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Particle Film, Surround WP, Effects on Glassy-winged Sharpshooter Behavior and Its Utility as a Barrier to Sharpshooter Infestations in Grape

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Abstract

Glassy-winged sharpshooter (GWSS) was recently introduced into California and poses a serious threat to the grape industry because it is a very effective vector of the bacterium that causes Pierce's disease. We studied how GWSS was affected by a new technology called particle film, Surround™ WP, that protects plants from insect feeding, oviposition, and infestation by coating the plant surfaces with a protective mineral barrier. In caged field studies, we found that GWSS nymphs and adults were highly repelled by lemon trees treated with Surround WP. Applications of Surround WP turn foliage white; thus, we compared the attractiveness of white and other colors with yellow, which is extremely attractive to GWSS. This study showed that yellow was the most attractive color, followed by orange, and that white was among the least attractive colors, suggesting that Surround WP applications may make plants unrecognizable as hosts. In a field study that compared three biweekly Surround WP treatments to six weekly contact insecticide treatments, Surround WP performed as well as insecticides in reducing GWSS adult numbers and oviposition.

Fig. 1. The glassy-winged sharpshooter transmits the bacterium *Xylella fastidiosa*, which causes Pierce's disease in grape amd eventually results in vine death.

The glassy-winged sharpshooter (GWSS), *Homalodisca coagulata* (Say), was introduced into southern California before 1990 (11). The consequences of this introduction became evident in 1997 when GWSS vectored the bacterium, *Xylella fastidiosa* Wells et al., to oleander, causing oleander leaf scorch disease (2). At that time, GWSS was restricted to Riverside and surrounding counties. Since then, this sharpshooter has spread throughout coastal southern California and northward into the southern San Joaquin Valley, where citrus is its primary host. The GWSS has become a significant problem to California agriculture because it feeds readily on grape and, in doing so, transmits *X. fastidiosa*, the causal agent of Pierce's disease (Fig. 1). This disease causes leaf scorching and vine die-back and eventually kills the grape vine within a few years (Fig. 2). Prior to the appearance of GWSS, California grape growers were able to manage Pierce's disease in grape that is vectored by a number of other indigenous sharpshooters (1). Unfortunately, the GWSS seems to be a more effective vector of Pierce's disease (7) and now threatens California's $40 billion grape industry.

Fig. 2. Grape vines infected with Pierce's disease.

Although contact insecticides offer short-term protection against infestations of GWSS, the continued immigration of sharpshooter adults from citrus soon re-infests grape. Treatment of grape vines with the systemic insecticide imidacloprid, Admire 2E (Bayer Co., Kansas City, MO), slowed the rate of Pierce's disease spread in Georgia, but ultimately only extended vineyard life by a year when infestations were severe (5). Clearly, there is a need to investigate other approaches or technologies that could prevent GWSS infestations before they feed upon grape vines and transmit Pierce's disease.

A new technology called particle film protects plants from insect feeding and oviposition by coating the plant surfaces with a protective mineral barrier (3,8). In this paper, we report how particle film treatments affect GWSS behavior in a series of choice and no-choice conditions. In field studies in which GWSS infestations were severe, we examined the attractiveness of the color white to GWSS adults and compared a standard chemical control program versus a particle film, Surround™ WP (Engelhard Corp., Iselin, NJ).

Choice and No-Choice Tests

The effect of Surround WP treatments of lemon on GWSS infestation and survival under no-choice conditions was determined using potted trees in field cages at Bakersfield, CA, July and August, 2001. 'Eureka' lemon trees were either treated with a 6% particle film solution (60 grams Surround WP per 1.0 liter water) or left untreated as a control. Trees were sprayed with Surround WP by a 4-liter hand-pump sprayer until all of the foliage was wetted and then allowed to dry. Either a treated or untreated tree was placed in screen-covered cages measuring 1 m^2 by 2 m high, and either 50 GWSS adults or 10 third- to fourth-instar nymphs were placed at the bases of the trees to disperse.

In choice studies, the lemon trees were pruned to leave only two 1-m long limbs. One limb was then treated with 6% Surround WP down to where the branches forked; the other limb was not treated. GWSS was released and caged as previously indicated. Both choice and no-choice experiments had 7 to 10 replications each for nymphs and adults over time. Numbers of GWSS on the trees and within the cages were recorded daily for 4 days to determine infestation rates and survival. GWSS numbers were converted to percentages and analyzed using analysis of variance (ANOVA). The treatment effect (F-test) was used to determine significant differences between the two treatment means, $P \leq 0.05$ (SAS Institute, 2001).

GWSS nymphs and adults were greatly repelled by Surround WP treatments in choice and no-choice experiments (Table 1). When either GWSS nymphs or adults were given no choice between Surround WP and untreated citrus, very few nymphs and no adults were able to colonize Surround WP-treated lemon. There were no significant day or treatment-by-day interactions for nymphs (P = 0.4) or adults (P = 0.19) in the no-choice tests, suggesting that GWSS did not attempt to move off treated or untreated trees over the 4-d period after they had found a suitable site on which to settle. Survival of nymphs under no-choice conditions was significantly reduced by Surround WP treatments ($P < 0.001$) after being exposed for 4 d, averaging 8.3 ± 4.2% on Surround WP versus 75.0 ± 15.2% on untreated trees. Adult survival was reduced to 0% on Surround WP treatments versus 18.8 ± 4.4% on untreated lemon 1 d after infestation. This relationship did not change over the 4-d period. Adult survival was extremely poor in caged tests because many individuals did not settle on lemon trees under caged conditions and clung to the cage sides until they died.

Table 1. Mean number (± SE) of glassy-winged sharpshooter nymphs (n = 20) and adults (n = 50) per tree after being released in cages containing a lemon tree treated with Surround WP or left untreated in a no-choice test, or given a choice between one limb treated with Surround WP and the other left untreated.

Experiment	**Treatments**	**Nymph**	**Adult**
No-choice	Surround WP (6%)	0.5 ± 0.5b	0.0 ± 0.0b
	Untreated	7.6 ± 0.6a	7.6 ± 0.6a
Choice	Surround WP (6%)	0.0 ± 0.0b	0.0 ± 0.0b
	Untreated	6.6 ± 0.6a	5.0 ± 0.6a

Means within a column for each experiment that are followed by the same letter are not significantly different, *F*-test, ($P = 0.05$).

The choice tests produced very similar results to the no-choice tests. Neither GWSS nymphs nor adults settled on Surround WP-treated lemon, which resulted in no colonization over the 4-day period. Treatment preferences of nymphs or adults did not change significantly over time. Survival of nymphs significantly declined over time, from 90.0 ± 4.5% at 1 d to 53.3 ± 6.4% at 4 d after infestation, and averaged 60.8 ± 4.6% over time. We believe the reason for this decline was that nymphs fell from the trees while moving between treated and untreated foliage and were unable to return to the trees. Survival did not decline in the no-choice test because untreated trees had more foliage for GWSS to move upon. Nymphs that were able to find the few untreated spots on Surround WP-treated foliage probably remained at those sites during the study period. In contrast, adult survival on Surround WP-treated foliage did not significantly change over time in either the choice or no-choice tests.

Adult Response to Colored Sticky Traps

GWSS adults are attracted to yellow sticky traps (Trece, Salinas, CA), and these traps are used extensively as a standard tool for monitoring GWSS flight activity. Surround WP treatments turn plant foliage a striking white color. To determine whether foliage treated with Surround WP was attractive, neutral, or repellent to migrating GWSS adults, we used sticky traps spanning a spectrum of colors and placed them in citrus groves located near Bakersfield, CA, during the beginning of a GWSS migration period in the spring of 2001. Round (25.4 cm in diameter), plastic, colored targets were coated with Tangle Foot™ (Grand Rapids, MI) clear sticky polymer and attached to bamboo poles 2 m above the ground. Plates (Solo, Urbana, IL) colored black, blue, yellow, green, red, white, and clear were used, and clear plates were painted pumpkin orange (Krylon, Cleveland, OH) or walnut brown (ColorPlace, Bentonville, AR). The colored traps were then placed within citrus groves at three sites adjacent to the Surround WP field studies beginning 1 April and ending after grape harvest on 30 September. The traps were placed within the tree rows spaced 7 m apart and replicated four times in a randomized complete block design. Numbers of GWSS adults per trap were recorded weekly. Data were analyzed by month using ANOVA, and treatment means were compared using the Ryan-Einot-Gabriel-Welsch multiple comparison (REGW) test, $P = 0.05$ (SAS Institute 2001).

Sites 1 and 2 were the only sites at which we trapped sufficient adult GWSS for data analysis. Differences between sites were not significant, so we combined the data from these two sites for further analysis. Adult GWSS distinctly preferred yellow, but shifted in color preference to orange during April through September (Fig. 3). Differences in trap catches by color were significant ($P < 0.0001$), as was color preference change over time ($P < 0.0001$). Approximately 50% of the total GWSS were captured by yellow from April through September. In April, GWSS were equally attracted to all colors except yellow. However, from May through September, orange ranked second to yellow in attractiveness to GWSS. In September, the percentage of GWSS trapped by orange nearly doubled to 30% compared with the percentage trapped by orange during the preceding months ($P < 0.0001$), whereas the trap catches for most of the other colors decreased as the season progressed. Another significant shift in color preference was noted for green, which was more attractive in April than during the following months ($P < 0.0007$). White, clear, red, black, brown, and blue were consistently the least attractive colors to GWSS during the 5-month study period.

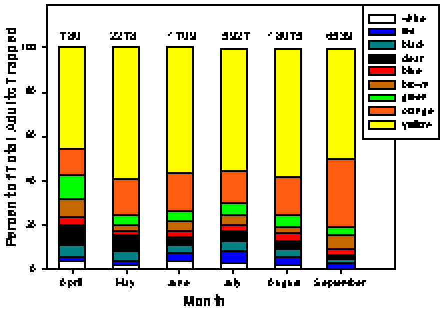

Fig. 3. Mean percentage of glassy-winged sharpshooter adults responding to 25.4-cm plastic plates painted a spectrum of colors, coated with TangleFoot™ (Grand Rapids, MI), and placed at a height of 2 m in two citrus groves bordering grape, Kern County, CA, 2001. Percentages based on total number of trap catches above each bar.

Surround WP Applications to Vineyards as a Barrier to GWSS

On 13 March, 2001, we initiated research at three vineyard sites bordering citrus near Bakersfield, CA. We examined the effect of 91.5 m or 247.5 m Surround WP barrier treatments to grape on movement of GWSS adults from citrus into grape. Site 1 was a mixed vineyard of ‘Flame Seedless’, ‘Chardonnay’, and ‘Thompson Seedless’. The site was divided into six blocks 164.6 m wide by 365.7 m long (6.5 ha) and assigned treatments of Surround WP or a chemical insecticide program. The treatments were replicated three times along the length of the citrus interface in a randomized complete block design. Surround WP treatments only extended 247.5 m into each block; the remaining 152.4 m was left untreated. The insecticides were applied the entire 365.7-m distance of the block. Site 2 was a ‘Flame Seedless’ vineyard with block sizes identical to Site 1, except there were four replications. Site 3 was a ‘Flame Seedless’ vineyard that was divided into six blocks 89.6 m wide by 164.6 m long (0.8 ha) with the two treatments arranged in a randomized complete block design with three replications. The Surround WP treatments extended 82.3 m into grape. These vineyard sites were managed by a single grower while only one of the three adjacent citrus groves (Site 3) was managed by this grower.

All three test sites had three bi-weekly applications of Surround WP (11.36 kg Surround per 378.5 liters water) and were compared to six weekly applications of insecticides (all applications at 467.6 to 654.8 liter/ha) (Figs. 4a and 4b). All treatment applications began 13 March. Surround WP applications ended on 14 April; insecticide treatments continued through 27 April at all three test sites. The insecticides used to control GWSS adults during the study period were dimethoate (Dimethoate 400, Platte Chemical Co., Greeley, CO) applied at 4.67 liter/ha, methomyl (Lannate LV, E. I. DuPont de Nemours & Co., Wilmington, DE) applied at 2.33 liter/ha, and naled (Dibrom 8E, AMVAC Chemical Corp., Los Angeles, CA) applied at 0.74 liter/ha.

Fig. 4a. Field study comparing 3 applications of Surround WP particle film (white vines) to 6 applications of conventional insecticides (foreground) in grape to control glassy-winged sharpshooter, April 2, 2001, Kern County, California.

Fig. 4b. Close-up of Surround-treated grape.

The plots to which treatments were to be applied were sampled one week before treatment applications. Yellow sticky traps were spaced every 30.5 m along two 365.7-m transects per block at Site 1 and one transect per bock at Sites 2 and 3. The transects began in grape at the citrus interface and extended into grape. The transects extended 152.4 m beyond the Surround treatments to allow us to estimate GWSS movements beyond the treatment barrier. We sampled the treatment blocks of each site weekly for GWSS adults and nymphs in 4.25 m vine row about every 30.5 m for a total of 12 samples in 365.7 m row. We sampled for GWSS egg masses on 4 May, 2001, by inspecting 25 leaves per vine every 30.5 m along the sticky trap transects in each block. Data were analyzed using ANOVA, and the treatment effect (*F*-test) was used to compare treatments means, $P \leq 0.05$ (10).

Monitoring GWSS activity with yellow sticky traps determined that Surround WP treatments reduced GWSS numbers trapped at Site 1, but not at Sites 2 and 3. Movement of GWSS into grape at Sites 2 and 3 occurred at such low levels that if there was a treatment effect, it could not be detected with the sampling protocol used. Traps in citrus bordering Site 1 caught ~40 times more adults than traps in grape, suggesting that GWSS infestation pressure for grape was high (Fig. 5). We noticed a border effect in grape where the vineyard interfaced the citrus grove at Site 1. Therefore, trap transects in grape were partitioned into distances of 0 to 4.3 m (Interface zone), 4.4 to 123.7 m (Zone A -- treated), 123.8 to 247.5 m (Zone B -- treated), and 247.6 to 365.7 m (Zone C; Surround WP -- untreated, chemical insecticides -- treated) for statistical analysis.

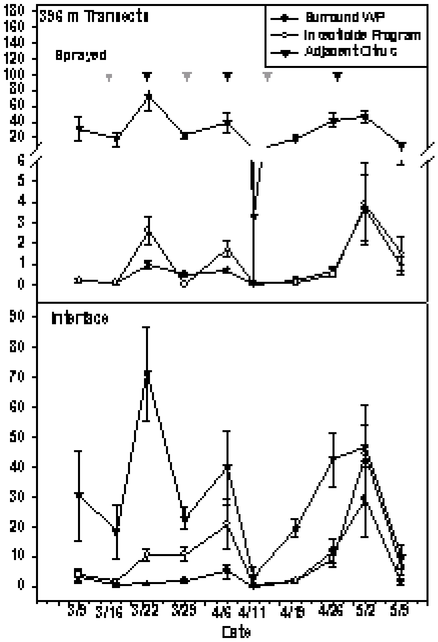

Fig. 5. Mean number (± SE) of glassy-winged sharpshooter adults caught per yellow sticky trap (Trece, Salinas, CA) placed 1 m high in the first grape vines in a vineyard bordering citrus (Interface) and placed every 30.5 m in two 365.7-m transects extending into each treatment block (Transect) in Site 1, Kern County, CA, 2001.

Data from five of the ten sample dates showed that the Interface zone traps caught approximately 10-fold more GWSS adults than traps in the other zones, whereas trap counts from other zones did not differ from one another. Therefore, treatment comparisons were based on GWSS counts for traps in the Interface zone, whereas trap counts for Zones A through C were averaged for the 396-m transects (Fig. 5). Interface zone traps in Surround WP treatments caught fewer GWSS than traps in the insecticide treatments from 9 March to 6 April, except on 16 March. After 6 April, there were no differences in Interface trap catches between treatments. Transect traps in Surround WP treatments trapped fewer GWSS on 22 March and 6 April; data from all other trap dates were not significantly different between treatments.

Visual counts of GWSS adults on grape also were separated into the aforementioned zones because of the border effect (data not shown). Counts of GWSS adults were significantly different between sample dates, treatments, and zones. Visual counts in the Interface zone revealed higher GWSS adult numbers in the insecticide treatment than in the Surround WP treatment on 22 March (Surround = 0.06 ± 0.06, insecticide = 0.6 ± 0.6), 29 March (Surround = 0.14 ± 0.02, insecticide = 0.56 ± 0.10), and 6 April (Surround = 0.0 ± 0.0, insecticide = 0.9 ± 0.5). GWSS visual counts were much lower in samples beyond the interface, with no significant differences between treatments for each zone. Although we attempted to record numbers of nymphs in these blocks, we encountered only a few during the entire study period. Therefore, these data were not analyzed.

On May 4, nearly 3 weeks after the last Surround WP application, GWSS adult oviposition activity was high at Site 1 and provided an opportunity to determine whether the treatments differed in suppression of oviposition (Fig. 6). Egg counts were divided into the aforementioned zones for analysis because of the border effect. Egg counts differed significantly between treatments (P = 0.0001) and treatment zones (P = 0.02). The insecticide treatment had significantly larger numbers of GWSS eggs at the grape-citrus interface zone than the other zones, and counts in Zone A were higher than in Zones B and C (P

< 0.0001). In contrast, zones averaged 0.0 to 0.9 GWSS eggs per zone in the Surround WP treatment and did not differ from one another (*P* = 0.50). Oviposition was drastically reduced by Surround WP compared to the insecticide treatments in each zone.

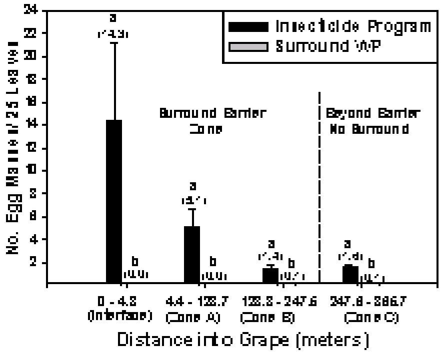

Fig. 6. Mean number (± SE) of glassy-winged sharpshooter eggs on 25 leaves per vine in the first grape vines in a vineyard bordering citrus (Interface) and from samples taken every 30.5 m into each treatment zone in Site 1, Kern County, CA. Identical letters for each pair of treatment means in each zone indicate no significant difference (*F*-test, *P* = 0.05).

Discussion and Conclusions

Surround WP-treated plants were found to be very undesirable hosts to both GWSS adults and nymphs in choice and no-choice environments (Table 1). In no-choice conditions, a few nymphs managed to find an untreated site on which to settle on Surround WP-treated plants, which stresses the importance of good coverage when using this material. Typically, Surround WP is applied bi-weekly for insect pest management, and repeated applications reduce the probability of untreated areas on the plants. When given a choice between Surround WP-treated or untreated foliage, no nymphs or adults infested the Surround WP-treated foliage. The choice study may be more representative of what occurs in the field than the no-choice study because GWSS can utilize more than 75 species of plants (12) and could easily move to other plants if they encountered Surround WP-treated plants.

Many insects that visually orient by color in their search for suitable hosts are often monitored by colored traps (9). Included among these insects is the GWSS; the adults' attraction to yellow is exploited by the use of yellow sticky traps (1). Although plant foliage reflectance is primarily shades of green, yellow is believed to be a supernormal foliage-type stimulus (9). Our study also found that yellow was the most attractive color for GWSS from April through September (Fig. 3). Orange was the second most attractive color, and preference toward this color increased in September, suggesting that visual orientation of migrating GWSS may shift with changes in plant phenology. Most relevant to our study is that white was among the least attractive colors we evaluated. It is well known that aphids, as well as leafhoppers, are highly attracted to yellow and that plants turned white by whitewash sprays are repellent to aphids (4,6). Thus, the mechanisms by which Surround WP acts against GWSS host location may be at least two-fold where: (1) camouflaging plants with a white coating makes them visually unperceivable, or (2) the white Surround WP coating on plants reflects sunlight, which repels leafhoppers, as it does aphids.

We had a rare opportunity to study the effects of Surround WP on natural populations of GWSS in grape bordering citrus during an aggressive control program in Kern County, CA. Our research sites were located at the northern edge of an expanding GWSS migration front that had moved into the southern San Joaquin Valley and was progressing northward. Extremely high densities of GWSS occurred at Site 1 in the adjacent navel orange grove. GWSS was not being controlled in citrus because there was no firm evidence that fruit yield or quality was affected. Comparison of three applications of Surround WP with six insecticide applications over a 2-month period showed that Surround WP was equally effective or better than numerous insecticide applications in reducing

GWSS movement into grape (Fig. 5). Fewer applications of Surround WP were needed because the repellent mineral barrier was more residual than contact insecticides. The relationship of GWSS numbers caught by yellow sticky traps to infestation levels in grape has not been established. Relevant to this study, we did not know whether GWSS adults were moving in or out of two treatments and, specifically, whether GWSS adults were settling or feeding and potentially transmitting Pierce's disease. Although visual sampling for GWSS adults on grape vines produced very low numbers, insecticide treatments had higher numbers of GWSS than Surround WP treatments at the citrus-grape interface. Both Surround WP and insecticide treatments greatly reduced numbers of GWSS in zones A through C. We noted that numbers of GWSS adults in zone C for both treatments did not differ, even though zone C was not treated in the Surround WP blocks but had the same insecticide treatment regime as the Interface zone, zone A, and zone B in the insecticide blocks. This suggests that the 247.5-m wide Surround WP barrier was sufficient to prevent GWSS adult migration from citrus into the neighboring vineyard. We encountered only a few nymphs in grape during the sampling period, even though eggs were present in the insecticide treatments, suggesting that weekly insecticide treatments prevented development of GWSS infestations.

The best measure of how the two treatments affected GWSS activity and host suitability was our egg mass sampling in grape on May 4 (Fig. 6). Although Surround WP treatments ended after April 14 and insecticide treatments continued to April 30 (Fig. 5), Surround WP held oviposition to undetectable levels, whereas insecticides did not prevent oviposition (Fig. 6). Clearly, the Surround WP treatments had enough residual activity 3 weeks after application to make grape an unsuitable host for infestation, whereas weekly applications of insecticides did not (Fig. 7a and 7a). Surprisingly, both GWSS trap catches (Fig. 5) and visual counts for adults in the Surround WP and insecticide treatments were at the same relative levels in Zones A through C. However, oviposition occurred only in the insecticide-treated blocks. This finding is consistent with our conclusion that yellow trap and visual counts may only indicate movement in crops and that other sampling methods such as egg counts should be employed when quantifying damaging infestation levels within in that crop. Based on our data from several different sampling methods, GWSS adults seemed to be moving in and out of Surround-treated field plots at low levels, but they did not find grape a suitable host to establish infestations because of the strong repellency of Surround WP.

Fig. 7a. Three-week-old particle film, Surround WP, residues on grape leaves were sufficient to prevent glassy-winged sharpshooter oviposition.

Fig. 7b. Conventional insecticide treatments incurred glassy-winged sharpshooter oviposition, visible as wax-coated egg masses.

Surround WP offers a feasible approach to minimize settling and oviposition of GWSS, potentially resulting in reduced spread of Pierce's disease in grape. The impact of particle film treatments on the spread of Pierce's disease in this study and others is still under assessment. Although systemic insecticides seem to be more effective than contact insecticides when infestations of GWSS are severe, imidacloprid treatments have extended vineyard life only by about 1 year (5). The inherent problem of controlling disease-vectoring insects with a systemic insecticide is that the insects must feed on the plants to become intoxicated, which might allow transmission of the causal organism of Pierce's disease in the process. The unique repellent mode of action of Surround WP reduces the chances of GWSS settling on treated plants, thus minimizing the chances for feeding and oviposition. Surround WP was implemented successfully as one of several key tools used in a large pilot study organized by USDA-APHIS to manage GWSS in Kern County, CA. In this program, Surround WP was applied as a 247.5-m barrier in grape bordering citrus to prevent GWSS movement out of citrus into grape in May and April so that this pest could be contained and controlled by insecticides in citrus. Surround WP also was effective in dis-infesting grape into which GWSS had already moved during the Spring and Fall in this program. In the northwestern US, Surround WP has been very successful in preventing early season oviposition and infestation of pear psylla in pear. Particle film technology also would be useful in preventing or controlling other insect pests, with potential for reducing the use of chemical insecticides.

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