BIOLOGY AND CONTROL OF WALNUT HUSK FLY USING REDUCED RISK PRODUCTS

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ABSTRACT

Studies were conducted to examine various parameters to improve walnut husk fly trap efficacy. The Alpha Scent trap/lure, Suterra trap/lure and Alpha Scent trap and Trécé Mega lures were the most effective trap/lure combinations. The increase in efficacy is related to the lure efficacy and not as much the trap efficacy. Host plant volatiles did not improve efficacy. Control of WHF with low volume (10 gal/ac), high speed (4 to 8 mph) with skip row technique resulted in similar infestation to the grower standard of volume (100 gal/ac), a low speed (2 to 3 mph) with every row treated. The modification of the equipment is very minor and inexpensive. The use of the low volume technique should reduce spray time by over 1/8 as compared to conventional applications and there is also a potential to reduce the amount of insecticide and maintain the same control. Walnuts are less susceptible to WHF infestation if they are small, have a thin husk, high trichome density and a dull reddish color.

OBJECTIVES

The walnut husk fly (WHF), *Rhagoletis completa*, is a serious pest of walnuts. Treatment initiation and evaluation of a treatment has relied on commercial WHF traps. These traps are yellow sticky panels with an attractant of an ammonium-releasing chemical such as ammonium carbonate. Growers and PCAs have not been satisfied with these traps in that they find WHF infestation with few WHF captured in the traps. Thus they are not able to determine the best time to initiate treatment or how often to reapply the treatment. Without this basic population data it is difficult to provide the best pest management decisions for the control of WHF. Studies were conducted to determine the most efficacious commercial trap/lure and possible trap improvements.

Control of WHF populations has relied on the combination of a neonicotinoid (NEONIC) or organophosphate (OP) insecticide and feeding stimulant (Nu-Lure Insect Bait, Monterey Insect Bait, molasses). However applications are costly and time consuming. Past research has demonstrated that effective control of WHF can be achieved with repeated low volume applications of GF-120. However, GF-120 needs to be applied more frequently and earlier in the season than conventional insecticides and control in tall trees or high WHF population is problematic. Low volume applications of a NEONIC or OP pesticide with feeding stimulant can provide comparable control to the conventional application of NEONIC or OP with feeding stimulant. Low volume applications are more cost effective because they can be applied more quickly than conventional treatments. Control may be achieved at lower rates of application, further reducing the cost of the low volume technique. Studies were conducted to determine whether WHF control can be achieved with a low volume of final spray solution and low volume and reduced rate of insecticide.

Seasonal and cultivar susceptibility is known to occur with WHF infestation in walnuts. However, the factors responsible for varied susceptibility are not well understood. Mid-season or late-season leafing cultivars such as Hartley and Franquette are highly susceptible while Chandler is much less susceptible. However, Chandler can become highly infested if there is not a more susceptible cultivar in the same orchard. Thus, simple phenological asynchrony does not appear to be a primary cause of the resistance. If the traits such as husk firmness, thickness, surface texture, chemical composition, etc. that infer resistance or susceptibility can be identified and quantified, then these traits can be used to more accurately initiate and terminate control programs and desirable characteristics can be incorporated into the breeding program. Studies were conducted to quantify nut characteristics.

SIGNIFICANT FINDINGS

- Alpha Scents traps/lures captured significantly more WHF than all other traps/lures except Suterra traps/lures.
- Low volume (10 gal/ac) applied at 8 mph was as efficacious in the control of WHF as standard volume (100 gal/ac) applied at 2 mph.
- Walnuts are less susceptible to WHF infestation if they are small, have a thin husk, high trichome density and a dull reddish color.

PROCEDURES

A. Trap and Bait Efficacy Comparisons

Trials were conducted in two commercial orchards and cultivars in Hollister (Payne), and Linden (Vina), CA. Eleven treatments were replicated four times in a randomized, complete block design. Each treatment (trap/lure type) was placed at about 6 ft. above the ground and traps placed 3 to 5 trees apart from each other. Traps were placed on 27 June and monitored and positions rotated weekly from 3 July through 11 September. In order to compensate for localized hot spots of WHF each trap/lure treatment was rotated into each position once through the study. The eleven treatments were: Trécé trap with UC Super-charged ammonium carbonate lure, Trécé trap with Trécé Mega lure, Trécé trap with Trécé Dual-Pak lure, Trécé trap with Alpha Scents RHACOM lure, Trécé trap with Suterra WHF biolure, Alpha Scents trap with Alpha Scents RHACOM lure, Alpha Scents traps with Suterra WHF biolure, Suterra trap with Suterra WHF biolure, Trécé trap with Trécé green leaf (GL) alcohol lure, Trécé trap with Trécé caryophyllene lure, and a blank Trécé trap (Table 1). Traps were changed once a month or when traps captured over 100 flies or the yellow panel surface became contaminated and lost its stickiness. UC Super-charged lures were changed weekly and all other lures were changed every four weeks. Due to a very low WHF population the Linden orchard was only treated once with 2 1/2 pt of Malathion Aquamul plus NuLure on 28 August. The Hollister orchard was treated on 15 July and 11 August with 2 pt/ac of both Malathion 57% and NuLure. The data was analyzed using ANOVA with mean separation using Fisher's protected LSD ($P \leq 0.05$).

B. Control of WHF with Reduced Amounts of Pesticide and Application Time

A trial was conducted in three commercial orchards in Linden (Vina), Modesto (Vina) and Rio Oso (Hartley). Three treatments were replicated once in each orchard. Each replicate was a minimum of 4 acres. The grower selected the insecticides and attractant/feeding stimulate (Nu-Lure) for the experiment and applied each at the suggested label rate for WHF in walnuts. All treatments were applied to every other row (skip row). The three treatments were: high concentration low volume (LV) applied at 10 gal/ac, identical rates of toxicant and bait applied at 100 gal/ac, the grower standard (GS), and an untreated check. The untreated check was not treated with label rate NuLure due to grower constraints. When infestation in the untreated check reached 2% damaged nuts, the untreated check was treated with the high concentration low volume or grower standard to stop any new infestation based on the grower's preference. The Modesto orchard reached 2% on 20 August and the Linden orchard reached 2% on 27 August (Table 4). The Rio Oso orchard never reached 2%. High concentration low volume applied at 10 gal/ac was applied using modification of the standard grower's speed sprayer. All but the top two nozzles were closed and the two top nozzles were replaced with ¼ in. barb adapters (Watts Water Technologies®, North Andover, Massachusetts). The barb adapters provided two high-pressure, solid streams of toxicant which were directed toward one another to meet about 10 to 15 ft. in the air. Upon meeting, the fluid dispersed in large droplets. Air baffles were adjusted to direct the air-flow vertically, enabling the fan to drive the toxicant 40 to 50 ft. in the air before subsequently spilling back over the tops of trees. The output of the two nozzles was measured and paired with an increased tractor speed between 3 and 9 mph that produced the desired output (10-20 gal./acre) and was determined by the grower to be safe for the given orchard conditions. GS was applied with standard air-blast speed sprayer delivering 100 to 125 gal./acre; operating at 2 to 3 mph. Treatments were applied two weeks after the first fly captures in the adult traps in each orchard. The LV and GS treatments were applied on the same day. Subsequent applications were applied upon consultation with PCA and project leader when necessary (approximately 2 to 4 applications for the season). Adult WHF populations were monitored using one ammonium carbonate super-charged yellow panel AM/NB trap placed high in the canopy of a centrally located tree in each replicate. These traps were inspected, and the ammonium carbonate bait replaced weekly from 10 June to 10 September. WHF nut infestation was monitored weekly by visually inspecting 300 nuts per replicate for stings, larval feeding and exits from 17 July through 19 September. Nuts were not removed during the infestation assessments.

C. Identification and Quantification of Nut Characteristics by Cultivar

Nut Characteristics: Ten nuts of each of nine cultivars were examined bi-weekly from 25 June to 19 August. Nuts were collected from the UC Davis variety "Stuke Block" and transported in egg cartons to the lab at UC Berkeley for analysis. Egg cartons were used to prevent damage to the trichomes. Each nut was measured for the following parameters: trichome density, weight, husk thickness, pressure to penetrate husk, and color. Cultivars evaluated included Earliest, Hartley, Chandler, Franquette, Vina, Payne, Tulare, Carmello, and Serr. Color/reflectance was determined by using a Konica Minolta

Chroma-Meter, and all nut weights were obtained using laboratory scales. Trichomes were counted under 20x magnification on a segment of husk cut using a 0.7 cm diameter corer. Husk thickness was measured using calipers at three places on the nut, adjacent to the stem, at mid-nut, and adjacent to the flower tip. Husk penetration pressure was determined using a penetrometer fitted with a small tip (6.5 mm diameter) to record maximum pressure before puncturing the husk.

Nut Suceptibility: Six additional nuts of each of the nine cultivars were collected and transported in egg cartons to the lab at UC Berkeley for exposure to adult WHF. One nut of each cultivar was placed in a plastic "bug dorm" rearing cage. There were six plastic "bug dorm" rearing cages. Each nut was held upright on top of a plastic container filled with a 3:1 water/citrus soda solution. Each container had been closed off with a foam plug with a small hole in the center. This was then covered with a small amount of plastic and sealed with a rubber band. Each nut cultivar had been cut in the field with a large portion of stem still intact, and the stem was placed through the plastic and the hole in the foam so that it was submerged in the water/soda solution in order to maintain viability and upright position. The soda served to increase the solution's acidity and provide sugar for increased nut viability. The nine cultivars were placed in a randomized block design in each cage. Fifteen adult female and male laboratory-reared WHF were then placed in the cage through the mesh opening, and the cage was sealed. All flies used in this experiment were at least three weeks old and had been fed with a sugar/water solution. The cages containing the cultivars also had a small amount of sugar/water solution along with regular water to sustain the flies during the experiment. After 24 hours of exposure, the walnut cultivars were removed from the each cage and stings were counted on each nut and recorded. A very small colored dot was placed next to each sting to keep track of how many stings occurred on each day. Once recorded, each nut was placed back in its respective cage and the stings were assessed again after a total of 48 hours of exposure. After 48 hours of exposure, nuts were taken out of the cages, and each sting was dissected to determine if eggs had been laid. This process was repeated on a biweekly basis. All data was analyzed using a Spearman Rank Order Correlation ($P \leq 0.05$).

RESULTS AND DISCUSSION

A. Trap and Bait Efficacy Comparisons

In the Hollister orchard, the Suterra trap with a Suterra lure and the Alpha Scents trap with an Alpha Scents lure captured significantly more female WHF than all treatments other than the Alpha Scents trap with a Trécé Mega lure (Table 2). Alpha Scent trap with a Trécé Mega lure captured significantly more female WHF than all treatments other than the Trécé trap with a UC Super-charged lure. The Trécé trap with a UC Super-charged lure captured significantly more female WHF than the Trécé trap with a green leaf alcohol bend lure, the Trécé trap with a caryophyllene lure and the Trécé trap with no lure, but was not significantly different from the Trécé trap with a Trécé Mega lure, the Trécé trap with a Dual-Pak lure, the Trécé trap with a Alpha Scents lure, or the Trécé trap with a Suterra lure.

The Alpha Scents trap with an Alpha Scents lure captured significantly more males than all other treatments, with the exception of the Alpha Scents trap with a Trécé Mega lure and the Suterra trap with a Suterra lure. The Alpha Scents trap with a Trécé Mega lure and the Suterra trap with a Suterra lure captured significantly more male WHF than all treatments except Trécé trap with a UC Super-charged lure. Trécé trap with a UC Super-charged lure captured significantly more WHF all other treatments except the Trécé trap with a Trécé Mega lure, the Trécé trap with a Suterra lure and the Trécé trap with an Alpha Scents lure. All of which captured significantly more than the Trécé trap with a green leaf alcohol bend lure, the Trécé trap with a caryophyllene lure and the Trécé trap with no lure, but was not significantly different from the Trécé trap with a Dual-Pak lure.

The Alpha Scents trap with an Alpha Scents lure captured significantly more total WHF than all treatments other than the Suterra trap with a Suterra lure. The Alpha Scents trap with an Alpha Scents lure and the Suterra trap with a Suterra lure captured significantly more total WHF than all other treatments except the Trécé trap with a UC Super-charged lure and the Alpha Scents trap with a Trécé Mega lure. The Trécé trap with a UC Super-charged lure captured significantly more total WHF than the Trécé trap with a Dual-Pak lure, but not more than the Trécé trap with a Trécé Mega lure, the Trécé trap with an AlphaScents lure, or the Trécé trap with a Suterra lure. The Trécé trap with a Trécé Mega lure, the Trécé trap with a Alpha Scents lure, and the Trécé trap with a Suterra lure were not significantly different from the Trécé trap with a Dual-Pak lure, however all captured significantly more total WHF than the Trécé trap with a green leaf alcohol bend lure, the Trécé trap with a caryophyllene lure, and the Trécé trap with no lure.

The percent females of total WHF captured by weekly without regards to trap or lure showed a declining female portion of the population through the season. The regression analysis produced $y= -2.7X + 57.9$ with $R^2 = 0.55$. A similar declining female portion of the fly captures was also observed in last year's studies.

In the Linden orchard, the Trécé trap with a UC Super-charged lure, the Alpha Scents trap with an Alpha Scents lure and the Suterra trap with a Suterra lure captured significantly more female WHF than all other treatments except the Trécé trap with a Trécé Mega lure, the Trécé trap with a Dual-Pak lure, the Trécé trap with a Suterra lure, and the Alpha Scent trap with a Trécé Mega lure (Table 3). The Trécé trap with a caryophyllene lure captured significantly more males than all other treatments. It is not known why there is a peak trap catch in the Trécé trap with a caryophyllene lure when it was not observed in other treatments. The Trécé trap with a caryophyllene lure captured significantly more total WHF than all other treatments except the Suterra trap with a Suterra lure, the Alpha Scents trap with an Alpha Scents lure, and the Trécé trap with a UC Super-charged lure. The Suterra trap with a Suterra lure and the Trécé trap with a UC Super-charged lure captured significantly more total WHF than the Trécé trap with an Alpha Scents lure. The Alpha Scents trap with an Alpha Scents lure was not significantly different from any other treatment

The low population in the Linden orchard resulted in little meaningful data. Most of the trap and lure combinations were not significantly different from the blank trap. What is interesting is that even with this low WHF adult population infested nuts occurred late in the season. In late July to early August there was a small peak of WHF flight, it appears that this low but untreated WHF population resulted in damaging infestation. Thus a treatment threshold is related to an increase in total trap capture not the number of flies captured per week and treatment should occur shortly after increased trap capture.

The Hollister orchard captured a large number of flies that resulted in meaningful data. It appears that the Alpha Scents and Suterra traps are superior to the Trécé traps since Alpha Scents traps with Alpha Scents or Mega lures captured more flies than Trécé traps with Alpha Scents and Mega lures. Also Suterra traps with Suterra lures captured more flies than Trécé traps with Suterra lures. This result was different from last year's study where no difference was observed between the Alpha Scents and Trécé traps. When the Trécé traps were used with various lures, the UC Super-charged lure captured more flies than the other lures but was only significantly better than the Trécé's Dual-Pak lure. The number of WHF captured with the green leaf alcohol blend and caryophyllene lures was very disappointing and these lures did not capture more flies than a trap without a lure.

The reason for the declining female portion of the population is not known. It could be that there was few females present in the population due to energy expended in oviposition or females do not respond to the traps late in the season. The reason for this decline will be examined next season.

B. Control of WHF with Reduced Amounts of Pesticide and Application Time

Each orchard was treated 1-3 times throughout the season with untreated plots terminated in Linden and Modesto in late August due to significant WHF infestation (Table 4). There was no significant difference in the number of WHF captured among the three treatments (Table 5). However, the LV treatment had the highest number of flies captured while the GS had the lowest number of flies captured. The LV and GS treatments were effective at suppressing WHF infestation throughout the season (Fig. 1). All orchards experienced an abrupt spike in WHF infestation late in the season that is attributed to poor pest management practices in surrounding orchards. However, due to a large variance there was no significant difference among the treatments at $P \leq 0.05$. Since there was no significant difference in WHF infestation among three treatments in the 2012 and 2013 studies, the data was combined and reanalyzed. When the 2012 data (only high concentration LV, GS and untreated check treatments) were combined with the 2013 data, there was significantly lower infestation in the LV and GS treatments compared to the untreated check and there was no significant difference between the LV and GS (Fig. 2). Thus the LV technique is a viable option that can reduce the time and cost of application and potentially reduce the amount of insecticides. The LV technique has difficulties when there is substantial canopy cover in the center of the row so that toxicant could not reach the upper canopy, as well as when low hanging branches forced the spray rig to maneuver around them. Also the high speed of application can be problematic in orchards that have rough orchard floors. The LV technique is most effective in mature orchards with minimal canopy closure and a smooth orchard floor.

The cost of WHF applications in orchards with the above characteristics can be significantly reduced while maintaining or improving WHF control.

C. Identification and Quantification of Nut Characteristics by Cultivar

Nut Characteristics:

Trichome Density: Mean trichome density ranged between 51.5 and 1042.9 trichomes per cm^2 (Table 6). Carmello had the fewest number of trichomes at 51.5 trichomes per cm^2 followed by Payne and Serr. Tulare had about twice as many trichomes per cm^2 as Carmello while Vina had a similar number to Tulare. Franquette and Hartley had comparable trichome densities at 154.2 and 162.8 trichomes per cm^2 respectively and Chandler had more than twice as many trichomes as Franquette and Hartley with 358.4 trichomes per cm^2. Earliest had the highest number of trichomes with 1042.9 per cm^2, while also having the largest standard error of all the cultivars. It was observed with Earliest that the trichome density was highly variable with patches of extremely high trichome density while other areas had a moderate density. The number of trichomes found in this study was very similar to the number found by Christofferson, et al. 2000 (Table 7). In cultivars shared by the two studies, the number of trichomes was similar and the rank order was the same except for Payne. The present study found a much lower number of trichomes in Payne than the Christofferson, et al. (2000) study.

Nut Weight: The mean nut weight ranged between 42.8 and 111.0 g (Table 8). Chandler and Franquette had the lowest nut weight, at 42.8 and 46.3 g. Hartley, Payne, Earliest, Tulare and Vina all had nut weights between 50 and 60 g. Serr had a slightly higher average weight at 74.0 g, while Carmello was the heaviest at 111.0 g. Nut weight correlated with nut size. Thus Chandler and Franquette had the smallest nuts and Carmello had the largest nuts.

Husk Thickness and Penetration Pressure: The mean husk thickness at the stem end ranged between 4.4 and 7.7 mm (Table 9). The cultivar with the thinnest husk thickness was Chandler at 4.4 mm followed by Tulare at 5.4 mm. The husks of Hartley, Payne and Vina were between 6.0 and 6.1 mm thick while Earliest, Franquette and Carmello all fell in a higher range between 6.6 and 7.0 mm. Serr had the thickest husk at the stem, with an average of 7.7 mm. The mean husk thickness mid-nut ranged between 4.3 and 7.4 mm (Table 10). Chandler had the thinnest husk thickness at mid-nut with 4.3 mm. Earliest, Tulare and Hartley had a range of 5.0-5.3 mm. Franquette, Carmello, Vina and Payne ranged between 5.6 and 6.3 mm. Serr had the largest husk thickness at mid-nut with 7.4 mm. The mean husk thickness at the flower end ranged between 4.3 and 6.1 mm (Table 11). In all cases, the husk at the flower end of the nut was thinner than in the middle or at the stem end of the nut. The husk penetration pressure ranged between 23.4 and 29.9 kg per cm^2 (Table 12). Earliest, Chandler, and Carmello produced nuts with the highest pressure required for penetration. Vina, Franquette and Tulare pressure ranged from 26.2 to 27.0 kg per cm^2 and fell in the middle range, while Serr, Hartley and Payne were all below 26.0 kg per cm^2.

Color: The red to green color measurement ranged between -8.2 and -12.6. As the number becomes more negative, this represents a "greener" nut. Earliest was the least "green," followed by Chandler (Table 13). Hartley, Franquette, Vina, Payne and Carmello all had similar color measurements and fell in between -11.0 and -12.0 range. Tulare and Serr had the "greenest" nuts and both measured at -12.6. The hue angle color measurement ranged between 107.1 and 115.2, with Earliest having the lowest hue angle measurement (Table 14). An increase in the hue angle relates to an increase in the intensity of the color. For example, on a chromaticity color diagram, a hue angle of 0 would mean that the color measurement falls within the boundaries of the most intense red color. A hue angle of 90 falls within the boundaries of the most intense yellow, and an angle of 180 is within the most intense green. Hartley, Chandler, Franquette, Vina, Payne and Carmello all fell in the middle range of measurements. Tulare and Serr had the highest hue angles, with measurements of 115.2 and 114.2.

Nut Susceptibility:

Trichome Density: There was a significant negative correlation between average trichome density and the total amount of stings and stings with eggs found on each cultivar over the season (Tables 15 and 16). This indicates a high trichome density may inhibit WHF infestation. Also, Christofferson, et al. 2000 found that similar trichome densities to those found in this study and stated "gradular trichome density does appear to influence codling moth establishment on tested last phenology varieties." This was not true in the early phenology varieties. Thus trichomes require further study this coming year. Earliest and Chandler with trichomes and with the trichomes removed will be exposed to WHF adult and resulting infestation will be determined.

Nut Weight: There was a significant positive correlation between nut weight and the total amount of stings and stings with eggs found on each cultivar over the season. This may be due to the increased size of a nut offering increased surface area for WHF egg deposition in comparison to a smaller nut. In addition, Riedl et al. (1981) found that larger sphere trap size resulted in greater WHF trap catch. Thus small nuts are less attractive. This is probably not a viable characteristic to select for WHF resistance because reduced nut size may result in reduced yield.

Husk Thickness and Penetration Pressure: There was no significant correlation between husk thickness at the stem-end or mid-nut to the total amount of stings or stings with eggs found on each cultivar over the season. There was a significant positive correlation between husk thickness at flower-end to the total amount of stings per cultivar over the season. There was no significant correlation between husk penetration pressure and the total amount of stings or stings with eggs found on any cultivar over the season. It is not known why there is a significant positive correlation with flower-end but not stem-end or mid-nut but it could be an artifact of the study. The nuts were placed with flower-end up in the oviposition cages and the flower-end received greater exposure to the flies. Thus there was a significant preference for WHF to oviposit into thick husk.

Color: There was a significant negative correlation between the mean red to green color range measurement and the total amount of stings and stings with eggs found on each cultivar over the season. The more negative the red to green color range measurement the increase in the "greenness" of a cultivar. WHF flies have been shown to be highly selective for various shades of green colors. Riedl et al. (1981) found significantly higher trap catch with traps that were Shamrock or Foliage green as compared to light green. There was also a significant positive correlation between the mean hue angle measurement and stings, but not with the total amount of stings containing eggs found on each cultivar over the season. This positive correlation showed that a larger hue angle in nut husks correlates with increased susceptibility to WHF infestation. In this case, as the hue angle gets closer to 180, the intensity of the green color increases. Therefore, nuts that are a brighter green color are more attractive than dull pale green nuts. The increase in the trichome density may cause the nuts to have more reddish dull color.

LITERATURE CITED

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Table 1. Trap and lure combination evaluated for WHF capture efficacy – 2013

Trap	Lure	Abbreviation
Trécé Pherocon® AM/NB	UC Super-charged[a]	T-Carb
Trécé Pherocon® AM/NB	Trécé - Mega	T-Mega
Trécé Pherocon® AM/NB	Trécé – Dual-Pak	T-DP
Trécé Pherocon® AM/NB	AlphaScents - RHACOM	T-Alpha
Trécé Pherocon® AM/NB	Suterra – WHF biolure	T-Sut
AlphaScents – Back folding	AlphaScents - RHACOM	AS-alpha
AlphaScents – Back folding	Trécé - Mega	AS-Mega
Suterra WHF	Suterra – WHF biolure	S-Sut
Trécé Pherocon® AM/NB	Trécé – green leaf (GL) alcohol	T-GL
Trécé Pherocon® AM/NB	Trécé - Caryophyllene	T-Cary
Trécé Pherocon® AM/NB[b]	---	T-Null

[a]Standard vial super charger: 6 ml vial with 4 mm opening containing 3.9 g of ammonium carbonate.
[b]Added in 2nd week of trial

Table 2. Seasonal mean total female and male WHF captured in Hollister, CA – 2013

Treatment	Females	Males	Total WHF
T-Carb	5.3 bc	7.0 bc	12.3 bc
T-Mega	4.1 c	5.1 cd	9.3 cd
T-DP	4.4 c	4.3 d	8.7 d
T- Alpha	4.5 c	5.7 cd	10.2 cd
T-Sut	4.9 c	5.2 cd	10.1 cd
AS-Alpha	8.4 a	10.4 a	18.8 a
AS-Mega	6.8 ab	8.4 ab	15.2 b
S-Sut	7.3 a	8.5 ab	15.8 ab
T- GL	0.3 d	0.6 e	0.9 e
T-Cary	0.1 d	0.3 e	0.5 e
T-Null	0.1 d	1.4 e	0.5 e

[a]Means followed by the same letter in a column are not significantly different (Fisher's protected LSD, $P \leq 0.05$)

Table 3. Seasonal mean total female and male WHF captured in Linden, CA – 2013

Treatment	Females		Males		Total WHF	
T-Carb	1.3	a	0.9	b	2.1	ab
T-Mega	1.0	ab	0.6	b	1.6	bc
T-DP	0.8	ab	0.5	b	1.3	bc
T- Alpha	0.4	b	0.3	b	0.8	c
T-Sut	0.9	ab	0.5	b	1.3	bc
AS-Alpha	1.3	a	0.5	b	1.8	abc
AS-Mega	0.7	ab	0.4	b	1.1	bc
S-Sut	1.3	a	0.9	b	2.2	ab
T- GL	0.4	b	0.6	b	1.0	bc
T-Cary	0.5	b	2.4	a	2.9	a
T-Null	0.5	b	0.7	b	1.2	bc

[a]Means followed by the same letter in a column are not significantly different (Fisher's protected LSD, $P \leq 0.05$)

Table 4. Weekly spray schedule for orchards by treatment, various locations, CA – 2013.

Treatment	31 Jun – 6 Jul	7 Jul – 13 Jul	14 Jul – 20 Jul	21 Jul – 27 Jul	28 Jul – 3 Aug	4 Aug – 10 Aug	11 Aug – 17 Aug	18 Aug – 24 Aug	25 Aug – 31 Aug	1 Sep – 7 Sep	8 Sep – 14 Sep
LV		Linden Modesto	Rio Oso		Rio Oso			Modesto	Linden		Modesto Rio Oso
GS		Linden Modesto	Rio Oso		Rio Oso			Modesto	Linden		Modesto Rio Oso
Untreated								Modesto	Linden		

Table 5. Mean[a] total WHF captured per trap per week in Modesto, Linden and Rio Oso, CA – 2013.

	Mean total WHF per trap per week												
Treatments	26-Jun	3-Jul	10-Jul	17-Jul	24-Jul	31-Jul	6-Aug	12-Aug	20-Aug	27-Aug	4-Sep	10-Sep	Total
LV	0.3 a	0.0 a	18.0 a	9.7 a	5.7 a	44.3 a	14.0 a	30.7 a	62.0 a	114.7 a	79.3 a	112.0 a	519.0 a
GS	0.7 a	1.7 a	24.3 a	7.3 a	11.3 a	14.7 a	4.0 a	3.0 a	7.0 a	4.7 a	29.0 a	11.7 a	161.3 a
Untreated	0.0 a	0.0 a	2.7 a	4.3 a	4.0 a	7.7 a	14.0 a	5.0 a	30.7 a	51.7 a	47.0 a	63.3 a	265.0 a

[a]Means followed by the same letter in a column are not significantly different (Fisher's protected LSD, $P \leq 0.05$)

Table 6. Mean number of trichomes per square centimeter in 10 nuts per cultivar, Davis, CA – 2013

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	338.2 ± 53.6	1125.6 ± 95.2	968.3 ± 118.8	1743.6 ± 473.9	1038.5 ± 131.9	1042.9 ± 223.6
Hartley	92.1 ± 12.4	170.4 ± 17.6	114.8 ± 6.6	148.1 ± 12.9	288.6 ± 53.9	162.8 ± 34.2
Chandler	243.4 ± 16.3	265.6 ± 26.5	376.0 ± 45.9	535.2 ± 26.9	371.7 ± 28.1	358.4 ± 51.8
Franquette	60.4 ± 7.2	87.3 ± 10.9	200.4 ± 38.0	147.2 ± 12.2	275.6 ± 23.7	154.2 ± 38.9
Vina	83.8 ± 15.9	102.0 ± 9.9	104.2 ± 13.5	135.1 ± 8.6	171.9 ± 20.3	119.4 ± 15.5
Payne	85.1 ± 14.6	45.4 ± 4.7	85.4 ± 14.6	77.5 ± 20.6	127.7 ± 13.3	84.2 ± 13.1
Tulare	42.9 ± 9.2	114.6 ± 25.5	104.9 ± 22.5	117.0 ± 10.1	170.0 ± 16.3	109.9 ± 20.3
Carmello	23.7 ± 7.2	36.7 ± 7.5	30.9 ± 7.7	88.8 ± 17.6	77.2 ± 11.7	51.5 ± 13.2
Serr	48.9 ± 8.0	71.4 ± 4.3	141.5 ± 10.4	102.6 ± 10.1	122.4 ± 8.2	97.4 ± 16.8

Table 7. Comparison of trichomes per square centimeter between the current study and those found by Christofferson et al. (2000)

	Trichomes per cm^2	
Cultivar	Van Steenwyk	Christofferson[a]
Serr	97.4 ± 16.8	110.0 ± 7.5
Vina	119.4 ± 15.5	117.0 ± 10.5
Payne	84.2 ± 13.1	179.0 ± 9.4
Franquette	154.2 ± 38.9	201.0 ± 16.1
Hartley	162.8 ± 34.2	223.0 ± 10.5
Chandler	358.4 ± 51.8	329.0 ± 13.4

[a]Christofferson et al. (2000) trichome density was measured in mm^2 and was converted to cm^2

Table 8. Mean nut weight in grams in 10 nuts per cultivar, Davis, CA – 2013

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	59.8 ± 1.7	49.1 ± 0.6	55.6 ± 2.3	56.0 ± 1.2	58.9 ± 2.7	55.9 ± 1.9
Hartley	50.9 ± 2.8	54.0 ± 2.0	52.3 ± 1.7	56.0 ± 2.4	51.1 ± 4.8	52.9 ± 1.0
Chandler	36.2 ± 2.4	44.3 ± 3.1	48.4 ± 1.0	42.4 ± 1.9	42.6 ± 3.1	42.8 ± 2.0
Franquette	36.0 ± 4.1	53.1 ± 5.0	48.5 ± 3.7	54.5 ± 2.6	39.5 ± 2.3	46.3 ± 3.7
Vina	54.4 ± 5.1	48.7 ± 2.0	63.5 ± 4.3	60.0 ± 4.3	62.7 ± 4.3	57.9 ± 2.8
Payne	48.8 ± 4.6	64.0 ± 2.2	53.4 ± 2.6	50.8 ± 4.7	51.3 ± 3.9	53.6 ± 2.7
Tulare	60.8 ± 0.9	56.2 ± 1.8	53.9 ± 1.9	64.3 ± 1.9	47.6 ± 3.7	56.4 ± 2.9
Carmello	106.2 ± 6.4	120.1 ± 3.9	111.2 ± 3.3	108.8 ± 6.7	108.6 ± 7.0	111.0 ± 2.4
Serr	76.1 ± 3.6	75.2 ± 2.1	70.1 ± 4.3	75.0 ± 4.8	73.8 ± 4.5	74.0 ± 1.1

Table 9. Mean thickness in millimeters of nut husk adjacent to the stem in 10 nuts per cultivar, Davis, CA – 2013

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	6.6 ± 0.1	6.7 ± 0.5	6.5 ± 0.3	7.4 ± 0.4	7.6 ± 0.6	7.0 ± 0.2
Hartley	5.7 ± 0.4	5.2 ± 0.3	6.6 ± 0.3	7.5 ± 0.5	5.2 ± 0.3	6.0 ± 0.5
Chandler	3.6 ± 0.3	3.9 ± 0.4	4.9 ± 0.3	4.7 ± 0.3	4.7 ± 0.3	4.4 ± 0.3
Franquette	5.0 ± 0.3	6.7 ± 0.5	6.5 ± 0.3	8.3 ± 0.4	6.6 ± 0.3	6.6 ± 0.5
Vina	5.8 ± 0.5	5.3 ± 0.3	6.2 ± 0.4	6.7 ± 0.3	6.5 ± 0.4	6.1 ± 0.2
Payne	5.7 ± 0.3	6.1 ± 0.2	6.4 ± 0.3	6.0 ± 0.5	5.7 ± 0.3	6.0 ± 0.1
Tulare	5.8 ± 0.4	4.9 ± 0.2	5.3 ± 0.3	5.6 ± 0.3	5.4 ± 0.3	5.4 ± 0.1
Carmello	6.8 ± 0.6	7.4 ± 0.3	6.3 ± 0.3	6.7 ± 0.6	6.1 ± 0.5	6.7 ± 0.2
Serr	7.5 ± 0.4	8.0 ± 0.2	7.7 ± 0.4	8.0 ± 0.3	7.1 ± 0.4	7.7 ± 0.2

Table 10. Mean thickness in millimeters of nut husk at mid-nut length in 10 nuts per cultivar, Davis, CA – 2013.

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	4.9 ± 0.3	4.7 ± 0.4	5.2 ± 0.2	4.8 ± 0.3	5.4 ± 0.4	5.0 ± 0.1
Hartley	5.2 ± 0.5	4.9 ± 0.4	5.2 ± 0.3	5.6 ± 0.3	5.4 ± 0.3	5.3 ± 0.1
Chandler	3.7 ± 0.2	4.3 ± 0.4	4.3 ± 0.3	4.5 ± 0.1	4.7 ± 0.3	4.3 ± 0.2
Franquette	4.4 ± 0.4	5.8 ± 0.5	5.4 ± 0.3	6.6 ± 0.3	6.0 ± 0.4	5.6 ± 0.4
Vina	5.9 ± 0.3	5.4 ± 0.3	6.2 ± 0.5	6.3 ± 0.3	6.3 ± 0.3	6.0 ± 0.2
Payne	5.6 ± 0.4	6.4 ± 0.3	7.0 ± 0.3	6.5 ± 0.5	5.9 ± 0.4	6.3 ± 0.2
Tulare	5.1 ± 0.3	5.2 ± 0.2	5.0 ± 0.2	5.2 ± 0.2	4.9 ± 0.4	5.1 ± 0.1
Carmello	5.8 ± 0.6	5.8 ± 0.2	5.6 ± 0.2	6.3 ± 0.4	6.2 ± 0.4	5.9 ± 0.1
Serr	7.6 ± 0.4	7.2 ± 0.2	7.6 ± 0.6	8.3 ± 0.2	6.4 ± 0.3	7.4 ± 0.3

Table 11. Mean thickness in millimeters of nut husk adjacent to the flower in 10 nuts per cultivar, Davis, CA – 2013.

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	4.5 ± 0.2	5.0 ± 0.2	4.8 ± 0.2	4.2 ± 0.2	5.1 ± 0.4	4.7 ± 0.2
Hartley	5.1 ± 0.3	4.9 ± 0.3	4.2 ± 0.2	5.0 ± 0.3	5.5 ± 0.3	4.9 ± 0.2
Chandler	3.6 ± 0.1	4.0 ± 0.2	4.9 ± 0.2	4.5 ± 0.2	4.3 ± 0.2	4.3 ± 0.2
Franquette	4.3 ± 0.4	5.3 ± 0.4	5.5 ± 0.4	5.7 ± 0.3	4.3 ± 0.2	5.0 ± 0.3
Vina	5.4 ± 0.4	5.3 ± 0.3	4.8 ± 0.2	6.1 ± 0.3	5.8 ± 0.2	5.5 ± 0.2
Payne	5.3 ± 0.3	5.6 ± 0.3	6.1 ± 0.2	5.8 ± 0.3	4.9 ± 0.2	5.6 ± 0.2
Tulare	5.3 ± 0.3	5.1 ± 0.2	4.8 ± 0.2	5.6 ± 0.3	5.1 ± 0.3	5.2 ± 0.1
Carmello	5.9 ± 0.4	6.1 ± 0.2	5.1 ± 0.2	6.0 ± 0.5	5.1 ± 0.2	5.7 ± 0.2
Serr	7.1 ± 0.3	5.8 ± 0.3	5.8 ± 0.4	6.6 ± 0.3	5.1 ± 0.3	6.1 ± 0.3

Table 12. Mean pressure to penetrate husk in kilograms per square centimeter in 10 nuts per cultivar, Davis, CA – 2013.

Cultivar	25 Jun	8 Jul	22 Jul	5 Aug	19 Aug	Mean
Earliest	26.1 ± 0.9	35.5 ± 1.3	29.9 ± 1.2	30.8 ± 1.1	27.2 ± 1.2	29.9 ± 1.6
Hartley	29.6 ± 1.0	26.3 ± 1.3	26.2 ± 1.1	21.7 ± 1.6	22.5 ± 1.3	25.3 ± 1.4
Chandler	29.8 ± 1.4	30.3 ± 2.3	27.8 ± 0.8	32.2 ± 1.3	24.8 ± 0.9	29.0 ± 1.3
Franquette	23.1 ± 0.7	28.6 ± 1.0	30.0 ± 1.1	25.0 ± 1.3	27.3 ± 1.1	26.8 ± 1.2
Vina	22.9 ± 1.7	28.6 ± 1.1	30.0 ± 1.5	22.6 ± 1.0	26.9 ± 0.6	26.2 ± 1.5
Payne	24.3 ± 1.5	24.9 ± 0.6	30.6 ± 0.9	23.7 ± 1.1	23.7 ± 0.8	25.5 ± 1.3
Tulare	25.5 ± 1.0	31.0 ± 0.6	25.7 ± 1.3	26.4 ± 0.8	26.4 ± 1.5	27.0 ± 1.0
Carmello	29.9 ± 0.6	25.0 ± 0.9	26.6 ± 0.9	31.1 ± 0.9	27.7 ± 1.3	28.1 ± 1.1
Serr	18.9 ± 1.3	25.0 ± 1.1	30.7 ± 1.3	23.2 ± 0.8	19.4 ± 1.0	23.4 ± 2.1

Table 13. Mean red to green color measurement in 10 nuts per cultivar, Davis, CA – 2013

Cultivar	5 Aug	19 Aug	Mean
Earliest	-8.4 ± 0.6	-8.0 ± 0.9	-8.2 ± 0.7
Hartley	-12.5 ± 0.1	-10.7 ± 0.4	-11.6 ± 0.2
Chandler	-11.0 ± 0.1	-9.7 ± 0.2	-10.3 ± 0.1
Franquette	-11.8 ± 0.1	-10.3 ± 0.3	-11.1 ± 0.2
Vina	-11.9 ± 0.2	-10.4 ± 0.3	-11.1 ± 0.2
Payne	-12.0 ± 0.2	-11.2 ± 0.2	-11.6 ± 0.1
Tulare	-13.0 ± 0.3	-12.2 ± 0.3	-12.6 ± 0.2
Carmello	-12.4 ± 0.3	-11.4 ± 0.4	-11.9 ± 0.2
Serr	-12.4 ± 0.2	-12.5 ± 0.2	-12.6 ± 0.1

Table 14. Mean hue angle color measurement in 10 nuts per cultivar, Davis, CA – 2013

Cultivar	5 Aug	19 Aug	Mean
Earliest	107.4 ± 1.4	106.7 ± 1.8	107.1 ± 1.4
Hartley	112.1 ± 0.4	113.0 ± 0.4	112.5 ± 0.3
Chandler	111.8 ± 0.2	112.8 ± 0.4	112.3 ± 0.2
Franquette	113.6 ± 0.3	112.5 ± 0.4	113.0 ± 0.3
Vina	112.2 ± 0.3	112.0 ± 0.5	112.1 ± 0.3
Payne	113.1 ± 0.6	112.3 ± 0.3	112.7 ± 0.3
Tulare	115.6 ± 0.5	114.9 ± 0.3	115.2 ± 0.3
Carmello	113.0 ± 0.4	112.5 ± 0.9	112.8 ± 0.4
Serr	114.7 ± 0.4	113.6 ± 0.3	114.2 ± 0.3

Table 15. Correlations between WHF stings and walnut characteristics by cultivar

		Mean over entire season							
	Total	Trichomes	Weight	Husk thickness (mm)			Husk penetration	Color	
Cultivar	stings	per cm^2	(g)	Stem-end	Mid-nut	Flower-end	per cm^2	Red/green	Hue angle
Earliest	9	1042.86	55.88	6.96	5.00	4.73	29.90	-8.19	107.06
Hartley	17	162.78	52.87	6.03	5.26	4.94	25.26	-11.61	112.55
Chandler	8	358.38	42.77	4.36	4.28	4.26	28.98	-10.34	112.31
Franquette	12	154.19	46.31	6.60	5.63	5.02	26.81	-11.07	113.05
Vina	12	119.41	57.86	6.10	5.99	5.47	26.20	-11.14	112.08
Payne	17	84.22	53.53	5.98	6.28	5.57	25.45	-11.59	112.69
Tulare	20	109.88	56.54	5.43	5.07	5.18	27.03	-12.64	115.24
Carmello	32	51.47	110.99	6.65	5.94	5.65	28.09	-11.90	112.78
Serr	25	97.37	74.04	7.65	7.40	6.09	23.43	-12.62	114.16
Correlation Coefficient[a]		**-0.840**	**0.723**	0.303	0.588	**0.824**	-0.454	**-0.908**	**0.706**
P Value		**0.002**	**0.025**	0.407	0.087	**0.004**	0.204	**0.000**	**0.030**

[a] Correlations in bold are statistically significant ($P<0.05$) using a Spearman Rank Correlation

Table 16. Correlations between WHF egg depositions and walnut characteristics by cultivar

		Mean over entire season							
	Total stings	Trichomes	Weight	Husk thickness (mm)			Husk penetration	Color	
Cultivar	w/ eggs	per cm^2	(g)	Stem-end	Mid-nut	Flower-end	per cm^2	Red/green	Hue angle
Earliest	8	1042.86	55.88	6.96	5.00	4.73	29.90	-8.19	107.06
Hartley	9	162.78	52.87	6.03	5.26	4.94	25.26	-11.61	112.55
Chandler	8	358.38	42.77	4.36	4.28	4.26	28.98	-10.34	112.31
Franquette	6	154.19	46.31	6.60	5.63	5.02	26.81	-11.07	113.05
Vina	8	119.41	57.86	6.10	5.99	5.47	26.20	-11.14	112.08
Payne	9	84.22	53.53	5.98	6.28	5.57	25.45	-11.59	112.69
Tulare	15	109.88	56.54	5.43	5.07	5.18	27.03	-12.64	115.24
Carmello	25	51.47	110.99	6.65	5.94	5.65	28.09	-11.90	112.78
Serr	22	97.37	74.04	7.65	7.40	6.09	23.43	-12.62	114.16
Correlation Coefficient[a]		**-0.724**	**0.707**	0.179	0.392	**0.681**	-0.281	**-0.843**	0.519
P Value		**0.025**	**0.030**	0.612	0.285	**0.036**	0.434	**0.000**	0.138

[a] Correlations in bold are statistically significant ($P<0.05$) using a Spearman Rank Correlation

Figure 1. Mean percent WHF infestation of orchards by treatment, various locations, CA – 2013.

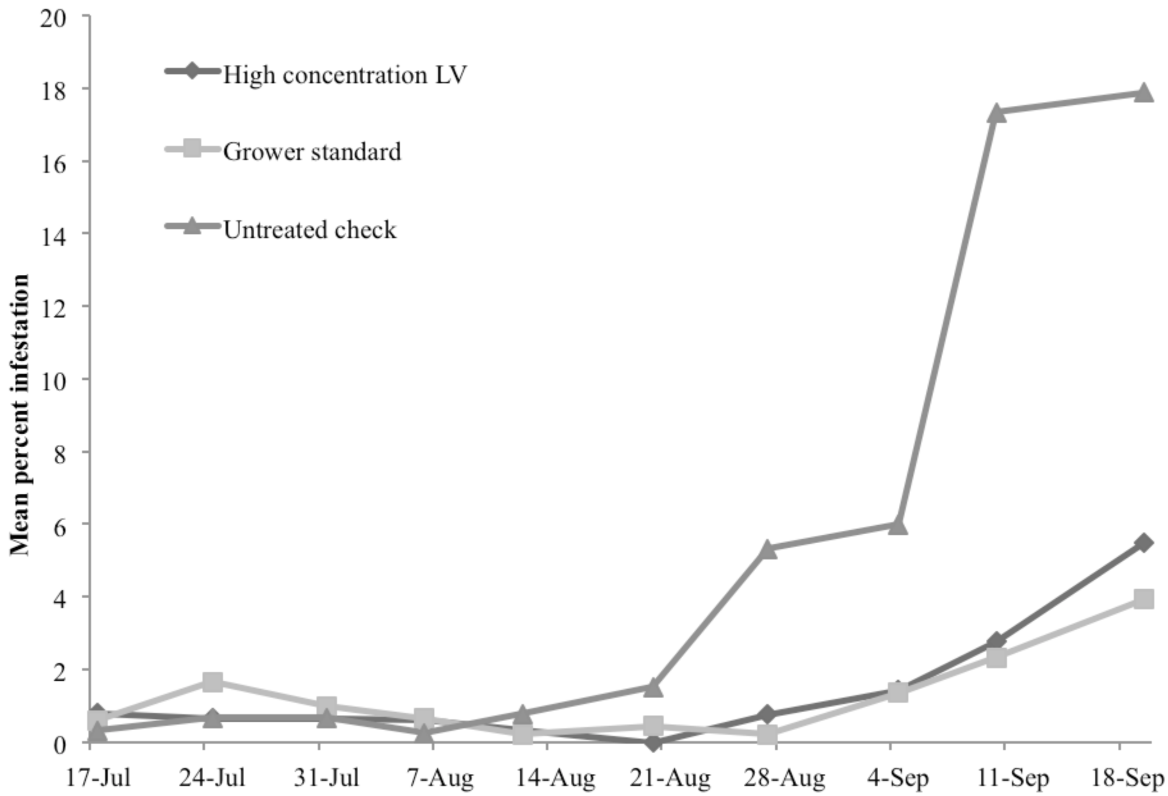

Figure 2. Mean percent WHF infestation per week for 2012 and 2013 combined in various locations, CA.