Preference for and Suitability of Selected Elms, *Ulmus spp.* and Their Hybrids for the Elm Leaf Beetle, (*Pyrrhalta luteola Coleoptera: Chrysomelidae*)[1]

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Abstract

Selected elms *Ulmus* spp. and their hybrids growing at the Morton Arboretum, Lisle, IL were evaluated in the laboratory for feeding preference by the elm leaf beetle, *Pyrrhalta luteola* (Muller). Results from the single-choice and multiple-choice feeding studies showed that *U. szechuanica* was the least suitable for feeding and reproduction by the adult elm leaf beetle. The hybrids *U. pumila* x *U. parvifolia* and *U. pumila* x *U. americana*, and *U. pumila* (control) appeared to be highly suitable for feeding and reproduction by the adult elm leaf beetle. Adult longevity and the pre-ovipositional period appeared to be a function of suitability as adults feeding on *U. szechuanica* had the shortest longevity and the the longest pre-ovipositional period. The converse was also true. Results from multiple-choice studies were consistent with the single-choice studies. The intermediately suitable species/hybrids of *U. japonica-wilsoniana* x *U. pumila, U. japonica, U. macrocarpa*, and *U. wilsoniana* show promise for further elm breeding programs. Further studies are needed to evaluate hybrid crosses of the intermediately and least preferred elms as potential sources of shade trees resistant to Dutch elm disease and not preferred by the elm leaf beetle.

Index words: Dutch elm disease, suitability, pre-ovipositional period, longevity, insect resistance preference, urban trees.

Species used in this study: Siberian elm (*Ulmus pumila* L.); *U. pumila* x lacebark elm (*U. parvifolia* Jacq.); *U. pumila* x American elm (*U. americana* L.); *U. japonica-wilsoniana* x *U. pumila*; Japanese elm (*U. japonica* Sarg.); large fruit elm (*U. macrocarpa* Hance); Wilson elm (*U. wilsoniana* Schneid.); szechuan elm (*U. szechuanica* Fang).

Significance to the Nursery Industry

The elm leaf beetle, *Pyrrhalta luteola,* is a serious pest of elms species in urban landscapes nationwide. Identification of elm species/hybrids resistant to Dutch elm disease (DED) as well as the elm leaf beetle will be a critical component in any plant health care (PHC) strategy for this leaf feeding beetle. The research project reported here evaluated eight elm species/hybrids for suitability for feeding by this insect, *P. luteola*. The szechwan elm, *Ulmus szechuanica*, and other Asiatic hybrids and species (*U. japonica-wilsoniana* x *U. pumila, U. japonica, U. macrocarpa, and U. wilsoniana)* appear to resist feeding by the elm leaf beetle. The Siberian elm, *U. pumila* and the hybrids of *U. pumila x U. parvifolia* (UPXP) and *U. pumila* x *U. americana* (UPXA) appear highly susceptible to elm leaf beetle feeding. Even though UPXP and UPXA appear to be resistant to DED, their potential for use will be limited in those urban landscape where high numbers of elm leaf beetles exist, is extremely limited. The least suitable species/hybrids show promise for future elm breeding programs which could result in elms resistant to both DED and the elm leaf beetle thus significantly reducing or perhaps eliminating the need for insecticidal and fungicidal treatments.

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Introduction

The elm leaf beetle (ELB), *Pyrrhalta luteola* (Muller), entered the United States in the 1830s from Europe and now is considered a pest of nationwide importance based on rankings of urban insect pests by city managers and urban forest pest surveys (13, 16, 22). Severe defoliation of elms, 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.

American elm, *Ulmus americana*, has a number of attributes that has made it successful and popular as a planted tree since the arrival of European settlers to North America nearly four centuries ago. The graceful arching arcades created in New England towns were re-created as pioneers moved westward and established towns in the heartland of the nation. Dutch elm disease (DED) brought about the decimation of American elms on streetscapes from the 1930s on. Both the aesthetic and functional qualities of American elms have been held up as qualities to simulate in the planting of replacement trees.

Confusion still exists over the suitability for American elm by the ELB. American elm in southern California was found to be less susceptible to defoliation as compared to Siberian elm, *U. pumila* or English elm, *U. procera* (14). Hall et al. (1987) found American elm intermediate in susceptibility to the beetle. In contrast, Craighead (1950), commenting on the ELB, states 'All the elms are attacked, and though the European species are usually the most injured, the American elm is also severely damaged.' Elm leaf beetle is listed as a defoliator of American elm, *U. americana* growing in shelterbelts of the northern Great Plains (18). Currently, there are few kinds of replacement elms, so research on attributes of elms for possible urban use is timely.

Siberian elm, *U. pumila,* was introduced into the Great Plains early in the century and was a significant component of shelterbelts planted during the 1930s. This elm was also widely planted as a townscape tree because of its rapid growth and capacity to tolerate ever-recurring drought episodes. From the beginning, it was evident that Siberian elm was quite vulnerable to periodic windstorms and icing episodes. In addition, huge infestations of elm leaf beetles often produced summer landscapes with greatly disfigured foliage of Siberian elms. Indeed, the skeletonized leaves gave a whitish look that greatly diminished the verdancy of whole towns. The shortcomings of Siberian elm still exist in the Plains states. In recent years, ELB infestations on various elm species appear to be making more of a detrimental impact on landscapes northward and east to the Atlantic.

Extensive breeding and selection programs have developed in recent years for insect-resistant trees for forest and landscape uses (1, 2, 4, 5, 12, 15, 17). Extensive USDA genetic improvement programs are being carried out with elms with efforts focusing on disease resistance (1, 19), but more recently to include resistance to the elm leaf beetle, *P. luteola*. Recent additions of little-known Chinese sources of elm seed has made possible significant enlargement and enhancement of the Elm Collection at the Morton Arboretum and are providing opportunities for evaluating and testing little-known elm species as urban trees (6). Information is needed on resistance to various elm maladies, including Dutch elm disease (DED), leafminers, elm yellows, and ELB. Asian elms generally appear to have good levels of resistance to Dutch elm disease, leafminers, and elm yellows (1, 11).

Previous efforts have focused on the preference for and suitability of various elm species and their hybrids for feeding by the ELB (7, 8, 9, 10, 14, 20). The Siberian elm, *U. pumila,* was found to be highly suitable, while *U. wilsoniana* and the Chinese elm, *U. parvifolia*, were least preferred. Hybrids of the susceptible 'Urban' elm and *U. wilsoniana* have exhibited intermediate suitability between the two parents (7).

In this study, five Asian species were screened for host suitability for ELB: *U. pumila* L., *U. japonica* Sarg., *U. macrocarpa* Hance, *U. wilsoniana* Schneid. and *U. szechuanica* Fang. *U. pumila* hybrids included the following three parents: *U. parvifolia* Jacq., *U. americana* L., and the hybrid *U. japonica* x *U. wilsoniana*. The above species/hybrids were selected on the basis of their availability at the Morton Arboretum and their potential as candidates for the nursery industry for eventual use in the urban landscape. Data gathered from this work will be used to enhance the elm breeding program through better selection of hybrids and their parents.

The objectives of this study were to 1) conduct an initial screening of these candidate elms as to their suitability for the ELB and 2) provide for the development of hybrids as part of a comprehensive elm breeding program for resistance to DED and to feeding by the ELB.

Materials and Methods

A series of single-choice and multiple-choice laboratory bioassay feeding preference studies for adult elm leaf beetles (ELB) were conducted during the 1988, 1989, 1991, and 1992 growing seasons. The elm tree species/hybrids evaluated in this study were located on the grounds of the Morton Arboretum at Lisle, IL. Sample trees were at least 2 meters in height with DBHs of 5–25 cm. Leaves were randomly collected from the lower halves in all four cardinal directions (N, S, E, W) of the sample trees, coinciding with first generation (late June-early July) and second generation (late July-early August) elm leaf beetle populations and held in cold storage in sealed plastic bags at 5°C (41°F) for no more than a maximum of three days before being used. The Siberian elm, *(Ulmus pumila),* a preferred host of the ELB, served as the control species.

Adults utilized in both the single-choice and multiple-choice feeding studies emerged from field-collected first and second generation third-instar larvae and pupae held in plastic trays and glass Petri dishes under constant light at approximately 25°C (77°F).

Single-choice feeding studies. A pair of newly emerged, unfed adult beetles (1 male, 1 female) was placed in each of 10 glass Petri dishes (10 cm × 1.3 cm), with fully expanded leaves from one of two to five trees per species or hybrid. The number of trees evaluated for each species/hybrid was dependent on the availability of trees that were of appropriate size and growth form. The Petri dishes were examined daily for evidence of feeding, onset of oviposition, fecundity, and beetle mortality. Foliage was replaced every 2–3 days. Males that died within the first four days of the experiment were replaced with unfed males.

The Petri dishes were placed in clear plastic bags to prevent dessication of the leaves and held at approximately 25°C (77°F) under constant light. Condensation of water on the Petri dish lid indicated a relative humidity of approximately 100%. Each adult male/female pair of beetles served as a replicate, with ten replicates per tree. The experiment was terminated after 14 days.

Multiple-choice feeding studies. A pair of newly emerged, unfed, adult beetles (1 male, 1 female) was placed in each of ten glass Petri dishes. Each adult male/female pair of beetles

Table 1. Mean number of eggs laid per adult female beetle (MELF), on *Ulmus* biotypes.

Species/hybrids[y]	N[x]	Mean number of eggs laid per female[z] 1988[w]	1989[v]	1991[u]	1992[t]	Mean
U. pumila	3	71bc	79c	131d	83b	91
U. pum. x U. parv.	5	123d	66b	123d	73b	96
U. pum. x U. americ.	3	105cd	31a	90cd	23a	62
U. jap-wil x U. pum.	3	35ab	39ab	85bcd	5a	41
U. japonica	2	26ab	2a	16ab	—[s]	15
U. macrocarpa	3	26ab	2a	42abc	17a	22
U. wilsoniana	3	14a	20a	1a	3a	10
U. szechuanica	3	0a	0a	0a	0a	0
Significance level		.00001	.00001	.00001	.00001	

[z]Values within columns followed by the same letter are not significantly different ($p < 0.05$; Student-Neuman-Keuls multiple comparison test).

[y]pum. = pumila; parv. = parvifolia; americ. = americana; jap-wils = japonica-wilsoniana.

[x]The total number of trees evaluated per species/hybrid.

[w]$F(7,249) = 16.91$.

[v]$F(7,249) = 9.50$.

[u]$F(7,249) = 15.42$.

[t]$F(6,229) = 10.13$.

[s]Species not evaluated due to a shortage of adult beetles.

served as a replication. Into each dish was placed four rectangular-shaped foliage sections (1.9 cm × 3.2 cm) of four different elm species/hybrids and arranged at right angles (90°) to each other in a cross-like pattern. Beetles were allowed equal access to all four foliage sections. The Petri dishes were examined daily, with the foliage sections removed from the dishes and replaced, and then evaluated for leaf tissue removed due to adult feeding. The Petri dishes were placed in plastic bags and held at approximately 25°C (75°F) under constant light. A feeding preference index (FPI), previously described by Hall and Townsend (1987), was defined, using a scale of 0–6 as follows: 0 = no leaf tissue removed; 1 = <5% leaf tissue removed; 2 = 6–20%; 3 = 21–40%; 4 = 41–60%; 5 = 61–80%; and 6 = 81–100% leaf tissue removed. No attempt was made to evaluate for onset of oviposition and fecundity by adult females. Due to time limitations, labor, and a shortage of adult beetles, all possible combinations of elm species/hybrids were not evaluated. Multiple-choice combinations included *Ulmus macrocarpa, U. pumila (control), U. pumila* x *U. parvifolia*, and *U. szechuanica* in study #1 and *U. japonica, U. japonica* x *U. wilsoniana, U. pumila* (standard), and *U. wilsoniana* in study #2. Combinations were determined, based on availability of trees and preliminary field observations for suitability. The study was terminated after seven days.

Statistical analysis. Measures of suitability were subject to an Analysis of Variance (ANOVA) using time as the main effect. Due to statistical significance within individual species/hybrids across years, pooling of the data was not possible. Therefore, an ANOVA was conducted for all species/hybrids evaluated for a given year. Where differences were significant at the 5% level, the ANOVA was followed by a Student-Neuman-Keuls multiple comparison test at the 5% level. Data were analyzed, using the Solo Statistical System 2.0 (BMDP Statistical Software).

Results and Discussion

The results of this study, examining for host suitability by adult ELB, are expressed as the mean number of eggs laid per female (MELF) and the mean percent of females ovipositing (MPFO).

Single-choice feeding studies. A summary of the single-choice feeding studies as a function of MELF and MPFO is presented in Tables 1 and 2. Beetles feeding on *U. pumila* and the hybrids of *U. pumila* x *U. parvifolia* (UPXP) and *U. pumila* x *U. americana* (UPXA) generally laid significantly more eggs than most other biotypes in most years throughout the four-year study (Table 1). The species/hybrids of *U. japonica-wilsoniana* x *U. pumila* (UJWP), the Japanese elm, *U. japonica* (UJAP), the large-fruited elm, *U. macrocarpa* (UMAC), and the Wilson elm, *U. wilsoniana* (UWIL), all exhibited intermediate suitablility with overall average MELF values of 41, 15, 22, and 10, respectively. Others have observed similar numbers of eggs laid per female for UJAP and UWIL as reported in this study (7, 8, 9).

The Szechuan elm, *U. szechuanica* (UZSE), was totally rejected by the adult elm leaf beetle, with no egg laying or feeding observed (Table 1).

The mean percent of females ovipositing (MPFO), was consistent with the MELF, with a significantly higher percentage of females ovipositing on UPXP, UPXA, and UPUM (Table 2). Intermediate suitability was observed with UJWP, UJAP, UMAC, and UWIL as compared with the least suitable UZSE (Table 2). Similar MPFO values for UJAP and UWIL have been reported in earlier studies (8, 9).

The mean pre-ovipositional period (MPOP) for adult female beetles is summarized in Table 3. There were significant differences in the MPOP across all species/hybrids in 1989 and 1991, but not in the other two years. MPOP values for highly suitable UPXP, UPXA, UPUM ranged from 5–9 days (mean = 6 days), while beetles feeding on less suitable

Table 2. Mean percent females ovipositing (MPFO) on *Ulmus* leaves.

		Mean percent females ovipositing[z]				
Species/hybrids[y]	N[x]	1988[w]	1989[v]	1991[u]	1992[t]	Mean
U. pumila	3	77c	83c	73c	40b	68
U. pum. x U. parv.	5	90c	76c	67c	74c	77
U. pum. x U. americ.	3	87c	60c	74c	37b	64
U. jap-wil x U. pum.	3	57b	73c	47b	10ab	47
U. japonica	2	30b	10a	30b	—[s]	23
U. macrocarpa	3	45b	10a	43b	40b	35
U. wilsoniana	3	20b	20b	5a	30b	19
U. szechuanica	3	0a	0a	0a	0a	0
Significance level		.0001	.0001	.0001	.0001	

[z]Values within columns followed by the same letter are not significantly different ($p < 0.05$; Student-Neuman-Keuls multiple comparison test).

[y]pum. = pumila; parv. = parvifolia; americ. = americana; jap-wils = japonica-wilsoniana.

[x]The total number of trees evaluated per species/hybrid.

[w]$F(7,249) = 19.85$.

[v]$F(7,249) = 21.73$.

[u]$F(7,249) = 22.72$.

[t]$F(6,229) = 11.35$.

[s]Species not evaluated due to a shortage of adult beetles.

Table 3. Mean pre-ovipositional period (MPOP) of adult female beetles.

		Mean pre-ovipositional period (days)[z]				
Species/hybrids[y]	N[x]	1988[w]	1989[v]	1991[u]	1992[t]	Mean
U. pumila	3	5a	5a	6a	6a	6
U. pum. x U. parv.	5	6a	5a	6a	6a	6
U. pum. x U. americ.	3	6a	6a	6a	9a	7
U. jap-wils x U. pum.	3	7a	6a	7a	6a	7
U. japonica	2	6a	5a	7a	—[s]	6
U. macrocarpa	3	7a	4a	7a	8a	7
U. wilsoniana	3	6a	10b	12b	8a	7
U. szechuanica	3	—	—	—	—	—
Significance level		NS	.0001	.0001	NS	

[z]Values within columns followed by the same letter are not significantly different ($p < 0.05$); Student-Neuman-Keuls multiple comparison test.

[y]pum. = pumila; parv. = parvifolia; americ. = americana; jap-wils = japonica-wilsoniana.

[x]The total number of trees evaluated per species/hybrid.

[w]$F(7,138) = 1.65$; $p < 0.1143$.

[v]$F(7,91) = 11.64$.

[u]$F(7,183) = 4.96$.

[t]$F(6,67) = 2.90$; $p < 0.1609$.

[s]Species not evaluated due to a shortage of adult beetles.

Table 4. Longevity of male and female adult elm leaf beetles fed elm leaves.

Species/hybrid[y]	N[x]	Male and female longevity (days)[z]							
		1988		1989		1991		1992	
		M[w]	F[v]	M[u]	F[t]	M[s]	F[r]	M[q]	F[p]
U. pumila	3	4b	4a	11b	11c	10bc	10b	11c	10cd
U. pum. x U. parv.	5	11c	12c	10b	11c	14c	14c	10c	11d
U. pum. x U. amer.	3	12c	10c	10b	11c	13c	13c	10c	9bc
U. jap-wils x U. pum	3	3a	5a	11b	12c	8bc	7b	6a	6a
U. japonica	2	3a	4a	8b	8b	6b	7b	—[o]	—[o]
U. macrocarpa	3	5b	6b	11b	9b	9bc	10b	8b	9bc
U. wilsoniana	3	3a	4a	5a	4a	6b	5a	7b	8b
U. szechuanica	3	3a	3a	5a	6a	5a	5a	4a	5a
Significance level		.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001

[z]Values within columns followed by the same letter are not significantly different ($p < 0.05$); Student-Neuman-Keuls multiple comparison test.

[y]pum. = pumila; parv. = parvifolia; americ. = americana; jap-wils = japonica-wilsoniana.

[x]The total number of trees evaluated per species/hybrid.

[w]$F(7,307) = 35.42$

[v]$F(7,309) = 24.76$

[u]$F(7,189) = 21.33$

[t]$F(7,189) = 31.26$

[s]$F(7,449) = 23.36$

[r]$F(7,449) = 25.00$

[q]$F(6,169) = 16.96$

[p]$F(6,169) = 16.84$

[o]Species not evaluated due to a shortage of adult beetles.

UJWP, UJAP, UMAC, and UWIL had a slightly longer MPOP of 6–12 days (mean = 7 days) (Table 3). Hall and Townsend (1987) observed UWIL to have a MPOP of approximately 11 days.

Adult male and female longevity within species/hybrids was generally similar (± 1–2 days), but longevity differed significantly between species/hybrids (Table 4). With the exception of UPUM (1988), male and female longevity for highly preferred UPXP, UPXA, and UPUM ranged between 9–14 days with a mean of approximately 11 days. Beetles feeding on UJWP, UJAP, and UMAC exhibited intermediate longevity of 5–12 days (mean = 7), while beetles feeding on the less suitable UWIL and UZSE had significantly shorter longevity of 3–7 days, with a mean across years of 5 and 4 days, respectively (Table 4). Hall and Young (1986) reported similar results for male and female longevity on UWIL of 5.1 and 4.2 days, respectively.

Multiple-choice feeding studies. A summary of the multiple-choice feeding studies for the 1988, 1989, 1991, and 1992 growing seasons, expressed as the mean feeding preference index (MFPI), is presented in Table 5. When presented with equally available choices of elm species/hybrids, adult beetles in study #1 consistently chose UPUM (MFPI = 2.5) and UPXP (MFPI = 2.5) over the less preferred UMAC and nonpreferred USZE (Table 5). In study #2, the beetles consistently chose UPUM (MPFI = 2.0) with UWIL being least preferred (MFPI = 0.4). UJXW and UJAP were intermediate in preference, with MFPI values of 0.7 and 1.2, respectively (Table 5). These results are consistent with findings by Hall (1986) in which UPUM (MFPI = 3.0) was consistently preferred over UWIL (MFPI = 0.0).

Results from the single-choice and multiple-choice feeding studies suggest that UZSE is the least suitable and UPXP, UPXA, and UPUM are the most suitable for feeding and reproduction by the adult elm leaf beetle. Adult longevity and the pre-ovipositional period appear to be a function of suitability as adults feeding on the least suitable species (UZSE) had the shortest longevity and the longest pre-ovipositional period. The converse also appears to be true. Results from the multiple-choice studies were consistent with the single-choice studies.

This study clearly indicates that the hybrids UPXP and UPXA are similarly preferred as the common preferred host UPUM. The UPUM genetic component appears to be significant as the Chinese elm, *U. parvifolia*, is not preferred by the elm leaf beetle as a suitable host (7, 9, 14, 20). American elm, *U. americana*, is a known host (3, 18), which may contribute to the suitability of the UPXA hybrid. Even though UPXP and UPXA appear to be resistant to Dutch elm disease (DED), their potential for use in the urban landscape where chronic populations of ELB exist, maybe extremely limited.

The intermediately suitable species of UJWP, UJAP, UMAC, and UWIL show promise for further elm breeding programs. Japanese elms growing at the Morton Arboretum have thrived in well-drained soils, attaining heights close to 14 meters (21). UMAC originates from northern China and has a growth form similar to the American elm, with a mature height of 10–13 meters (21). The UWIL elm is also resistant to DED. Others also have observed similar results with UWIL as reported in this study (7, 8, 20). The nonpreferred USZE appears to be an excellent candidate for use in areas with consistent ELB outbreaks. The Szechuan

Table 5. Mean feeding preference index (MFPI) for multiple-choice feeding studies of elm leaf beetle on elm leaves.

Multiple-choice study #1		Mean feeding preference index (MFPI)[z]				
Species/hybrid[y]	N[x]	1988[w]	1989[v]	1991[u]	1992[t]	Mean
U. macrocarpa	10	0.1a	0.8b	0.9b	0.6b	0.7
U. pumila	10	2.5b	2.2c	3.0d	1.3c	2.5
U. pumila x U. parv.	10	3.0b	2.9d	1.5c	1.2c	2.5
U. szechuanica	10	0.0a	0.0a	0.0a	0.0a	0.0
Significance level		.0001	.0001	.0001	.0001	

Multiple-choice study #2		Mean feeding preference index (MFPI)[z]				
Species/hybrid[y]	N[x]	1988[s]	1989[r]	1991[q]	1992	Mean
U. japonica	10	2.1c	0.6b	1.6c	—[p]	1.2
U. jap.x U. wils.	10	1.3b	0.2a	0.9b	—[p]	0.7
U. pumila	10	1.9c	1.6c	2.4d	—[p]	2.0
U. wilsoniana	10	0.4a	0.7b	0.0a	—[p]	0.4
Significance level		.0001	.0001	.0001		

[z]Values within columns followed by the same letter are not significantly different ($p < 0.05$); Student-Neuman-Keuls multiple comparison test.

[y]parv. = parvifolia; jap = japonica; wils. = wilsoniana.

[x]Represents ten male/female pairs of adult beetles for each of two to five trees.

[w]$F(3,279) = 156.93$

[v]$F(3,279) = 88.52$

[u]$F(3,279) = 74.62$

[t]$F(3,279) = 70.23$

[s]$F(3,279) = 30.48$

[r]$F(3,279) = 34.06$

[q]$F(3,279) = 61.84$

[p]Species not evaluated due to a shortage of adult beetles.

elm, *U. szechuanica,* is resistant to DED, originates from the Szechuan region of China and is a small tree up to 9 meters in height. It has an umbrella-like canopy with emerging red spring foliage and subdued purplish-red fall color (21).

Further studies are needed to evaluate hybrid crosses of UMAC, UWIL, UJAP, and USZE as potential sources of shade trees resistant to DED and not preferred by the ELB.

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