Potential Resistance of Crape Myrtle Cultivars to Flea Beetle (Coleoptera: Chrysomelidae) and Japanese Beetle (Coleoptera: Scarabaeidae) Damage

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J. Econ. Entomol. 97(3): 981–992 (2004)

ABSTRACT Field and laboratory studies were conducted to identify potential resistance among crape myrtles, *Lagerstroemia* spp., to Japanese beetle, *Popillia japonica* Newman and to flea beetles, *Altica* spp. Damage ratings revealed variation among cultivars in susceptibility to beetle feeding. Cultivars with *Lagerstroemia fauriei* Koehne in their parentage exhibited the least amount of damage in choice and no-choice experiments, with few exceptions. The data indicate that both beetle species cause more feeding damage on certain cultivars of *Lagerstroemia indica* L., such as 'Country Red', 'Twilight', and 'Carolina Beauty' than interspecific cultivars with *L. fauriei* in their parentage, such as 'Natchez', 'Tonto', and 'Muskogee'. When comparing the effect of parentage on all of the major pests of crape myrtle, *L. faurei* confers resistance to all pests except crape myrtle aphid. No correlation was found between leaf toughness, leaf color, and leaf nutrients in estimating flea beetle cultivar preference. With this information, growers can more effectively target scouting measures to the most susceptible cultivars, and breeders can select plants that will require the fewest chemical inputs.

KEY WORDS *Altica* spp., *Popillia japonica*, *Lagerstroemia* spp., host plant resistance, *Tinocallis kahawaluokalani*

THE GENUS *Lagerstroemia* L. encompasses 56 species of crape myrtle that are primarily native to tropical regions of Southeast Asia and Indo-Malaysia (Furtado and Srisuko 1969). Most have small inconspicuous pale white to lavender flowers, with approximately 10 species in cultivation as ornamentals. Those species with sufficient cold hardiness to be grown in temperate regions of the United States include *Lagerstroemia indica* L., *Lagerstroemia fauriei* Koehne, *Lagerstroemia subcostata* Koehne, and *Lagerstroemia limii* Merr. (*Lagerstroemia chekiangensis* Cheng) (Egolf and Andrick 1978). Although crape myrtle is grown primarily in the southern United States, it rivals crabapple (*Malus* spp.) as the most popular deciduous flowering tree in the United States. Wholesale revenue during 1998 exceeded 31 million dollars (www.nass.usda.gov).

Until the early 1980s, nurseries produced *L. indica* cultivars that were all similar except for differences in flower color and growth habit. Cultivars were plagued by disease problems such as powdery mildew, *Erisyphe lagerstroemiae* E. West; Cercospora leaf spot, *Cercospora lythracearum* Heald & Wolf; and various root rots (Egolf and Andrick 1978). A crape myrtle breeding program initiated in Washington, DC, at the U.S. National Arboretum in 1962 had only moderate success in dealing with the plant's limitations until the discovery that *L. fauriei*, introduced from Japan in 1956 (Creech 1985), was resistant to powdery mildew. More than 20 interspecific hybrids (Egolf 1981a,b, 1986a,b, 1987, 1990; Pooler and Dix 1999) have resulted from this breeding program that successfully incorporated the powdery mildew resistance of *L. fauriei* and other horticultural traits that could be attributed to heterosis between the two species. Several of the National Arboretum releases have also demonstrated increased resistance to Cercospora leaf spot (Hagan et al. 1998). Up to now, however, limited evaluation of crape myrtle cultivars has been conducted for resistance to three of its most common arthropod pests, flea beetles, *Altica* spp. (Coleoptera: Chrysomelidae); the crape myrtle aphid, *Tinocallis kahawaluokalani* (Kirkaldy); and the Japanese beetle, *Popillia japonica* Newman.

Altica spp. are primarily a problem on crape myrtle in the nursery and not of established landscape plantings. The few published accounts of this beetle in refereed journal articles (Capogreco 1989, Mizell and Knox 1993) and other publications (Byers 1997) only cursorily mention the beetle as a pest in Florida and other areas of the southern United States.

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Adult *Altica* spp. are metallic blue to green and have saltatorial metathoracic legs that allow them to jump and scatter from plants when disturbed. Flea beetle feeding on crape myrtle foliage regularly causes dramatic defoliation of new growth during commercial production in a region from Oklahoma to Virginia and south to the Gulf Coast. Outbreaks, which occur typically in late spring to early summer, are sudden and unpredictable, with strong aggregation behavior apparent.

Many of the *Altica* spp. feed on plants in only one or two families. The adult *Altica* spp., which is a problem on crape myrtle, is believed to migrate from wild herbaceous hosts in the Onagraceae and Lythraceae families. Several weed species that may grow in or around crape myrtle production nurseries, primarily evening primroses, *Oenothera* spp., are included in these plant families, and beetles have been collected from them before and during pest outbreaks on crape myrtle (Lythraceae) (Schultz et al. 2001, D.W.B. and G.V.P., personal observation). Proper elucidation of species has not been made for flea beetles found on plants in the Lythraceae and Onagraceae families. Classification of beetles in the genus *Altica* is notoriously difficult because many species are morphologically indistinguishable and may differ only in host plant choice (LeSage 1995).

Gravid females oviposit small orange eggs on the upper and lower surfaces of the leaves of wild hosts; the larvae hatch and feed on the mesophyll of the leaves through three instars. Larvae then drop or crawl to the ground where they bury themselves in the soil or leaf litter and pupate. They emerge as adults the following spring. Beetles feed on native vegetation during most of their life cycle and are opportunistic feeders of new flushes of crape myrtle foliage at nurseries during population peaks of sexually active adults. They fly into production nurseries in large numbers from surrounding vegetation and can decimate entire fields of crape myrtles in just a few days (Byers 1997; G.V.P. and D.W.B., personal observation). These beetles have two to three generations per year (LeSage 1995).

Another important pest of crape myrtle that was introduced in 1916 is the Japanese beetle, which has become established throughout the eastern United States (Johnson and Lyon 1991). They feed on >300 species of wild and cultivated plants (Hawley and Metzger 1940, Fleming 1972), and crape myrtle is among the preferred hosts. Gravid female Japanese beetles lay up to 20–40 eggs in clutches 5–10 cm in the ground soon after emerging in the spring. Larvae feed on the roots of grasses, ornamentals, and vegetables and move down through the soil profile to overwinter. In the spring, grubs move upward to complete feeding near the soil surface before pupating and emerging in early to midsummer (Tashiro 1987). After emergence, adult beetles disperse into landscapes and nurseries from surrounding areas. Beetles aggregate on crape myrtles, skeletonizing leaves and feeding on flowers. Adult beetles feed on suitable hosts throughout the summer. Japanese beetles have one generation per year in the areas in which crape myrtle is commercially produced.

Control of *Altica* spp. and Japanese beetle is possible using labeled pesticides; however, identification of germplasm with natural resistance would reduce expenses associated with pesticide applications and minimize worker exposure to chemicals. Several choice and no-choice experiments were conducted to elucidate the range of susceptibility of commercially available cultivars to *Altica* spp. and Japanese beetle and to compare these data to published information on susceptibilities to disease and other insect pests. The purpose of this study was to identify germplasm with greater resistance.

In an effort to discover sources of resistance of certain cultivars to beetle feeding, toughness of crape myrtle leaves was measured as well as leaf color and leaf nutrients. Parentage of resistant plant material was then examined to determine whether it contributes to increased resistance and to assist in future breeding efforts.

Materials and Methods

Flea Beetle Choice Trials. Crape myrtle varieties from three nurseries were evaluated after each nursery had an outbreak of *Altica* spp. Two of the nurseries are located in southern Mississippi with one specializing in large containerized trees (94.6-liter containers) and the other growing crape myrtles in 11.4- and 26.5-liter containers. The third nursery is located in northern Alabama and specializes in crape myrtle liner production. Ratings were taken from three terminal branches of 10 randomly selected trees from all available crape myrtle cultivars at the two Mississippi nurseries. Ratings were taken from one terminal branch of 10 randomly selected liners at the nursery in Alabama. The rating scale was from 1 to 5 with the following criteria: 1, no damage; 2, 1–25% of the leaves damaged; 3, 26–50% of the leaves damaged; 4, 51–75% of the leaves damaged; and 5, 76–100% of the leaves damaged (Holcomb 1997). Data for each container size were analyzed separately.

An additional choice trial was conducted in Dearing, GA, at the Center for Applied Nursery Research. Twenty-two cultivars of crape myrtle in 94.6-liter containers, with six replications of each cultivar, were arranged in a completely randomized design on black weed-barrier cloth. Visual estimates of the percent of leaf area damaged were made after a naturally occurring infestation of beetles on a rating scale of 1–4 with 1 being no damage; 2, minimum damage (1–3%); 3, low damage (8–10%); and 4, medium damage (11–15%). This rating scale was chosen because of the relatively small amount of damage sustained overall by these large plants. Two observers made ratings which were averaged.

Flea Beetle No-Choice Trials. Several no-choice laboratory assays were performed to determine whether the beetles would feed on crape myrtle cultivars when given only one option.

Trial 1. Twenty-two cultivars of crape myrtle were used in this trial. One leaf each of the large-leaf cultivars and two or three leaves of the small-leaf cultivars were used so that each dish had approximately the same amount of leaf material. The leaves were placed in a 150 by 15-mm petri dish with moist filter paper and three adult flea beetles. The lids of the dishes had a 5-cm-diameter hole that was covered with muslin material to allow air flow. The edges of the lids were sealed with Parafilm (Pechiney Plastic Packaging, Menasha, WI) to prevent escape of the beetles. Five replicates were used for each cultivar. The petri dishes were placed in an incubator set at 25 ± 2°C, a photoperiod of 14:10 (L:D) h, and 50 ± 10% RH.

After 24 h, the petri dishes were removed, the number of live beetles was counted in each dish, and the leaves were scanned using Adobe Photoshop software (Adobe Systems, San Jose, CA) and a flat-top scanner. The total area of the leaves and the total area of eaten leaf tissue were determined using Image-Pro Express software (Media Cybernetics, Silver Spring, MD). The percentage of leaf tissue eaten per live beetle was used in the analysis.

Trial 2. Plant material used in this trial was taken from containerized crape myrtles grown in Griffin, GA, during 2001. One 12.7-cm cutting was taken from a terminal branch of each of four blocks of 23 cultivars and placed in plastic cages according to the methods of Klingeman et al. (2000). Two adult beetles were placed in each cage. Cages were placed in an incubator set at 25 ± 2°C and a photoperiod of 14:10 (L:D) h in a randomized complete block design, where shelves in the incubator were considered blocks, because of possible light differences from shelf to shelf. After 7 d, cages were removed from the incubator, and ratings were made by three observers and averaged. Defoliation ratings were based on a scale of 0–10 with 0, 0% defoliation; 1, 1–10% defoliation; 2, 11–20%; 3, 21–30%; 4, 31–40%; 5, 41–50%; 6, 51–60%; 7, 61–70%; 8, 71–80%; 9, 81–90%; and 10, 91–100%.

Trial 3. Plant material for this 2002 trial was again gathered from containerized crape myrtles grown in Griffin. The fourth newly expanded leaf was removed from each of six blocks of 41 cultivars and placed in a 32-ml clear plastic cup containing moist sand. The 32-ml cups were covered with clear plastic lids. Two adult beetles were added to each cup and cups were placed in an incubator set at 25 ± 2°C and a photoperiod of 14:10 (L:D) in a randomized complete block design, where shelves in the incubator were considered blocks. Cups were removed after 24 h, and defoliation ratings were made by two observers on a scale of 0–10, and ratings were averaged.

Trial 4. Twenty-five cultivars were chosen based on trial 3 and cuttings were taken as in trial 2. The stem of each cutting was placed in moist sand in the bottom of a 0.35-liter translucent plastic drinking cup. The cup was covered with two layers of cheesecloth for ventilation and a rubber band was placed around the top to prevent escape. Two adults were added to each cup. Cups were placed in an incubator set at 25 ± 2°C and a photoperiod of 14:10 (L:D) h in a randomized complete block design with four blocks, where shelves in the incubator were considered blocks. Cups were removed after 7 d, and ratings were made by three observers and averaged. Defoliation damage was based on a scale of 0–3, where 0 is no damage, 1 is minimum, 2 is moderate, and 3 is heavy feeding.

Japanese Beetle Trials. Trials were conducted in 1999 (choice) and 2002 (no-choice) to determine susceptibility of crape myrtle to Japanese beetles.

Japanese Beetle 1999 (Choice). Seventeen cultivars of crape myrtle in 11.4-liter containers, with six replications of each, were placed in a randomized complete block design on weed-barrier cloth, in Griffin. Ratings were based on the average of three observers determining percentage of terminals damaged from a naturally occurring infestation of Japanese beetles.

Japanese Beetle 2002 (No-Choice). For this no-choice trial, four Japanese beetle adults (two females, two males) were confined on containerized plants in translucent cloth sleeves that covered ≈25 cm of a terminal branch and were secured with light gauge metal wire. There were 41 cultivars in 11.4-liter pots, with six replications of each, arranged in a randomized complete block design on black weed-barrier cloth in Griffin. Beetles were starved for 24 h before the test and sleeves remained on the plants for 48 h, after which two evaluators estimated percentage of damage and ratings were averaged.

Sources of Resistance. Leaf toughness, color, and nutrients were measured and compared against *Altica* spp. feeding data to identify possible sources of resistance. Leaves for these trials were collected concurrently from the plants used in trial 3 of the flea beetle no-choice trials. Leaf toughness measurements were taken with a penetrometer from the fourth newly expanded leaf and from the 14th fully expanded leaf. A Minolta model CR-200 chroma meter (Minolta, Ramsey, NJ) was used for color measurements on the fourth newly expanded leaf of each cultivar. Dried and ground samples of leaves were sent to the University of Georgia, Soil, Plant and Water Laboratory for analysis of minerals, nitrogen, and sulfur. Pearson correlation coefficients and analysis of variance (ANOVA) were used to build a model relating *Altica* spp. feeding damage from trial 3 to potential resistance sources.

Statistical Analyses. In all trials, unless otherwise specified, data were subjected to ANOVA using the GLM procedure, and mean separations were performed using Fisher's least significant difference test. Cases in which the percent area of eaten tissue was evaluated, data were arcsine square-root transformed before statistical analysis (Zar 1999), and the untransformed data are presented.

Insects. Voucher specimens of *Altica* spp. and Japanese beetles were submitted to the Museum of Natural History, Collection of Arthropods, University of Georgia, Athens, GA.

Results

Flea Beetle Choice Trials. Ten cultivars were available in 94.6-liter containers. 'Biloxi', 'Muskogee',

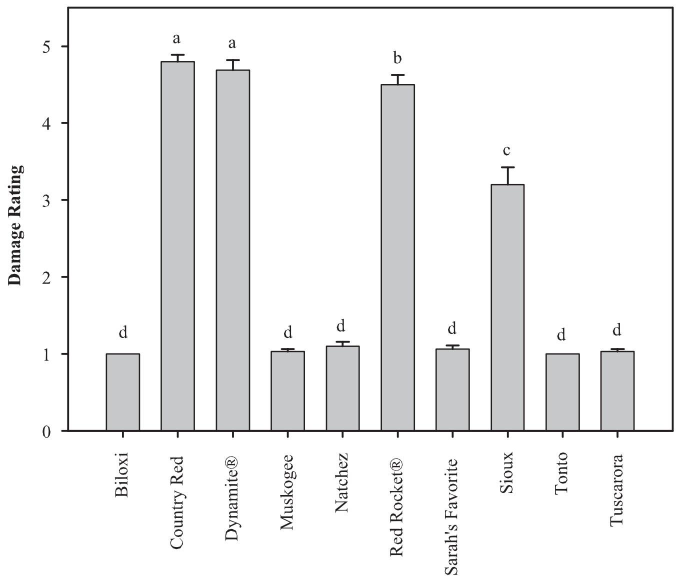

Fig. 1. Mean damage rating ($n = 30$) from *Altica* spp. feeding on crape myrtle cultivars in 94.6-liter containers. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

'Natchez', 'Sarah's Favorite', 'Tonto', and 'Tuscarora' had damage ratings at or near 1 (Fig. 1). Four cultivars had significantly more damage than the other six ($F = 302.65$, df = 9, $P < 0.0001$). 'Country Red', 'Dynamite', and 'Red Rocket' had average damage ratings >4.5, and 'Sioux' had an average rating near 3.

'Biloxi' had an average damage rating of 3.8, which was higher than the remaining varieties that had an average damage rating near 1: 'Miami', 'Natchez', 'Tonto', and 'Tuscarora' (Fig. 2) in the 26.5-liter containers. Three cultivars received a significantly higher ($F = 234.55$, df = 7, $P < 0.0001$) damage rating (near 5) than the other five cultivars available: 'Carolina Beauty', 'Dynamite', and 'Twilight'.

'Biloxi', 'Chickasaw', 'Miami', 'Natchez', 'Tonto', 'Tuscarora', and 'Yuma' (Fig. 3) had average damage ratings at or below 1.5 in the 11.4-liter containers. 'Carolina Beauty' and 'Dynamite' had an average damage rating >4. 'Twilight' had the highest damage rating (4.97) of the 12 cultivars and was significantly higher

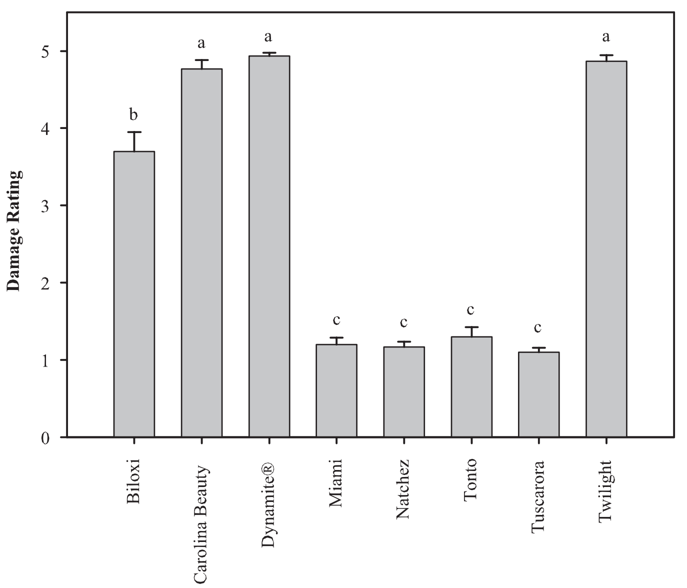

Fig. 2. Mean damage rating ($n = 30$) from *Altica* spp. feeding on crape myrtle cultivars in 26.5-liter containers. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

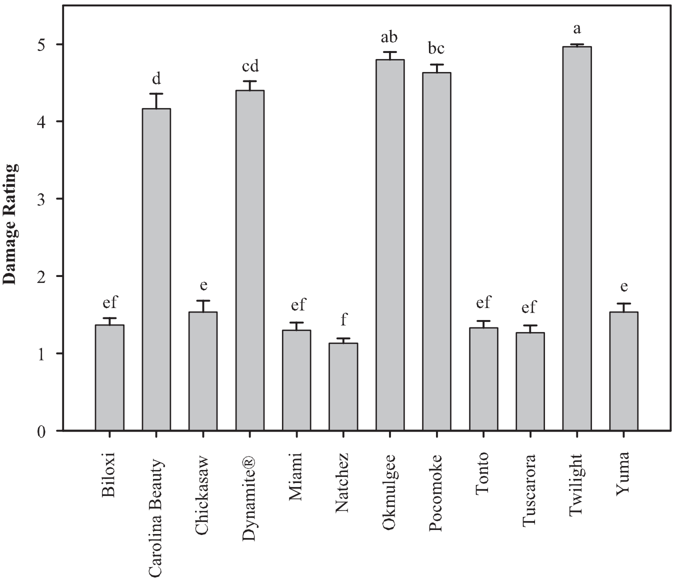

Fig. 3. Mean damage rating ($n = 30$) from *Altica* spp. feeding on crape myrtle cultivars in 11.4-liter containers. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

($F = 230.53$, df = 11, $P < 0.0001$) than all others except 'Okmulgee' and 'Pocomoke' (4.80 and 4.63, respectively).

Those cultivars with the lowest average damage ratings in liners were 'Apalachee', 'Chickasaw', 'Miami', 'Natchez', 'Pecos', 'Pocomoke', 'Tonto', and 'Wichita' (Fig. 4). Three cultivars ('Comanche', 'Tightwad Red', and 'Yuma') received average damage ratings significantly different from the highest and lowest ratings ($F = 48.90$, df = 19, $P < 0.0001$). The following nine cultivars in liners had the highest damage ratings: 'Catawba', 'Centennial', 'Centennial Spirit', 'Hope', 'Hopi', 'Raspberry Sundae', 'Red Rocket', 'Velma's Royal Delight', and 'Zuni'.

Three cultivars, 'Tuscarora', 'Sioux', and 'Tonto', had ratings <1.17 (Fig. 5) at the Dearing, GA, location.

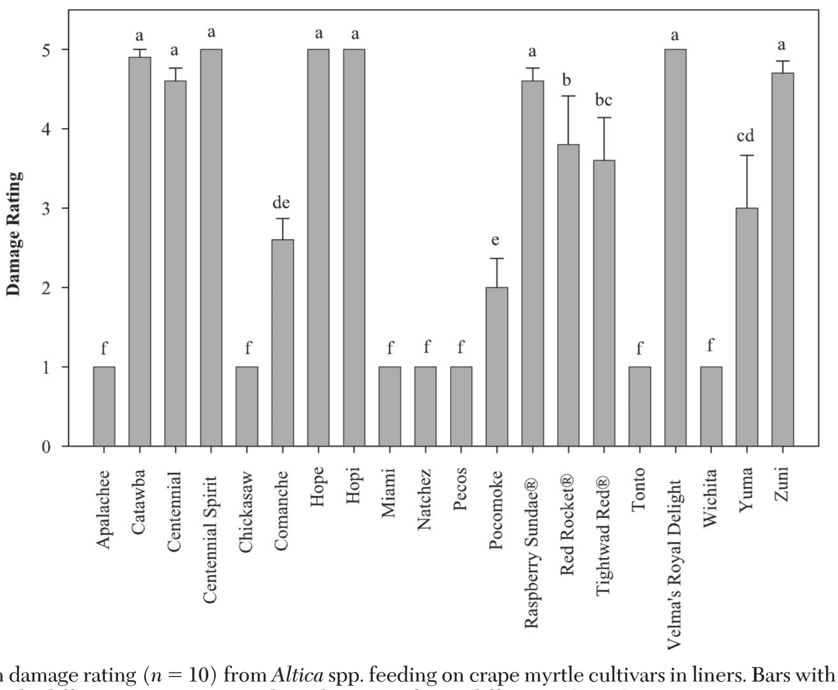

Fig. 4. Mean damage rating ($n = 10$) from *Altica* spp. feeding on crape myrtle cultivars in liners. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

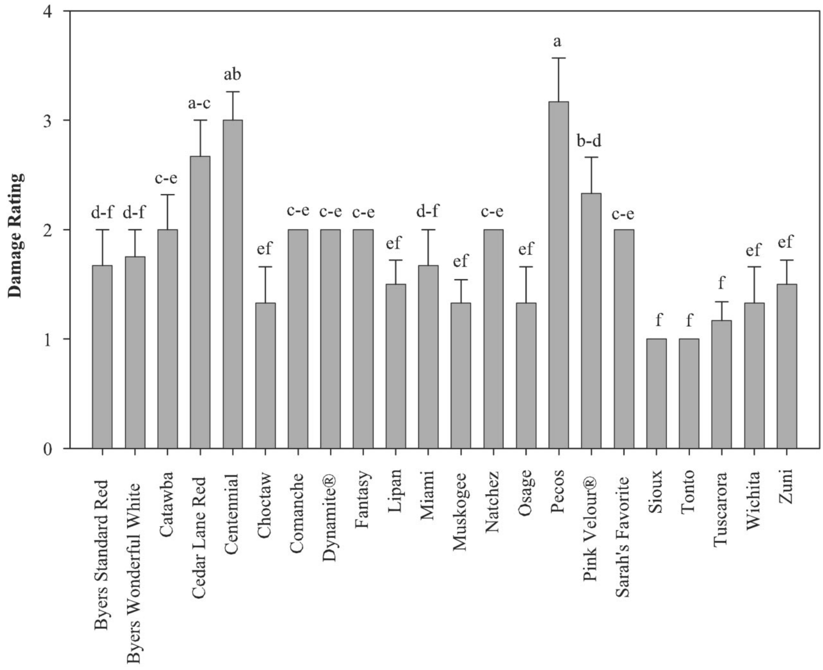

Fig. 5. Mean damage rating ($n = 6$) from *Altica* spp. feeding on crape myrtle cultivars; 94.6-liter containers. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

Three of the containerize plants had significantly higher damage ratings ($F = 4.51$, df = 26, $P < 0.0001$) than the other 18 cultivars with ratings >2.67: 'Pecos', 'Centennial', and 'Cedar Lane Red'.

Flea Beetle No-Choice Trials. *Trial 1.* Significant differences were detected among the cultivars in the petri dish evaluations ($F = 11.24$, df = 21, $P < 0.0001$). Three cultivars had no observed feeding damage: 'Acoma', 'Muskogee', and 'Tonto'. Six other cultivars showed slight feeding but were not significantly different than those with no feeding: 'Apalachee', 'Fantasy', 'Miami', 'Natchez', 'Osage', and 'Sarah's Favorite'. 'Seminole' and 'Pink Ruffles' had the highest feeding damage percentage, and 11 other cultivars were not significantly different from them: 'Arapaho', 'Biloxi', 'Carolina Beauty', 'Cheyenne', 'Country Red', 'Dynamite', *L. limii,* 'Low Flame', 'Pecos', 'Red Rocket', and 'Sioux' (Fig. 6).

Trial 2. Eight cultivars exhibited no feeding damage in this trial. These were 'Osage', 'Natchez', 'Lipan', 'Fantasy', 'Tonto', 'Tuscarora', 'Wichita', and 'Zuni'. Significant differences in feeding ($F = 3037$, df = 27, $P < 0.0001$) were seen and the most damaged cultivars were 'Byers Standard Red', 'Choctaw', 'Cedar Lane Red', 'Comanche' and 'Byers Wonderful White', with 17.8–30% defoliation (Fig. 7).

Trial 3. Eleven cultivars had no feeding ($F = 2.33$, df = 45, $P < 0.0001$): 'Pecos', 'Yuma', 'Tuskegee', 'Carolina Beauty', 'Lipan', 'Miami', 'Natchez', 'Osage', 'Acoma', 'Muskogee', and 'Tuscarora'. The most damaged cultivars had defoliation ratings of 33.3 to 76.7%: 'Hopi', 'Ozark', 'Victor', and 'Wichita' A number of cultivars had relatively low damage ratings between 11.7 and 31.7%: 'Comanche', 'Byers Wonderful White', 'Pink Velour', 'Choctaw', 'Byers Standard Red', 'Wm. Toovey', 'Centennial Spirit', 'Regal Red', 'Hardy Lavender', 'Biloxi', 'Powhatan', 'Zuni', 'Sioux', and 'Pokomoke' (Fig. 8).

Trial 4. All cultivars in this trial had at least some feeding damage, but those cultivars that showed <10% damage ($F = 4.66$, df = 27, $P < 0.0001$) were 'Biloxi', 'Lipan', 'Tuscarora', and 'Tonto'. Cultivars that showed >20% damage were 'Catawba', 'Hopi', 'Hardy Lavender', 'Comanche', and 'Velma's Royal Delight' (Fig. 9).

Japanese Beetle Trials. *Japanese Beetle 1999 (Choice).* Five cultivars had <55% damaged terminals ($F = 10.30$, df = 19, $P < 0.0001$). Damage ratings of these five cultivars ('Cordon Blue', 'Tonto', 'Lipan', 'New Orleans', and 'Acoma') were between 20.3 and 54.5%, but they were not significantly different from one another. The cultivars that had the greatest number of terminals damaged, with ratings between 93.8 and 100% were 'Regal Red', 'Tuscarora', 'Zuni', 'Miami', and 'Carolina Beauty' (Fig. 10).

Japanese Beetle 2002 (No-Choice). Significant differences were found among cultivars in this no-choice trial ($F = 3.0$, df = 45, $P < 0.0001$). Thirteen cultivars had <10.5% damage and were not significantly different: 'Wichita', 'Potomac', 'Lipan', 'Comanche', 'Choctaw', 'Biloxi', 'Tuscarora', 'Catawba', 'Yuma', 'Chickasaw', 'Centennial Spirit', 'Sioux', and 'Pokomoke'. The most damaged cultivars, with ratings >17% were 'Red Rocket', 'Victor', 'Byers Standard Red', 'Byers Wonderful White', 'Raspberry Sundae', 'Zuni', and 'Seminole' (Fig. 11).

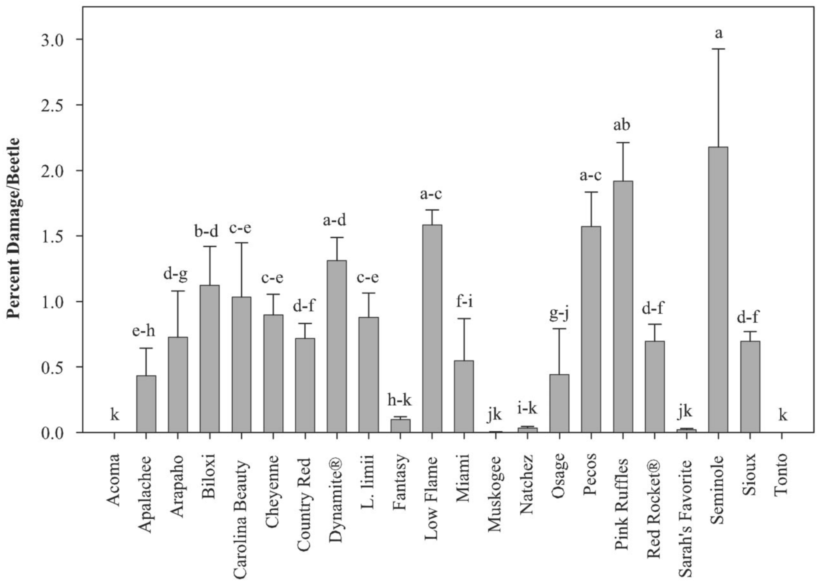

Fig. 6. Mean percentage of damage per *Altica* spp. ($n = 5$) to crape myrtle cultivars in a petri dish study. Arcsine square-root transformation of means with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test). Nontransformed means are presented.

Sources of Resistance. Significant differences were found among cultivars for leaf color, toughness, and nutrients (data not shown); however, no significant correlations could be found with *Altica* spp. feeding damage and any of these factors.

Discussion

From the results of the choice and no-choice trials, a few cultivars seem to be resistant to *Altica* spp. feeding by consistently being among the least dam-

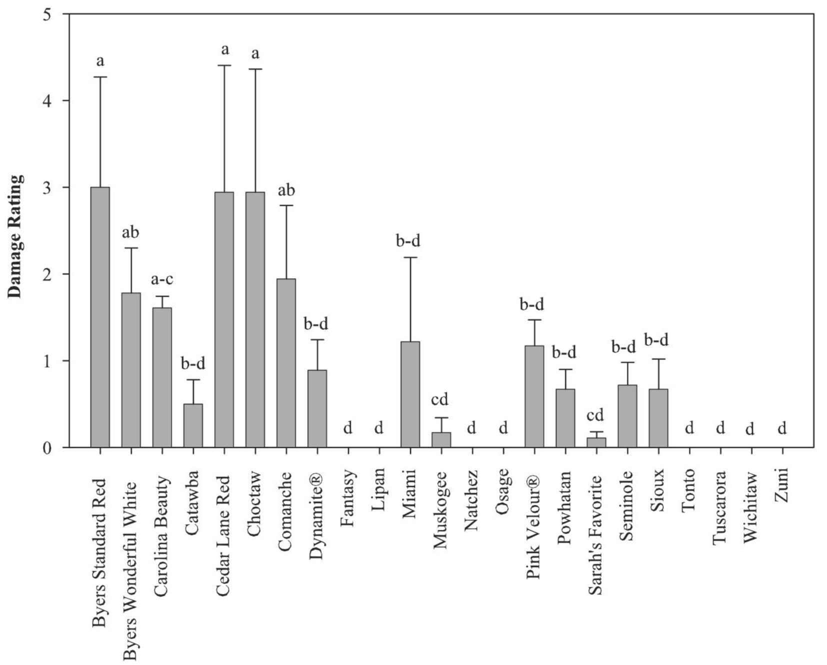

Fig. 7. Mean damage rating ($n = 4$) from *Altica* spp. feeding on crape myrtle cultivars in plastic cages. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

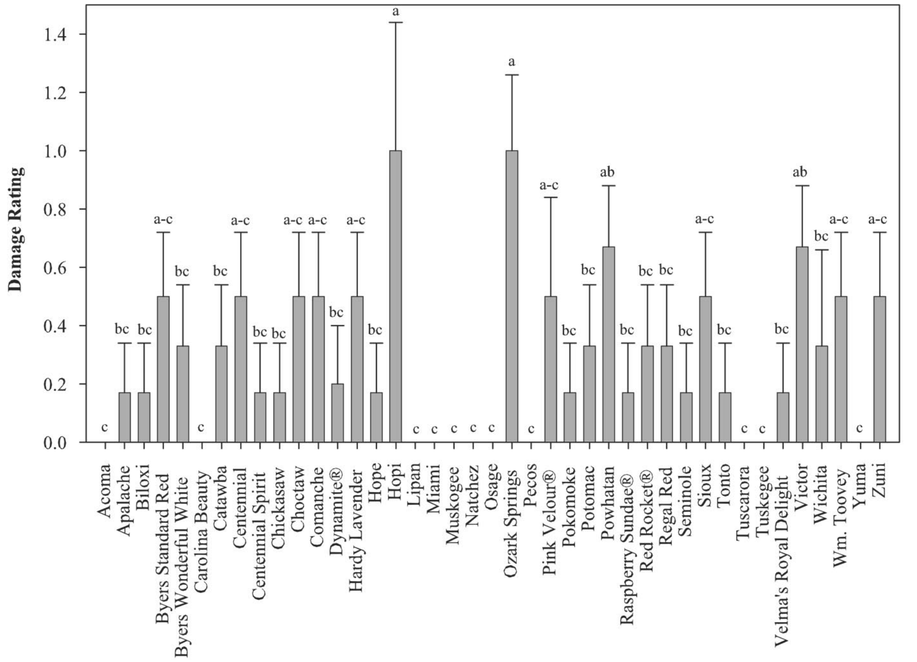

Fig. 8. Mean damage rating ($n = 6$) from *Altica* spp. feeding on crape myrtle cultivars in 32-ml clear plastic cups. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

aged in two or more of the trials. The resistant cultivars are 'Acoma', 'Apalachee', 'Biloxi', 'Lipan', 'Natchez', 'Osage', 'Tonto', 'Tuscarora', 'Wichita', and 'Yuma'. The cultivars that exhibited the highest damage in two or more trials are 'Byers Standard Red', 'Byers Wonderful White', 'Carolina Beauty', 'Cedar Lane Red',

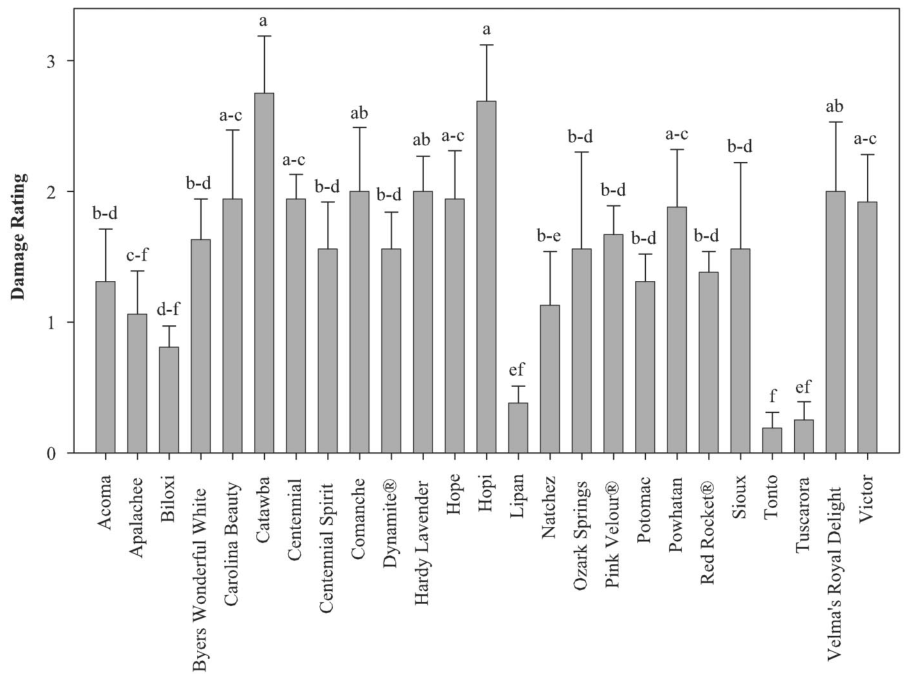

Fig. 9. Mean damage rating ($n = 4$) from *Altica* spp. feeding on crape myrtle cultivars in 0.35-liter translucent plastic drinking cups. Bars with the same letter are not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test).

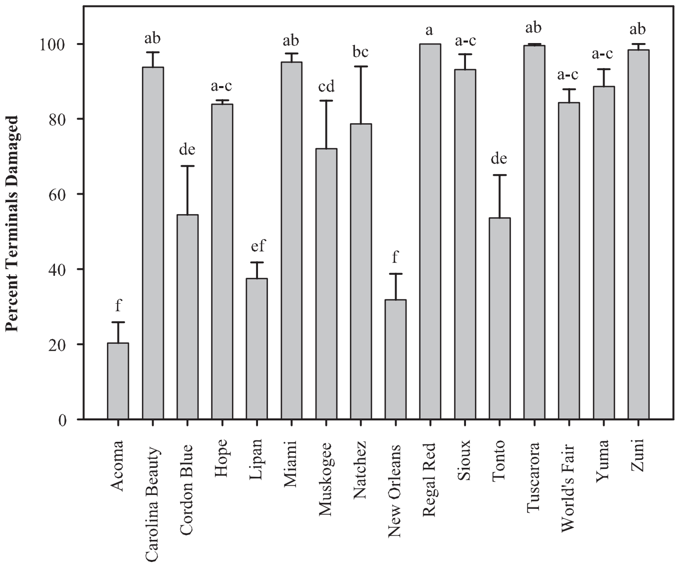

Fig. 10. Mean percentage of damaged terminals ($n = 6$) from Japanese beetle to crape myrtle cultivars. Arcsine square-root transformation of means with the same letter is not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test). Nontransformed means are presented.

'Centennial Spirit', 'Choctaw', 'Comanche', 'Hopi', and 'Pink Velour' (Table 1). Despite that different rating scales and populations of *Altica* were used, the consistent results found in similar studies conducted in different states strengthens the conclusions that have now been developed on a regional rather than a single location basis. Voucher specimens are being held and may merit another look once the taxonomy of the genus *Altica* is clarified.

Resistance of crape myrtles to *Altica* spp. feeding follows a general trend based on parentage of the crape myrtle cultivars (Table 2). Among each nursery

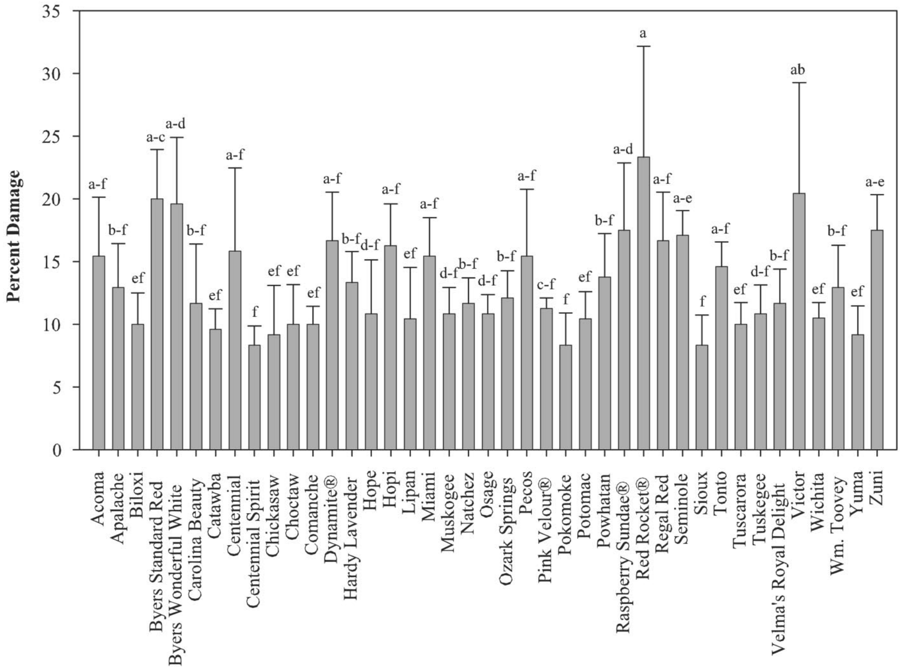

Fig. 11. Mean percentage of damage ($n = 6$) from Japanese beetle to crape myrtle cultivars. Arcsine square-root transformation of means with the same letter is not significantly different ($P > 0.05$) (Fisher's least significant difference [LSD] test). Nontransformed means are presented.

Table 1. Parentage of *Lagerstroemia* spp. and relative resistance to Japanese beetle and *Altica* spp. feeding based on choice and no-choice feeding trials

Cultivar	*L. faurei* parentage	*Altica* spp. resistance[a]	Japanese beetle resistance[b]
Acoma	Yes	Resistant	Resistant
Apalachee	Yes	Moderately resistant	Moderately susceptible
Arapaho	Yes	Moderately resistant	Unknown
Biloxi	Yes	Moderately resistant	Moderately resistant
Byers Standard Red	No	Moderately susceptible	Moderately susceptible
Byers Wonderful White	No	Moderately susceptible	Moderately susceptible
Carolina Beauty	No	Moderately susceptible	Moderately susceptible
Catawba	No	Susceptible	Moderately resistant
Cedar Lane Red	No	Moderately susceptible	Unknown
Centennial	No	Moderately susceptible	Moderately susceptible
Centennial Spirit	No	Moderately susceptible	Moderately susceptible
Cheyenne	Yes	Moderately resistant[c]	Unknown
Chickasaw	Yes	Moderately resistant[c]	Moderately resistant
Choctaw	Yes	Moderately susceptible	Moderately resistant
Comanche	Yes	Moderately susceptible	Moderately resistant
Cordon Bleu	No	Unknown	Moderately resistant
Country Red	No	Moderately susceptible	Unknown
Dynamite®	No	Susceptible	Moderately susceptible
Fantasy	Yes	Moderately resistant	Unknown
Hardy Lavender	No	Moderately susceptible	Moderately susceptible
Hope	No	Moderately susceptible	Moderately susceptible
Hopi	Yes	Susceptible	Moderately susceptible
Lipan	Yes	Resistant	Moderately resistant
Low Fame	No	Moderately susceptible[c]	Unknown
Miami	Yes	Moderately resistant	Moderately susceptible
Muskogee	Yes	Resistant	Moderately resistant
Natchez	Yes	Resistant	Moderately susceptible
Okmulgee	No	Moderately susceptible[c]	Unknown
Osage	Yes	Resistant	Moderately resistant
Ozark Springs	No	Moderately susceptible	Moderately susceptible
Pecos	Yes	Moderately susceptible	Moderately susceptible
Pink Ruffles	No	Moderately susceptible[c]	Unknown
Pink Velour	No	Moderately susceptible	Moderately resistant
Pocomoke	Yes	Moderately resistant	Resistant
Potomac	No	Moderately susceptible	Moderately resistant
Powhatan	No	Moderately susceptible	Moderately susceptible
Raspberry Sundae®	No	Moderately susceptible	Moderately susceptible
Red Rocket®	No	Moderately susceptible	Susceptible
Regal Red	No	Moderately susceptible[c]	Susceptible
Sarah's Favorite	Yes	Moderately resistant	Unknown
Seminole	No	Moderately susceptible	Moderately susceptible
Sioux	Yes	Moderately resistant	Moderately resistant
Tightwad Red	No	Susceptible	Unknown
Tonto	Yes	Resistant	Moderately susceptible
Tuscarora	Yes	Resistant	Moderately susceptible
Tuskegee	Yes	Moderately resistant[c]	Moderately resistant
Twilight	No	Moderately susceptible	Unknown
Velma's Royal Delight	No	Moderately susceptible	Moderately susceptible
Victor	No	Moderately susceptible	Moderately susceptible
Wichita	Yes	Moderately resistant	Moderately resistant
Wm. Toovey	No	Moderately susceptible[c]	Moderately susceptible
World's Fair	No	Unknown	Moderately susceptible
Yuma	Yes	Moderately resistant	Moderately susceptible
Zuni	Yes	Moderately susceptible	Unknown

[a] Resistant, no damage in two or more trials; moderately resistant, low damage in two or more trials or no to low damage in only one trial; moderately susceptible, high damage in two or more trials, or moderate to high damage in one trial; susceptible, highest damage in two or more trials.

[b] Resistant, lowest damage in one or more trials; moderately resistant, low damage in one or more trials; moderately susceptible, high damage in one or more trials; susceptible, highest damage in one or more trials.

[c] Represented in only one trial.

rating, those crape myrtle cultivars with *L. fauriei* in their parentage typically had little or no flea beetle damage. Notable exceptions to this trend are 'Sioux' in the 94.6-liter containers; 'Biloxi' in the 26.5-liter containers; 'Pocomoke' in the 11.4-liter containers; and liners of 'Comanche', 'Hopi', 'Pocomoke', 'Yuma', and 'Zuni'. With only one exception, 'Carolina Beauty' in trial 3 of the no-choice flea beetle feeding trials, those crape myrtle cultivars lacking *L. fauriei* in their parentage had the highest levels of damage.

The general trend found in the nursery ratings was supported by the no-choice studies. Those cultivars lacking *L. fauriei* in their parentage exhibited the highest percentage of damage per beetle. Several cultivars,

Table 2. Relationship of *Altica* spp. and Japanese beetle feeding in choice and no-choice trials to *L. faurei* parentage

	Parentage		*F*, df, *P*
	L. indica	*L. indica* × *L. faurei*	
Altica spp. trials			
94.6-liter Containers (1–5 rating)	4.64 ± 0.07a	1.35 ± 0.06b	$F = 970.56$; df = 1,298; $P < 0.0001$
26.5-liter Containers (1–5 rating)	4.86 ± 0.05a	1.69 ± 1.25b	$F = 529.48$; df = 1,238; $P < 0.0001$
11.4-liter Containers (1–5 rating)	4.58 ± 0.07a	1.76 ± 0.08b	$F = 534.17$; df = 1,358; $P < 0.0001$
Liners (1–5 rating)	4.56 ± 0.12a	1.94 ± 0.14b	$F = 174.40$; df = 1,208; $P < 0.0001$
GA trial (1–4 rating)	2.26 ± 0.14a	1.66 ± 0.10b	$F = 12.00$; df = 1,85; $P < 0.0008$
No-choice trial 1 (1–10 rating)	1.48 ± 0.25a	0.50 ± 0.16b	$F = 8.96$; df = 1,91; $P < 0.0036$
No-choice trial 2 (% damage/beetle)	1.35 ± 0.15a	0.47 ± 0.08b	$F = 44.03$; df = 1,103; $P < 0.0001$
No-choice trial 3 (1–10 rating)	0.34 ± 0.05a	0.20 ± 0.04b	$F = 7.81$; df = 1,243; $P < 0.0056$
No-choice trial 4 (0–3 rating)	1.80 ± 0.10a	1.14 ± 0.16b	$F = 13.77$; df = 1,97; $P < 0.0003$
Japanese beetle trials			
Choice trial (% damage)	75.10 ± 8.06a	74.73 ± 10.68a	$F = 0.00$; df = 1,16; $P = 0.9786$
No-choice trial (% damage)	14.65 ± 0.99a	11.80 ± 0.64b	$F = 5.92$; df = 1,244; $P < 0.0157$

each with *L. fauriei* in their parentage, had no apparent damage in at least two trials ('Acoma', 'Lipan', 'Natchez', 'Osage', 'Pecos', 'Tuscarora', 'Tuskegee', 'Wichita', 'Yuma', and 'Zuni'). Other cultivars with *L. fauriei* in their parentage were not significantly different from the above-mentioned undamaged cultivars in trial 1 of the no-choice flea beetle feeding trials, with the following exceptions: 'Arapaho', 'Biloxi', 'Cheyenne', 'Pecos', and 'Sioux'.

Comparing the Japanese beetle trials with the *Altica* spp. trials reveals no direct relationship between resistance of the two insects. 'Acoma', 'Lipan', and 'Tonto' were resistant to both species. 'Byers Standard Red', 'Byers Wonderful White', 'Raspberry Sundae', and 'Hopi' are susceptible to *Altica* spp. feeding, but they are apparently resistant to feeding by Japanese beetles.

Hagan et al. (1998) rated 43 cultivars of crape myrtle for susceptibility to powdery mildew and Cercospora leaf spot in Alabama. During 3 yr of evaluation, *L. indica* × *fauriei* hybrids 'Tuscarora', 'Tuskegee', and 'Tonto' as well as *L. fauriei* 'Fantasy' suffered little damage from either disease. Cultivars with moderate resistance to both diseases included three *L. indica* × *fauriei* hybrids, 'Apalachee', 'Basham's Party Pink', and 'Caddo' as well as two *L. indica* cultivars, 'Cherokee' and 'Glendora White'. Other *L.indica* × *fauriei* hybrids generally displayed good resistance to powdery mildew, the disease of emphasis in the National Arboretum breeding program, but no resistance to Cercospora leaf spot. Results from the Alabama study support the findings that the crape myrtle cultivars released by the National Arboretum show variation, including high levels of resistance, to pests that were not evaluated previously.

Mizell and Knox (1993) examined 37 cultivars of crape myrtle for susceptibility to crape myrtle aphid. Their findings revealed that plants that had *L. faurei* parentage averaged twice as many aphids per leaf as those without *L. faurei.* All of the most resistant cultivars were pure *L. indica* clones. Susceptibility of *L. indica* × *L. faurei* cultivars to crape myrtle aphid is an exception to the resistance of the National Arboretum cultivars to the other major pests of crape myrtle. Individual cultivars with *L. faurei* parentage, however, that exhibited lower crape myrtle aphid numbers were 'Miami', 'Natchez', 'Pecos', 'Sioux', and 'Tuskegee'. These cultivars may be the most promising for breeding programs that target the major pests of crape myrtle. These cultivars performed well in all the other trials, with the exception of 'Pecos' in trial 1 of the no-choice flea beetle feeding studies.

Table 2 shows that in all trials with *Altica* spp., plants with *L. faurei* in their parentage had significantly lower feeding damage. Damage values were significantly lower on *L. faurei* plants in the 2002 Japanese beetle trial as well; however, no significant differences were found in the 1999 Japanese beetle trial.

Because of the failure of the three tested sources of resistance (leaf toughness, leaf color, and nutrients) to predict flea beetle feeding damage (unpublished data), a possible link between other mechanisms of resistance, such as reflectance of surface waxes, compounds in surface waxes, or secondary compounds within the leaf should be evaluated. Although our observations indicate that cultivars with red-colored new growth are most susceptible, these observations were not supported by the color data taken in this study. This discrepancy could be because many of the color measuring systems cannot distinguish between the base color and a surface "blush." Such is the case with the colorimeter that integrates color over an area and reports color coordinates based on integrated spectral responses (Voss 1992), as with the Minolta chroma meter. Often, the base color can be almost totally obscured by red blush as has been found in trials with peach flesh color (Willison 1941). The Minolta chroma meter functions best in measuring color differences, as opposed to a spectrophotometer, which measures the reflectance of a specimen throughout the visible spectrum from 380 to 780 nm (Voss 1992). Therefore, measuring leaf color using a spectrophotometer or some other color measuring device may be necessary before color is dismissed as a resistance factor.

Cultivars released by the National Arboretum resulted from complex crosses of *L. indica* and *L. fauriei* (Pooler 2003), which were selected for powdery mildew resistance in combination with horticultural traits such as growth habit and floral display. Arthropod susceptibility was not a factor in the selection process of these cultivars; therefore, they should vary in their susceptibility to feeding if feeding resistance is not linked to powdery mildew resistance. Observations reported in this study indicate that the genetic diversity within *L. fauriei* and other *Lagerstroemia* species should be evaluated thoroughly to establish and define sources of resistance to insect feeding. For a majority of the pests that cause damage to crape myrtle, *L. faurei* seems to confer resistance, with the exception of crape myrtle aphid in which *L. faurei* is reported to increase susceptibility. From a breeding perspective, knowing which species and cultivars are resistant to major pests provides information necessary to select parents that can be used to develop new cultivars with a range of desirable horticultural traits incorporating multiple sources of resistance.

Integrated pest management practices should be implemented for control of *Altica* spp. and Japanese beetle outbreaks in production nurseries. Scouting at regular intervals for presence of beetles should focus on new growth flushes of pure *L. indica* cultivars, such as 'Carolina Beauty', 'Country Red', 'Dynamite', 'Red Rocket', 'Twilight', and 'Regal Red'. Cultivars that had little or no damage in the trials conducted ('Natchez', 'Muskogee', and 'Acoma') will require minimal monitoring for *Altica* spp. or Japanese beetles and will likely require no pesticide application for these beetles. However, those cultivars that are susceptible will probably need treatment to control infestations, so the susceptible and resistant cultivars should be grown separately.

Acknowledgments

We thank Drs. Wayne Gardner (University of Georgia), Gary Knox (University of Florida), and two anonymous reviewers for critical reviews of an earlier draft of this manuscript, and J. Carroll and D. Pastorek (both from USDA–ARS, Poplarville, MS) for technical assistance. Special thanks to the following nurseries for allowing part of this research to be conducted on their sites: Green Forest Nursery (Perkinston, MS), Rocky Creek Nursery (Lucedale, MS), and Byers Wholesale Nursery (Huntsville, AL). We also thank the Center for Applied Nursery Research for partial funding (to G.V.P.).

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Received 6 November 2003; accepted 23 February 2004.