. Ten replicate rows received the strands each year. To simulate

mummy almonds that would remain on the trees through the winter, strands were placed in the field after the local almonds were harvested on 1 November 2010 and 31 October 2011, and thereby were exposed to the remainder of the fall *A. transitella* flight. On 6 December 2010 and 30 November 2011, before the first heavy storm of winter, the almond strands were collected, grouped by replicate, and placed under a porch roof in Davis, CA, so that any *A. transitella* larvae present would be subjected to winter temperatures but the almonds would not be lost in the wind and rain. Almonds were returned to the field and rerandomized within their replicate rows for the spring *A. transitella* flight just after the spring biofix (beginning of a consistent increase in egg laying on *A. transitella* egg traps) on 4 April 2011 and 26 April 2012. The strands were returned to the lab for data collection after  $\approx 800$  DD had accumulated on 11 July 2011 and 25 June 2012 so that the nuts would only be exposed to oviposition by the first spring flight. Strands were bagged in sealed brown paper bags and held at room temperature (25°C) for 2 wk to allow any freshly laid eggs to hatch.

The almond strands were then cracked and categorized into one of three damage categories: *A. transitella* damage alone, *A. transitella* and bird damage, or bird damage alone. Bird damage was described as a clear hole through the shell and into the nutmeat resulting in penetration of the pellicle, whereas *A. transitella* damage was described as presence of any of the following: frass, larvae, or pupae.

**Statistical Analyses.** For the lab study, total moths emerged was analyzed using the Fit model platform of JMP statistical software (JMP version 9.0.0, SAS Institute Inc., Cary, NC) with Damage (artificial damage treatments), Variety (almond variety), and the interaction of Damage\*Variety as model effects. The Shapiro–Wilk test was used to check the assumption of normality of residual errors. The residual errors failed a Levene test of homoscedasticity for the Variety factor; therefore, the analyses were rerun using weighted least squares methods, in which the weighting factor was the reciprocal of Variety residual variance. Means comparisons were subsequently performed using a Tukey's honestly significant difference (HSD) test.

This analysis was also performed with the response variable DDs to emergence for adult male and female *A. transitella* that emerged. The analysis was performed separately for each sex because of a difference in emergence time between males and females. Varieties in which no adult moths emerged were excluded in the analysis of DDs to emergence to avoid a loss of degrees of freedom. The Shapiro–Wilk test was used to check the assumption of normality of residual errors and data were log transformed to meet this assumption. In both cases the analyses were rerun using weighted least squares methods in which the weighting factor was the reciprocal of the Damage\*Variety sample residual variance to adjust for a failed Levene test in that factor. Means comparisons were subsequently performed using a Tukey's HSD test.

For the field study, percent *A. transitella* infestation (*A. transitella* infestation only combined with *A. tran-*

*sitella* and bird damage) was analyzed using the Fit model platform of JMP with Year, Variety, and the interaction of Year\*Variety as model effects. Percent bird damage (bird damage only combined with *A. transitella* and bird damage) was analyzed using the same model effects. The Shapiro–Wilk test was used to check the assumption of normality of residual errors and data were log transformed to meet this assumption in both analyses. The analyses were rerun using weighted least squares methods in which the weighting factor was the reciprocal of the Variety residual variance to adjust for failed Levene test in that factor. Means comparisons of varieties for percent infestation and percent bird damage were compared using a Tukey's HSD. A Pearson product-moment correlation was calculated for the bivariate scatter plot of percent *A. transitella* infestation against percent bird damage using the 95% density ellipse command under the Fit Y by X platform of JMP.

## Results

Both damage treatment and almond variety were found to have significant impact on the number of adult *A. transitella* to emerge. This effect was dependent upon the variety as well as the damage, though damage showed the more significant *P* value: Damage  $F_{2,65} = 131.48$ ,  $P < 0.0001$ ; Variety  $F_{10,65} = 3.63$ ,  $P = 0.0024$ ; Damage\*Variety  $F_{20,65} = 4.23$ ,  $P = 0.0001$ . Although the multiplicative effect indicates that the effect of damage is dependent upon the variety, the overall trend for damage was that increasing damage increased moth emergence, with the most moths emerging from the scratched damage treatment and the fewest emerging from the unshelled treatment: Tukey's HSD (letter denote significant differences in Damage means at  $P < 0.05$ ): Scratched = A, Shelled = B, and Unshelled = C. The single exception was the Nonpareil variety, where the fewest moths emerged from the shelled treatment. A means comparison of moths emerged for the varieties placed the varieties in a continuum when damage was not considered, with Nonpareil exhibiting significantly better performance than Carmel. In general, in the scratched treatment Monterey, Plateau, and Nonpareil had overall higher survival than Carmel and Price. In the shelled treatment *A. transitella* survival was highest in Monterey, Padre, and Sonora, with the fewest moths emerging from Nonpareil. Nonpareil, Johlyn, and Sonora had the most moths emerge from unshelled nuts, and Padre, Plateau, Aldrich, and Carmel had no survivors (Table 1).

Because moths did not emerge from all treatments, DDs to emergence could only be analyzed for varieties that had emergence in all three damage treatments because of the loss of degrees of freedom. Males in general emerged 3% earlier than females (14 DD °C), and male emergence time was impacted by both variety and damage treatment with damage again greater (Figs. 1 and 2). Variety and damage were found to have a multiplicative effect for males: Damage  $F_{2,248} = 29.85$ ,  $P < 0.0001$ ; Variety  $F_{6,248} = 2.63$ ,  $P =$

**Table 1.** Mean ± SE adult *Amyelois transitella* emerged from each artificial damage treatment and variety

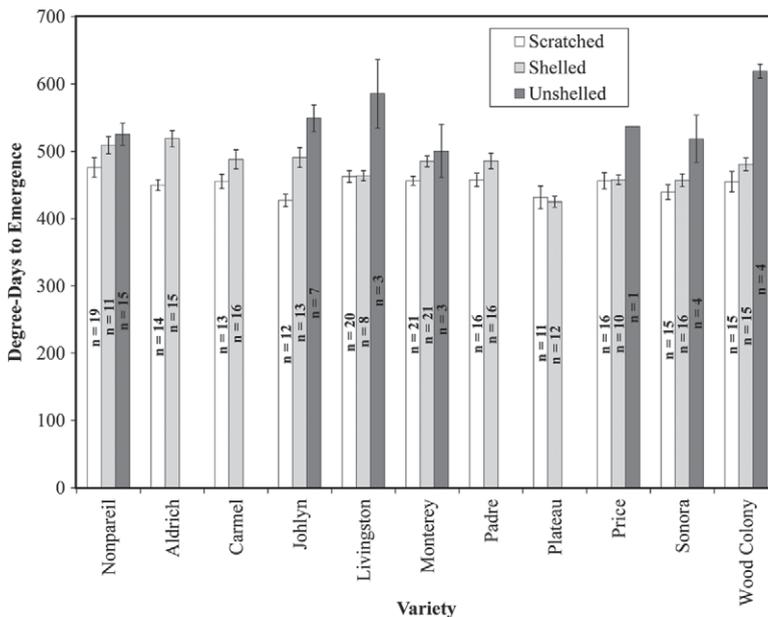
Variety	Scratched	Shelled	Unshelled	Tukey's HSD <sup>a</sup>
	Mean ± SE	Mean ± SE	Mean ± SE	
Nonpareil	16.5 ± 0.5	8.5 ± 1.5	12.5 ± 2.5	A
Johlyn	16.0 ± 1.0	11.0 ± 1.0	7.0 ± 2.0	AB
Livingston	15.0 ± 1.0	10.0 ± 1.0	4.5 ± 0.5	ABC
Wood Colony	14.5 ± 0.5	10.5 ± 0.5	3.0 ± 1.0	ABC
Padre	15.5 ± 1.5	13.5 ± 0.5	0.0 ± 0.0	ABC
Price	11.5 ± 4.5	10.0 ± 3.0	2.0 ± 1.0	ABC
Sonora	13.5 ± 3.5	13.0 ± 2.0	6.5 ± 2.5	ABC
Plateau	16.5 ± 1.5	11.5 ± 1.5	0.0 ± 0.0	ABC
Aldrich	13.5 ± 0.5	12.0 ± 0.0	0.0 ± 0.0	BC
Monterey	17.5 ± 0.5	15.0 ± 1.0	4.0 ± 4.0	ABC
Carmel	11.5 ± 0.5	11.0 ± 2.0	0.0 ± 0.0	C

<sup>a</sup> Letters denote significant differences ( $P < 0.05$ ) in Variety means separated by Tukey's HSD.

0.0175; Damage\*Variety  $F_{12,248} = 3.61, P < 0.0001$ . Female emergence appeared unaffected by the multiplicative effect and variety, but showed similar responses to damage: Damage  $F_{2,198} = 50.67, P < 0.0001$ ; Variety  $F_{6,198} = 1.94, P = 0.0764$ ; Damage\*Variety  $F_{12,198} = 1.26, P = 0.2470$ . Both sexes emerged earlier from scratched nuts than from unshelled nuts, with shelled being intermediate: Tukey's HSD (letter denote significant differences in Damage means at  $P < 0.05$ ): Unshelled = A, Shelled = B, and Scratched = C (Table 2). Variety means comparisons were uninformative for males despite the significant variety effect as the varieties fell within a continuum. For unshelled nuts, both males and females emerged earliest from Monterey nuts and Sonora, and latest from Wood Colony. For the shelled nuts, males emerged earliest from Plateau and latest from Aldrich. Females simi-

larly emerged earliest from Plateau, but emerged latest from Nonpareil for shelled nuts. For scratched nuts, males emerged earliest from Johlyn and Plateau and latest from Nonpareil. Females emerged earliest from Johlyn and Plateau as well, but emerged latest from Aldrich and Wood Colony for scratched nuts. Male DD °C to emergence ranged from 378 to 707 DD °C, whereas female DD °C ranged from the earliest of 390 to the latest individual at 707 DD °C.

On average nine strands of each variety were recovered in the spring, and 84% of the 20 nuts per strand were recovered. Variety, Year, and the multiplicative effect of Variety\*Year were significant in terms of *A. transitella* infestation: Variety  $F_{10,203} = 18.69, P < 0.0001$ ; Year  $F_{1,203} = 13.43, P = 0.0003$ ; Variety\*Year  $F_{10,203} = 4.35, P < 0.0001$ . *A. transitella* infestation was significantly higher in 2011 than 2012 (Table 3; Figs. 3 and 4), with Nonpareil, Sonora, Wood Colony, and Livingston exhibiting over 20% damage (Table 3). In 2012, Monterey showed the greatest *A. transitella* infestation, at 20%. For both years, the least infestation was seen in Padre, with one and 0%, respectively (Table 3). A Tukey's HSD of varietal means separated the percent *A. transitella* infestation between Livingston and Padre (the least infested), with all other varieties overlapping. In terms of percent bird damage, Variety showed the more significant  $P$  value, though Year and the interaction of Year\*Variety were also significant: Variety  $F_{10,203} = 17.86, P < 0.0001$ ; Year  $F_{1,203} = 4.98, P = 0.0269$ ; Variety\*Year  $F_{10,203} = 2.37, P = 0.0117$ . Overall bird damage was greater in 2011 (Figs. 3 and 4), and a Tukey's HSD comparing bird damage between varieties was able to separate Sonora from Padre (the least bird damaged) with all other



**Fig. 1.** Mean ± SE male *Amyelois transitella* degree-days °C to emergence and total male moths emerged from all replicates for each almond variety and damage class.

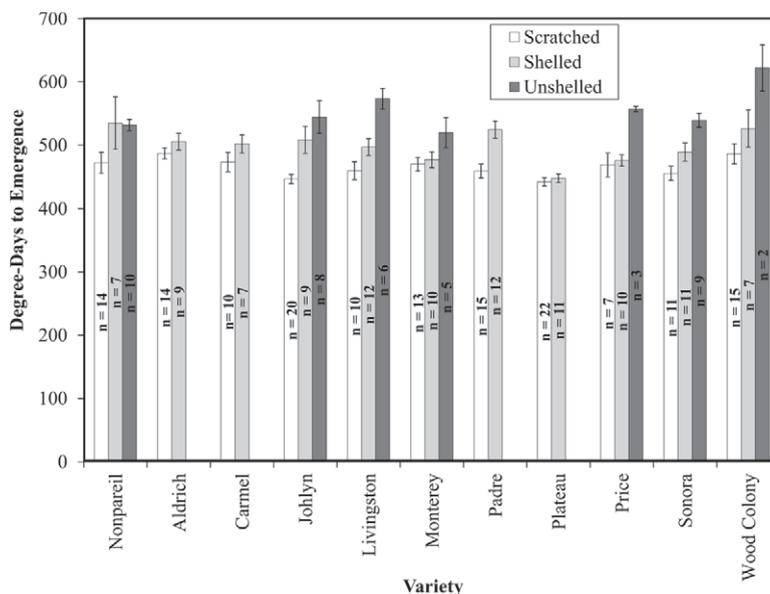


Fig. 2. Mean ± SE female *Amyelois transitella* degree-days °C to emergence and total female moths emerged from all replicates for each almond variety and damage class.

varieties falling intermediate (Table 3). The Pearson correlation of *A. transitella* infestation against bird damage revealed a strong positive correlation ( $r = 0.7969$ ;  $P < 0.0001$ ) between bird damage and *A. transitella* infestation (Fig. 5). *A. transitella* damage occurred without bird damage, however, this category represented the smallest percentage of the damaged nuts (Figs. 3 and 4). In 2011, *A. transitella* and bird damage was the most common field damage category, whereas in 2012 bird damage was the most frequent damage category (Figs. 3 and 4).

Discussion

*A. transitella* success when reared on eleven almond varieties, measured in the current study by total moths emerged and DD °C to emergence, was influenced by the individual variety, the damage status of the almond, and the interaction of the two factors. The varieties were chosen to represent both expected and

outlying hullsplit and shell seal *A. transitella* damage characteristics from the Hamby et al. (2011) study. Sonora was the only variety that fell along the regression line for proportion *A. transitella* damage in relation to both shell seal and hull split timing. Nonpareil, Price, Wood Colony, and Padre all receive less *A. transitella* damage than predicted by the regression in relation to hull split date, while Johlyn and Plateau receive more damage than expected. Livingston, Aldrich, Monterey, and Carmel fall along the regression line for hull split date. With respect to shell seal, Monterey, Carmel, and Padre all represent expected *A. transitella* damage. Nonpareil, Livingston, Aldrich, Price, and Wood Colony receive less damage than expected relative to shell seal, and Johlyn and Plateau receive more (Hamby et al. 2011). Statistically outlying varieties were presumed to possess some other qualities, which affect their suitability for *A. transitella* and therefore affect *A. transitella* performance.

Table 2. Mean ± SE *Amyelois transitella* degree-days °C to emergence of females and males for each variety and damage class

Variety	Females			Males		
	Scratched mean ± SE	Shelled mean ± SE	Unshelled mean ± SE	Scratched mean ± SE	Shelled mean ± SE	Unshelled mean ± SE
Nonpareil	472.3 ± 16.3	535.1 ± 41.4	531.9 ± 8.9	475.8 ± 14.5	509.1 ± 12.8	525.4 ± 16.3
Aldrich	487.1 ± 8.7	505.6 ± 13.2	—	449.7 ± 8.1	518.9 ± 12.1	—
Carmel	473.4 ± 14.9	501.9 ± 14.4	—	455.2 ± 10.7	488.0 ± 14.2	—
Johlyn	447.1 ± 7.2	508.3 ± 21.3	544.4 ± 25.8	427.0 ± 9.0	490.8 ± 14.9	549.0 ± 19.6
Livingston	459.9 ± 14.0	497.2 ± 13.4	573.4 ± 16.4	462.4 ± 8.8	463.6 ± 7.6	585.6 ± 50.8
Monterey	470.2 ± 10.6	477.0 ± 12.5	519.7 ± 23.7	456.0 ± 6.8	485.1 ± 8.0	500.2 ± 39.2
Padre	459.5 ± 10.6	524.6 ± 13.5	—	457.5 ± 10.0	485.7 ± 11.7	—
Plateau	442.5 ± 6.8	448.1 ± 7.0	—	431.4 ± 16.7	425.0 ± 8.0	—
Price	468.8 ± 18.8	475.8 ± 8.9	557.1 ± 4.1	456.0 ± 12.1	457.5 ± 7.1	536.8 ± 0.0
Sonora	455.8 ± 11.1	489.1 ± 14.3	539.5 ± 11.1	439.2 ± 11.0	456.7 ± 9.5	518.5 ± 35.0
Wood Colony	486.4 ± 15.8	526.3 ± 29.6	622.2 ± 36.6	454.7 ± 15.3	480.7 ± 9.4	619.2 ± 10.4

**Table 3.** Mean  $\pm$  SE almonds remaining per strand (of 20) and mean  $\pm$  SE *Amyelois transitella* damage and bird damage on remaining almonds and strands for 2011 and 2012

Variety	Strands remaining		Almonds remaining mean $\pm$ SE		% infestation mean $\pm$ SE			% bird damage mean $\pm$ SE		
	2011	2012	2011	2012	2011	2012	Tukey's HSD <sup>a</sup>	2011	2012	Tukey's HSD <sup>a</sup>
Nonpareil	8	9	17.8 $\pm$ 0.5	13.8 $\pm$ 1.8	33.9 $\pm$ 7.4	11.4 $\pm$ 7.6	ABC	50.6 $\pm$ 10.8	33.6 $\pm$ 8.9	AB
Sonora	8	10	13.3 $\pm$ 1.6	12.4 $\pm$ 2.0	26.5 $\pm$ 7.1	8.3 $\pm$ 1.4	AB	73.1 $\pm$ 12.0	44.1 $\pm$ 11.3	A
Wood Colony	10	10	16.3 $\pm$ 1.0	17.4 $\pm$ 0.6	25.4 $\pm$ 4.0	8.0 $\pm$ 3.5	AB	35.4 $\pm$ 7.9	19.5 $\pm$ 5.2	BC
Livingston	10	9	16.1 $\pm$ 0.5	17.7 $\pm$ 1.0	22.0 $\pm$ 4.8	15.9 $\pm$ 4.2	A	29.9 $\pm$ 4.6	34.7 $\pm$ 8.8	ABC
Johlyn	9	7	14.0 $\pm$ 1.3	17.9 $\pm$ 0.8	18.5 $\pm$ 8.6	12.2 $\pm$ 3.4	ABCD	24.8 $\pm$ 6.1	26.8 $\pm$ 10.6	BCD
Aldrich	9	10	16.7 $\pm$ 0.8	19.1 $\pm$ 0.5	14.0 $\pm$ 5.0	8.9 $\pm$ 2.1	ABCD	18.6 $\pm$ 5.7	11.6 $\pm$ 2.7	CDE
Price	10	10	18.5 $\pm$ 0.5	18.7 $\pm$ 0.6	9.6 $\pm$ 2.8	2.6 $\pm$ 1.1	BCD	13.9 $\pm$ 4.4	5.6 $\pm$ 1.6	DEF
Monterey	9	10	16.9 $\pm$ 0.9	17.2 $\pm$ 1.1	5.9 $\pm$ 2.0	20.4 $\pm$ 3.2	AB	13.9 $\pm$ 5.6	20.6 $\pm$ 4.2	BCDE
Carmel	8	10	15.8 $\pm$ 2.2	19.0 $\pm$ 0.5	5.6 $\pm$ 2.3	1.5 $\pm$ 1.1	DE	12.7 $\pm$ 2.8	7.6 $\pm$ 2.5	DE
Plateau	9	10	17.2 $\pm$ 0.5	17.4 $\pm$ 0.8	4.6 $\pm$ 2.2	5.2 $\pm$ 2.0	CDE	3.8 $\pm$ 1.3	10.7 $\pm$ 2.1	EF
Padre	10	10	18.7 $\pm$ 0.4	19.5 $\pm$ 0.3	1.0 $\pm$ 1.0	0.0 $\pm$ 0.0	E	4.9 $\pm$ 2.5	1.1 $\pm$ 1.1	F

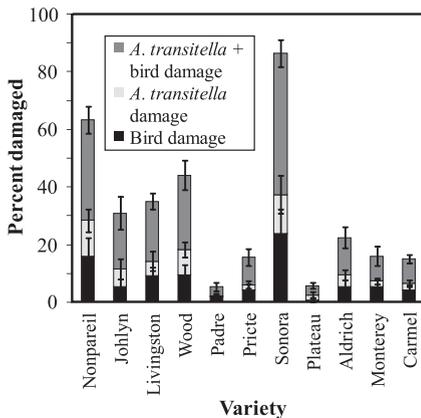
<sup>a</sup> Letters denote significant differences ( $P < 0.05$ ) in Variety means separated by Tukey's HSD.

Unfortunately, statistical resolution was poor for varietal difference in *A. transitella* performance, likely stemming from the relatively large number of varieties evaluated. Therefore, we will not speculate as to whether performance is a factor that is responsible for varieties becoming outliers in terms of previous hull split and shell seal *A. transitella* regressions (Hamby et al. 2011) although variety had a significant impact on male moth DD to emergence and on the number of moths surviving. It is unsurprising that almond variety would impact development of *A. transitella* as both almonds and pistachios have been described as dynamic nutrient resources, with nut stage, age, variety, and quality impacting survival and development (Siegel and Kuenen 2011, Siegel et al. 2010). Although the almond varieties used in those studies were collected from multiple orchards, which could exaggerate varietal differences by including variance because of locality, the variability between varieties is supported by our study with almonds collected from a single orchard that was uniformly managed. In fact, this study reduced variation as much as possible by using a controlled lab environment with constant temperature, L:D cycle, a single colony line, and almonds collected

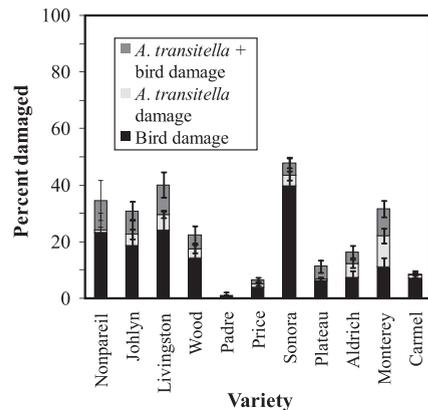
from a single orchard, yet variety had a significant impact on survival and DD to emergence. One potential reason for the differences between varieties is the variability in chemical composition and nutrient content of the nuts (Calixto et al. 1981, Garcia-Lopez et al. 1996, Ahrens et al. 2005, Milbury et al. 2006).

Before this study, the impact of artificial almond damage on *A. transitella* development and survivorship had not been quantified. Shelled nuts would be expected to facilitate larval infestation and result in faster development times with increased survival relative to unshelled nuts, as larvae are thought to infest the kernel through cracks in the shell and shelled nuts would provide easier access (Soderstrom 1977). In addition, hard shelled varieties or varieties with tighter shell seal are less susceptible to *A. transitella* presumably because of a lack of access points (Crane and Summers 1971, Soderstrom 1977).

Interestingly, scratched and shelled nuts were significantly different in terms of *A. transitella* performance. Siegel et al. (2010) suggest that Seaman and Barnes (1984) method of punching tunnels into mummy nuts and placing neonate larvae underestimates development time and maximizes establish-



**Fig. 3.** Mean  $\pm$  SE percent almonds damaged  $\pm$  SE by *Amyelois transitella*, birds and both in 2011.



**Fig. 4.** Mean  $\pm$  SE percent almonds damaged  $\pm$  SE by *Amyelois transitella*, birds and both in 2012.

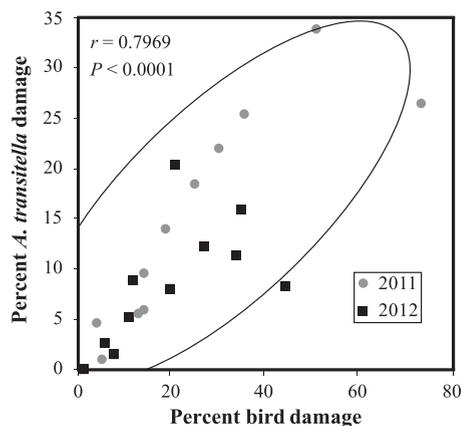


Fig. 5. Pearson correlation analysis of percent *Amyelois transitella* infestation and percent bird damage for each variety using a 95% density ellipse.

ment. Siegel et al. (2010) goes on to provide a potential mechanism for the faster development rate and higher *A. transitella* survival as a reduction in both exposure to allelochemicals in the shell and hull as well as energy expenditure during establishment. However, one might not expect a single 1 mm scratch in the pellicle to result in a significant improvement in establishment relative to a shelled nut. Almond pellicles are potential sources of antioxidants, and chemicals such as flavonoids, tannins, and other phenolic compounds can be found in both almond pellicles and shells (Frison-Norrie and Sporns 2002, Amarowicz et al. 2005, Milbury et al. 2006, Garrido et al. 2008). In fact, flavones found in citrus fruit are known to inhibit growth of *A. transitella* larvae (Mahoney et al. 1989). Therefore, scratched nutmeat treatments may reduce exposure to nutrients or negative allelochemicals, influencing *A. transitella* performance, presuming the larvae start feeding at the scratch or damage.

For this to be true, the *A. transitella* larvae would have to orient to the artificial damage and use this entry point to invade the kernel. Recently, Beck et al. (2012) created a host plant volatile blend that included volatiles derived from mechanically damaged almonds. This blend attracted both male and female moths to delta traps (Beck et al. 2012). *A. transitella* females prefer to oviposit on mummy nuts that have been previously infested by conspecifics, which would provide a ready-made entry point (Caltagirone et al. 1968, Curtis and Barnes 1977, Andrews and Barnes 1982). In the field, damage is also possible from either peach twig borer *Anarsia lineatella* (Zeller) (that feeds on new crop nuts, damaging the pellicle as well as feeding on almond shoots) or bird damage to shells and kernels (Reil et al. 1981, Hasey and Salmon 1993).

Bird damage has become a greater concern for growers in the last 20 yr, as the grower surveys of Hasey and Salmon (1993) reported that passerine birds in the family Corvidae (specifically crow, black-bird, and magpie in that study) are causing increasing fruit damage in multiple crops. The 2011 and 2012 field

data from our study confirm that bird damage might be a concern, as damage of our placed nuts reached up to 73% in 2011, and 44% in 2012. Hasey and Salmon (1993) predicted that bird consumption of mummy nuts would reduce *A. transitella* infestation, however our data suggest otherwise. The mummy kernels on our almond strands were rarely entirely consumed by birds. In fact, increasing percent bird damage correlated with increasing percent *A. transitella* infestation, and this trend was seen in both years. One caveat to the amount of damage observed is that the almonds were attached to strands, which may facilitate bird feeding on the nuts.

The impact of damage on performance varied based on almond variety, as indicated by a significant multiplicative effect of Variety\*Damage in many of the performance responses. Varieties differ in shape, shell seal, and chemical composition; therefore, damaging the shell and pellicle would have a different impact on survivorship and emergence time depending on variety. Interestingly, bird damage also had a significant variety component, which may indicate that birds prefer a specific shell seal, shape, or chemical composition in the nut. Although some of the varieties included in this study are not regularly planted in commercial production, the trends observed indicate that preventing damage to almond shells and pellicles has more value than just the direct increase in marketable fruit, it also may reduce the number of *A. transitella* emerging in the spring.

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