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Mechanisms Underlying Resistance of Strawberry Cultivars to Tarnished Plant Bugs.

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A project on pest-resistant crops, with findings that could be applied throughout the Northeast United States

Abstract. The present study investigated mechanisms that underlie resistance of strawberry cultivars to tarnished plant bugs, *Lygus lineolaris* (Hemiptera: Miridae). Inter-plant distribution of emerged nymphs in cage experiments suggests that females lay more eggs on plants with numerous fruits, although cultivar *per se* did not influence oviposition behaviour of females. A large number of nymphs emerged from the inflorescence of strawberry plants, which suggests that ovipositing females may cause extensive damage to strawberry fruits. Distinct within-plant distribution of emerged nymphs for different cultivars further suggest that the relative damage caused by ovipositing females may vary for different cultivars. Foraging nymphs did not exhibit a preference for any strawberry cultivar, although the incidence of nymphs increased with fruit weight, especially for late instars; these results suggest that the phenology of host plants rather than cultivar *per se* may influence the distribution of plant bugs. Lack of impact of fruit weight on incidence of emerged nymphs, combined with a weak, inconsistent effect of fruit weight on feeding choice exhibited by early instars, suggests that the size of strawberry fruits as a food resource for early instars is not a significant component affecting their development or survival. Evaluating density and field impact of plant bugs for different cultivars under field conditions revealed that some host plant attributes affect the abundance of plant bugs, such as early fruiting season and high productivity. Decreasing number of emerged nymphs per fruit per plant with increasing density of fruits per plant suggests that females lay relatively more eggs per fruit on plants with few fruits; this pattern of oviposition may explain, in part, why patches with low density of plants typically have high incidence of damage. Planting a high yielding early season cultivar such as Cavendish may provide a line of defense against plant bugs, because fruits may escape damage in both space (dilution effect, with the impact of plant bugs being reduced when plants produce numerous fruits) and time (low incidence of damage early in the season).

Background and Justification. Tarnished plant bugs (TPB), *Lygus lineolaris* (Hemiptera: Miridae) is an important pest of strawberry (Schaeffers 1963, 1980). Feeding by TPB on achenes of strawberry flowers interferes with translocation of auxin and disrupts development of the receptacle (Handley and Pollard 1993a). Symptoms of feeding by TPB are characterized by deformed fruits with a compact mass of hollow, undeveloped achenes at the apex ("catfaced" or "buttonned" fruits) (Parker et al. 1978, Spangler et al. 1988). TPB causes direct economic loss to growers, because damaged fruits are small and often unmarketable (Schaeffers 1980, Mailloux and Bostanian 1988). In untreated strawberry fields heavily infested with TPB, damage may approach 100% and harvesting is not economically profitable (Schaeffers 1963). Development of alternative control measures against TPB is highly needed, because insecticides applications are often difficult to schedule and may disrupt the activity of insect pollinators or other beneficial arthropods (Allen and Gaede 1963, Schaeffers 1966, 1972, Mailloux and Bostanian 1988). Economic analyses indicate that a lack of reliable, effective measures for controlling TPB without synthetic pesticides severely constrain profitability of organic strawberries in the northeastern United States (Rhainds et al. 2002). Planting cultivars resistant to TPB may represent an alternative management strategy to applications of insecticides: field experiments reveal that incidence of damage by TPB and other plant bugs greatly vary for different strawberry cultivars (Handley et al. 1991, 1993, Daugaard and Linhard 2000, Easterbrook and Simpson 2000; Rhainds et al. 2001, 2002). However, mechanisms underlying resistance of strawberry cultivar to TPB have not yet been investigated.

Research objectives

1) evaluate oviposition preference of adults for different cultivars;
2) evaluate emergence of nymphs for different cultivars;
3) evaluate development and survival of nymphs for different cultivars;
4) evaluate development of nymphs and survival to adult stage for different cultivars;
5) evaluate tolerance to insect feeding for different cultivars;
6) evaluate feeding preference of nymphs for different cultivars;
7) evaluate the relationship between density of nymphs and incidence of damage under field conditions for different cultivars;
8) evaluate the relationship between density of strawberry plants and incidence of damage by TPB;
9) evaluate the relation between density of strawberry plants and incidence of damage under field conditions for different cultivars.

Methods by objective

OBJECTIVE 1: EVALUATE OVIPOSITION PREFERENCE OF ADULTS FOR DIFFERENT CULTIVARS

Throughout the spring and summer 2001, we experienced several problems with our potted strawberry plants (incidence of fungal disease, low incidence of flowering, poor fruit set); in addition, our laboratory-reared colony of TPB periodically collapsed. As a result, we had a shortage of either flowering plants or TPB for large periods of time. Thus, we were unable to conduct the experiment pertaining to objective 1, although data obtained from the experiment on emergence of nymphs for different cultivars provided some insight on oviposition preference of females.

OBJECTIVE 2: EVALUATE EMERGENCE OF NYMPHS FOR DIFFERENT CULTIVARS

The experiment was carried out in a walk-in growth chamber at 25ºC, 60% RH, and 16:8 (L:D), using 45 x 75 x 50 cm high wooden cage with a glass cover and 3 screened sides. Eighteen 6 – 8 week-old potted flowering strawberry plants (3 plants per cultivar for 6 out of 9 cultivars:

Allstar, Cavendish, Earliglow, Honeoye, Jewel, Kent, North, Raritan, Redchief) were introduced in the cage with 70 field-collected adult TPB for 2 days; the position of each plant within the cage was randomly assigned, and availability of flowering plants determined which cultivars were included in each replicate. Three days after adults had been removed from the cage, plants were dissected, and the fresh weight of different plant structures (individual flowers or green fruits, petiole, stem, and foliage) was assessed to the nearest 0.01 g. Different plant structures were then confined in 30 ml plastic cups (individual flowers or green fruits; petioles; stem) or one l plastic containers (foliage) kept in the growth chamber, and monitored daily to record the presence of eclosed nymphs. The experiment was replicated 8 times between 28 August – 10 September 2001, and included at least 9 plants for each cultivar. Factorial ANOVA was used to compare density of nymphs per plant, density of nymphs per fruit per plant, incidence of fruits per plant, and average weight of fruits per plant for different plant structures and/or cultivars, with individual plants treated as repeated measurements. For different cultivars, ANOVA followed by Duncan's multiple range test was used to compare incidence of nymphs on different plant structures. To reduce heterogeneity of variance, data were subjected to square-root (density of fruits per plant), logarithmic (average weight of fruits per plant) or rank transformations (density of nymphs per plant or per fruit per plant).

OBJECTIVES 3 AND 4: EVALUATE DEVELOPMENT AND SURVIVAL OF TPB TO THE ADULT STAGE FOR DIFFERENT CULTIVARS

Due to a shortage of flowering strawberry plants and nymph TPB, we did not conduct the experiment pertaining to objectives 3 and 4. Because these objectives are critical to assess mechanisms that underlie cultivar-specific resistance to TPB, we intend to carry out to the following experiment in the spring of 2002. The procedure we intend to follow can be described as follows. For each of 9 cultivars (Allstar, Cavendish, Earliglow, Honeoye, Jewel, Kent, North, Raritan, Redchief), potted flowering strawberry plants will be individually enclosed in a small screen cage with 5 first instar nymphs. After 2 weeks, plants will be inspected daily for the presence of emergent adults, and each adult sexed and weighed. The experiment will be replicated 6 to 8 times for each cultivar. Number and weight of adults, as well as timing of adult emergence, will be compared with relative number and size of strawberry fruits for different cultivars.

OBJECTIVE 5: EVALUATE TOLERANCE TO INSECT FEEDING FOR DIFFERENT CULTIVARS

While evaluating the incidence and feeding impact of TPB for different cultivars under field conditions (see objective 7), we attempted to quantify tolerance to insect feeding by assessing the proportion of nonviable achenes on ripe fruits. Unfortunately, the method described by Handley et al. (1993b) was extremely time consuming and was not suitable for processing large sample of strawberry fruits. We further attempted to separate damaged and undamaged seeds using a pectinase enzyme. Unfortunately, the action of the enzyme was not stable from day to day. While conducting experiments that pertain to objectives 3 and 4, we will attempt to develop a reliable, cost-effective method for separating damaged and undamaged seeds.

OBJECTIVE 6: EVALUATE FEEDING PREFERENCE OF NYMPHS FOR DIFFERENT CULTIVARS

An experiment was conducted in a walk-in growth chamber at 25ºC, 60% RH, and 16:8 (L:D), using 38 x 48 x 15 cm high plastic cage with 6 equidistant holes at the bottom (2 rows with each 3 holes 10 cm in circumference, with a distance between rows and holes of 10 cm) and a screen cover made of cheesecloth. For each of 6 cultivars (Cavendish, Earliglow, Honeoye, Jewel, Kent,, Redchief), inflorescences of two 6-8 week old potted strawberry plants were inserted inside the cage through holes, and 60 laboratory-reared nymphs (references; ask Steve) introduced into the cage between 10:00 and 12:00 (30 early instars and 30 late instars: instars I-II and IV-V, respectively); the position of different cultivars within the cage was randomly assigned. The empty space around petioles of inflorescences for each hole was covered with tape to prevent nymphs from leaving the cage. One day after nymphs were introduced, each flower or small green fruit was individually cut and rapidly transferred inside a 30 ml plastic cup, and the cup was then covered with a lid; in rare instances where nymphs left the flower or fruit before being confined into the cup, they were captured and transferred into their respective cup. After all fruits or inflorescences had been cut and confined into plastic cups, each fruit was weighed to the nearest 0.01 g and the presence of early and late instars was recorded. Due to a lack of flowering plants, some replicates included only 5 cultivars and 50 (rather than 60) nymphs; the empty hole without inflorescence was covered with tape. The experiment was replicated 12 times between 27 May – 1 July 2001, and included at least 16 inflorescences for each cultivar.

In a second experiment, sampling was carried out in a field with 5 year-old Earliglow strawberry plants (see objective 8). A white plate was placed below individual flowers or green fruits before they were cut, and the presence of early or late instar plant bugs in the plate was recorded. Fruits with nymphs were then weighed to the nearest 0.01 mg. In total, 278 flowers or green fruits with nymphs were weighed between 4 – 12 June 2001.

In the cage experiment, the impact of developmental stage of plant bugs, strawberry cultivar, and weight of fruits on the abundance of nymphs was evaluated using factorial ANOVA with completely randomized design, treating developmental stage and cultivar as fixed variables, and fruit weight as a continuous variable. Regression analyses were used to evaluate the relationship between abundance of early and late instars as a function of fruit weight for different cultivars. Weight of Earliglow fruits infested in the field by either early or late instars was compared using t-test. Heterogeneity of variance was reduced by subjecting data to rank (number of nymphs per fruit) or log transformations (weight of fruits, in mg).

OBJECTIVE 7: EVALUATE THE RELATIONSHIP BETWEEN DENSITY OF NYMPHS AND INCIDENCE OF DAMAGE UNDER FIELD CONDITIONS FOR DIFFERENT CULTIVARS

In October 2000, 4 month-old plants of 6 strawberry cultivars (Cavendish, Earliglow, Honeoye, Jewel, Kent, Redchief) were transplanted in four 7 x 15 m plots 10 to 15 m apart located at the New York State Agricultural Experiment Station in Geneva, New York State. For different cultivars, groups of 4 to 8 strawberry plants were transplanted 2 m apart along rows spaced 1.5 to 2 m apart; the position of different cultivars within rows was randomly assigned. Due to unequal number of plants available for different cultivars, an unbalanced plot was used for different plots, with 3 plots including 18 plants for each cultivar, and one plot including 36 Earliglow, 24 Cavendish, 24 Jewel, 24 Honeoye, and 12 Redchief. In late November 2000, dormant strawberry plants were covered with straw mulch throughout the winter to prevent crowns from freezing or desiccating. Plots were manually weeded every 2 to 3 weeks throughout the fruiting season in 2001. Starting shortly before flowering, strawberry plants were sampled every 2 – 5 days between 23 May – 28 June 2001 for the incidence of nymphs. Nymphs were sampled by shaking 3 inflorescences over a white plastic plate and counting nymphs in the plate; nymphs then were returned on strawberry plants in the same location where they had been sampled. Yield of strawberry plants and damage by plant bugs were assessed by harvesting fruits from all plants 11 times between 12 June – 9 July, and by recording the number of fruits and the incidence of damage by plant bug (Parker et al. 1978, Spangler et al. 1988) for each fruit.

Number of nymphs per inflorescence, number of fruits per patch, and proportion of damaged fruits were compared for different dates and cultivars using nested ANOVA, with date and cultivar treated as fixed factors and plot as a random factor. Density and feeding impact of plant bugs (cumulative number of nymphs per inflorescence per patch, cumulative proportion of damaged fruits) and parameters of yield (total number of fruits per patch, mean harvest date) were compared for different cultivars using ANOVA followed by Duncan's multiple range test. Multiple regression models were used to simultaneously evaluate the impact of cumulative density of nymphs and total number of fruits per patch on the proportion of damaged fruits for strawberry cultivars that produce fruits early (Cavendish, Earliglow, Honeoye) and late during the season (Jewel, Kent, Redchiedf). Whenever necessary heterogeneity of variance was reduced by subjecting data to rank or arcsin transformations.

OBJECTIVE 8: EVALUATE THE RELATIONSHIP BETWEEN DENSITY OF STRAWBERRY PLANTS AND INCIDENCE OF DAMAGE BY TPB

The experiment was conducted in eight 15 x 20 m plots (4 rows with each 3 plots, with a distance between rows and plots of 10 - 15 m) located in a 1 ha site at the New York State Agricultural Experiment Station in Geneva, New York State. Each plot was divided into 3 sections with 6 contiguous rows, and each section was randomly assigned to one of three strawberry cultivars: Earliglow, Honeoye and two sibling dayneutrals (Tribute and Tristar, considered herein as one cultivar). Strawberry plants were established in the spring of 1996 and managed through early summer of 2000 according to recommendations outlined in the Strawberry Production Guide (Pritts and Handley 1998, Rhainds et al. 2001, 2002). In the fall of 2000, plot sections with dayneutral strawberries were plowed. Shortly before plowing, dayneutral strawberries were uprooted and transplanted in recently plowed plot sections, using different density of plants and patch size: 1) 75 plants in 1 m^2 patch; 2) 15 plants in 0.4 m^2 patch; 3) 30 plants in 0.4 m^2 patch; and 4) 6 plants in 0.4 m^2 patch; the periphery of patches was delimited with sticks attached to the ground using strings of wire. The experiment was repeated in 8 plots, with 6 plots including 16 patches of plants (4 patches per treatment), and 2 plots including only 12 patches (3 patches per treatment) due to a shortage of plants.

The population of adult plant bugs was monitored between 3 May – 2 July 2001 with 2.5 x 10 x 100 cm high white sticks covered with an adhesive (Tanglefoot, Grand Rapids, MI), using 4 traps per plot (one for each experimental treatment). Traps were replaced every 5 days, and the number of adults recorded. In all patches, strawberry plants were sampled every 2 – 5 days between 16 May – 5 October for the incidence of nymph plant bugs by shaking 3 inflorescences over a white plastic plate and counting nymphs in the plate; nymphs then were returned on strawberry plants in the same patch where they had been sampled. Yield of strawberry plants and damage by plant bugs were assessed by harvesting fruits from all patches 25 times between 12 June - 15 October, and by recording the number of fruits and the incidence of damage by plant bug (Parker et al. 1978, Spangler et al. 1988) for each fruit.

OBJECTIVE 9: EVALUATE THE RELATION BETWEEN DENSITY OF STRAWBERRY PLANTS AND INCIDENCE OF DAMAGE UNDER FIELD CONDITIONS FOR DIFFERENT CULTIVARS

Due to limited availability of strawberry plants, this experiment was cancelled. Existing potted strawberry plants will be used to conduct experiments pertaining to objectives 3 and 4.

Results and Discussion

OBJECTIVE 2: EVALUATE EMERGENCE OF NYMPHS FOR DIFFERENT CULTIVARS

Comparing the incidence of emerged nymphs on different plant structures of different cultivars indicated a significant impact of cultivar ($F = 4.13$, $df = 8,32$; $P = 0.002$), with Redchief, Honeoye and Kent yielding more nymphs than Allstar, Earliglow and Cavendish (Fig. 1). The incidence of emerged nymphs varied on different plant structures ($F = 43.00$, $df = 3,21$; $P < 0.0001$), although the significant interaction between plant structure and cultivar ($F = 1.88$, $df = 24,96$; $P = 0.016$) indicated that within-plant distribution of nymphs varied for different cultivars. For some cultivars, nymphs were more abundant on inflorescences than on other plant structures (Redchief, Honeoye, Earliglow), whereas for the other cultivars the incidence of nymphs was similar on inflorescence and on the foliage or on the stem; few nymphs emerged from petioles (Fig. 1). Both the abundance of emerged nymphs per plant ($F = 4.35$, $df = 8,32$; $P = 0.001$) and the number of fruits per plant ($F = 14.98$, $df = 8,32$; $P < 0.0001$) varied for different cultivars in a similar manner, as indicated by a positive correlation between density of fruits and emerged nymphs per plant, and by high number of nymphs typically emerging on cultivars that produce numerous fruits (Fig. 2). The incidence of nymphs per fruit per plant was not affected by cultivar ($F = 1.56$, $df = 8,32$; $P = 0.176$) and decreased with the number of fruits per plant (Fig. 2). Average weight per fruit per plant varied for different cultivars ($F = 3.18$, $df = 8,32$; $P = 0.009$), with North and Cavendish yielding larger fruits than Raritan or Kent; the weight of fruits did not affect the incidence of emerged nymphs (Fig. 2).

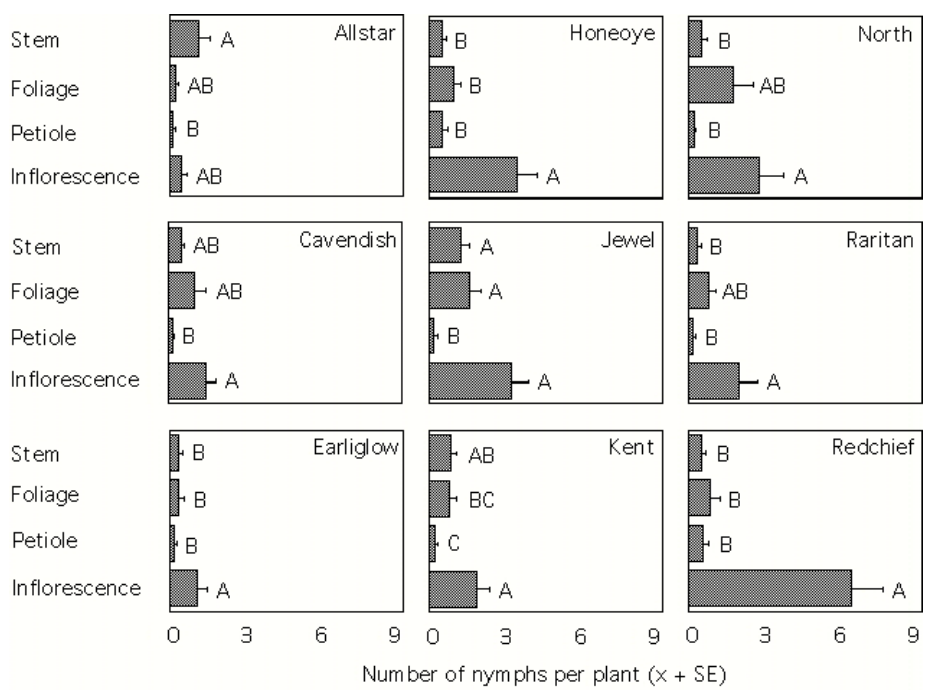

Fig. 1. Within-plant distribution of emerged nymphs for different cultivars. The incidence of nymphs on different plant structures for different cultivars was compared using non-parametric ANOVA followed by Duncan's multiple range test. Bars superscripted by different letters are significantly different ($P < 0.05$).

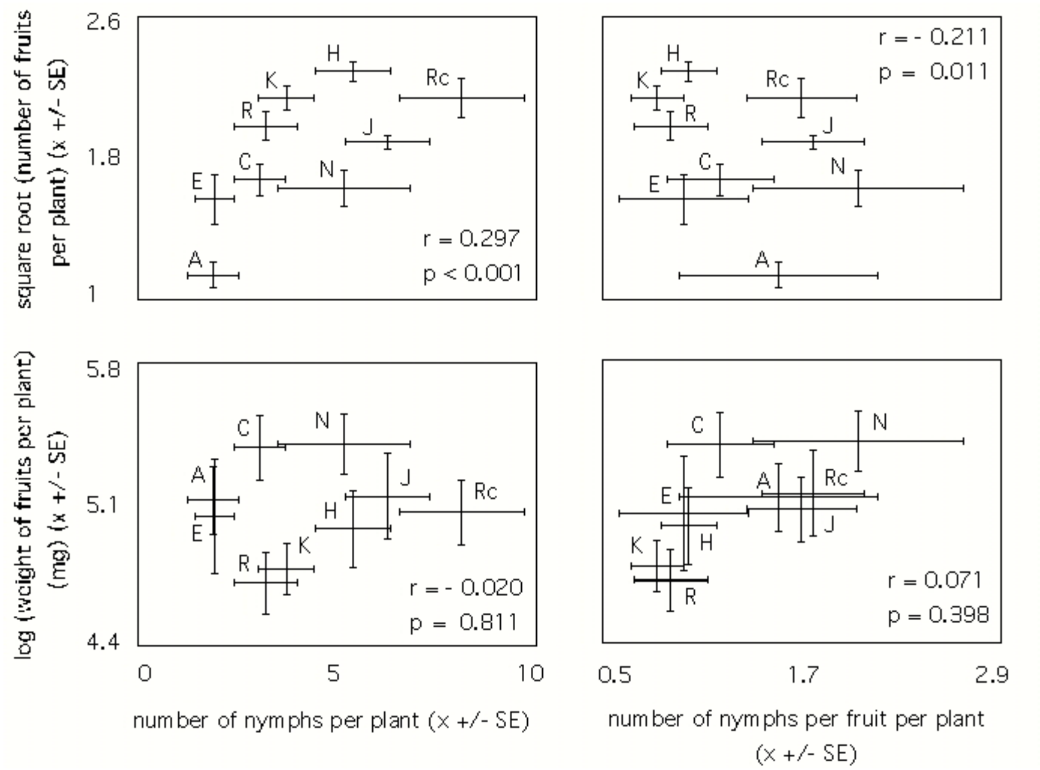

Fig. 2.. Relationship between density of nymphs (on either a per plant or per fruit per plant basis) and number of fruits per plant or average weight per fruit per plant. Correlation models were carried out using values for individual plants. Scatter plot represent mean values for different cultivars (A: Allstar; C: Cavendish; E: Earliglow; H: Honeoye; J: Jewel; K: Kent; N: North; R: Raritan; Rc: Redchief).

Differences in abundance of emerged nymphs on different cultivars may have resulted from either oviposition preference of females, mortality during the egg stage, or a combination of both. Preliminary observations suggest that the number of emerged nymphs is a good indicator of the number of eggs laid per fruit (Rhainds, unpublished results), which indicate that differences between cultivars was, at least in part, due to oviposition preference by females. Relatively high number of emerged nymphs on cultivars such as Redchief, Honeoye and Jewel was likely due to preference of females for plants with numerous fruits rather than cultivar-induced oviposition preference *per se*, as indicated by a positive correlation between density of fruits and emerged nymphs and by the absence of impact of cultivar on density of nymphs per fruit per plant (Fig. 2). Low incidence of nymphs on some cultivars with relatively high incidence of fruits, such as Kent or Raritan (Fig. 2), indicates that additional as yet unknown attributes of different strawberry cultivars may still mediate oviposition behaviour of females. Decreasing incidence of emerged nymphs per fruit per plant with increasing density of fruits per plant (Fig. 2) suggests that females lay relatively more eggs on plants with few fruits; this pattern of oviposition may explain, in part, why patches with low density of plants typically have high incidence of damage (Handley et al. 1991; Rhainds et al. 2001, 2002). Lack of impact of fruit weight on incidence of emerged nymphs (Fig. 2), combined with weak, inconsistent effect of fruit weight on feeding choice exhibited by early instars (Fig. 3), suggests that the size of strawberry fruits as a food resource for early instar TPB is not a significant component affecting their development or survival. As reported for another plant bug damaging strawberry fruits, *Lygus hesperus* Knight (Hemiptera: Miridae) (Udayagiri and Welter 2000), female TPB seem to lay a majority of their eggs on inflorescence (Fig. 1), and may severely damage developing fruits in the process. Distinct within-plant distribution of emerged nymphs for different cultivars (Fig. 1) suggest that damage caused to strawberry fruits by ovipositing females may vary for different cultivars.

OBJECTIVE 6: EVALUATE FEEDING PREFERENCE OF NYMPHS FOR DIFFERENT CULTIVARS

Of 660 nymphs released in the cage experiment, significantly more late instars (42: 137 of 330) than early instars (36%: 117 of 330) were recovered on inflorescences of strawberry plants ($F = 5.68$; $df = 1,607$ $P = 0.018$); number of nymphs was neither affected by strawberry cultivar ($F = 0.53$; $df = 5,607$; $P = 0.755$) nor by the interactions between cultivar and nymphal stage ($F = 1.52$; $df = 5,607$; $P = 0.183$) or between fruit weight and cultivar ($F = 0.64$; $df = 5,607$; $P = 0.666$). Nymphs were more abundant on large fruits ($F = 46.44$; $df = 1,607$; $P < 0.0001$), although the significant interactions between fruit weight and nymphal stage ($F = 6.29$; $df = 1,607$; $P = 0.012$) indicated that the relationship between fruit weight and incidence of nymphs varied for early and late instars. Regression models carried out for different cultivars indicated that incidence of nymphs increased with fruit weight to a large extent for late instars, but only to a relatively minor extent for early instars (Fig. 3). Recording the incidence of nymphs in field plantings of Earliglow indicated a similar trend, with fruits infested with late instars being significantly heavier (2.4 ± 0.3; $N = 50$) than fruits with early instars (1.5 ± 0.1; $N = 228$) ($t_{276} = 4.09$; $P < 0.0001$).

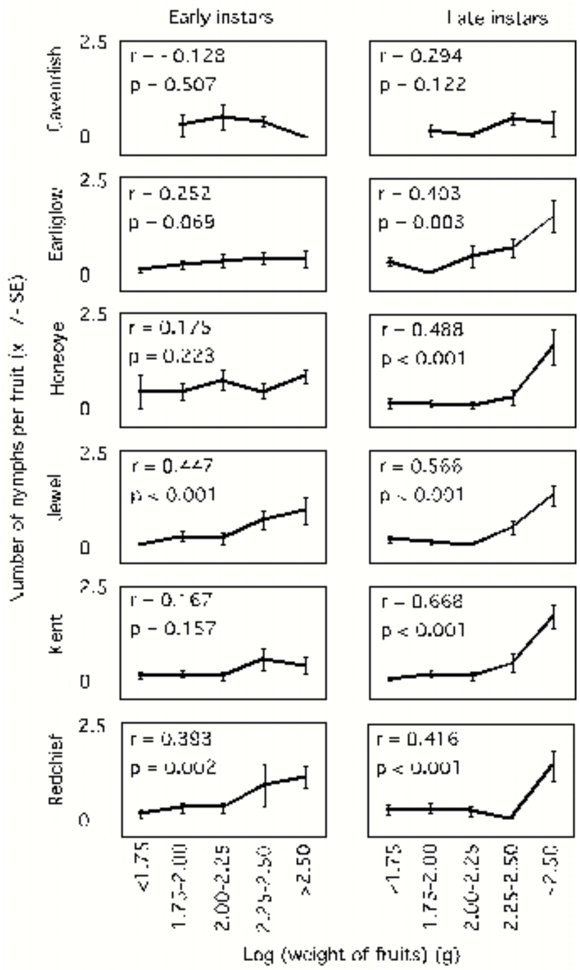

Fig. 3. Regression models assessing the impact of fruit weight on incidence of early and late instar tarnished plant bugs for different strawberry cultivars. For analysis, weight of fruits was transformed using logarithmic transformations.

In the cage experiment, nymphs did not exhibit a preference for any strawberry cultivar, although the incidence of nymphs increased with the fruit weight within a range of 0.01 to 2.60 g, especially for late instars (Fig. 3). These results suggest that the phenology of host plants rather than cultivar *per se* may influence the distribution of TPB. In both field and cage experiments, nymphs were relatively more abundant on small green fruits than on the most immature fruits. Feeding activity of TPB has been hypothesized to cause more intense damage when it occurs during early fruit developmental stage (Handley and Pollard 1993). In both field and cage experiments, nymphs were relatively more abundant on small green fruits than on flowers, suggesting that nymphs may damage strawberry fruits to a relatively low extent in comparison with ovipositing females (see objective 2).

OBJECTIVE 7: EVALUATE THE RELATIONSHIP BETWEEN DENSITY OF NYMPHS AND INCIDENCE OF DAMAGE UNDER FIELD CONDITIONS FOR DIFFERENT CULTIVARS

The incidence of nymphs fluctuated with time ($F = 11.56$; $df = 12,36$; $P < 0.0001$), reaching a peak of about 0.4 nymphs per inflorescence in mid to late June (Fig. 2), and was greater for

Cavendish than for other cultivars, although the difference was not significant ($F = 2.77$; df = 5,14; $P = 0.061$) (Fig. 4); the interaction between cultivar and time was not statistically significant ($F = 1.05$; df = 60,857; $P = 0.348$). Abundance of fruits varied with time and was highest from mid to late June ($F = 27.62$; df = 10,30; $P < 0.0001$) (Fig. 4). Yield of strawberry plants varied between cultivars ($F = 9.09$; df = 5,14; $P = 0.0005$), with Kent and Earliglow being the most and least productive, respectively (Fig. 5). The significant interaction between cultivar and time (F = 1.05; df = 60,857; $P = 0.348$) indicated distinct phenology for different cultivars: comparing mean harvest date for different cultivars indicated that Earliglow produced fruits earlier during the season than either Jewel, Kent or Redchief (Fig. 5). Proportion of fruits damaged by plant bugs steadily increased between mid to late June ($F = 17.92$; df = 9,27; $P < 0.0001$) (Fig. 4) but was neither affected by cultivar ($F = 0.87$; df = 5,14; $P = 0.526$) nor the interaction between cultivar and time ($F = 1.31$; df = 45,611; $P = 0.092$). Comparing cumulative number of nymphs and proportion of damaged fruits indicated that Cavendish was least susceptible to TPB (Fig. 5). Multiple regression models evaluating the impact of fruit and nymph density on incidence of damage by plant bugs for early (Earliglow, Honeoye, Cavendish) and late season (Kent, Jewel, Redchief) strawberry cultivars indicated that for early season cultivars proportion of damaged fruits increased with nymph density ($t = 4.89$; df = 1,40; $P < 0.0001$) and decreased with fruit density ($t = -2.53$; df = 1,40; $P < 0.015$), whereas for late season cultivars proportion of damaged fruits also increased with nymph density ($t = 2.12$; df = 1,30; $P = 0.043$) but was not affected by fruit density ($t = -0.20$; df = 1,30; $P = 0.840$).

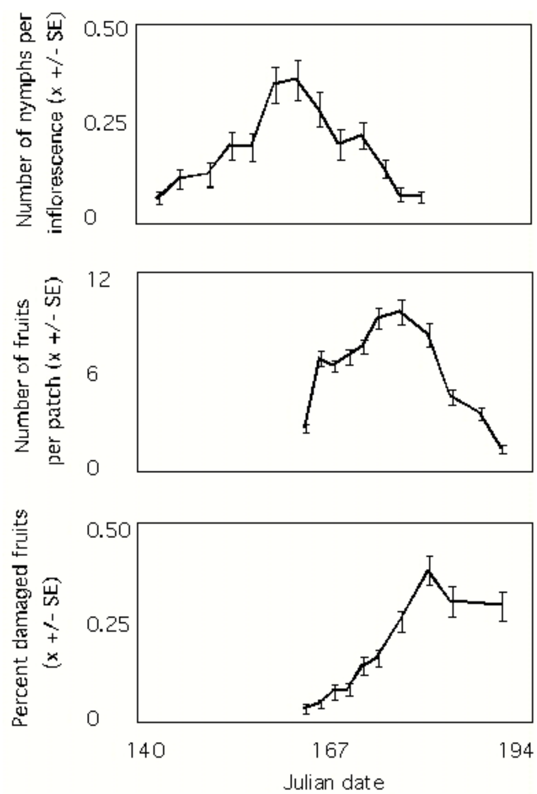

Fig.4. Variations in density and feeding impact of tarnished plant and yield of strawberry plants as a function of time through the growing season in 2001 for all cultivars combined. Due to low abundance of fruits for some cultivars late in the season, proportion of damaged fruits was calculated by combining the last 2 harvesting dates. For statistical analyses, heterogeneity of variance was reduced by subjecting data to arcsin (percent damaged fruits) or rank (number of nymphs per inflorescence, number of fruits per patch) transformations.

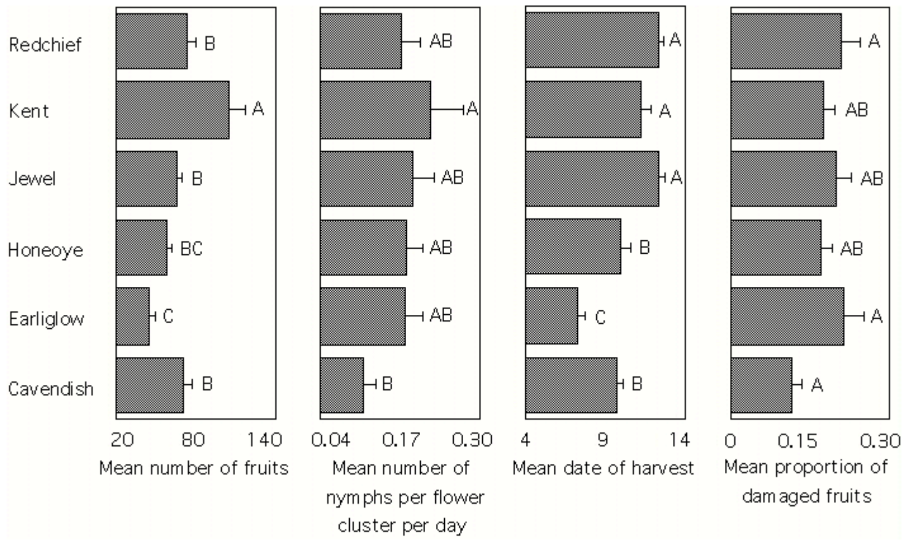

Fig. 5. Density and feeding impact of tarnished plant bug (number of nymphs per inflorescence, proportion of damaged fruits) and parameters of yield of strawberry plants (number of fruits per patch, mean harvest date) for different strawberry cultivars. Lines above each bar indicate the standard-error of the mean. Bars superscripted by different letters are statistically different (ANOVA followed by Duncan's multiple range test, $P < 0.05$).

Evaluating density and field impact of TPB for different cultivars under field conditions revealed that some host plant attributes affect the incidence of TPB, such as early fruiting season and high productivity (Figs. 2, 3; see also Rhainds et al. 2001, 2002,). In comparison with other cultivars, Cavendish had lower incidence of nymphs and damaged fruits (Fig. 5), although it remains unclear whether this is due to cultivar *per se* or to high productivity and early flowering of Cavendish plants. Planting a high yielding early season cultivar such as Cavendish may provide a line of defense against TPB, because fruits may escape damage in both space (dilution effect, with the impact of TPB being reduced when plants produce numerous fruits) and time (low incidence of damage early in the season).

Objective 8: Evaluate the relationship between density of strawberry plants and incidence of damage by TPB

Results from this experiment have not yet been thoroughly analyzed statistically, but they clearly indicate that the relative impact of TPB was higher in small patches and increased with increasing density of strawberry plants, suggesting that maintaining wide rows of highly productive strawberry plants may provide a line of defense against TPB.

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