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Fedding and Ovipositional Responses of Adult Elm Leaf Beetle (Coleoptera: Chrysomelidae) to Simple and Complex Asian Elm Hybrid Selections

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Abstract

Nine recently developed simple and complex Asian hybrids with Ulmus davidiana, U. japonica, U. parvifolia, U. pumila, U. szechuanica and/or U. wilsoniana parentage were evaluated in no-choice laboratory bioassays for their suitability for the adult elm leaf beetle, Xanthogaleruca luteola (Müller). Suitability of each biotype was defined by the mean percentage of leaf tissue removed, the mean percentage of females ovipositing, and the mean number of eggs laid per female. Adult female beetles laid significantly more eggs on U. pumila (control) and the complex hybrid U. 'Morton Red Tip'-Danada Charm™ indicating their greater suitability for ELB. The least suitable single and complex hybrids for adult elm leaf beetles, as indicated by feeding and reproduction, were U. davidiana x U. 'Morton'-Accolade™ and U. szechuanica x U. japonica. Females feeding on more suitable elms oviposited 3 days earlier than females feeding on less suitable elms. Adult beetle fecundity was correlated with the length of the preovipositional period, but mean percentage of females ovipositing was not correlated with length of the preovipositional period. Adult males and females lived approximately 4 days longer on the more suitable elms than on less suitable elms, but adult longevity was not correlated with suitability. The percentage of leaf tissue removed by adult beetles on the different biotypes was correlated with beetle fecundity. Less suitable selections of U. davidiana x U. 'Morton'-Accolade™ and U. szechuanica x U. japonica, seem promising for future elm breeding programs.

Index words: Xanthogaleruca luteola, elm leaf beetle, Dutch elm disease, preovipositional period.

Species used in this study: Siberian elm (Ulmus pumila L.).

Significance to the Nursery Industry

Certain common elm species, growing in urban landscapes and forests, can experience serious defoliation by elm leaf beetle adults and larvae. Development and identification of simple and complex Asian elm hybrids resistant to Dutch elm disease (DED) and leaf-feeding insect pests such as the elm leaf beetle will greatly add to our pool of elm genetic material for future elm breeding programs. Overall, Asiatic elms appear to be resistant to DED.

In this study, we report the suitability of nine simple and complex hybrids for feeding and oviposition by the adult elm leaf beetle. Ulmus davidiana x U. ‘Morton’-Accolade™ and U. szechuanica x U. japonica appear to have low suitability for adult elm leaf beetles. Previous studies by Miller and Ware (9, 10, 11) have shown low larval and adult suitability and low preference for the parents of these simple and complex hybrids, as well as the simple hybrid U. ‘Morton’-Accolade™ (U. japonica x U. wilsoniana).

These simple and complex Asian hybrids and their parents provide a rich source of genetic material for use in future elm breeding programs, resulting not only in improved elm biotypes resistant to DED and common leaf-feeding insect pests, but also in reducing the need for chemical pesticides.

Introduction

The elm leaf beetle, Xanthogaleruca luteola (Müller), entered the United States in the 1830s from Europe and is considered a pest of nationwide importance. It has been ranked in the top five urban insect pests by city managers and in urban forest pest surveys (7, 12, 16). Severe defoliation of elms (Ulmus spp.), the reaction of urban dwellers to high beetle densities, and the tendency of the adults to enter homes to overwinter have all contributed to its pest status.

In the past, genetic improvement programs with elms have focused on disease resistance (13). In the last decade, extensive breeding and selection programs have focused on insect-resistant elm trees for use in forests and landscapes (2, 3, 4, 5, 9, 10, 11, 14, 15, 17). Previous studies found Siberian elm, Ulmus pumila L., to be highly suitable for elm leaf beetle development, while U. wilsoniana Schneider and the Chinese elm, U. parvifolia Jacq., were less suitable (4, 5, 8, 9, 10, 11). In all of these studies, suitability is defined as the mean number of eggs laid per adult female and mean percent of females ovipositing in no-choice feeding studies.

Acquisitions from China of elm species such as U. davidiana Planchon and U. japonica Sargent, have provided additional sources of variability for elm breeding programs. In his Ulmus monograph, Fu (1) considered U. davidiana to include a number of related taxa. Four of these taxa may be treated as species because of their separate geographic ranges, special ecological attributes, and distinctive qualities. The U. davidiana complex includes U. davidiana, U. japonica, U. wilsoniana, and U. propinquaa Koidzumi (1). Fu (1) recognized the closely related U. szechuanica Fang as a separate species. In our recent studies, U. davidiana, U. japonica, and U. szechuanica were not suitable for elm leaf beetle (9, 10, 11). These elm species have medium-sized leaves and branching patterns somewhat similar to those of American elm (U. americana) (14, 15).
Materials and Methods

No-choice laboratory bioassays. No-choice laboratory feeding bioassays were conducted on first generation (late June-early July) adult elm leaf beetles during 1998. Asian elm simple and complex hybrids evaluated are listed in Table 1. Since the early 1970s, hundreds of Asian elm crosses have been made by us, focusing on ten species, including *U. pumila*, and members of the *U. davidiana* complex that also show promise as urban trees. About 100 different young hybrids have been identified as outstanding possibilities for landscape planting (14, 15). More recently, a number of simple and complex hybrids have been developed using *U. pumila* and members of the *U. davidiana* complex as parents (Table 1).

Selection of the hybrids evaluated in this study was based on results of previous studies of parent biotypes for larval development of elm hybrids as part of a wider breeding program. For selection of hybrids, we also took into account other important horticultural characteristics for use in landscape and street tree plantings (9, 10, 11, 14, 15).

Our objective was to screen nine newly developed simple and complex Asian elm hybrids containing *U. davidiana, U. japonica, U. parvifolia, U. pumila, U. szechuanica*, and/or *U. wilsoniana* parentage for suitability for the adult elm leaf beetle (Table 1). Results of this effort will affect the development of elm hybrids as part of a wider breeding program for resistance to other defoliating insect pests and Dutch elm disease.

### Table 1. Parentage and percentage of simple and complex Asian hybrids consisting of *U. davidiana*, *U. japonica*, *U. parvifolia*, *U. pumila*, *U. szechuanica*, and *U. wilsoniana.*

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Parentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>U. davidiana</em> x <em>U. japonica-wilsoniana-pumila</em></td>
<td><em>U. davidiana</em> (50%), <em>U. japonica-wilsoniana</em> (25%), <em>U. pumila</em> (25%)</td>
</tr>
<tr>
<td><em>U. davidiana</em> x <em>U. ‘Morton’-Accolade™</em></td>
<td><em>U. davidiana</em> (50%), <em>U. ‘Morton’-Accolade™</em> (50%)</td>
</tr>
<tr>
<td><em>U. szechuanica</em> x <em>U. japonica</em></td>
<td><em>U. szechuanica</em> (50%), <em>U. japonica</em> (50%)</td>
</tr>
<tr>
<td><em>U. ‘Morton’-Accolade™</em> x <em>U. japonica</em> (Accolade™ = <em>U. japonica</em> x <em>U. wilsoniana</em>)</td>
<td><em>U. ‘Morton’-Accolade™</em> (50%), <em>U. japonica</em> (50%)</td>
</tr>
<tr>
<td><em>U. ‘Morton Glossy’-Triumph™ (Accolade™ x Vanguard™)</em></td>
<td>Accolade™ (50%), Vanguard™ (50%)</td>
</tr>
<tr>
<td>*U. ‘Morton Plainsman’-Vanguard™ x <em>U. davidiana</em> (Vanguard™ = <em>U. japonica</em> x <em>U. pumila</em>)</td>
<td>*U. ‘Morton Plainsman’-Vanguard™ (50%), <em>U. davidiana</em> (50%)</td>
</tr>
<tr>
<td>*U. ‘Morton Plainsman’-Vanguard™ x <em>U. japonica-wilsoniana-pumila</em></td>
<td>*U. ‘Morton Plainsman’-Vanguard™ (50%), <em>U. japonica-wilsoniana-pumila</em> (50%)</td>
</tr>
<tr>
<td>*U. ‘Morton Plainsman’-Vanguard™ x <em>U. parvifolia</em></td>
<td>*U. ‘Morton Plainsman’-Vanguard™ (50%), <em>U. parvifolia</em> (50%)</td>
</tr>
<tr>
<td>*U. ‘Morton Red Tip’-Danada Charm™ (Accolade™ x <em>U. pumila)</em></td>
<td>Accolade™ (50%), <em>U. pumila</em> (50%)</td>
</tr>
</tbody>
</table>

Adult beetles used in the no-choice tests were from field-collected, wandering third instars and pupae from *U. pumila* trees that were shipped overnight from sites in and near North Platte, NE. Upon arrival, they were held in a growth chamber under a photoperiod of 16:8 (L:D) h at ~25°C until adult emergence.

One newly emerged (<6 h old), unfed male and unfed female were placed together in each of six petri dishes (10.0 x 6.0 cm (3.9 x 2.4 in)) with one whole leaf from one of five trees of a given progeny for a total of 30 adult male-female pairs per test elm progeny. All replications were performed simultaneously. Leaves from all test elm progenies were comparable in size. Petri dishes were examined daily for evidence of feeding, onset of oviposition, fecundity and beetle mortality. Foliage was replaced every 2 days. Beetles that died within the first 2 days were replaced with newly emerged, same sex, adults. Petri dishes were placed in clear plastic bags to prevent drying of the foliage and were randomly arranged in an incubator under a photoperiod of 16:8 (L:D) h at 25°C. Two days after the initiation of the feeding test, at the time of the first leaf change, the leaf in each dish was rated for the amount of tissue removed using the following scale: NF = no tissue removed; VL = very light (<10%); L = light (11–33%); M = moderate (34–66%); and H = heavy (67–100% of the leaf tissue removed). Templates of known defoliation were used to assign the ratings.

Mean number of eggs laid per female was calculated by totaling all of the eggs laid by each adult female in each individual petri dish within a given biotype during the 21-day study. We also determined the overall percentage of females that oviposited on each progeny, and the mean preovipositional period together with male and female longevity from the date that beetles were introduced to the test foliage. The measure of suitability for each biotype was defined as the mean number of eggs laid per female and the mean percent of females ovipositing.

Statistical analysis. Measures of suitability were subjected to Analysis of Variance (ANOVA) using species/hybrid as the main effect. The mean percentage of leaf tissue removed...

<table>
<thead>
<tr>
<th>Progeny group</th>
<th>N</th>
<th>Eggs per female</th>
<th>Percent females ovipositing</th>
<th>Preovipositional period</th>
<th>Male longevity</th>
<th>Female longevity</th>
<th>PLTR rating</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>U. davidiana</em> x <em>U. japonica-wilsoniana-pumila</em></td>
<td>5</td>
<td>66 ± 15.5ab</td>
<td>57 ± 9.2ab</td>
<td>8 ± 0.4b</td>
<td>11 ± 1.0ab</td>
<td>12 ± 1.2b</td>
<td>L</td>
</tr>
<tr>
<td><em>U. davidiana</em> x <em>U. ‘Morton’-Accolade™</em></td>
<td>5</td>
<td>29 ± 8.7a</td>
<td>37 ± 9.0a</td>
<td>11 ± 1.0c</td>
<td>11 ± 1.3ab</td>
<td>12 ± 1.3b</td>
<td>L</td>
</tr>
<tr>
<td><em>U. szechuanica</em> x <em>U. japonica</em></td>
<td>5</td>
<td>29 ± 12.0a</td>
<td>27 ± 8.2a</td>
<td>7 ± 0.8ab</td>
<td>8 ± 1.0a</td>
<td>9 ± 1.3a</td>
<td>VL</td>
</tr>
<tr>
<td><em>U. ‘Morton’-Accolade™ x U. japonica</em></td>
<td>5</td>
<td>49 ± 10.7ab</td>
<td>67 ± 8.8b</td>
<td>9 ± 0.3b</td>
<td>15 ± 1.0b</td>
<td>16 ± 1.0c</td>
<td>M</td>
</tr>
<tr>
<td><em>U. Morton Glossy ‘Triumph’™</em></td>
<td>5</td>
<td>60 ± 13.1ab</td>
<td>57 ± 9.2b</td>
<td>7 ± 0.3ab</td>
<td>11 ± 1.0ab</td>
<td>10 ± 1.0a</td>
<td>L</td>
</tr>
<tr>
<td><em>U. Morton Plainsman ‘U. davidiana</em></td>
<td>5</td>
<td>44 ± 13.6ab</td>
<td>35 ± 9.0a</td>
<td>8 ± 0.5b</td>
<td>13 ± 1.1b</td>
<td>12 ± 1.1b</td>
<td>L</td>
</tr>
<tr>
<td><em>U. ‘Morton Red Tip’-Vanguard™ x U. japonica-wilsoniana-pumila</em></td>
<td>5</td>
<td>40 ± 11.9ab</td>
<td>43 ± 9.2ab</td>
<td>8 ± 0.3b</td>
<td>10 ± 1.0a</td>
<td>9 ± 0.9a</td>
<td>L</td>
</tr>
<tr>
<td><em>U. Morton Plainsman’-Vanguard™ x U. parvifolia</em></td>
<td>5</td>
<td>53 ± 12.7ab</td>
<td>67 ± 8.8b</td>
<td>6 ± 0.3a</td>
<td>11 ± 0.9ab</td>
<td>9 ± 0.7a</td>
<td>M</td>
</tr>
<tr>
<td><em>U. ‘Morton Red Tip’-Danada Charm™</em></td>
<td>5</td>
<td>105 ± 19.4b</td>
<td>67 ± 8.8b</td>
<td>6 ± 0.2a</td>
<td>14 ± 1.1b</td>
<td>16 ± 1.1c</td>
<td>M</td>
</tr>
<tr>
<td><em>U. pumila</em> (reference)</td>
<td>5</td>
<td>110 ± 22.1b</td>
<td>67 ± 8.8b</td>
<td>6 ± 0.5a</td>
<td>10 ± 1.2a</td>
<td>12 ± 1.1b</td>
<td>M</td>
</tr>
</tbody>
</table>

Significance level

|        | <0.0003 | <0.0004 | <0.0001 | <0.0001 | <0.0001 |

The total number of trees evaluated per species/hybrid.

Values within columns followed by the same letter are not significantly different (P = 0.05; Student-Newman-Keuls (SNK) multiple comparison test).

Percent Leaf Tissue Removed (PLTR) rating: NF = no leaf tissue removed; VL = very light (<10%); L = light (11-33%); M = moderate (34-66%); and H = heavy amounts of leaf tissue removed (67-100%).

Results and Discussion

Individual trees of each species had no significant effect on the mean number of eggs laid per female (*F* = 7.55; df = 4, 29; *P* = 0.11), the mean percentage of females ovipositing (*F* = 3.56; df = 4, 29; *P* = 0.81), preovipositional period (*F* = 11.7; df = 4, 29; *P* = 0.20), male longevity (*F* = 4.22; df = 4, 29; *P* = 0.38), or female longevity (*F* = 3.38; df = 4, 29; *P* = 0.50). Data were thus pooled.

There were significant differences among progeny groups for the mean number of eggs laid per female and the mean percentage of females ovipositing (Table 2). Adult female beetles laid significantly more eggs on *U. ‘Morton Red Tip’-Danada Charm™* and *U. pumila* (control) than on *U. davidiana* x *U. ‘Morton’-Accolade™* and *U. szechuanica* x *U. japonica* where the fewest eggs were laid (Table 2). Fecundity on *U. pumila* and *U. ‘Morton Red Tip’-Danada Charm™* in this study is similar to results of previous studies (2, 3, 4, 9, 10). Fecundity of all other progeny groups ranged between these two groups (Table 2). These results indicate *U. Morton Red Tip’-Danada Charm™* and *U. pumila* (control) are the most suitable hosts for elm leaf beetle and *U. davidiana* x *U. ‘Morton’-Accolade™* and *U. szechuanica* x *U. japonica* are the least suitable.

The mean percentage of females ovipositing was correlated with the ranking for the mean number of eggs laid per female (*R*² = 0.53, *F* = 8.9, df = 9, *P* = 0.02, *y* = 29.3 + 0.396x). The two highly suitable elm biotypes (highest number eggs/female) had 67% of the females ovipositing whereas <38% of the females laid eggs on the least suitable elm biotypes (lowest number eggs/female). Previous studies (3, 4, 9, 10) report similar mean percentage of females ovipositing for *U. pumila* and *U. ‘Morton Red Tip’-Danada Charm™*.

Significant differences were also observed among species/hybrids for preovipositional period, male longevity, and female longevity (Table 2). Adult females feeding on the more suitable species and hybrids laid eggs within 6 days of the initiation of the study or 3 days earlier (mean = 6 days) than females feeding on least suitable hybrids, on which eggs were laid after 7–11 days or 3 days later (mean = 9 days). Miller and Ware (9, 10) reported that adult females feeding on *U. pumila* laid eggs 6 days into their studies. Fecundity of adult female beetles was correlated with preovipositional period, (*R*² = 0.40, *F* = 5.30, *df* = 9, *P* = 0.05, *y* = 9.65 – 0.0350x), but mean percentage females ovipositing (*R*² = 0.20, *F* = 2.0, *df* = 9, *P* = 0.20, *y* = 9.98 – 0.0454x) were not correlated with preovipositional period.

Across all biotypes tested, the mean adult longevity for males and females was similar (11 ± 2 days). Adult male beetles tended to live longer (10–15 days; mean = 13 days) on the more suitable species and hybrids; whereas adult male beetles feeding on the least preferred hybrids lived 8–11 days (mean = 9 days) (Table 2). A similar ranking was observed for adult male beetles in which females lived the longest (12–16 days; mean = 14 days) on the most suitable biotypes and lived 9–12 days (mean = 10 days) on the least suitable elm biotypes (Table 2). Female longevity was not correlated with suitability (eggs laid per females; *R*² = 0.21, *F* = 2.1, *df* = 9, *P* = 0.19, *y* = 9.25 + 0.0419x) nor with percentage females ovipositing: (*R*² = 0.21, *F* = 2.1, *df* = 9, *P* = 0.18, *y* = 7.64 + 0.0776x). In addition, female longevity was not a good predictor of preovipositional period (*R*² = 0.02, *F* = 0.20, *df* = 9, *P* = 0.67, *y* = 6.51 + 0.0934x).

Percentage leaf tissue removed (PLTR) ratings for the no-choice bioassay feeding study were correlated with adult suitability (eggs laid per female, *R*² = 0.42, *F* = 5.9, *df* = 9, *P* = 0.04, *y* = 4.61 + 27.4x; percentage females ovipositing, *R*² = 0.79, *F* = 30.1, *df* = 9, *P* = 0.006, *y* = 0.275 + 0.0386x).
The least preferred biotypes (viz. *U. davidiana* x *U. ‘Morton’-Accolade™, *U. szechuanica* x *U. japonica*,) had very light (VL) (<10% leaf tissue removed) to light (L) (11–33% leaf tissue removed) PLTR ratings, while the highly preferred biotypes of *U. pumila* (reference) and *U. ‘Morton Red Tip’-Danada Charm™ had moderate (M) (34–66% leaf tissue removed) PLTR ratings (Table 2). The preovipositional period was not correlated with the percentage leaf tissue removed ($R^2 = 0.08$, $F = 0.75$, df = 9, $P = 0.41$, $y = 9.17 - 0.683x$). In addition, neither male ($R^2 = 0.39$, $F = 5.04$, df = 9, $P = 0.06$, $y = 7.02 + 1.90x$) nor female ($R^2 = 0.31$, $F = 3.61$, df = 9, $P = 0.09$, $y = 6.71 + 2.17x$) longevity was correlated with the amount of leaf tissue removed by adult beetles.

Results from this study suggest that *U. davidiana*, *U. japonica*, *U. pumila*, *U. szechuanica*, and *U. wilsoniana* are major genetic sources of varying host suitability for elm leaf beetle. *Ulmus szechuanica*, when taken alone, has extremely low adult suitability (9). Low suitability was also observed for the parent elms of *U. szechuanica* x *U. japonica*, with parent elms of very low to low adult suitability, respectively, in past studies (9, 10, 11).

As does *U. szechuanica*, *U. davidiana* alone also has low adult suitability (10, 11) and when hybridized with *U. ‘Morton’-Accolade™*, seedlings also have low adult suitability. When *U. davidiana* is hybridized with *U. japonica*-wilsoniana-pumila, however, suitability is enhanced. The influence of *U. pumila* in enhancing suitability is clearly seen in the complex hybrids of *U. ‘Morton Red Tip’-Danada Charm™* and the hybrids containing *U. ‘Morton Plainsman’-Vanguard™* (*U. japonica* x *U. pumila*), *Ulmus ‘Morton’-Accolade™*, which is *U. japonica* x *U. wilsoniana*, consistently exhibits low adult suitability (10), but when crossed with *U. pumila* to form *U. ‘Morton Red Tip’-Danada Charm™*, its suitability is greatly enhanced (10) (Table 2). In comparison, the complex hybrid, *U. ‘Morton’-Accolade™* x *U. japonica* was moderately suitable.

The *Ulmus pumila* influence is also seen with the *U. ‘Morton Plainsman’-Vanguard™* complex hybrids. *Ulmus ‘Morton Plainsman’-Vanguard™* is a *U. japonica* x *U. pumila* hybrid. Previous studies by Miller and Ware (10, 11) have shown that when *U. davidiana*, *U. parvifolia*, and *U. ‘Morton’-Accolade™* are studied alone, all show very low to low adult suitability. As seen in this study, complex hybrids including *U. ‘Morton Plainsman’-Vanguard™* and the aforementioned biotypes resulted in enhanced (i.e., moderate) suitability (Table 2).

In summary, of the nine simple and complex elm hybrids tested in this study, *U. davidiana* x *U. ‘Morton’-Accolade™* and *U. szechuanica* x *U. japonica* look promising for future elm breeding programs for least suitable hosts of elm leaf beetle. The moderately preferred biotypes of *U. davidiana* x *U. japonica*-wilsoniana-pumila; *U. ‘Morton’-Accolade™* x *U. japonica*; *U. ‘Morton Plainsman’-Vanguard™ x *U. davidiana*; *U. ‘Morton Plainsman’-Vanguard™ x *U. parvifolia*; *U. ‘Morton Glossy’-Triumph™;* and *U. ‘Morton Plainsman’-Vanguard™* x *U. japonica*-wilsoniana-pumila may be suitable for use in areas where chronic elm leaf beetle populations are not common. The highly suitable complex hybrid, *U. ‘Morton Red Tip’-Danada Charm™* does not seem to be appropriate for use in areas where heavy elm leaf beetle populations are present. Further studies are needed, first to ascertain the horticultural attributes and qualities of these elm biotypes for use in the urban landscape, and second to determine their resistance to elm leafminer (*Fenusa ulmi*), Japanese beetle (*Popillia japonica*), and Dutch elm disease.

**Literature Cited**