

# Interactions of plant resistance and insecticides on the development and survival of *Bactericerca cockerelli* [Sulc] (Homoptera: Psyllidae)

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## Abstract

Relatively few studies have investigated potential interactions of host plant resistance and insecticides for insect control. To examine possible interactions, host plant resistance was measured independently for four tomato cultivars and one wild tomato accession against tomato psyllids, *Bactericerca* [*Paratrioza*] *cockerelli* [Sulc] (Homoptera: Psyllidae). Plant lines tested included the commercial cultivars ‘Shady Lady’, ‘Yellow Pear’, ‘7718 VFN’, ‘QualiT 21’ and the plant accession PI 134417. Cultivars showed variable resistance; PI 134417 was the most resistant line tested with significantly reduced developmental rates and survivorship. Insecticides tested against the commercial cultivars included a kaolin-based particle film, pymetrozine, pyriproxyfen, spinosad and imidacloprid. Although all chemicals significantly reduced egg–adult survivorship, the effectiveness of some insecticides varied between-plant lines as measured by survivorship, development time and growth index (GI) data, which indicated significant interactions between-plant lines and insecticides. For example, survivorship from egg to adult varied significantly between cultivars under pymetrozine treatment. For kaolin-based particle film applications, numbers of days required to reach the adult stage were significantly different between cultivars. GI values were also variable between cultivars for pymetrozine and spinosad. Although all chemicals tested had potential for psyllid control within an integrated pest management program, imidacloprid and pyriproxyfen worked consistently well on all cultivars tested. For the other chemicals, cultivar selection could influence pesticide efficacy.

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## 1. Introduction

Interactions between-plant lines and pesticides can complicate pest control. Unique cultivar characteristics such as days to harvest expose some cultivars to higher insect densities, resulting in substantially greater crop damage (Story et al., 1983; Gonzalez and Wyman, 1991). Allelochemicals that induce production of enzymes in insects can increase tolerance to pesticides (Kennedy, 1984; Brewer et al., 1995). In addition, biological control agents may be affected by plant surface features (van Lenteren et al., 1995) or by

allelochemical content of some plant lines (Barbour et al., 1993; Braman and Joyce, 2002). Other studies have demonstrated that plant developmental stage can affect pesticide resistance in insects (Attah and van Emden, 1993), and that the architecture of crop canopies impacts coverage of foliar applications (Cooley and Lerner, 1994). Abro and Wright (1989) demonstrated that feeding rates (and thereby pesticide ingestion) could vary with plant line such that resistant lines reduced pesticide intoxication. In contrast, resistant plant lines also have negative effects on insect body size and vigor, leading to stress that can increase the effectiveness of pesticides (Eigenbrode and Trumble, 1994; van den Berg et al., 1994). Therefore, integrating plant resistance into integrated pest management (IPM) programs may not always be a simple process.

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An IPM program is needed for the psyllid (*Bactericera [Paratrioza] cockerelli* [Sulc]) (Homoptera: Psyllidae) on tomatoes in Mexico and California. This insect recently developed high densities on fresh market tomatoes in Baja, Mexico resulting in losses of up to 85% of mature plants (Liu and Trumble, 2004). In California, substantial losses have occurred in southern and central California (John T. Trumble, pers. ob.). Until recently, sustainable, low input IPM strategies for tomato production in California's \$350 million tomato industry were widely adopted. Pesticide use on tomatoes declined by nearly 50% from the late 1980s to the late 1990s (California Department of Food and Agriculture, 1989, 1997). Unfortunately, these recent gains have been jeopardized by the development of large densities of the tomato psyllid.

Tomato psyllid nymphs and adults cause damage by injecting a toxin. In extreme cases, plant death can occur (Pletsch, 1947). However, a more common effect is plant stunting that results in little or no production of commercial grade fruit (Al-Jabar, 1999). Because the psyllid develops rapidly (less than 2 weeks) and can oviposit in excess of 1400 eggs/female, populations build explosively (Knowlton and James, 1931). Not surprisingly, the initial grower response has been to spray pesticides. The effects have been problematic because common broad-spectrum carbamates increase psyllid densities (Cranshaw, 1985, 1989). Other pesticides registered in California on fresh market tomatoes such as fenvalerate, esfenvalerate, endosulfan, methamidophos and phorate have been shown to reduce densities of biological control agents, resulting in outbreaks of secondary pests such as *Liriomyza* leafminers and spider mites (Trumble, 1990, 1998). The resulting pesticide use pattern is threatening to eliminate current IPM programs in tomatoes and may promote rapid development of insecticide resistance. Thus, an IPM strategy is required that is based on alternatives to broad-spectrum insecticides.

In a previous study, the behavioral responses of tomato psyllids were compared in response to five biorational chemicals and five tomato plant lines (Liu and Trumble, 2004). Psyllid behavioral responses were variable across plant lines, between chemical treatments within a plant line, and an interaction was detected between-plant lines and some insecticides. These results were useful, but information on development and survival of the psyllid in response to plant lines, insecticides and their possible interactions was necessary before an IPM program could be created. Therefore, the primary goals of this study were to (1) evaluate psyllid development and survival on selected tomato lines, (2) measure survival and development with exposure to selected insecticides that do not disrupt our existing IPM program, and (3) to document any potential interactions between-plant lines and pesticides.

## 2. Materials and methods

### 2.1. Insects

Adults collected from fresh market tomatoes in Orange County in December 2002 and August 2003 were used to establish a laboratory colony. The colony was maintained at  $25 \pm 1$  °C, and a photoperiod of 14:10 (L:D). Host plants were potatoes (*Solanum tuberosum*, VanZyverden Russett, Meridian, MS). A plant genus other than *Lycopersicon* was chosen as the rearing host because Tavormina (1982) and Via (1984a, b) demonstrated that some insect species developed a preference for the host species from which they had been reared. Adults used in all tests were standardized by selection of insects with teneral coloration (light or pale green) indicating that they had emerged within the previous 2–3 d. Because oviposition does not occur within the first 3 d (Knowlton and James, 1931), selection of 2–3-d-old adults eliminated problems with oviposition status variability. Nymphal instar determination was made based on the maximum body width of the 1st–5th nymphal instar (0.2, 0.3, 0.5, 0.7 and 1.1 mm, respectively), and the development of wing pads (Rowe and Knowlton, 1935; Pletsch, 1947).

### 2.2. Plants

Tomato plants used in all tests were grown in 15-cm diameter pots with UC mix (Matkin and Chandler, 1957) and fertilized three times weekly with the label rate of Miracle Gro nutrient solution (Scotts Company, Ohio, USA). All plants used were between 1 and 2 months of age with 5–10 fully expanded leaves, at the developmental stage achieved approximately 1 week after transplanting in the field. Although damage can occur at any time, young plants are particularly susceptible (Carter, 1950). Plants of different cultivars with similar size and vigor were used for all replications. Plant leaves used as substrates for oviposition were standardized by selecting the upper-most fully expanded leaf.

Five tomato lines were tested, including four cultivars of *Lycopersicon esculentum* Mill. (Petoseed '7718 VFN', Petoseed 'Yellow Pear', Rogers 'QualiT 21' and Sunseeds 'Shady Lady'), and a *Lycopersicon hirsutum* f. *glabratum* accession, PI 134417. The 'Yellow Pear' cultivar is a variety commonly planted by consumers. The cultivars 'QualiT 21' and 'Shady Lady' are widely used commercial varieties in California, while Petoseed '7718 VFN' is an older commercial variety known to be susceptible to many insect pests (Eigenbrode et al., 1993). PI 134417 is a wild-type accession with considerable insect resistance that has been studied extensively (Farrar and Kennedy, 1992; Eigenbrode and Trumble, 1993). The line PI 134417 was not included in any

pesticide trials because this accession does not produce edible fruit, would not be exposed to pesticides in the field, and the diversity of insect resistance mechanisms in the wild-type plant that would not be found in a commercialized cultivar would likely confound insecticide–plant interactions.

### 2.3. Pesticides

We evaluated five pesticides; one soil-applied systemic material and four that were applied to foliage. All pesticides were selected for their potential usefulness in sustainable IPM programs that include beneficial insects (Trumble and Alvarado-Rodriguez, 1993; Trumble et al., 1994). Chemicals and rates included in the study were pyriproxyfen (Knack (with 103 g AI/l), Valent, USA, Walnut Creek, CA, 0.78 ml/l, applied with a hand sprayer), a kaolin-based particle film (Surround WP, Engelhard Corporation, Iselin, NJ, 50 g/l, applied with a pressurized sprayer), pymetrozine (Fulfill (with 50% of AI by weight), Syngenta, Greensboro, NC, 1.873 g/l, applied with a hand sprayer), spinosad (Conserve 120 SC, Dow AgroSciences Inc., Indianapolis, IN, 1.72 ml/l, applied with a hand sprayer) and imidacloprid (Admire 2 Flowable, Bayer Corporation, Kansas City, MO, 0.94 ml Admire/l, applied to the soil at 100 ml/pot). All test insecticides except imidacloprid were sprayed until runoff; about 50 ml/plant. Plants were exposed to ovipositing adults 24–48 h after treatment for all insecticides except imidacloprid. Plants in soil treated with imidacloprid were used 1 week after treatment.

None of the chemicals have reported activity against hymenopterous parasitoids, but do provide suppression of other psyllids and related insects (Carson et al., 1996; Naranjo et al., 2004; Sechser et al., 2002; Zalom et al., 2000). Pyriproxyfen, a juvenile hormone mimic, is labeled for pear psylla (*Cacopsylla pyricola* Foerster) on pome fruits, and also reduces egg hatch and adult eclosion of greenhouse whitefly (*Trialeurodes vaporariorum* Westwood) (Ishaaya et al., 1994; Bi et al., 2002). The kaolin-based particle film forms a barrier film on plants providing control of various insect species (Jifon and Syvertsen, 2003). This material has been shown to alter leaf temperature and leaf whiteness, as well as leaf physiology (net CO<sub>2</sub> assimilation rate) (Jifon and Syvertsen, 2003). Spinosad is a secondary metabolite from the aerobic fermentation of *Saccharopolyspora spinosa* (a soil-dwelling bacterium) on nutrient media (McPherson et al., 2003), and has minimal impact on parasites of *Liriomyza* species in fresh market tomatoes (Carson et al., 1996). Pymetrozine, in the group of azomethine pyridines, has a spectrum of activity that covers sucking pests such as aphids, whiteflies and planthoppers, yet has no negative effects on natural enemies (Sechser et al., 2002). Imidacloprid is a systemic, chloro-nicotinyl insecticide used for the control of

insects that is already included in current tomato recommendations to control whiteflies and other pests (Zalom et al., 2000).

### 2.4. Bioassay

Newly emerged adults were held on fresh leaves in a Petri dish for 3 d, after which 10–15 adults were caged on each treatment (plant line, plant line × insecticide) and allowed to oviposit for 4–8 h. Five to 20 eggs were allowed to remain on each plant. If more than 20 eggs were produced, excess numbers were removed to simplify tracking of individuals. For each cultivar except the wild accession, six treatments were tested including the five insecticides and a control. No insecticide treatment of the wild accession was included because this line is not planted commercially and is never exposed to pesticides. Including a wild-type plant line with extremely low psyllid survivorship in studies with chemical treatments was judged a priori to be likely to confound the documentation of potential interactions between commercial cultivars and insecticides. Each treatment was replicated 10 times. All tests were conducted at 26 °C and a photoperiod of LD: 14-10, treated plants were randomly arranged on the shelves in the experimental chamber.

Each replicate was monitored for mortality until the last nymph developed to adult. As in all experiments, test plants were held in the same walk-in environmental chamber throughout the study. Initially, nymphal instar was checked daily, the numbers of early instar (including the 1st and 2nd instar) nymphs and late instar (including the 3rd–5th instar) nymphs were recorded. As nymphs reached the 3–5 instar, treatments were checked twice daily for adult eclosion, so an accurate development time from egg to adult could be calculated.

### 2.5. Growth index

Insect development was characterized using the growth index (GI) introduced by Zhang et al. (1993). GI values were calculated as

$$GI = \frac{\sum_{i=1}^{i_{\max}} [n_{(i)}i] + \sum_{i=1}^{i_{\max}} [n'_{(i)}(i-1)]}{Ni_{\max}}$$

where  $i_{\max} = 4$  is the highest attainable stage of the insect at day 35 and  $n_{(i)}$  the number of insects alive at stage  $i$ ,  $n'_{(i)}$  the number of insects dead at stage  $i$ ,  $N$  the total number of insects tested. Stages were chosen as 1 = egg hatch, 2 = instars 1 + 2, 3 = instars 3 + 4 + 5 and 4 = adult. This index provides an indication of the developmental stage reached by the cohort of test insects at the completion of the test, with values approaching one indicating a large proportion reaching the adult

stage and values near zero indicating few insects surviving beyond the first stage.

2.6. Data processing and statistical analysis

Due to the non-normal distribution of data, some survivorship and developmental time analyses for within-plant line comparisons were conducted with the Mann–Whitney *U*-test (StatView, 1998). A separate analysis of variance (ANOVA) was conducted for comparisons of psyllid development and survivorship between the commercial cultivars and PI 134417 because there were no insecticidal treatments of PI 134417 (SAS, 2002). All GI data were transformed (square root of the arcsine) prior to analysis. Where appropriate (data were normal), survivorship, developmental time and GI were analyzed across cultivars by two-way ANOVA to identify interactions between-plant line and pesticide (Proc GLM procedure of SAS, 2002) ( $P < 0.05$  level). Where data were not normal, survivorship comparisons within a cultivar between treatments of spinosad, imidacloprid and pyriproxyfen were conducted using Mann–Whitney *U*-test ( $P < 0.05$  level, StatView, 1998). Following the two-way ANOVA with interactions, differences in means within an insecticide treatment were assessed by the Tukey test controlling for overall experimentwise error rates (the ‘lsmeans’ line in the Proc GLM two-way ANOVA was as follows: lsmeans cultivar chemical cultivar\*chemical/stderr pdiff adjust=Tukey. This step calculates errors from three sources including cultivar, chemical and cultivar\*chemical; it also makes multiple mean comparisons adjusting with the Tukey test). These procedures allowed initial comparisons of development, growth indices and pesticidal effects both within a cultivar and across cultivars. These selected comparisons were chosen a priori.

3. Results

3.1. Within-cultivar comparisons

Treatment with any of the five chemicals significantly reduced the egg–adult survivorship on every cultivar (Fig. 1,  $F = 54.03$ ;  $df = 2, 108$ ;  $P < 0.01$ ). For ‘7718 VFN’, imidacloprid and pyriproxyfen did not allow development to the adult stage. Application of spinosad allowed less than 6% survival, suggesting any of these three materials could be used to provide population suppression. The number of days to adult emergence was extended significantly as compared to the control by both pymetrozine and spinosad, but not by kaolin-based particle film (Fig. 2,  $F = 3.19$ ;  $df = 7, 126$ ;  $P < 0.01$ ). Similarly, the GI was reduced by all chemicals (Fig. 3,  $F = 105.42$ ;  $df = 5, 216$ ;  $P < 0.01$ ). However, the

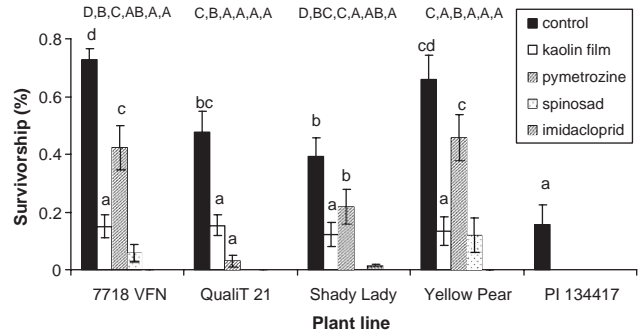


Fig. 1. Comparisons of egg–adult survivorship for the tomato psyllid exposed to insecticide treatments on various plant lines. The upper-most row of capital letters indicates within-plant line comparisons. Lower case letters immediately above bars indicate between-plant line comparisons. Bars with different letters are significantly different at the  $P < 0.05$  level, ANOVA. A two-way ANOVA was conducted on treatments excluding imidacloprid, spinosad and pyriproxyfen; where the data were not normal and a Mann–Whitney *U*-test was used. Treatments of spinosad, imidacloprid and pyriproxyfen that do not have bars in the figure did not allow any adult development.

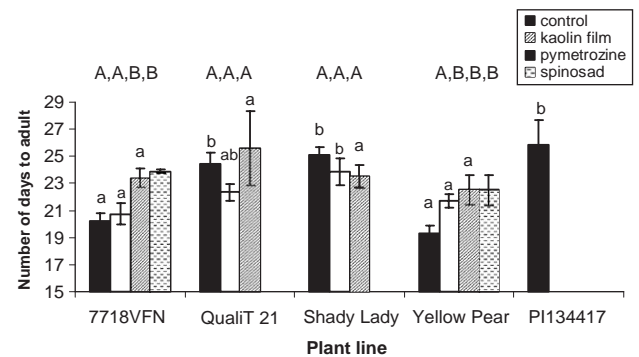


Fig. 2. Comparisons of egg–adult development times for the tomato psyllid exposed to insecticide treatments on various plant lines. The upper-most row of capital letters indicates within-plant line comparisons. Lower case letters immediately above bars indicate between-plant line comparisons. Bars with different letters are significantly different at the  $P < 0.05$  level, ANOVA. A two-way ANOVA was conducted excluding treatments of imidacloprid, spinosad and pyriproxyfen, since no survivorship to adult was found on spinosad-treated ‘QualiT 21’ or ‘Shady Lady’, or in treatments of imidacloprid and pyriproxyfen. No differences were found between spinosad treatments.

kaolin-based particle film, which allowed 20% egg to adult survivorship (as compared to the control), had a GI intermediate to imidacloprid and spinosad, indicating that only a few insects (about 25% of test insects) survived beyond the early nymphal stage. The comparatively high GI of pymetrozine is not surprising because egg to adult survivorship was second only to the control treatment.

The patterns observed for survivorship, development and the GI on ‘Yellow Pear’ were similar to those seen on ‘7718 VFN’ (Figs. 1–3). Imidacloprid, pyriproxyfen, spinosad and kaolin-based particle film allowed few

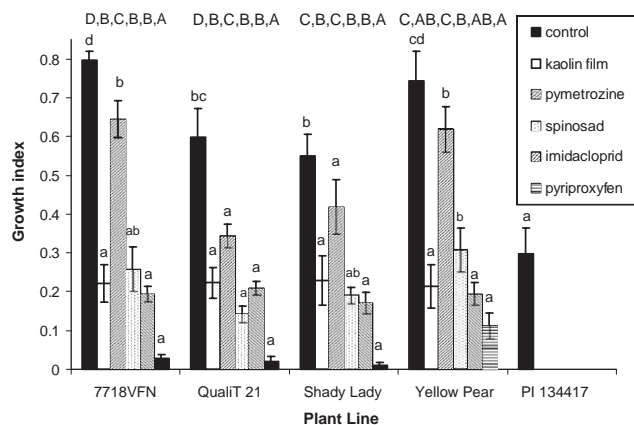


Fig. 3. Comparisons of tomato psyllid GI values on plant lines exposed to insecticide treatments. The upper-most row of capital letters indicates within-plant line comparisons. Lower case letters immediately above bars indicate between-plant line comparisons. Bars with different letters are significantly different at the  $P < 0.05$  level, two-way ANOVA.

insects to complete development to the adult stage. Once again, pymetrozine increased the development time (Fig. 2,  $F = 4.75$ ;  $df = 3, 126$ ;  $P < 0.05$ ), but permitted many of the test cohort to complete development. The GI values suggested that many of these insects died in the later stages of development. Kaolin-based particle film did increase time to development as compared to the untreated control (Fig. 2,  $F = 4.75$ ;  $df = 3, 126$ ;  $P < 0.05$ ), but the GI value was low indicating that most insects died in the early developmental stages (Fig. 3).

The commercial cultivar ‘Shady Lady’ allowed relatively few psyllids to complete development (Fig. 1,  $F = 10.94$ ;  $df = 3, 108$ ;  $P < 0.01$ ). Only about 40% survived to the adult stage on untreated plants. Survival was eliminated or substantially suppressed following applications of imidacloprid, pyriproxyfen, spinosad and kaolin-based particle film (Fig. 1,  $F = 54.03$ ;  $df = 2, 108$ ;  $P < 0.01$ ; Mann–Whitney  $U$ -test,  $P < 0.05$ ). However, no significant changes were seen for any treatment in the number of days needed to reach the adult stage. Pymetrozine allowed greater survivorship and survival to later stages ( $> GI$ ) as compared to all other chemical treatments (Fig. 1,  $F = 54.03$ ;  $df = 2, 108$ ;  $P < 0.01$ ; Fig. 3,  $F = 105.42$ ;  $df = 5, 216$ ;  $P < 0.01$ ).

The other commercial cultivar, ‘QualiT 21’, allowed less than 50% of the psyllids to complete development to the adult stage. Survival to the adult was eliminated by imidacloprid, pyriproxyfen or spinosad, and nearly eliminated by pymetrozine (Fig. 1,  $F = 54.03$ ;  $df = 2, 108$ ;  $P < 0.01$ ; Mann–Whitney  $U$ -test,  $P < 0.05$ ). Kaolin-based particle film application reduced survival by 70% as compared to the control. No differences were observed for numbers of days needed to reach the adult stage for any treatment, but pymetrozine did produce a significantly higher GI value as compared to the other chemicals (Fig. 3,  $F = 105.42$ ;  $df = 5, 216$ ;  $P < 0.01$ ).

### 3.2. Between-cultivar comparisons

Significant differences were detected between untreated plant lines for survivorship (Fig. 1,  $F = 11.55$ ;  $df = 5, 45$ ;  $P < 0.01$ ), number of days to adult emergence (Fig. 2,  $F = 14.33$ ;  $df = 5, 45$ ;  $P < 0.01$ ) and GI (Fig. 3,  $F = 9.93$ ;  $df = 4, 45$ ;  $P < 0.01$ ). The greatest survivorship was observed for ‘7718 VFN’ and ‘Yellow Pear’. The line PI 134417 allowed significantly less survivorship than all the cultivars. The remaining plant lines were intermediate. The numbers of days required to reach the adult stage were lowest for ‘7718 VFN’ and ‘Yellow Pear’, and increased by 20–25% for ‘Shady Lady’, ‘QualiT 21’ and the wild-type accession PI 134417. Not surprisingly the GI followed a similar pattern, with PI 134417 causing death early in the life cycle, and ‘7718 VFN’ and ‘Yellow Pear’ allowing most insects to complete development to the adult stage. Again, ‘Shady Lady’ and ‘QualiT 21’ were intermediate.

Some pesticides performed differently on different cultivars. For pymetrozine, survivorship from egg to adult varied significantly between cultivars (Fig. 1,  $F = 3.79$ ;  $df = 6, 108$ ;  $P < 0.01$ ). The greatest impact was on ‘QualiT 21’, followed by ‘Shady Lady’ and then both ‘7718 VFN’ and ‘Yellow Pear’. For kaolin-based particle film applications, numbers of days required to reach the adult stage were significantly greater on ‘Shady Lady’ than either ‘7718 VFN’ or ‘Yellow Pear’ (Fig. 2,  $F = 3.19$ ;  $df = 7, 126$ ;  $P < 0.01$ ). GI values were also variable between cultivars for pymetrozine and spinosad (Fig. 3,  $F = 2.17$ ;  $df = 15, 216$ ;  $P < 0.01$ ). For pymetrozine, the commercial cultivars ‘Shady Lady’ and ‘QualiT 21’ had significantly reduced values compared to either ‘7718 VFN’ or ‘Yellow Pear’. With spinosad, significant differences in GI values were detected between ‘QualiT 21’ and ‘Yellow Pear’.

## 4. Discussion and conclusion

### 4.1. Within-cultivar comparisons

The psyllids had the lowest survivorship, the longest development time from egg to adult, and the lowest GI on the wild plant line PI 134417. Although, 15% of the eggs survived to the adult stage, our previous studies on the behavior of adult tomato psyllids demonstrated that adult feeding time was reduced by 98% (as compared to ‘7718 VFN’) and there was a significantly greater propensity for adults to abandon the leaves of PI 134417 (Liu and Trumble, 2004). Thus, the potential for population expansion on this plant line is minimal, and PI 134417 should be further evaluated for resistance factors that could be transferred to commercial lines. Several earlier studies identified compounds in type VI glandular trichomes responsible for defense against

other insects (see Kennedy, 2003 and references therein), but there was evidence that much of the resistance was not directly associated with the trichomes (Liu and Trumble, 2004).

The commercial cultivars ‘Shady Lady’ and ‘Quali T 21’ exhibited partial resistance in our assays, which agrees with the reduced levels of probing and feeding reported earlier (Liu and Trumble, 2004), but field failures from Baja, California (Mexico) north to Hollister, California (USA) have demonstrated that these commercial cultivars are not resistant enough to prevent economically damaging outbreaks. The planting of highly preferred and susceptible varieties such as ‘Yellow Pear’ in adjacent urban gardens appears to increase the possibility of exposure to psyllid inoculations into commercial operations (Liu and Trumble, 2004).

#### 4.2. Between-cultivar comparisons

Although there are many examples of insecticides performing variably for different populations of the same insect species, there are relatively few studies that have examined the effect of plant cultivar on insecticidal performance for a single insect population (van Emden, 1991; Eigenbrode and Trumble, 1994). Our study indicates that not all insecticides will produce equivalent effects across tomato cultivars for survivorship, required developmental time or GI. However, imidacloprid and pyriproxyfen were consistent across all cultivars and provided commercially acceptable control. Unfortunately, these chemicals are subject to restrictions that limit season-long use, at least in California. Thus, alternate chemicals will likely be required during the 12–14-week period plants are in the field. Because the plant lines with a higher level of psyllid resistance generally showed improved insecticidal efficacy, it is probable that less pesticide will ultimately be needed on these cultivars. While the role of plant resistance to tomato psyllids in commercial production still needs to be evaluated in the field, our data suggest resistant cultivars can play a significant role in IPM programs for fresh market tomatoes.

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