MANAGEMENT OF INSECT PESTS OF CRAPEMYRTLE (*LAGERSTROEMIA* SPP.) WITH SPECIAL REFERENCE TO THE ECOLOGY AND BIOLOGY OF *ALTICA LITIGATA* FALL (COLEOPTERA: CHRYSOMELIDAE)

by

GRETCHEN V. PETTIS

(Under the Direction of S. Kristine Braman)

ABSTRACT

Japanese beetles (*Popillia japonica* Newman) and crapemyrtle aphids (*Tinocallis kahawaluokalani* Kirkaldy) are the two primary insect pests of crapemyrtle. The flea beetle *Altica litigata* Fall (Coleoptera: Chrysomelidae) has become an important economic pest of container-grown crapemyrtle (*Lagerstroemia* spp.) in southeastern United States nurseries in the past decade. Until now, chemical management has been the primary control strategy used by commercial crapemyrtle producers. Ecological and biological information is needed to establish integrated management options for these three economically important pests and particularly for the emergent beetle pest, *A. litigata*.

Identification of pest-resistant crapemyrtle cultivars provides a foundational and immediate pest management strategy. Field and lab, choice and no-choice, multi-state and multi-year feeding trials with Japanese beetle and *A. litigata* revealed a spectrum of resistance present in the crapemyrtle genome. Cultivars with *L. faurei* parentage were less preferred than *L. faurei x L. indica* crosses.

Elucidating the mechanisms that impart pest-resistance to currently available Lagerstroemia spp. cultivars provides additional tools for future plant improvement efforts for academic and commercial interests. Leaf color, nutrient content and toughness of were evaluated for correlations with beetle feeding preference. No significant relationships emerged between feeding damage and the leaf characteristics measured.

Finally, a better understanding of the basic phenology of *A. litigata* allows for more precise targeting of pest management efforts. Degree day models revealed that, when averaged among the six host plants examined, larval and pupal development required 237.3 degree-days (DD) above a threshold of 9.2 $^{o}$C. Eggs required 87.5 DD above a 9.8 $^{o}$C threshold. *Altica litigata* developed most rapidly on *Oenothera* spp. and most slowly on *Gaura* spp. Temperature had a significant positive correlation with development and there were significant temperature by host plant interactions.

Overall, the series of basic and applied studies presented in this dissertation permits the development of a holistic management plan for two established and one emerging pest of an important woody ornamental crop by incorporating the foundations of an Integrated Pest Management (IPM) program.

INDEX WORDS: Crapemyrtle, Lagerstroemia, Altica litigata, Flea beetle, Host plant resistance, Phenology, Degree days, Integrated Pest Management

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B.S., The University of Georgia, 1999

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2005

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May 2005

ACKNOWLEDGEMENTS

This work would not and could not have been completed without the unwavering support provided by my advisor and mentor, Kristine Braman. She has seen me ungracefully progress from a single, carefree, long-haired graduate student to a wife, mother, and home-owning Ph.D.; and has endured it all with great fortitude and care. Thank you to my husband Stephen, who had no idea what he was getting into, for all of the sacrifices he made and for trying (sometimes successfully!) to help me keep my perspective. Calvin Dale, my son, deserves a special thanks and a big kiss for reminding me of what it's all about in the first place and for keeping me *very* humble.

Gratitude goes to those who have helped me along the way: Paul Guillebeau who convinced me to take this journey and who has supported me with humor and gainful employment throughout the process; Detsy Bridges who always greeted me with a smile and helped take care of many pesky details; Danny Finley for his technological wizardry; Michael Seagraves for his sagacity; Elizabeth Reese, Erica Chiao, Erika Kratzer, Greg Hodges, Wayne Gardner, Tracie Jenkins, David Knauft, Beverly Sparks and Ron Oetting for friendship and guidance. Special thanks go to Terry All and all of the office staff in the Entomology Department. Finally, it is certain that this work could not have been finished without the friendship, support, laughter and babysitting by my dear "mom" friends: Ashley Foreman (and River), Michele Stringham (and Annabelle), Lee Ann Kelly (and Ayden), Nicole Routh (and Maya), Rose Pezzuti Dyer (and Franklin) and all the other moms (and babies!) who gave me their words of wisdom and encouragement.

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# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

## Introduction

Unprecedented opportunities exist for the development and adoption of Integrated Pest Management (IPM) for insect pests of ornamental plants in nursery production and landscape settings (Braman and Latimer 2002, Raupp et al. 1993, Latimer et al. 1996 a, b). Heightened awareness and acceptance of IPM practices, improved pesticide chemistries and formulations, and technological advancements are among contributing factors.

Lack of information on the biology and life cycles of the diverse group of pests and beneficials associated with ornamentals reduces adoption of IPM in these systems. This is especially true of insects newly achieving pest status. One such example is a metallic blue chrysomelid beetle, *Altica litigata* Fall, that has become a significant pest of crapemyrtle (Mizell and Knox 1993), particularly in container nurseries (Pettis et al. 2004, Pounders et al. 2004) in Florida, Georgia, Alabama and along the Gulf Coast of the U.S.

*Altica* adults primarily feed on crapemyrtles (Lythraceae) in plant nurseries and on other cultivated and wild Onagraceae and Lythraceae in the nursery and the landscape. Damage from adult feeding resembles “shot holes” in the leaves. Appearance of large aggregations of this flea beetle, primarily in nursery situations, is sudden and unpredictable and can potentially cause complete defoliation of plants in a short span of time.

As a landscape pest, *Altica* typically do not build to damaging levels on crapemyrtle as in a commercial production setting. Indeed, adults and larvae are rarely found on specimen crapemyrtles in the landscape for unknown reasons. Size of the plants is unlikely to be a factor because large crapemyrtles are known to sustain beetle feeding in nurseries (Pettis et al. 2004). Age or physiological state of landscape plants may contribute to low beetle pressure. Alternatively, leaves of crapemyrtle in the landscape may be tougher, have a different nutrient content or different color than in the nursery setting, among other potential differences. The third possibility is that there is simply a smaller concentration of crapemyrtle plants leading to decreased apparency.

The structure of landscapes may affect the visual location of an ideal food source by the beetles. Weedy and cultivated primroses (Onagraceae) on which *Altica* are commonly found en masse generally occur in large swaths, unlike specimen plantings within most landscapes. *Altica* are assumed to emit aggregation pheromones (Bach and Carr 1990, Wan and Harris 1996), so it is possible that beetles do not build to high enough levels on plants in the landscape to attract large numbers of conspecifics.

Aside from feeding on *Lagerstroemia* spp., beetles may become localized pests on other Onagraceae and Lythraceae in the landscape. The reason for this is unknown. Apparency may play a role in this situation as well. Perennials within these two plant families are becoming more popular and are planted in greater numbers, thereby contributing to increased beetle presence.

Beetles could also potentially be transported in the pots of containerized perennials because beetles can complete development on these herbaceous plants and may burrow into the media to pupate. It is unlikely that this occurs on crapemyrtles because larval development of beetles has not been observed on these plants. A final and more likely option is that leaves of herbaceous perennials are available early in the spring when beetles are actively searching for mates and make many and frequent short hops and flights to disperse over a large area in search of host plants. Crapemyrtles develop leaves later in the season and, thus, may temporally avoid the majority of beetle feeding.

Management options for these flea beetles are limited both in the landscape and the nursery. Applying pesticides at the first sighting of *Altica* and repeated treatments at recommended intervals has been the primary control option available. Commonly recommended pesticides are effective on adults and larvae; however, the number of available pesticides available for use to IPM practitioners is diminishing due to regulatory actions.

There are ecological and economic impacts of this chemical-based management practice. Runoff from pesticide applications may cause point and non-point source pollution of water. Secondary pest outbreaks, such as aphids, resulting from pesticide applications diminishing natural controls also may occur. Economically, labor required for pesticide applications costs nurseries significant amounts of money every year as well as increases liability due to worker exposure. The expense of the pesticide products also affects the commercial bottom line. However, risks of not treating infested plants or of treating too late results in unsalable stock in the current season. Additionally, beetle consumption of leaves may compromise growth of the plants.

An ideal management plan of *Altica* flea beetles would include a combination of tactics such as scouting, targeted pesticide applications and use of resistant plant material. Barriers to such management options for the nursery industry include lack of knowledge of: 1) resistant varieties of crapemyrtles; 2) origin of plant resistance; and 3) knowledge of *Altica* biology and ecology which would allow more precise, targeted pesticide applications.

An additional underpinning of a successful IPM strategy is proper pest diagnosis. Uncertain taxonomy of the tribe Alticinae in which *A. litigata* is placed is an additional complicating factor in flea beetle management on Onagraceae and Lythraceae. Because of its associations with many plants in Lythraceae and Onagraceae, control of this chrysomelid beetle on a horticulturally important ornamental such as crapemyrtle (Lythraceae) requires an improved understanding of the classification of the beetle species potentially involved.

Extensive morphological, behavioral, molecular and hybridization studies would be required for a conclusive revision. Additionally, it is likely that a complex of beetle species or biotypes is involved, further complicating proper identification. Information about the biology of *Altica* presented here, however, may be taken into account when the genus is taxonomically revised.

*Altica* infestations in the nursery are unpredictable and can completely devastate an entire crop in a 24-hour period. Due to the economic importance of crapemyrtle specifically, and the increasing importance of the nursery industry in general in the U.S., study of this flea beetle is warranted. Additionally, a flea beetle identified as *Altica litigata*, which is among the taxonomic identifications of the beetles that have been found on crapemyrtle, is being examined as a potential biological control of a wetland weed, purple loosestrife (*Lythrum salicaria* L.). A better understanding of the potential impact of beetles within the genus *Altica* to the nursery industry should precede any wide scale release of the beetle. A literature review of both crapemyrtle and the genus *Altica* follows.

**Crapemyrtle (*Lagerstroemia* spp.) production and economic importance**

Crapemyrtle, *Lagerstroemia indica* L., was first brought to the United States circa 1750 from Asia and was described and named by Carl Linnaeus in 1759 (Byers 1997). Its summer flowers, fall color and bark characteristics make it one of the most popular retail plants in the southern U.S. (USDA hardiness zones 7-10). This exotic woody ornamental grows under a wide range of site and soil conditions and is easy to propagate and grow with sizes ranging from dwarf shrubs to small trees (Mizell and Knox 1999). Liners can be produced in quart pots in one summer with softwood propagation (Byers 1997). *Lagerstroemia* generally thrives in sun and heat, provided there is adequate moisture (Tripp 1996), and there are presently over 75 cultivars in production (Knox 1999) with many more yet to be released.

Crapemyrtle has flourished in mild environments around the world in such places as Iraq, Sri Lanka, Ceylon, Malay, New Guinea, the Philippines, India, China, Australia, Japan and France. The different growth habits and colors of crapemyrtle meet most landscape needs (Byers 1997, Egolf and Andrich 1978). Crapemyrtles provide year-round interest. Spring offers lustrous medium to dark green leaves with textures that range from fine to medium. In summer the plant is covered with abundant long-blooming flowers in colors varying from white, pink, and purple to deep red with 15-20 cm long and 7-12.5

cm wide panicles. Fall leaf color displays are yellow, orange and red often with all colors interspersed on the same tree. The bark is the focal point in winter after leaves have dropped. The smooth gray bark often exfoliates to reveal vari-colored underbark in shades of brown to gray (Dirr 1998).

Spread of the wide variety of crapemyrtle cultivars in the U.S. can be attributed to Donald Egolf, the late research horticulturist with the United States National Arboretum in Washington, DC. His program focused on *Lagerstroemia indica* breeding and selection in order to identify and minimize powdery mildew problems. Dr. John L. Creech of the New Crops Research Branch, U. S. Department of Agriculture, brought *Lagerstroemia fauriei* into the United States in 1956 from a small island, Yaku-shima, off the southern-most tip of Japan. *Lagerstroemia fauriei* L. proved to be strongly resistant to and perhaps even immune to powdery mildew (Byers 1997). The introduction of this resistant plant material led to extensive crossing between *L. fauriei* and *L. indica*, which resulting in the wide variety of crapemyrtle cultivars presently available (Byers 1997, Egolf and Andrich 1978).

Use of extant, commercially available, cultivars of crapemyrtles is ubiquitous within the southern United States; continued development of new cultivars is likely. Dwarf and semi-dwarf cultivars of crapemyrtle have typically been underutilized in the nursery and landscape (Knox 1999). Dwarf, semi-dwarf and medium height plants have been produced by selections from *L. indica* backcrosses and *L indica* crosses with *L. subcosta* to *L. fauriei* germplasm (Mizell and Knox 1993). These new releases may find a niche as bedding and container plants due to their drought resistance and the wide variety of foliage and flower colors. Municipalities favor medium height crapemyrtles for their beauty, relative pest resistance, drought tolerance and for their use under power lines. Uses in the landscape by landscape architects and the general public include focal points as specimen plants. A surge in interest for new landscape material may well push forward additional breeding and marketing efforts, thereby increasing the marketplace impact of crapemyrtle, which is valued at greater than $32 million according to the 1998 census as reported by the National Agricultural Statistics Service (http://www.nass.usda.gov).

Crapemyrtle, in addition to its varied horticultural characteristics, can serve an additional purpose in the landscape. Because the crapemyrtle aphid, *Tinocallis kahawaluokalani* Kirkaldy, is host specific to crapemyrtle, it does not feed on other plants. Crapemyrtle aphids and their accompanying honeydew serve as food for 20 to 30 species of beneficial insect predators and numerous bees and wasps. Thus, crapemyrtle aphids can serve as an alternate food source and encourage beneficials to remain in the area while attracting additional predators and parasites to the area (Mizell and Knox 1999). However, because crapemyrtle aphid is not the preferred host to native species of beneficials, they are likely to leave crapemyrtle periodically to search the surrounding vegetation for their preferred prey on other ornamental plantings. Crapemyrtle is probably the most important woody landscape plant in the southeastern U.S. for augmenting and sustaining many beneficial insects. During excessive drought periods crapemyrtle aphids may be the only food available to many beneficial insects (Mizell and Knox 1999). Breeding programs that could produce plants that were resistant to powdery mildew and possessed reduced susceptibility to crapemyrtle aphid would fit ideally into an IPM landscape.

**Crapemyrtle pests**

Pests on crapemyrtle are relatively few when compared to many popular landscape plants. Japanese beetle, *Popillia japonica* Newman and *Callirhopalus bipunctalus*, an exotic weevil, found in the upper South, can cause feeding damage. *Colaspis floridana*, a brown striped beetle, has been reported as an occasional pest (Mizell and Knox 1999). Asian ambrosia beetle, *Xylosandrus crassiusculus* (Motschulsky), may cause numerous pinpoint size holes along the lower trunks of the plant. Cross sections of the damage reveal galleries as well as staining of the surrounding tissue by introduced fungi (Byers 1997). Crapemyrtle aphid, *Tinocallis kahawaluokalani* Kirkaldy, currently is considered the most serious arthropod pest of *Lagerstroemia* (Alverson and Allen 1992).

Crapemyrtle aphid is host specific to crapemyrtle in the U.S. and apparently was introduced to the U.S. mainland along with the plant (Mizell and Knox 1993). It was first described from the Hawaiian Islands, but can be found throughout the entire range of its host, *L. indica* (Alverson and Allen 1992). The only other two hosts for crapemyrtle aphid are henna, *Lawsonia alba* L., used for making a vegetable dye in India and pomegranate, *Punica granatum* L., in the Philippines (Mizell and Knox 1993). The aphid, which has a tremendous reproductive capacity (Alverson and Allen 1991), produces large amounts of honeydew while feeding. The honeydew, in turn, provides a substrate on the crapemyrtle leaves for the growth of sooty mold (Mizell and Knox 1993). This black mold covers all parts of the plant and by mid-summer flowering may be slowed, and foliage may drop prematurely, rendering them unsalable on the commercial market.

In addition to the above arthropod pests, two fungal diseases frequently infect crapemyrtle in the southeastern U.S., powdery mildew, *Erysiphe lagerstroemiae* E. West, and Cercospora leaf spot, *Cercospora lythracearum* Heald & Wolf. These crapemyrtle diseases may cause premature defoliation in field and container-grown plants as well as specimens in the landscape. This early defoliation compromises crapemyrtle fall color display in ornamental plantings and may reduce plant vigor. Symptoms of powdery mildew are typically seen by mid-May in the Southeast, while symptoms of Cercospora are not manifest until August or early September (Hagan et al. 1997).

In addition to untimely leaf drop, these two fungal pathogens induce other symptoms on the leaves and flowers of crapemyrtle. Cercospora leaf spot infection causes distinct, dark brown, irregular leaf spots that eventually yellows and distorts leaves followed by premature, heavy defoliation (Alifieri 1976). The sensitivity of many cultivars to *Cercospora* is largely unknown. Powdery mildew over winters in the buds of crapemyrtle, and the fungus spreads from the diseased buds to the stems and can expand to cover the entire plant in less than 2 wks under favorable conditions.  Symptoms on young shoots are stunting and floral abortion.  Severely infected leaves and buds will drop within a few weeks, but shoots will typically outgrow the infection. During the hot summer months there may be a period of reduced fungal activity on the plant, but renewed fungal growth can occur in autumn (Sinclair et al. 1993). Powdery mildew is prevalent on crapemyrtle and a related plant, *Lagerstroemia parviflora* Roxb., in the eastern, western and southern United States and is most severe on plants that are shaded or planted as hedges.

Among the three main arthropod pests of crapemyrtle is the flea beetle in the genus *Altica*. Few published reports of this chrysomelid collected from crapemyrtle exist. Accounts in refereed journal articles (Capogreco 1989, Mizell and Knox 1993) only cursorily mention *Altica* as a pest in Florida and along the Gulf Coast. However, within the past decade, reports from nursery owners of large outbreaks of beetles on Onagraceae and Lythraceae have increased. Personal communications have revealed *Altica* beetles from GA, FL, TN, TX, VA, MS, AL, NY and CO. It is certain that these beetles could be found throughout their host plant range. However, the origin of this beetle and the true extent of the population are unknown.

**Ecology, biology and pest status of *Altica* spp**

Following is a seminal review of the ecology and biology of the genus *Altica* as it relates to *A. litigata* and its pest status on Onagraceae and Lythraceae.

Ecology, biology and pest status of *Altica* spp

***Altica* Description**

Many North American species of *Altica* have similar size, shape and/or color (LeSage 2000). Often, *Altica* species are confused with one another due to this close resemblance (Barstow and Gittins 1973). General body color is blue green to green blue with occasional reflections of purplish and bronze tones (LeSage 1995). The elongate to ovoid body is approximately 3-9 mm long. Adults have saltitorial metathoracic legs that allow them to jump and scatter from plants when disturbed. Females of the genus *Altica* are typically larger than males (LeSage 2000). This is supported by samples of *A. litigata* collected from Onagraceae and Lythraceae in Georgia. Sweep net and aspirator samples from reported host plants generally reveal several morphotypes of beetles representing variations in color and size. Larvae of *A. litigata* are dark brown to black, 3-5 mm in length and of typical chrysomelid form.

***Altica* ecology and biology**

*Altica* spp. are terrestrial, oviparous, oligophagous beetles that are often associated with plants in waterlogged areas but generally prefer to pupate in drier soil (Rickelman and Bach 1991, Eberhard et al. 1993). *Altica* that are from a given locality generally have the same life history. They typically have 2-3 generations per season (LeSage 1995, Phillips 1977a), which decreases in higher latitudes (LeSage 1995). *Altica* observed in Georgia on Onagraceae and Lythraceae are multi-voltine and are sexually active throughout the season.

*Altica* overwinter as adults and mature sexually over the winter (LeSage 1995). After emergence from pupal cells in early spring there is a 1-2 week pre-oviposition period in which adults seek out appropriate hosts by making short hops and flights (LeSage 1995). During this time adults are very active. Beetles have been first observed in late March or early April in the southeastern United States.

The mechanism of mate finding is unknown. Hypotheses include the employment of pheromones emanating from adult beetles or frass left on plant leaves, or via visual attraction. Parthenogenesis has been suggested as a method of reproduction when males are rare (Phillips 1979). During copulation the male mounts the back of the female and grasps her prothorax. Multiple copulations are common (LeSage 1995). Males also have been witnessed to mount the backs of other males, antennating for a few moments, and then hopping off (personal observation).

Gravid females lay varying numbers of 1-2 mm long, orange, oblong eggs on the upper and lower surfaces of leaves in small clusters of short horizontal rows (LeSage 1995). *A. litigata* collected in Georgia and observed in the lab and the field typically lay 5-15 eggs in a clutch. Some species of *Altica* oviposit to 100 eggs in a mass and can oviposit up to 400 eggs in a lifetime (LeSage 1995).

Small, darkly pigmented larvae feed exposed on the mesophyll of the underside of a leaf after eclosion (LeSage 1995). These exophitic larvae consume leaves and stems above ground unlike other Alticinae whose larvae may feed on roots internally or externally (Jolivet and Petitpierre 1998, LeSage 1995). Later instar larvae and adults may leave only the main veins of leaves and can occasionally consume the entire stem (LeSage 1995). Observations from the field on primroses (Onagraceae) and gaura (Lythraceae) in Georgia support this. Additionally, adults and larvae display a clear ability to 'monitor leaf age' (Phillips 1977a), preferring young leaves.

Fully mature larvae crawl or drop to the ground and dig a cell in which to pupate (Jolivet and Petitpierre 1998, LeSage 1995). Mucus secreted from maxillary glands is used to make the chamber (LeSage 1995). As the first cool evenings of fall approach adults usually hide under rocks, leaf litter and soil. This is true for the vast majority of *Altica* spp. The only report of beetles overwintering in the egg stage is *A. torquata* LeConte (LeSage 1995).

Many *Altica* species are gregarious, but LeSage (1995) notes that they do not always appear on the same trees or bushes year after year as would be expected. Instead they tend to appear and disappear suddenly and in different locations, which I have also observed of beetle aggregations on crapemyrtles and other Onagraceae and Lythraceae.

The reasons for this are unknown. Due to this lack of understanding of this beetle's behavior, knowledge of *A. litigata* phenology and basic biology is important for successful management.

Aggregation behavior is commonly reported from the Alticinae, such as *A. subplicata* LeConte, a specialist on sand-dune willow, *Salix cordata* [*Salix eriocephala* Michx.] (Bach and Carr 1990) and aggregation pheromones are implicated. Pheromones, however, have not been biochemically demonstrated for any of the reported species. I believe that *A. litigata* forms groups in reaction to pheromones. I based this on observations of plants in the wild and nursery in which there would be clusters of beetles on one plant next to the same species of plant which had few to no beetles on it.

Morris et al. (1992) also suggest that host utilization by *Altica* spp. is linked to aggregation when he observed *A. carduorum* Guer. collecting on stands of host thistle, *Cirsium arvense* (L.) Scop. Damage to *C. aravense,* but not other thistles, elicited aggregation behavior. Also, feces from *C. aravense,* but not other thistles, caused aggregation of the opposite sex. Larval feces also caused aggregation (Wan and Harris 1996).

Morris et al. (1992) additionally proposed that host finding is by random encounter from beetles that have overwintered in *C. aravense* stands. They may make short flights after feeding and may land on another *C. aravense* which attracts more beetles. In effect, he suggests that a 'secondary aggregation' is created and in this way beetle populations spread. Alternatively, the beetle does not land on the correct host (Wan and Harris 1996). Because he intimates that the beetles must contact and bite the plant leaf for recognition of specific host *C. aravense* (Wan and Harris 1996), thus if a beetle lands on a non-host, it will make additional jumps until alighting on a true host. This is a likely scenario for the *Altica* that are a pest on crapemyrtle. This leads to the supposition that beetle encounters with plants may be initially random. However, differences within the chemical or physical makeup of the plant cause the beetle to choose one host over the other.

***Altica* natural enemies**

*Altica* are generally not subject to high rates of parasitism, but natural controls have been noted (LeSage 1995). Flies in the Family Tachinidae may parasitize adult beetles, while wasps of the Braconidae may parasitize adults and larvae. *Lebia* (Coleoptera: Carabidae) larvae may parasitize the pre-pupae of *Altica* (LeSage 1995) and have been observed in Georgia. *Lebia viridis* Say is a known natural enemy of *Altica* flea beetles in northern Florida. The larval carabid acts as an ectoparasitoid of *Altica* prepupae; whereas, adult *Lebia* act as predators of larval *Altica* (Capogreco 1989). *Lebia* closely mimics the genus *Altica* in size and color. I have observed low numbers of adult *Lebia* predating larvae on host plant leaves, accounting for approximately one predator per 50-100 beetles.

Adults and larvae of *Altica* may also be susceptible to an additional entomogenic fungal pathogen. The entomopathogen *Spirotrichum* has been observed to kill large numbers of beetles (LeSage 1995). Natural *Beauveria bassiana* (Balsamo) Vuillemis infestations of adult beetles (identification by Wayne Gardner) have been observed in the field in Georgia, after particularly wet periods. *B. bassiana* epozootics were often a problem when attempts were made to colonize beetles in the lab.

Birds may serve as primary predators of the flea beetles. One organic nursery owner in Atlanta, during the course of this project, frequently used chickens to manage flea beetle populations on crapemyrtle and ornamental loosestrife with reasonable success for the scale of her operation (Ladyslipper Nursery, Atlanta, GA).

### ***Altica* host plant associations**

The genus *Altica* has many host plant associations. One genus is known to feed on plants from up to 100 plant families. Reportedly, albeit rarely, mosses and ferns are fed on by Alticine beetles (Jolivet and Petitpierre 1998). However, the majority of *Altica* are mono- or oligophagous, preferring to feed on only a few plant families and typically have specialized ‘host’ plants for each genus (Jolivet and Petitpierre 1998, Phillips 1977b). *Altica* are most often reported on plants in the Onagraceae, Lythraceae, Vitaceae and Rosaceae. In these cases, they have variably been reported to feed on one, some, or all of the aforementioned plant families (Phillips 1977b). It is presumed that Alticinae evolved from oligophagous insects and became specialized and well adapted on one or a few hosts. Of the subfamilies in Alticinae, *Altica* are the most specialized on food plants (Jolivet and Petitpierre 1998).

Alticinae are observed to feed on entirely different host plants at the end of the season (Jolivet and Petitpierre 1998, personal observations) in both temperate and tropical climes (Jolivet and Petitpierre 1998). *Altica litigata* in Georgia displays the same behavior. It feeds on primrose, *Oenothera* spp., early in the spring as a primary host and seems to utilize crapemyrtle as an alternate host late in the season. *Altica lythri* was shown to oviposit after 7 days on some hosts on which it would not feed (*Fragaria vesca*

L., *Filipendula ulmaria* (L.) Maxim (Rosaceae), *Cirsium arvense* (L.) Scop. and *Calluna vulgaris* (L.) Hull), in one study (Phillips 1977b).

***Altica* taxonomy**

There are greater than 500 genera of alticines worldwide (Duckett 1999). A majority of species of this monophyletic, cosmopolitan genus in the tribe of Galerucinae (Blanco 2001) have been identified from the Paleartic region composed of temperate and cold parts of Eurasia and North Africa as well as several archipelagos and islands in the Atlantic and Pacific oceans. However, future revisions of the Alticinae may cause the shifting of this designation. In addition to the palearctic regions, *Altica* also are known from Africa and North America, but need to be verified to determine if they are the result of introductions. In summary, the current diversity of palearctic flea beetle fauna ‘can be explained through immigration from Asia, the Middle East and Africa, combined with local speciation under the influence of tertiary aridization and quaternary glaciation’ (http://www.sel.barc.usda.gov/Coleoptera/fleabeetles/339.htm). The genus is a relatively recent evolutionary group, most likely evolving with Galerucinae from Chrysomelinae (Jolivet and Petitpierre 1998).

The phylogeny of Chrysomelidae in general is of interest because of host plant associations with angiosperms from a historical perspective. Chrysomelicae: Galerucinae: Alticinae, in particular, is of interest to taxonomists because of the diversity at generic and species levels. For example, the beetle *Disonycha* is interesting because of close associations with specific host plants, mimicry complexes and utility in biological control (Duckett 1999) as with the *Altica* which feed on crapemyrtle and other Onagraceae and Lythraceae.

The *Altica* genus has long been recognized as taxonomically 'difficult' (Phillips 1979, Barstow and Gittin 1973, Phillips 1977a, b). Problems in classification may be due in part to parthenogenesis and sibling species (Phillips 1979). LeSage (1995) covers the extensive revisions and nomenclatural difficulties associated with the genus. Taxonomy of *Altica* is represented by scattered publications dealing with type descriptions, synonymies and descriptions. Less than 10% of the North American species is known and these are the most common species (LeSage 1995).There has been no taxonomic revision of this branch of the Alticinae.

Additionally, the author of the genus *Altica* is uncertain; Konstantinov says that Geoffrey, 1762, is the author of *Altica* and that LeSage (1995) incorrectly attributes it to Muller (http://www.sel.barc.usda.gov/Coleoptera/fleabeetles/339.htm). Geoffrey proposed the name *Altica* in 1762. Since that time, much taxonomic 'refinement' has ensued although there is still a great amount of controversy over the placement and status of species within the genus as a whole (LeSage 1995). Even such characteristics as the male aedeagus which can usually be used to identify to the species level is often not sufficient to differentiate conspecifics such as *A. guatemalensis* Jacoby and *A. ambiens* Leclerc and close relatives. In this case, host plants and external characteristics must be used as well as female genitalia.

Genitalia must be used to separate *Altica* accurately, with males being easier to separate. However, this may pose a problem when populations of males are low or lacking as in at least one instance (Phillips 1979) The sex ratio is usually even, but may be highly baised in favor of females (100:1) such as with *A. tombacina* (Mannerheim) (LeSage 1995). Males are also rare in the Finnish species of *Altica* Muller (Kangas and

Rutanen 1993). When in doubt, the first tarsomere of the front leg is a sexual characteristic, being wider in males than females (LeSage 2000). The genetalia of most female North American species is unknown except for the costate species (LeSage 2000). LeSage (1995) found that use of the spermathecae and styli allowed accurate determinations of all costate species when combined with host plant associations and external features.

General body measurements also have not shown value in differentiating species. Philips (1979) in measurements of *Altica*, found that body dimensions overlapped in many species even though t-tests could separate the populations overall. Color also should not be used to determine species exclusively as it is not a good diagnostic feature (Kangas and Rutanen 1993, Phillips 1979). External characteristics are not very useful due to intra and inter-specific differences in such characteristics as elytral shape and puncturation, among others (Phillips 1979).

Host plant knowledge can facilitate taxonomic identification, although it is thought that many incorrect identifications have been made due to the morphological issue (Phillips 1977b). Taxonomic value has been attributed to host plants as well (LeSage 1995, Phillips 1977a). LeSage (1995) recognized subspecies of the costate *Altica*, ecologically by host plant association, elytral costa, and geographically. However, he did not study the contact zone between two subspecies, but suggests that the likelihood of the existence of sibling species is highly probable. Nothing is known about populations in contact zones (LeSage 1995). I believe that a complex of beetles in the Alticinae, consisting of sibling species or biotypes, feed on plants in Onagraceae and Lythraceae families.

Molecular taxonomic techniques may be the best way to separate species. Combined with morphological, ecological and phenological differences clarifications of relations within beetle complexes may be possible. Molecular analysis is potentially promising using AFLP's or mitochondrial regions of Alticinae for separating species and sub or cryptic species (Bacerra 2004, unpublished data).

***Altica* spp. use in biological control**

Several *Altica* have been considered for biocontrol of weeds, most notabley *A. carduorum* (Guérin) for the control of Canada thistle (LeSage 1995) and several species of L*udwigia* (water primrose) (McGregor et al. 1996). More recently, *A. litigata* has been recommended for the control of purple loosestrife (*Lythrum salicaria* L.) (Debra Hoyme, personal communication 2000). *Lythrum salicaria* L. (Lythraceae), native to Eurasia, is most abundant in cooler areas of North America and is a popular cultivated ornamental plant in Europe and North America. Some beekeepers use it as a source of nectar. In the wild, however, purple loosestrife displaces native wildlife food sources. Chemical control is impractical because of the sensitivity of the freshwater environment, and mechanical control is frequently not feasible because of the extensiveness of the established populations (Batra et al. 1986)

Phillips (1979) made the observation that over half of the *Altica* collection at the Tomlin collection (n=254) was misidentified due to reliance on external characteristics alone. Until a complete taxonomic revision of the *Altica* genus is done and host range and specificity tests have been conducted for the species in question, *Altica* spp. should not be used as weed biological control agents, particularly in light of the economic impact *Altica* presently has on an important woody ornamental in the Southeast and on other herbaceous plants that have become prominent in the green industry/landscape.

Generally, *Altica* are associated with a beetle that looks virtually indistinguishable, except for lighter colored legs. These beetles, collected from crapemyrtle, were sent to Alex Konstantinov of the Smithsonian in 2002 and were identified as *Lysathia ludoviciana* (Fall.), previously *Altica ludoviciana*. They have been recorded from crapemyrtle, *Oenothera*, *Ludwigia* and *Myriophyllum* (McGregor et al. 1996) and are proposed for use as biological control of water primrose. Ratios of approximately 5:2 (*Altica*:*Lysathia*) were collected in sweep net samples from Mississippi (David Boyd, personal communication 2002). Observations of *Lysathia* from Georgia revealed far fewer of these light-legged beetles. Additionally, populations of *Lysathia* were more likely to be found on crapemyrtle and showy primrose than cutleaf evening primrose. *Lysathia* generally feed on aquatic plants in Onagraceae and Lythraceae but, obviously, are capable of utilizing alternate hosts.

Host plant resistance

In order to use chemical insecticides more advantageously, systems for integrated pest management were recommended in 1975 by the National Academy of Sciences, U.S. Department of Agriculture and the Entomological Society of America. Among the various alternatives to chemical insecticides, the use of insect resistant plants, in combination with good cultural practice, is perhaps the most effective, convenient, economical and environmentally acceptable method of insect control.  In addition, it is a method that is completely compatible with both chemical and other biological control measures (Hedin 1977).

Host plant resistance has been recognized since the early 1800's. Three proposed mechanisms account for a plant's resistance to insect damage: non-preference, tolerance and antibiosis. Non-preference is the result of the lack of feeding stimulants or, often, the presence of chemical and physical deterrents and is the most likely mechanism of crapemyrtle resistance to crapemyrtle aphid. There is no evidence of antibiosis, a plant's defensive mechanism that has adverse influence on growth, survival or reproduction of the insect by means of chemical or morphological factors (Hedin 1977), in *Lagerstroemia*, as beetles were capable of feeding and surviving on non-preferred hosts in no-choice trials. Crapemyrtle also does not have any significant morphological characteristics such as pubescent leaf surfaces or sticky sap that would act as morphological deterrents. Leaf toughness, histology, color and surface waxes may have some influence on resistance but until now have not been investigated.

Plants that are inherently less severely damaged or less infested by a phytophagous pest under comparable environments in the field are termed "resistant" (Hedin 1977). While considerable success has been achieved in breeding for resistance to certain key insect pests, little is often known about the chemistry of resistance. Information derived from basic insect-plant interactions from host plant resistance programs contributes materially to the field of insect behavior and control methodology. A resistant plant is not necessarily nutritionally inadequate to the pest, and more frequently than not, nutrition does not appear to be a primary factor in resistance (Hedin 1977). Specific resistance traits such as, leaf toughness or sugar and nitrogen content may be traced back or related to parental genetic strains for crossing purposes.

Much of the research that has been done on host plant resistance to flea beetles has been performed on high value cruciferous crops such as canola and cabbage. Many of these crops have well known leaf chemistries that have been extensively studied from many angles from host plant resistance to biological control agent response to volatiles, leaf surface evaluations and others (Finch and Collier 2001).

Because of observations that *Altica* flea beetles seem to prefer plants with red-colored foliage and, along with other *Altica* species, seem to prefer young foliage, we examined leaf color, toughness and nutrient content for correlation to flea beetle feeding preference. Another reason for choosing these three factors is that plant breeders in the ornamental industry have traditionally received less financial support than field crop counterparts. This is due, in part, to the lower economic status of ornamental crops, although this is changing as the interest in gardening and green industry rapidly grows.

Simple, inexpensive methods of measuring pest resistance among large numbers of seedlings/plants are needed. By choosing such methods, expensive, time-consuming mass-rearings of pest species of interest are avoided. It also permits anyone, including minimally trained technicians, to perform analyses. Targeting simple, easy to perform screening methods for host plant resistance may also allow for a standardized and quantitative method for comparison amongst cultivars, which do not necessarily require an extensive understanding of the underlying biochemical or physical causes of the external factors measured. Additionally, the rapidly growing green industry requires a shorter breeding facility-to-outlet period, which could enhance profits and speed the development and release of improved cultivars.

**Management potential for crapemyrtle pests**

The currently recommended management practices for *Altica* flea beetles in the nursery is general scouting of susceptible plants (Onagraceae and Lythraceae) and pesticide sprays at the first sighting of beetles. This dissertation presents evaluation of short and long term management options for this emergent pest of the burgeoning ornamental industry. Our first objective was to evaluate relatively new and established pesticides for the management of two other primary pests of crapemyrtle, Japanese beetle and crapemyrtle aphid. Secondly, we evaluated cultivars of crapemyrtle for susceptibility to the chrysomelid pest in order to allow growers to more specifically focus their scouting and pesticide treatment efforts and long term to help guide plant breeders in selecting the most resistant breeding stock. Third, we studied the phenology of *Altica* under a controlled temperature experiment on several potential host plants to obtain a better understanding of the biology of this pest and to target the susceptible life stages for management. Observations of host plant associations lend support to weed management plans which eliminate weedy hosts of *Altica* in and around nurseries. This series of basic and applied studies will permit the development of a holistic management plan for an emerging pest of an important woody ornamental crop, *Lagerstroemia* spp.

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# CHAPTER 2

# TEMPERATURE AND HOST PLANT INFLUENCE RATES OF DEVELOPMENT OF *ALTICA LITIGATA* FALL[1]

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[1]Gretchen V. Pettis and S. Kristine Braman. To be submitted to *Journal of Entomological Science*.

**Abstract**

*Altica litigata* Fall (Coleoptera: Chrysomelidae), a nursery and landscape pest, completed development between 15 and 30 $^{o}$C on six weedy or cultivated hosts: *Gaura lindheimeri* Engelman & A. Gray 'Siskyou pink', *G. lindheimeri* 'Corries gold', *G. lindheimeri* 'Whirling butterflies', *Oenothera speciosa* Nutt., *Oenothera laciniata* J. Hill and *Oenothera missourensis* Simms. Development was optimal on *Oenothera* species. Duration of development from eclosion to adult emergence ranged from 13.3 days at 30 $^{o}$C on *O. speciosa* to 64.0 days at 15 $^{o}$C on *G. lindeimeri* 'Whirling butterflies'. Egg eclosion required from 4.5 days at 30 $^{o}$C to 15.8 days at 15 $^{o}$C. The relationship between temperature and rate of development was expressed as a linear thermal unit model for each stage and for combined larval/pupal development. Development parameters varied with host plant. Averaged among the six hosts, larval and pupal development required 237.3 degree-days (DD) above a threshold of 9.2 $^{o}$C. Eggs required 87.5 DD above a 9.8 $^{o}$C threshold. Observation of beetles or feeding injury on indicator plants such as weedy or cultivated *Oenothera* spp. in late winter or early spring can alert nursery or landscape managers to anticipate a new generation within 300- 400 DD above the approximate 10$^{o}$C developmental threshold used for many DD calculator models for landscape and nursery pests.

**Key Words:** *Oenothera* spp., *Gaura* spp., *Lagerstroemia* spp, flea beetle, temperature, development, ornamentals

**Introduction**

*Altica litigata* Fall (Coleoptera: Chrysomelidae) is oligophagus, feeding on numerous plants in the Lythraceae and Onagraceae plant families including weeds and cultivated plants, such as primroses (*Oenothera* spp.). These plants can often be found in the vicinity of commercial nurseries. Adult beetles are 3-5mm long and are a metallic blue to blue-green with enlarged hind femora, which allow them to jump and scatter from plants when disturbed. *Altica litigata* are important pests of crapemyrtles (*Lagerstroemia* spp.; Lythraceae) grown in container nurseries in the southeastern United States (Pettis et al. 2004). Adult *A. litigata* emerge from overwintering pupal cells in the ground as sexually mature adults and fly to suitable ovipositional host plants such as the weed, *O. laciniata* J. Hill (cutleaf evening primrose), or the herbaceous perennials, *O. speciosa* Nutt. (Showy primrose), *O. missourensis* Simms (Missouri primrose). Several *Gaura lindheimeri* Engelman & A.Gray cultivars are suitable hosts as well. Adults migrate to the crapemyrtle plants as secondary hosts and damage plants by chewing small holes in the leaves. Beetles may defoliate entire plants leaving only stems and the mid veins of leaves (Pounders et al. 2004). Oviposition typically does not occur on crapemyrtles. Mated females lay eggs in clusters of 1-15 on the upper and lower surfaces of leaves of the aforementioned herbaceous plants on which the larvae feed after hatching. Once the larvae have reached the third instar, they migrate to the base of the plant where the burrow 1-2 cm into the soil and create a pupal chamber where molting occurs. Approximately 2-3 generations per year occur in areas in which crapemyrtle are extensively grown (LeSage 1995).

Outbreaks of masses of adult beetles on Lythraceae and Onagraceae in commercial nurseries are sudden and can be quite severe. Hundreds of plants may be defoliated in a 24-hour period (Byers 1997). Knowledge of the development of *Altica* spp. flea beetles may optimize management of this pest by improving the nursery producer's ability to predict outbreaks. While commonly recommended pesticides easily control these beetles, knowing when to time applications to avoid large defoliation events could prevent further profit losses.

The objective of our research was to define more closely the relationship between temperature, host plant and development of *A. litigata* to permit prediction of damaging stages of the beetle on landscape and nursery plants. The degree-day approach in predicting phenology of ornamental plant pests has been implemented with success (e.g., Potter and Timmons 1983, Braman et al. 1992, Herms 2004). We provide thermal unit models for development of *A. litigata* reared on six potential 'host plants' commonly found in or near commercial nurseries.

**Materials and Methods**

***Temperature effects on development of Altica litigata on a single host (Trial 1)***

Developmental periods for the eggs, larvae and pupae of *A. litigata* were measured at four constant temperatures: 15, 20, 25 and 30 $^{o}C$ [all ± 0.5 $^{o}C$ and 14:10 (L:D) photoperiod]. $F_1$ progeny of field- collected adults were used. Adults were collected from naturalized stands of *O. speciosa* and *O. laciniata* in Pike and Spalding Counties, GA. Adults were confined to *O. speciosa* cuttings to meet moisture and food requirements and for oviposition in plastic rearing cages described by Klingeman (2001). Eggs deposited during a 24 h period at 24 $^{o}C$ were moved to *G. lindheimeri* 'Whirling butterflies' cuttings using a number 0 fine sable hair paintbrush. Our observations of heavy populations of beetles on this plant in landscape and nursery settings prompted its use in the study. Each 4-5cm long cutting of *G. lindheimeri* 'Whirling butterflies' which had been grown in a screen house in containers in Griffin, GA was placed in a clear plastic petri dish (9cm diameter and 1.5cm high) with a friction fitting lid. Moistened, autoclaved playground sand was placed in the container at a depth of approximately 3mm and the stems of the horizontally placed cuttings were pressed into the damp sand to maintain plant turgor. 10 petri dishes with 10 eggs each (initial n=100) were placed at each temperature. Dishes were checked every 24 hours for eclosion, pupation and adult emergence.

***Host effects on development of <u>Altica litigata</u> at three temperatures (Trial 2)***

Developmental times for larvae and pupae of *A. litigata* were compared among six host plants at three temperatures. Temperatures were 15, 25 and 30 $^{o}$C [all ± 0.5 $^{o}$C and 14:10 (L:D) photoperiod]. Host plants were *Gaura lindheimeri* 'Siskyou pink', *G. lindheimeri* 'Corries gold', *G. lindheimeri* 'Whirling butterflies', *Oenothera speciosa*, *O. laciniata* and *O. missourensis* ). $F_1$ progeny of adults collected from *O. speciosa* in Spalding County, GA were used. Moist autoclaved playground sand was placed at a depth of approximately 1 cm in the bottom of 32 ml translucent plastic cups. Stems of a 2-3 cm cutting of each of the 6 host plants were pressed into the moist sand to maintain leaf turgor. One newly eclosed first instar larvae was placed on the cutting in each container. Clear plastic snap type lids were used to prevent escape of the beetle larvae. Cups were checked every 24 hours for pupation and adult emergence. Each temperature by host plant combination was replicated between 8 and 25 times.

***Statistical Analyses and Thermal Unit Model.***

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. To express the relationship between development and temperature, the reciprocal of development time, in days, was regressed on temperature using a linear least squares technique (Steel and Torrie 1960). Temperature thresholds ($T_o$) for each stage were determined by extrapolation of the regression line to the abscissa. Mean thermal unit requirements (K) for each stage were calculated by taking the mean (across all temperatures) of $K_t$ which was calculated by the following equation:

$$K_t = (T - T_o)^* D_t$$

where T = 15, 20, 25, or 30; $T_o$ = temperature threshold for a particular stage; $D_t$ = mean development time (in days) for a particular stage at temperature T.

## Results

Temperature effects on development of *Altica litigata* on a single host (Trial 1). Although eggs hatched at 15$^o$C, no beetles completed development at this temperature when *G. lindheimeri* was the host (Table 1). *A. litigata* completed development on this host at 20, 25 and 30 $^o$C. Duration of development of the egg stage varied with temperature ($F$=156.46, df=9, 3, $P$<0.0001) from 4.5 to 15.8 days. Larval development required from 12.1 to 36.2 days ($F$=29.67, df=9, 2, $P$<0.0001), while time spent in the pupal stage ranged from 5.8 to 14.3 days ($F$=6.31, df=9, 2, $P$=0.0449). Almost two months were required to complete the life cycle at 20 $^o$C, while less than one month was necessary at 25 or 30 $^o$C ($F$=24.54, df=15, $P$=0.0036).

### ***Host effects on development of Altica litigata at three temperatures (Trial 2)***

Duration of larval development varied with host plant ($F$=18.0; df=17, 5; $P$=0.0001) and temperature ($F$=950.0; df=17,2; $P$=0.0001) with a significant interaction ($F$=6.6; df=17,9; $P$=0.0001). Pupal development was influenced more by temperature ($F$=55.5; df=17, 2; $P$=0.0001) than by host ($F$=1.0; df=17, 5; $P$=0.40) although a significant interaction was observed ($F$= 2.6; df=17,9; $P$=0.01). Complete development also varied with host plant ($F$= 9.5; df=17, 5; $P$=0.0001) and temperature ($F$= 899.1; df=17, 2; $P$=0.0001) with a significant interaction ($F$= 2.1; df=17,9; $P$=0.03). Development was therefore compared within each temperature and host plant combination (Table 2). Duration of larval development ranged from 9.9 days on *O. missouriensis* at 30 $^oC$ to 53.0 days on *G. lindheimeri* 'Whirling butterflies' at 15 $^oC$. Pupal development was most rapid (3.2 days) at 30 $^oC$ when larvae had fed on *O. speciosa*, and longest (13.0 days) at 15 $^oC$ on *O. missourensis*. Complete development ranged from 13.3 days at 30 $^oC$ on *O. speciosa* to 64.0 days at 15 $^oC$ on G. *lindheimeri* 'Whirling butterflies'. Survival (Table 2) was least on *G. lindheimeri* 'Siskiyou Pink' (25.6% averaged among temperatures) and greatest on *O. speciosa* (69.8% averaged among temperatures). On optimal hosts, *O. speciosa* and *O. missourensis*, survival was greatest at 30 $^oC$ ($\geq$ 90%). Survival on all other hosts was greatest at 25 $^oC$ and always least at 15 $^oC$.

### ***Thermal Unit Models***

Regression equations for the reciprocal development times on temperature for each life stage, and values for $T_o$ and K differed when development was averaged among multiple hosts rather than based on that which occurred on a single host (Table 3). $T_o$

values for larval, pupal and complete development derived from trial 1 data on a single host plant cultivar, *G. lindheimeri* 'Whirling Butterflies', were considerably higher than the same values derived from combined trial 2 data that included development on apparently more suitable hosts (*Oenothera* spp.). During trial 1, development was arrested at 15 $^{o}$C, although some larvae survived to the point of burrowing into the sandy substrate prior to pupation, and the base temperature of 14.45 reflects this occurrence. During trial 2, some survival at 15 $^{o}$C did occur even on *Gaura* cultivars and was as high as 50% on *O. missourensis* although development was considerably prolonged at this temperature. The lower thresholds of 9.2 (larval), 9.8 (pupal) and 9.2 (eclosion to pupation) are more similar to the 9.7 (egg) developmental threshold calculated from trial 1 data where egg hatch did occur at 15 $^{o}$C.

**Discussion**

The $F_1$ progeny of *A. litigata* collected from *Oenothera* spp. developed successfully from 15 to 30 $^{o}$C on *Oenothera* spp., but were less able to develop at 15 $^{o}$C on *G. lindheimeri* cultivars. It is possible that the prior parental host relationship affected the success of larvae on *Gaura.* All the potential hosts included in this study are well represented in nurseries, landscapes, wildflower plant mixes, etc. where these highly mobile beetles have access to multiple food and ovipositional hosts. Anecdotal information from growers indicates that beetles are often first observed on Missouri primrose, *O. missourensis*. This species was among the most suitable for the beetle in this study with a high survival rate and short developmental times similar to Showy primrose, *O. speciosa.* We have observed larvae feeding in abundance on Showy primrose in March in the landscape and in roadside wildflower plots. Beetles that attack new growth on crapemyrtles in May and June are probably second generation adults. Whirling butterflies and other *Gaura* cultivars are also commonly infested in late spring through mid summer. Beetle activity declines during the late summer months. Recently perennial plant growers have been treating high populations on susceptible plants as late as October in north Georgia. Sufficient thermal units accumulate in central and north Georgia (average of 4,845 DD above a threshold of 10 $^{o}$C during the last four years from January 1 to October 31 in Griffin (or central), GA) for several generations of the beetle to occur. The apparent summer aestivation may in some situations precede feeding by one or two final fall generations prior to overwintering. Observation of beetles or feeding injury on indicator plants such as weedy or cultivated *Oenothera* spp. in late winter or early spring can alert nursery or landscape managers to anticipate a new generation within 300- 400 DD above an approximate 10$^{o}$C developmental threshold.

The severity of the pest problem attributed to feeding by these beetles has increased substantially during the past decade. The increasing provision of suitable food sources and ovipositional hosts in nursery and landscape situations may have fostered an increase in the population numbers of this insect as has been demonstrated for other chrysomelid beetles recently. *Phaedon desotonus* Balsbaugh, a chrysomelid previously considered rare (Wheeler and Hoebeke 2001), is currently abundant and damaging in nursery and landscape plantings of *Coreopsis* spp. (Braman and Corley 1996, Braman et al. 2002).

**Table 1**. Mean ± S.E. duration of development of *A. litigata* (Coleoptera: Chrysomelidae) on *G. lindheimeri* 'Whirling butterflies' (Trial 1)

| Temp ($^oC$) | Egg | Larva | Pupa | Complete |
|---|---|---|---|---|
| 15 | 15.8 ± 0.4 a | ---- | ---- | ---- |
| 20 | 9.3 ± 0.2 b | 36.2± 1.1 a | 14.3± 1.2 a | 59 ± 0.6 a |
| 25 | 5.2 ± 0.1 c | 17.2 ± 1.0 b | 7.1 ± 0.3 b | 28.8 ± 1.0 b |
| 30 | 4.5 ± 0.2 d | 12.1 ± 0.3 c | 5.8 ± 0.7 b | 22.5 ± 0.8 c |

**Table 2**. Host plant and temperature influences on development of *Altica litigata* (Coleoptera: Chrysomelidae) (Trial 2)

| Temp °C | *G. lindheimeri* 'Whirling butterflies' | *G. lindheimeri* 'Corries Gold' | *G. lindheimeri* 'Siskyou Pink' | *O. speciosa* | *O. laciniata** | *O. missouriensis* |
|---|---|---|---|---|---|---|
| | Larval Development time (days) ± SE | | | | | |
| 15 | 53.0 ± 0 Aa | 46.0 ABa [1] | -- | 40.7 ± 1.8 BCa | 35.0 ± 0 Ca | 39.3 ± 1.8 (7)BCa |
| 25 | 16.0 ± 0.6 Bb | 15.8 ± 1.1 Bb | 17.0 ± 0 B | 10.7 ± 0.2 Ab | 11.3 ± 0.3 Ab | 10.4 ± 0.2 (16)Ab |
| 30 | 11.0 ± 0 ABc | 12.0 ± Ab | 10.0 ± 0 BC | 9.7 ± 0.1 Cb | 10.3 ± 0.3 BCc | 9.9 ± 0.2 (18)BCb |
| | Pupal Development time (days) ± SE | | | | | |
| 15 | 11.0 ± 0 Aa | 11.0 Aa [1] | -- | 12.3 ± 0.3 Aa | 11.0 Aa [1] | 13.0 ± 1.3 (7)Aa |
| 25 | 4.5 ± 0.3 Ac | 4.2 ± 0.5 Aa | 4.0 ± 0 Aa | 5.4 ± 0.7 Ab | 6.2 ± 0.6 Aa | 6.1 ± 0.3 (16)Ab |
| 30 | 8.0 ± 1 Ab | 4.0 Ba [1] | 6.0 ± 3 ABa | 3.2 ± 0.2 Bc | 3.7 ± 0.3 Ba | 4.2 ± 0.5 (18)Bc |
| | Complete (larval/pupal) Development time (days) ± SE (% survival) | | | | | |
| 15 | 64.0 ± 0 Aa (33.3) | 57.0 Ba [1] (11.1) | 57.0 Ba [1] (11.1) | 47.4 ± 4.6 BCa (48.0) | 49.5 ± 3.5 Ca (22.2) | 52.3 ± 1.4 BCa (50.0) |
| 25 | 20.5 ± 0.3 Bb (50.0) | 20.0 ± 0.6 Bb (75.0) | 20.0 ± 0 Bb (50.0) | 16.1 ± 0.5 Ab (70.0) | 17.9 ± 0.5 Ab (58.3) | 16.5 ± 0.3 Ab (68.0) |
| 30 | 19.0 ± 1 Ab (25.0) | 15.3 ± 0.3 BCb (37.5) | 17.0 ± 2 ABb (15.8) | 13.3 ± 0.4 Cb (91.3) | 14.0 ± 0 BCb (23.0) | 14.1 ± 0.4 Cc (90.0) |

* plant cuttings were collected from the field
[1] too few individuals for a SE
*Note*. Means followed by the same capital letters in a row and by the same small letters within a column are not significantly different ($p > 0.05$)

**Table 3**. Linear thermal unit models, threshold temperatures ($T_o$ ) and mean thermal unit requirements (K) for development of each stage of *Altica litigata* Fall

| stage | Equation and $R^2$ | $T_o$, °C | K, DD |
|---|---|---|---|
| Trial 1 (reared on *G. Lindheimeri* 'Whirling butterflies') | | | |
| Egg | $Y^1 = 0.011t - 0.11$<br>$R^2 = .93$ | 9.71 | 87.52 |
| Larval | $Y = 0.01t - 0.08$<br>$R^2 = .91$ | 14.45 | 190.18 |
| Pupal | $Y = 0.01t - 0.14$<br>$R^2 = .62$ | 12.76 | 96.97 |
| Egg eclosion through pupation | $Y = 0.003t - 0.05$<br>$R^2 = .87$ | 13.36 | 301.63 |
| Complete | $Y = 0.003t - 0.03$<br>$R^2 = .89$ | 12.69 | 391.76 |
| Trial 2 (average development over six hosts) | | | |
| Egg[2] | *** | *** | *** |
| Larval | $Y = 0.005t - 0.05$<br>$R^2 = .0.83$ | 9.19 | 213.17 |
| Pupal | $Y = 0.01t - 0.14$<br>$R^2 = .37$ | 9.83 | 75.22 |
| Eclosion to pupation | $Y = 0.003t - 0.03$<br>$R^2 = .85$ | 9.20 | 237.35 |

[1]Y= reciprocal of mean developmental times; t = temperature; $R^2$ = coefficient of correlation.
[2]Data for days for eggs to develop was not collected in this trial

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# CHAPTER 3

# POTENTIAL RESISTANCE OF CRAPEMYRTLE CULTIVARS TO FLEA BEETLE (COLEOPTERA: CHRYSOMELIDAE) AND JAPANESE BEETLE (COLEOPTERA: SCARABAEIDAE) DAMAGE[1]

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[1]Gretchen V. Pettis, David Boyd, S. Kristine Braman, Cecil Pounders. 2003. *J. Econ. Entomol*. 97(3): 981-992. Reprinted here with permission of publisher.

**Abstract**

Field and laboratory studies were conducted to identify potential resistance among crapemyrtles, *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 crapemyrtle, *L. faurei* confers resistance to all pests except crapemyrtle 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*

**Introduction**

The genus *Lagerstroemia* L. encompasses 56 species of crapemyrtle 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 ten species in cultivation as ornamentals. Those species with sufficient cold hardiness to be grown in temperate regions of the U.S. include *Lagerstroemia indica* L., *Lagerstroemia fauriei* Koehne, *Lagerstroemia subcostata* Koehne and *Lagerstroemia limii* Merr. (*Lagerstroemia chekiangensis* Cheng) (Egolf and Andrick 1978). Although crapemyrtle 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 (http://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 crapemyrtle breeding program initiated in Washington, D.C., 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, 1981b, 1986a, 1986b, 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 this point, however, limited evaluation of crapemyrtle cultivars has been conducted for resistance to three of its most common arthropod pests, flea beetles, *Altica* spp. (Coleoptera: Chrysomelidae); the crapemyrtle aphid, *Tinocallis kahawaluokalani* [Kirkaldy], and the Japanese beetle, *Popillia japonica* Newman.

*Altica* spp. are primarily a problem on crapemyrtle 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.

Adult *Altica* spp. are metallic blue to green and have saltitorial metathoracic legs that allow them to jump and scatter from plants when disturbed. Flea beetle feeding on crapemyrtle 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 crapemyrtle, is believed to migrate from wild herbaceous hosts in the Onagraceae and Lythraceae families. Several weed species that may grow in or around crapemyrtle 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 crapemyrtle (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 crapemyrtle 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 crapemyrtles 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 crapemyrtle 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 over 300 species of wild and cultivated plants (Hawley and Metzger 1940, Fleming 1972) and crapemyrtle 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 migrate 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 mid summer (Tashiro 1987). After emergence, adult beetles disperse into landscapes and nurseries from surrounding areas. Beetles aggregate on crapemyrtles, 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 crapemyrtle 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 the *Altica* spp. and Japanese beetle and to compare these data to published information on susceptibilities to disease and other insect pests. The purpose of these studies was to identify germplasm with greater resistance.

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

**Materials and Methods**

***Flea Beetle Choice Trials***

Crapemyrtle 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 crapemyrtles in 11.4- and 26.5-liter containers. The third nursery is located in north Alabama and specializes in crapemyrtle liner production. Ratings were taken from three terminal branches of ten randomly selected trees from all available crapemyrtle cultivars at the two Mississippi nurseries. Ratings were taken from one terminal branch of ten 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 crapemyrtle 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 if the beetles fed on crapemyrtle cultivars when given only one option.

*Trial 1.* Twenty-two cultivars of crapemyrtles 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, 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 Inc., 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 materials used in this trial were taken from containerized crapemyrtles 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, 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 crapemyrtles 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, 14:10 (L:D) h 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 2 layers of cheese cloth 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 seven 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 crapemyrtle to Japanese beetles.

#### ***Japanese Beetle 1999 (Choice)***

Seventeen cultivars of crapemyrtle 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 female, two male) were confined on containerized plants in translucent cloth sleeves that covered approximately 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 percent 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 fourteenth 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', '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 above 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 greater than 4. ‘Twilight’ had the highest damage rating (4.97) of the twelve cultivars and was significantly higher ($F = 230.53$, 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 below 1.17 (Fig. 5) at the Dearing, GA, location. 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 above 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 less than 10% damage ($F = 4.66$, $df = 27$, $P < 0.0001$) were ‘Biloxi’, ‘Lipan’, ‘Tuscarora’ and ‘Tonto’. Cultivars that showed greater than 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 less than 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 less than 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 greater than 17% were, 'Red Rocket', 'Victor', 'Byers Standard Red', 'Byers Wonderful White', 'Raspberry Sundae', 'Zuni' and 'Seminole' (Fig. 11).

## 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 damaged 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’, ‘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 crapemyrtles to *Altica* spp. feeding follows a general trend based on parentage of the crapemyrtle cultivars (Table 2). Among each nursery rating, those crapemyrtle 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 crapemyrtle 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 percent damage per beetle. Several cultivars, 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 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 are apparently resistant to feeding by Japanese beetles.

Hagan et al. (1998) rated 43 cultivars of crapemyrtle for susceptibility to powdery mildew and Cercospora leaf spot in Alabama. During 3 yr of evaluation *L. indica* x *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* x *fauriei* hybrids, ‘Apalachee’, ‘Basham’s Party Pink’ and ‘Caddo’ as well as two *L. indica* cultivars, ‘Cherokee’ and ‘Glendora White’. Other *L.indica* x *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 crapemyrtle cultivars released by the National Arboretum show variation, including high levels of resistance, to pests which were not evaluated previously.

Mizell and Knox (1993) examined 37 cultivars of crapemyrtle for susceptibility to crapemyrtle 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 x L. faurei* cultivars to crapemyrtle aphid is an exception to the resistance of the National Arboretum cultivars to the other major pests of crapemyrtle. Individual cultivars with *L. faurei* parentage, however, that exhibited lower crapemyrtle 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 crapemyrtle. 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), such as with the Minolta chroma meter. In many cases 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 crapemyrtle, *L. faurei* seems to confer resistance, with the exception of crapemyrtle 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 (e.g., ‘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.

**Figure legends**

**Figure 1**. Mean damage rating (n = 30) from flea beetle feeding on crapemyrtle cultivars in 25 gal containers. Bars with the same letter are not significantly different at $p = 0.05$ (Fisher's LSD test).

**Figure 2.** Mean damage rating (n = 30) from *Altica* spp. feeding on crapemyrtle 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).

**Figure 3**. Mean damage rating (n = 30) from *Altica* spp. feeding on crapemyrtle 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).

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

**Figure 5**. Mean damage rating (n = 6) from *Altica* spp. feeding on crapemyrtle cultivars on 94.6-liter containers in, Dearing, GA. Bars with the same letter are not significantly different ($p > 0.05$) (Fisher's least significant difference [LSD] test).

**Figure 6**. Mean percent damage per metallic *Altica* spp. (n = 5) to crapemyrtle 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). Non-transformed means are presented.

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

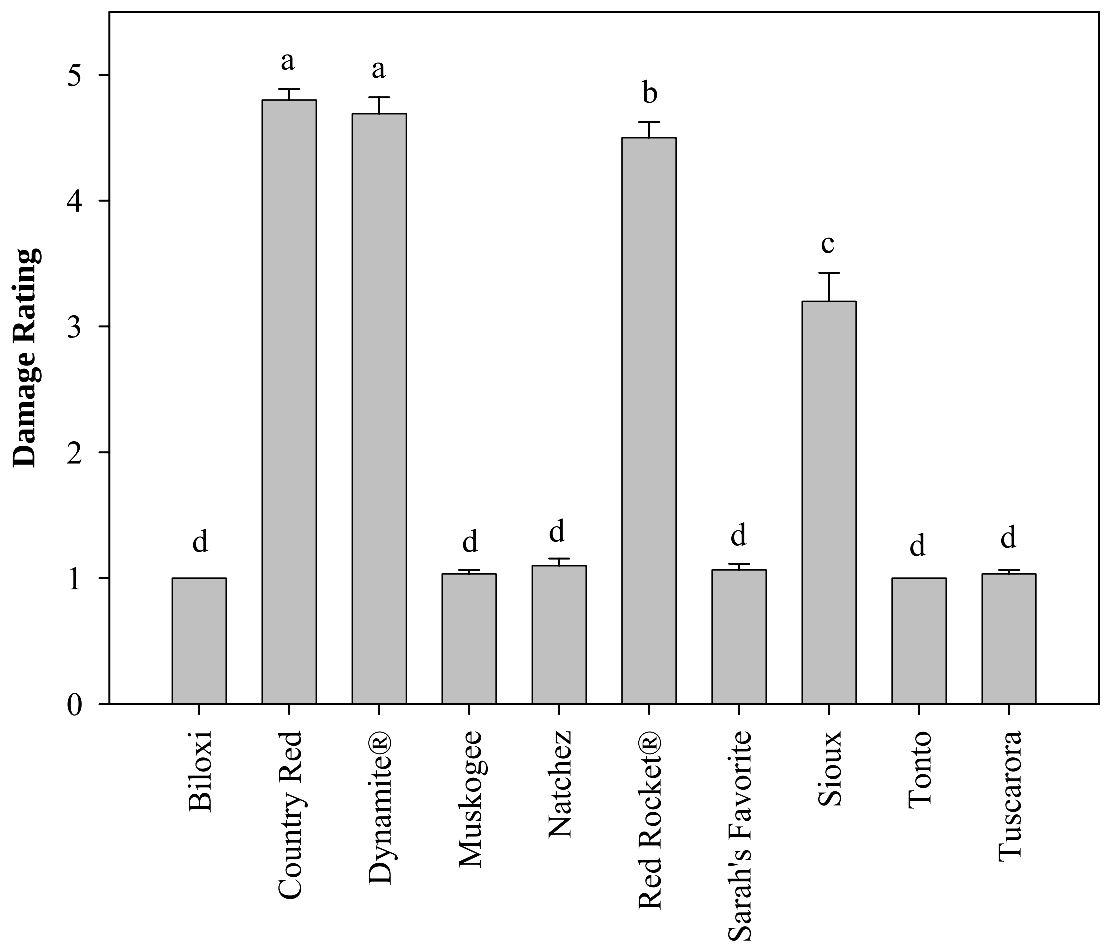
**Figure 8**. Mean damage rating (n =6) from *Altica* spp. feeding on crapemyrtle cultivars in 32 ml clear plastic cups. Bars with the same letter are not significantly different ($p > 0.05$) (Fisher's least significant difference [LSD] test).

**Figure 9**. Mean damage rating (n =4) from *Altica* spp. feeding on crapemyrtle 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).

**Figure 10**. Mean percent damaged terminals (n=6) from Japanese beetle to crapemyrtle cultivars. Arcsine-square-root transformation of means with the same letter are not significantly different ($p > 0.05$) (Fisher's least significant difference [LSD] test). Non-transformed means are presented.

**Figure 11**. Mean percent damage (n=6) from Japanese beetle to crapemyrtle cultivars. Arcsine-square-root transformation of means with the same letter are not significantly different ($p > 0.05$) (Fisher's least significant difference [LSD] test). Non-transformed means are presented

**Figure 1**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3
4
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a
b
c
d
d
d
d
d
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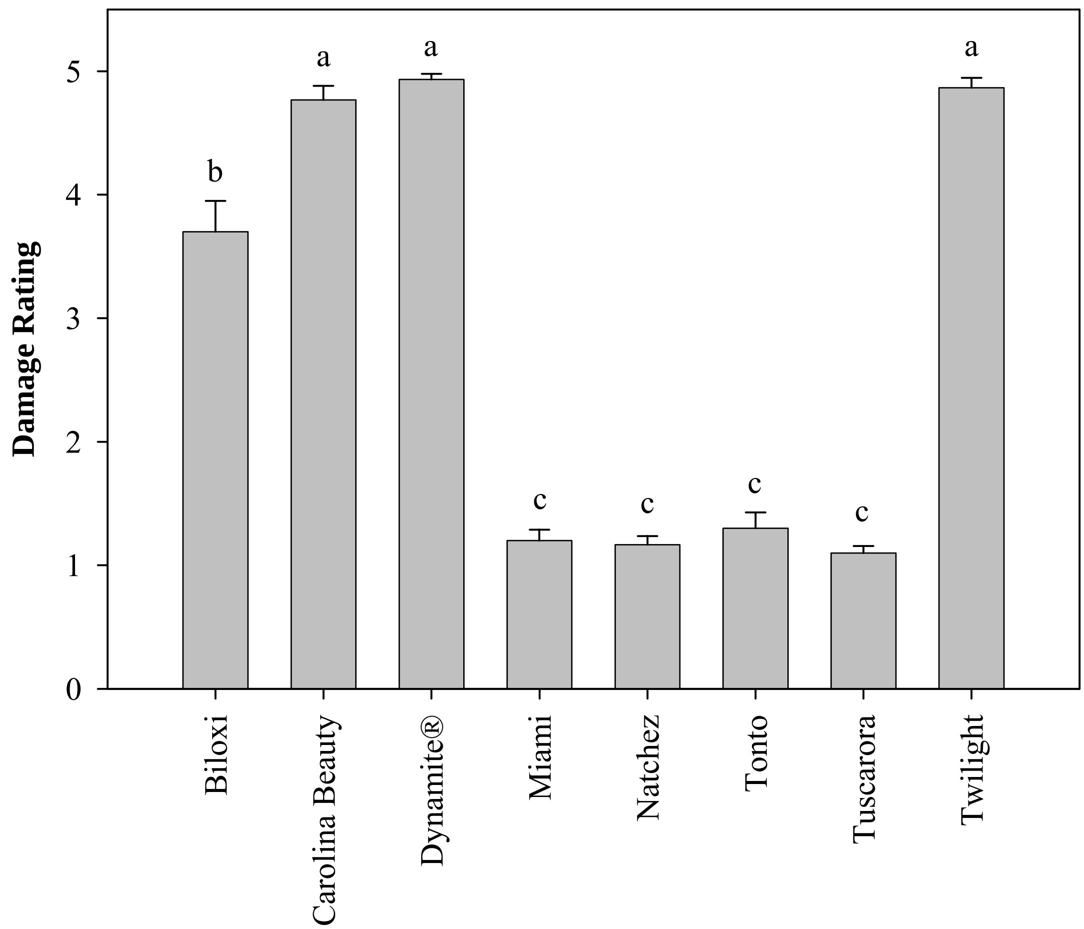
Country Red
Dynamite®
Muskogee
Natchez
Red Rocket®
Sarah's Favorite
Sioux
Tonto
Tuscarora

**Figure 2**


Damage Rating
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2
3
4
5
b
a
a
c
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c
c
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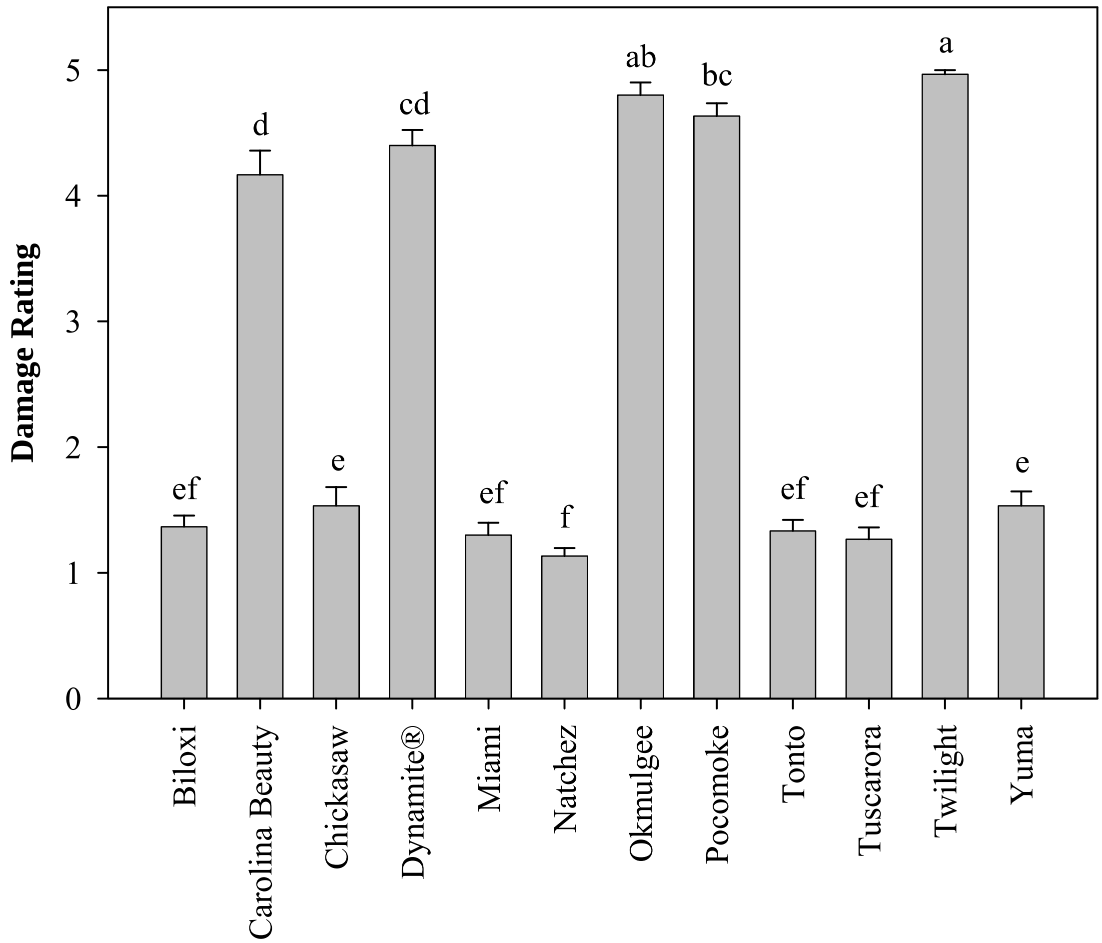
Dynamite®
Miami
Natchez
Tonto
Tuscarora
Twilight

**Figure 3**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3
4
5
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f
ab
bc
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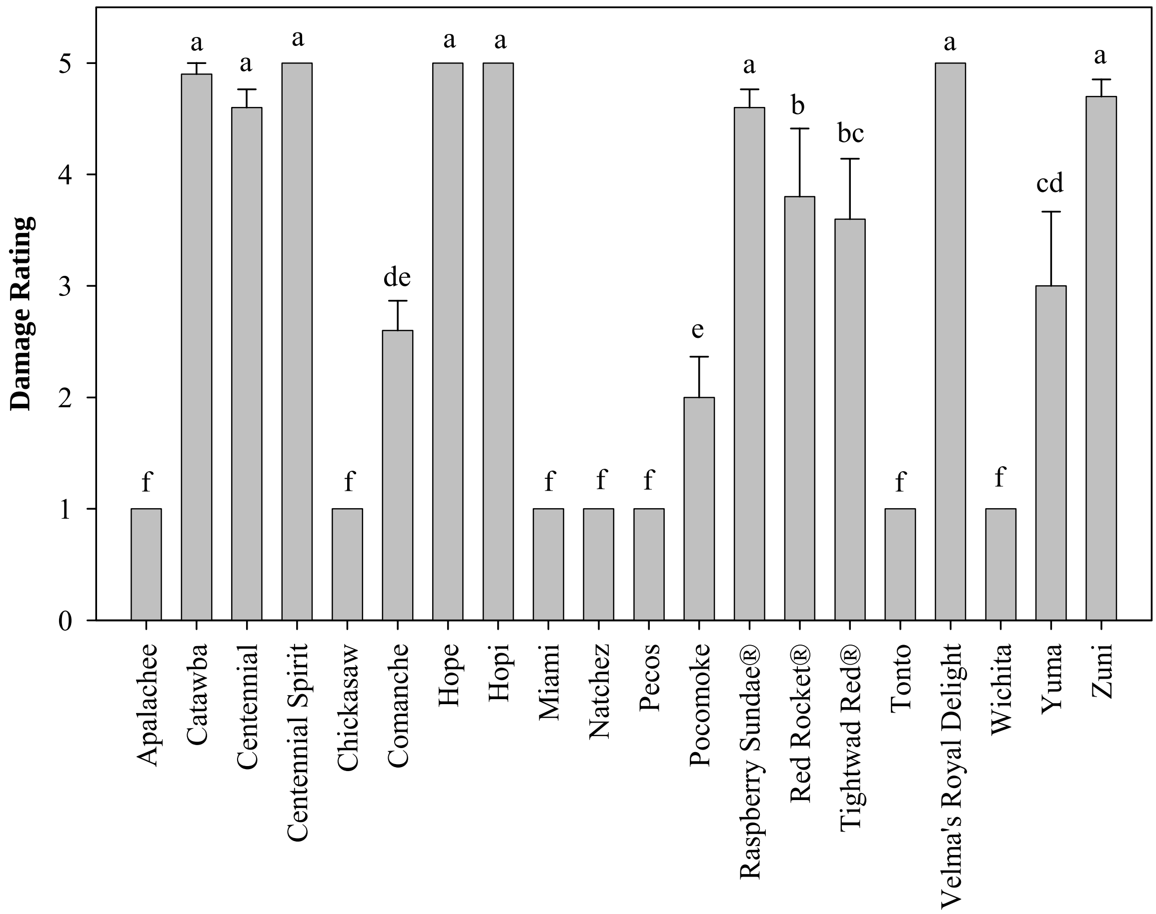
a
e
Biloxi
Carolina Beauty
Chickasaw
Dynamite®
Miami
Natchez
Okmulgee
Pocomoke
Tonto
Tuscarora
Twilight
Yuma

**Figure 4**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3
4
5
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a
a
a
f
de
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a
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f
f
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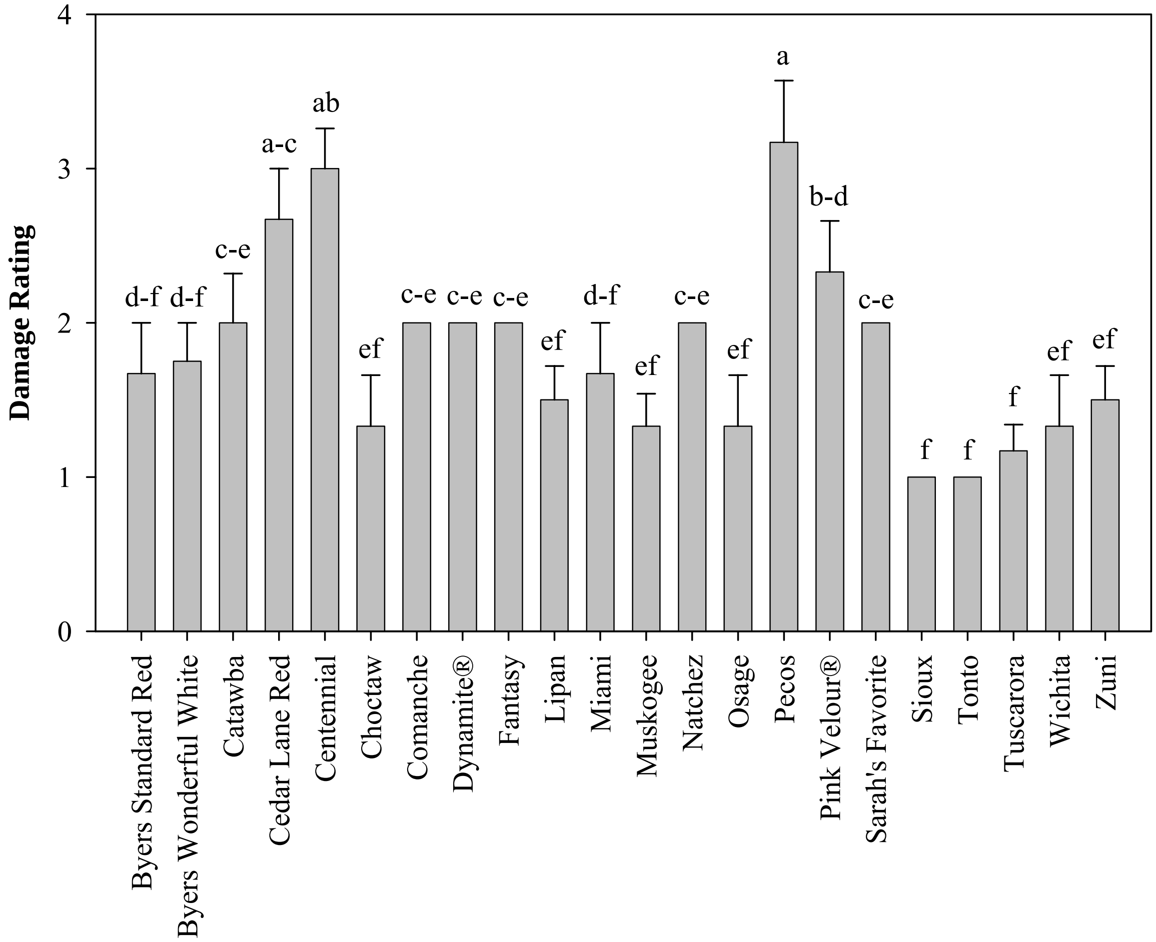
b
bc
f
a
f
cd
a
Apalachee
Catawba
Centennial
Centennial Spirit
Chickasaw
Comanche
Hope
Hopi
Miami
Natchez
Pecos
Pocomoke
Raspberry Sundae®
Red Rocket®
Tightwad Red®
Tonto
Velma's Royal Delight
Wichita
Yuma
Zuni

**Figure 5**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3
4
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c-e
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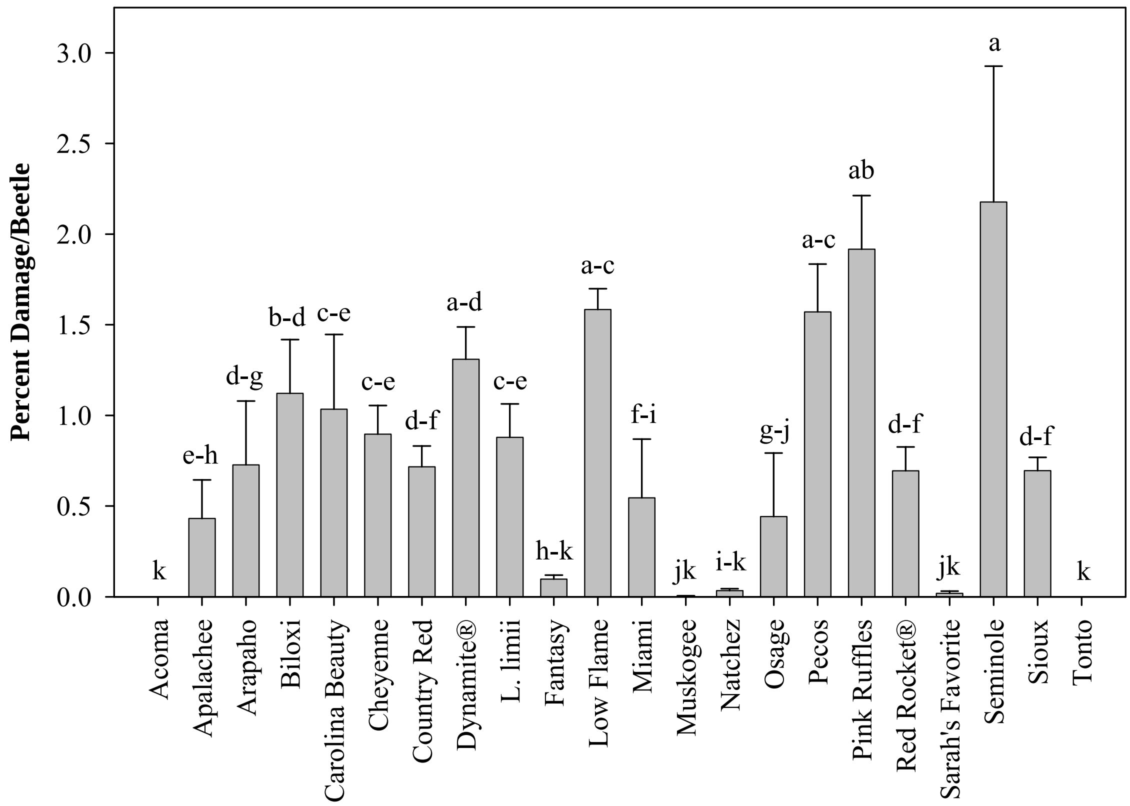
c-e
ef
d-f
ef
c-e
ef
a
b-d
c-e
f
f
f
ef
ef
Byers Standard Red
Byers Wonderful White
Catawba
Cedar Lane Red
Centennial
Choctaw
Comanche
Dynamite®
Fantasy
Lipan
Miami
Muskogee
Natchez
Osage
Pecos
Pink Velour®
Sarah's Favorite
Sioux
Tonto
Tuscarora
Wichita
Zuni

**Figure 6**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0.5
1.0
1.5
2.0
2.5
3.0
k
e-h
d-g
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c-e
d-f
a-d
c-e
h-k
a-c
f-i
jk
i-k
g-j
a-c
ab
d-f
jk
a
d-f
k
Acoma
Apalachee
Arapaho
Biloxi
Carolina Beauty
Cheyenne
Country Red
Dynamite®
L. limii
Fantasy
Low Flame
Miami
Muskogee
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Osage
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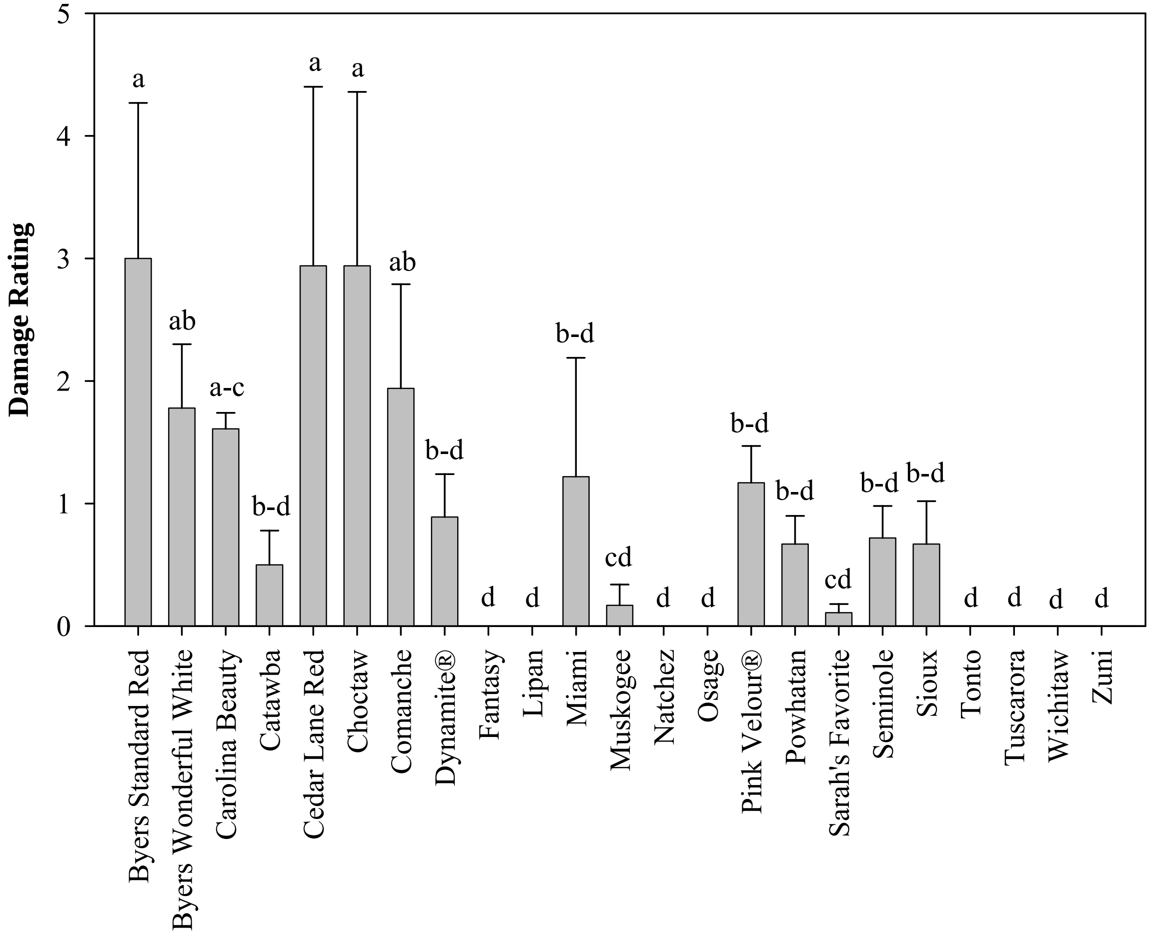
Red Rocket®
Sarah's Favorite
Seminole
Sioux
Tonto

**Figure 7**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3
4
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ab
a-c
b-d
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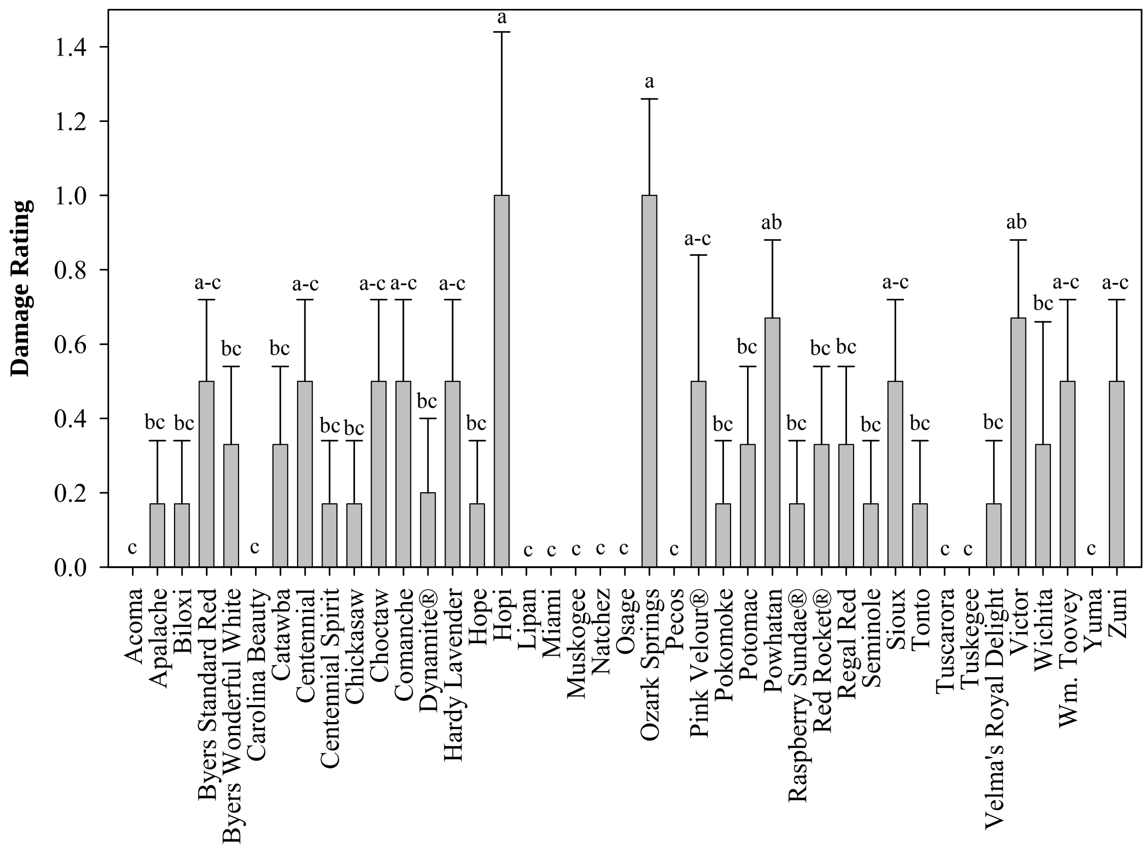
cd
d
d
b-d
b-d
cd
b-d
b-d
d
d
d
d
Byers Standard Red
Byers Wonderful White
Carolina Beauty
Catawba
Cedar Lane Red
Choctaw
Comanche
Dynamite®
Fantasy
Lipan
Miami
Muskogee
Natchez
Osage
Pink Velour®
Powhatan
Sarah's Favorite
Seminole
Sioux
Tonto
Tuscarora
Wichitaw
Zuni

**Figure 8**


Damage Rating
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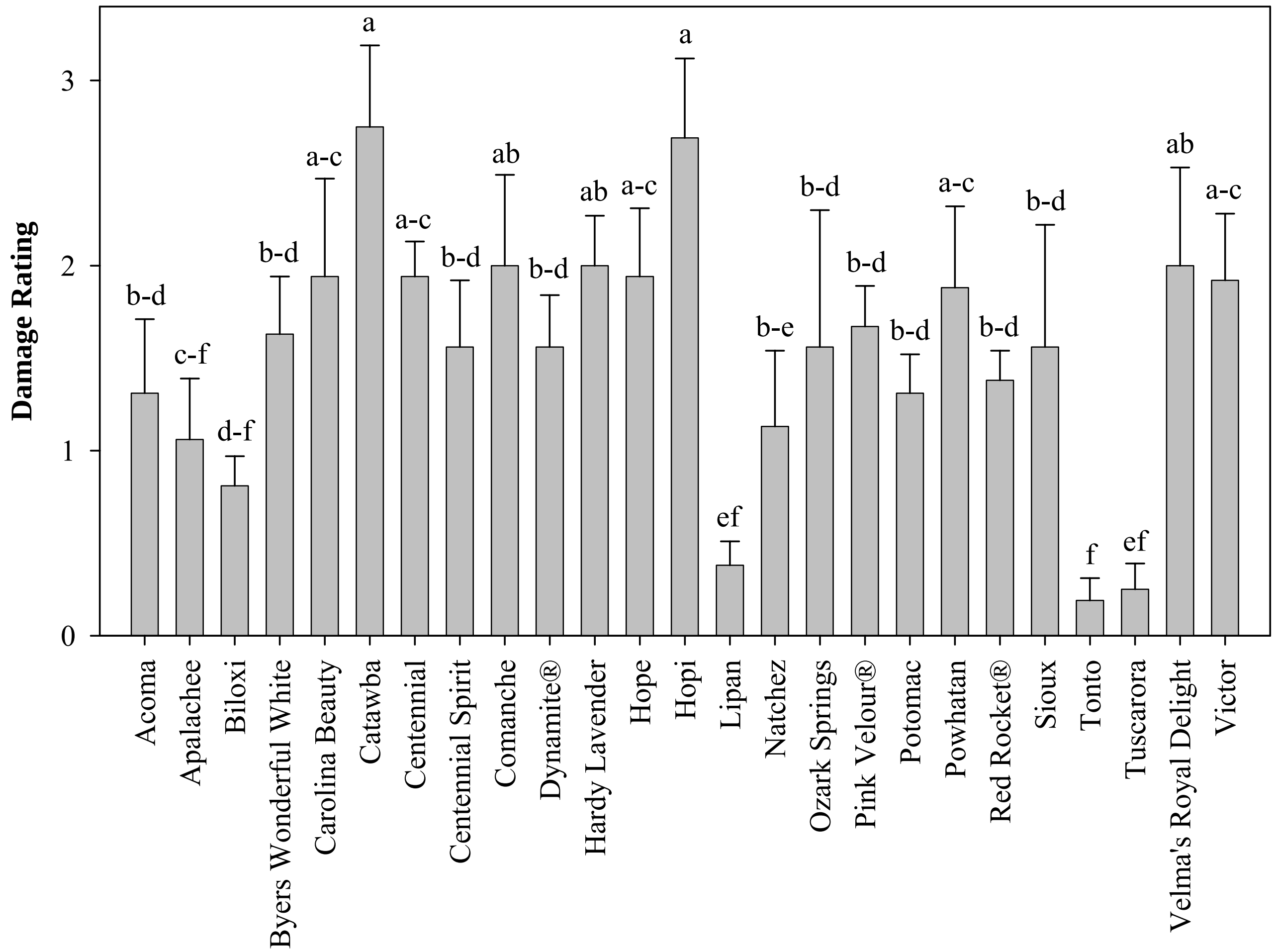
0.6
0.8
1.0
1.2
1.4
Acoma
Apalache
Biloxi
Byers Standard Red
Byers Wonderful White
Carolina Beauty
Catawba
Centennial
Centennial Spirit
Chickasaw
Choctaw
Comanche
Dynamite®
Hardy Lavender
Hope
Hopi
Lipan
Miami
Muskogee
Natchez
Osage
Ozark Springs
Pecos
Pink Velour®
Pokomoke
Potomac
Powhatan
Raspberry Sundae®
Red Rocket®
Regal Red
Seminole
Sioux
Tonto
Tuscarora
Tuskegee
Velma's Royal Delight
Victor
Wichita
Wm. Toovey
Yuma
Zuni

**Figure 9**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2
3
b-d
c-f
d-f
b-d
a-c
a
a-c
b-d
ab
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a-c
a
ef
b-e
b-d
b-d
b-d
a-c
b-d
b-d
f
ef
ab
a-c
Acoma
Apalachee
Biloxi
Byers Wonderful White
Carolina Beauty
Catawba
Centennial
Centennial Spirit
Comanche
Dynamite®
Hardy Lavender
Hope
Hopi
Lipan
Natchez
Ozark Springs
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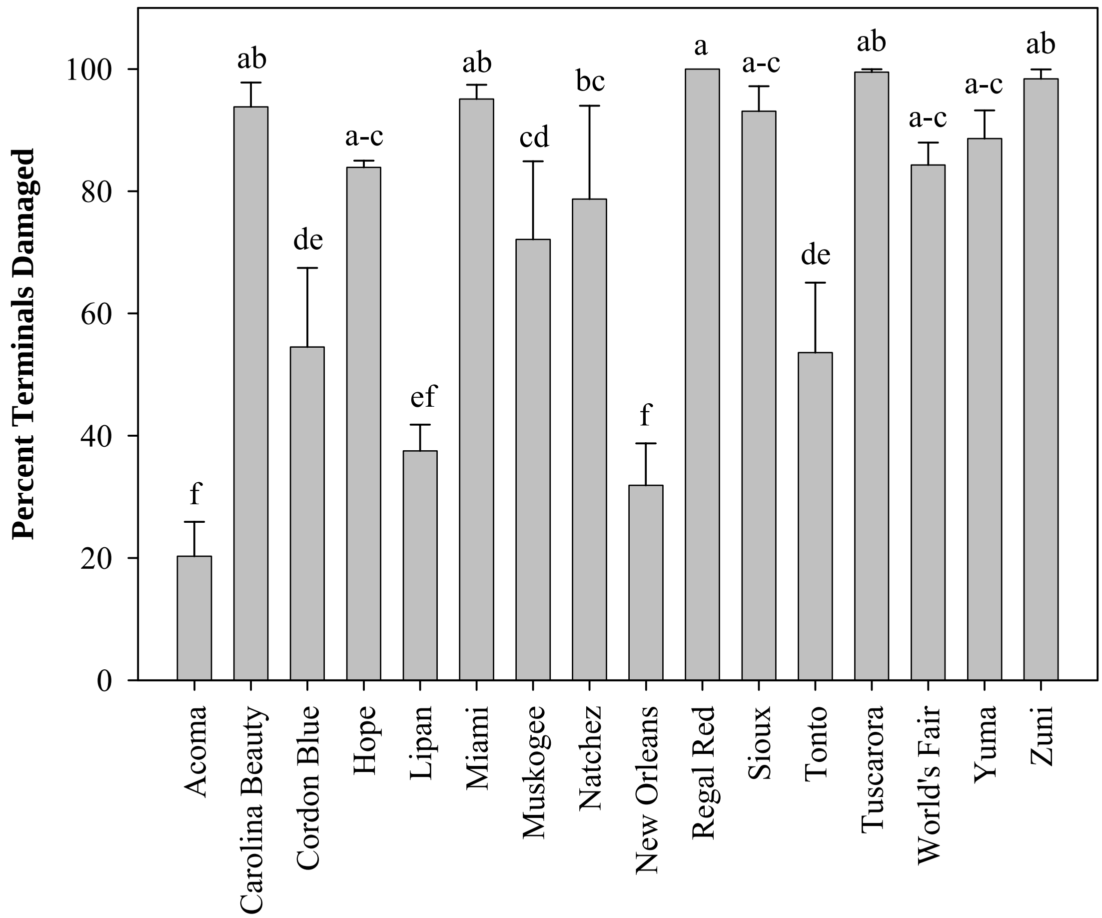
Potomac
Powhatan
Red Rocket®
Sioux
Tonto
Tuscarora
Velma's Royal Delight
Victor

**Figure 10**


Percent Terminals Damaged
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20
40
60
80
100
f
ab
de
a-c
ef
ab
cd
bc
f
a
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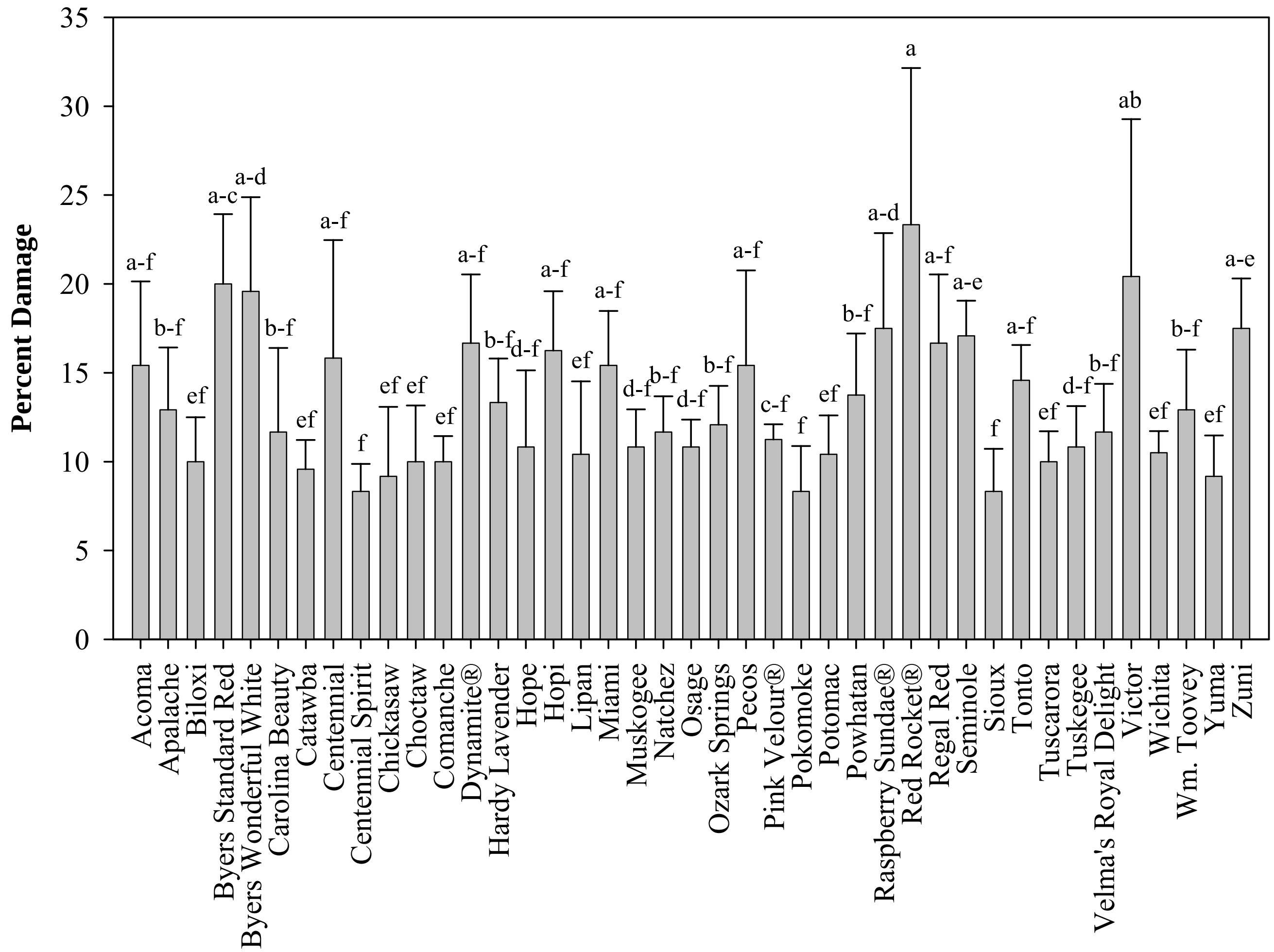
de
ab
a-c
a-c
ab
Acoma
Carolina Beauty
Cordon Blue
Hope
Lipan
Miami
Muskogee
Natchez
New Orleans
Regal Red
Sioux
Tonto
Tuscarora
World's Fair
Yuma
Zuni

**Figure 11**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10
15
20
25
30
35
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b-f
ef
a-c
a-d
b-f
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ef
d-f
b-f
ab
ef
b-f
ef
a-e
Acoma
Apalache
Biloxi
Byers Standard Red
Byers Wonderful White
Carolina Beauty
Catawba
Centennial
Centennial Spirit
Chickasaw
Choctaw
Comanche
Dynamite®
Hardy Lavender
Hope
Hopi
Lipan
Miami
Muskogee
Natchez
Osage
Ozark Springs
Pecos
Pink Velour®
Pokomoke
Potomac
Powhatan
Raspberry Sundae®
Red Rocket®
Regal Red
Seminole
Sioux
Tonto
Tuscarora
Tuskegee
Velma's Royal Delight
Victor
Wichita
Wm. Toovey
Yuma
Zuni

**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[1] | Japanese beetle resistance[2] |
|---|---|---|---|
| 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[3] | Unknown |
| Chickasaw | Yes | Moderately resistant[3] | 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[3] | Unknown |
| Miami | Yes | Moderately resistant | Moderately susceptible |
| Muskogee | Yes | Resistant | Moderately resistant |
| Natchez | Yes | Resistant | Moderately susceptible |
| Okmulgee | No | Moderately susceptible[3] | Unknown |
| Osage | Yes | Resistant | Moderately resistant |
| Ozark Springs | No | Moderately susceptible | Moderately susceptible |
| Pecos | Yes | Moderately susceptible | Moderately susceptible |
| Pink Ruffles | No | Moderately susceptible[3] | 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[3] | 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[3] | 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[3] | Moderately susceptible |
| World's Fair | No | Unknown | Moderately susceptible |
| Yuma | Yes | Moderately resistant | Moderately susceptible |
| Zuni | Yes | Moderately susceptible | Unknown |

[1]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
[2]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
[3]Represented in only one trial

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

| | | Parentage | | |
|---|---|---|---|---|
| | | *L. indica* | *L. indica* X *L. faurei* | *F*, df, *P* |
| *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±10.68 a | *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 |

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# CHAPTER 4

# PROSPECTIVE RESISTANCE MECHANISMS OF CRAPEMYRTLE TO *ALTICA LITIGATA* FALL

## Introduction

Pettis et al., 2004, assessed relative preference of *Altica litigata* Fall and Japanese beetle to *Lagerstroemia* spp. in choice and no-choice trials and found significant differences in feeding susceptibility. Beetle preference was negatively correlated with *Lagerstroemia faurei* parentage and antixenosis was proposed as the type of resistance. Non-preference was suspected because, in no-choice trials, beetles enclosed on some non-preferred hosts, based on field observations, would feed with no apparent ill effects. In the absence of obvious chemical deterrents this study attempts to link *Altica litigata* feeding to three prospective resistance mechanisms: leaf color, leaf toughness and plant quality as based on nutritional content of leaves.

The value of crapemyrtle in the horticultural industry exceeded 32 million dollars in 1998 (http://www.nass.usda.gov) and plant breeders continue to develop new cultivars at a rapid pace to meet consumer demand. The new varieties of crapemyrtle include a large number of dwarf cultivars and particularly cultivars with red tinted leaves and red flowers (Michael Dirr, personal communication). Suburbs and their concomitant landscaping continue to expand throughout the southern United States into the regions where crapemyrtle is grown; add to this the burgeoning green industry within these areas and the value of *Lagerstroemia* spp. is bound to increase.

As new cultivars become available, it is important to evaluate them in light of susceptibility to damaging landscape and nursery pests. Primary and secondary compounds as well as physical properties of the plant can all contribute to plant resistance (Coley 1983). Measurement of leaf waxes and volatiles, which have been performed on high value crucifer (Brassicaceae) crops such as canola and cabbage (Eigenbrode et al. 2000, Chapman & Bernays 1989, Renwick & Huang 1995, Schoonhoven 1982, Stok 1980, Smith 1989, Visser 1986) can be time consuming and difficult to measure accurately, requiring expensive specialized equipment. Many agronomic crops, unlike most ornamentals, have well profiled leaf chemistries that have been extensively studied from many angles for host plant resistance (Visser 1986). For these reasons, we examined factors that may influence the host plant resistance of certain crapemyrtle cultivars to flea beetle and Japanese beetle feeding and which do not require expensive equipment. Additionally, measurements can be conducted quickly in the field or lab for the expediting of assessing relative resistance of extant and emerging crapemyrtle cultivars.

It is first important to understand how insects discriminate among a mixture of plant species. Herbivorous insects may use vision and be attracted by colors, reflectance, or plant or leaf form over long distance. As the insect nears a potentially desirable host the olfactory system is triggered by a large number of volatiles, such as thiocyanates or mustard oils. Leaf alcohols may help the insect determine if the leaf is suitable from an even closer range. If the insect then decides to land or stop on the leaf taste and olfaction work together to aid the insect in determining the suitability of the host plant for feeding (Thorsteinson 1960, Mitchell 1988).

Because observations of *Altica* flea beetles have indicated that they prefer plants with red colored foliage and along with other *Altica* species prefer young foliage (Pettis et al. 2004, Wan 1996, Gannon 1994, Philips 1976) both color and leaf toughness were examined to evaluate if these factors correlate with flea beetle feeding. Additionally, plant quality has been suggested as an important factor in insect food selection (McNeill & Southwood 1978, Tabashnik 1982, Bryant et al. 1987, Lindroth et al. 1997, Ritchie 2000); hence, leaf nutrients were also quantified. Intraspecific variation of feeding preference has not previously been quantified using precise quantitative measurement of color as measured here with a Minolta tristimulus colorimeter.

With the advent of the tristimulus colorimeter, objective measurement of color became more uniform and less subject to the vagaries of human error. Differing lighting conditions, inexperience, or visual fatigue has been shown to influence "true" color determination (Kwolek 1982, Aulenbach 1973). Tristimulus color values have been used extensively in food science to evaluate quality. Color has also been correlated with certain chemical aspects of fresh produce such as peppers (Gómez-Ladrón de Guevara et al. 1996), ripeness of peaches (Aulenbach & Worthington 1973, respectively), tomato skin color for Lycopene content (Meir et al. 1992) and to link leaf color to chlorophyll content of watercress (Arias 2000). Using the colorimeter that is already widely accepted in the textile and food industries could standardize the evaluation of crapemyrtle cultivars as well as many other valuable ornamental crops.

Another reason for choosing to measure color as a resistance factor is that leaf and flower color have a great impact on the marketability of crapemyrtle. There has been a significant increase in the number of available red leaved cultivars in the past few years with the likelihood of more due to the popularity of these varieties. However, classifying the color of leaves has typically been performed with the aid of the Royal Horticultural Society color charts and inconsistencies abound based on lighting and observer differences. Use of a quantitative measuring device would hopefully ameliorate those problems and standardize color reporting.

## Materials and methods

### *Plant material*

For all trials conducted, leaves were collected from one year old containerized plants grown in Griffin, Georgia, in a randomized complete block design with six reps of 41 cultivars. Plants were grown in three gallon pots with in Metromix 300 potting soil with starter fertilizer on weed barrier cloth and watered as needed with overhead irrigation. No further fertilizer applications were made. Leaves were collected in July from twenty four cultivars prescreened to represent a complete range of beetle susceptibility in no choice trials. After collection, leaves were kept in plastic zip top bags in a cooler with ice until measurements could be taken. Flea beetle no-choice feeding trials (Pettis et al. 2004) were conducted concurrent with host plant resistance assessments. Four blocks of 24 cultivars were measured for the leaf color trial and leaf toughness trial. For the leaf nutrient trial, leaves from each of the 24 cultivars were pooled across six blocks.

### *Leaf color measurements*

A Minolta model CR-200 colorimeter (Minolta, Ramsey, NJ) was used to measure lightness (L* value), redness/greenness (a* value) and yellowness/blueness (b* value). The CIE L*a*b* color space  (Commission Internationale de l'Eclairage ) was chosen from among other color measurements systems as it is the most widely used and accepted method for measuring and ordering object color. L*a*b* has also been shown to be sufficient to assess plant color differences (Kwolek 1982).

Three readings were taken from the adaxial surface of the $4^{th}$ newly expanded leaf to the left of the midrib in blemish free areas of the leaf tip, middle and base. Even though Kwolek, 1982, found little “within-leaf variation” and averaged readings across leaves, we felt that the leaf tip represented the reddest part of crapemyrtle leaves (hence potentially more attractive to flea beetles), so only leaf tip values were used for analysis. The colorimeter was calibrated under D65 diffused illumination conditions with a 0° viewing angle using a Minolta white standard plate before initial measurements (Minolta Camera Co. 1987). Values for a* were squared prior to analysis to stabilize heterogeneity of variances. Untransformed means are presented.

***Leaf toughness measurements***

A purpose-built penetrometer was used to measure leaf toughness by quantifying the mass in grams required to push a 5-mm diameter metal rod through each leaf. Leaves were held between two 2-in. steel plates to prevent leaf movement. A guide hole in the plates provided passage of the penetrometer stylus. A flat stage on the top end of the penetrometer stylus held a glass beaker into which water was slowly poured until the penetrometer punctured the leaf. The beaker and water were then weighed in grams.

Measurements were taken on the $4^{th}$ newly expanded leaf and the $14^{th}$ fully expanded leaf, thereby representing young and mature growth, in an attempt to reveal why adult beetles seem to prefer flushes of new growth. Two penetrometer readings were taken for each leaf, one on the right and one on the left side of the midvein, and between cross veins, so that only leaf tissue was punctured. Penetrometer readings were averaged for each leaf. Readings were log transformed for analysis to stabilize heterogeneity of variances. Untransformed means are presented.

***Leaf nutrient measurements***

Leaves from six different blocks of the 24 cultivars were combined and dried at 90ºF for three days and then ground through a twenty mesh strainer to achieve 2-3 grams of dried plant material per cultivar. Samples were sent to the University of Georgia College of Agricultural and Environmental Science Soil, Plant and Water Laboratory for analysis of minerals, nitrogen and sulfur.

***Statistical analysis***

Linear regressions were used to examine relationships of leaf color and toughness values to the response variables of crapemyrtle parentage, cultivar and damage. Means were separated using t-tests (Least Significant Difference [LSD]). A stepwise selection process (at 0.05 level of inclusion/exclusion) was used to build models relating parentage, cultivar and damage and leaf and toughness values.

Principle Component Analysis (PCA) was used to attempt to pare down the 27 variables measured for each cultivar for potentially creating a model to predict crapemyrtle damage. PROC MIXED with the Residual Maximum Likelihood (REML) parameter was used to build a predicted means table from which PCA was done. PROC MIXED accounts for a mixed effects model and heterogeneity of standard errors related to random block effects. All analyses were done with the SAS statistical package, version 8.01)

## Results and Discussion

Damage ratings were previously shown to be significantly different for each of the cultivars and were negatively correlated with *L. faurei* parentage (Pettis 2004). Examination of the leaf characteristics of toughness of mature leaves and the three color parameters showed significant differences based on *L. faurei* parentage as well (Table 1); however, damage ratings, even for cultivars with *L. faurei* parentage, were not correlated via linear regression with any of the toughness or color values. A model for predicting parentage based on toughness of mature leaves was developed ($Y=-5.93+1.04$, $F=14.5$, d.f. 1, $p=0.0003$).Cultivars showed significant differences for leaf toughness and color. Cultivars could also be determined by b* values with the following model: $Y=36.03-0.74$ ($F=6.33$, d.f.=1, $p=0.01$) (Table 2).

The correlation matrix of the Principle Component Analysis did not show any significant relationships between toughness, color and nutrients. The only minor relationship to emerge was levels of calcium and magnesium at the 67% level. PCA revealed that, of the factors analyzed it would take six factors to account for 75% of the variation and 12 to account for 96%. However, upon examination of factor scores of the first six principle components, none were higher than 0.50, showing a low correlation among the measured factors.

**Conclusions**

Because of the failure of the three tested sources of resistance (leaf toughness, leaf color and nutrients) to predict flea beetle feeding damage, 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 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 attributed to the fact that 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), such as with the Minolta colorimeter. In many cases 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 colorimeter 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.

One result of this research is the linkage between crapemyrtle cultivars and the color values evaluated. The tristimulus colorimeter, then, could potentially be used as a tool to quickly and easily segregate cultivars for use in supporting Plant Variety Protection (PVP) cases (Pallottini et al. 2004).

In the absence of a correlation between leaf toughness and feeding damage, it may be that beetles merely show a photo tactic response to plants by feeding on the tips of branches. Heaviest feeding by beetles is often observed in mid-day (personal observations, GVP). Also, the hypothesis that beetles don't feed on landscape plants based on leaf toughness may also be discounted. Plant height and lack of monoculture in the landscape could account for the lack of beetle feeding.

Breeders who work with ornamental crops require methods that are relatively simple, quick, inexpensive, repeatable and that adequately represent the host plant resistance level of a specified plant to a specific pest. These methods, ideally, would not require the extensive labor required for mass rearing to perform insect choice and no-choice trials. Epicuticular leaf waxes, color, trichomes, tough leaves, primary compounds, and secondary compounds are some of the antixenosis qualities that plants exhibit. Of these characteristics, leaf color and leaf toughness are the most obvious choices for use by a practitioner in the greenhouse or breeding facility. The equipment that can be used is portable and easily operated, thereby allowing even minimally trained technicians to perform analyses.

Targeting simple, easy to perform screening methods may also allow for a standardized and quantitative method for comparison amongst cultivars. It does not necessarily require an extensive understanding of the underlying biochemical or physical causes of the external factors measured. Additionally the rapidly growing green industry requires a shorter breeding facility-to-outlet period in order to enhance profits and speed the development of improved, pest resistant cultivars.

Further evaluation of resistance mechanisms to pests of ornamental crops is warranted due to the increasing economic value of this commodity and parentage, when possible, should be linked to pest resistance factors. Further investigation would be required to examine the links found in our correlation analysis between nutrients and toughness, nutrients and color and color and toughness.

**Table 1**. Parentage effects on leaf characteristics of *Lagerstroemia* spp. (mean ± s.e.)

| *L. faurei* parentage? | Yes | No | F, d.f., p-value |
|---|---|---|---|
| Toughness – mature leaves (g) | $478.4 \pm 11.2^{a}$ | $419.1 \pm 9.7^{b}$ | 2.87, 30, p=.0002 |
| Toughness - young leaves (g) | $277.5 \pm 13.3^{a}$ | $255.5 \pm 10.8^{a}$ | 2.69, 30, p=.0005 |
| L* (lightness) | $41.2 \pm 0.5^{a}$ | $39.8 \pm 0.4^{b}$ | 13.53, 30, p<.0001 |
| a* (redness) | $-8.0 \pm 0.8^{a}$ | $-5.8 \pm 0.7^{b}$ | 5.63, 30, p<.0001 |
| b* (yellowness) | $23.7 \pm 0.7^{a}$ | $21.2 \pm 0.6^{b}$ | 17.10, 30, p<.0001 |

Means with the same letter are not significantly different at the p=0.05 level

**Table 2**: Cultivar effects of leaf characteristics of *Lagerstroemia* spp. (Mean ± s.e.)

| Cultivar | Toughness – mature leaves (F=2.86, d.f.=30, p=0.0002) | Toughness – young leaves (F=2.68, d.f.= 30, p=0.0005) | L* (lighness) (F=13.76, d.f.=30, p<.0001 | a* (redness) (F=4.93, d.f.=30, p<.0001) | b* (yellowness) (F=17.10, d.f.=30, p<.0001) |
|---|---|---|---|---|---|
| 1 | 431.7±41.4 cdef | 235.1±33.9 bcdef | 43.5±0.6 abca | -11.40.5± abcd | 26.5±1.0 ab |
| 3 | 437.2±27.7 bcdef | 318.8±54.5 ab | 41.2±0.5 defg | -7.5±1.0 efghi | 24.6±0.9 bcde |
| 4 | 435.8±36.8 cdef | 281.5±39.1 abcde | 42.0±0.8 bcde | -8.4±1.2 cdefg | 25.4±1.2 abc |
| 6 | 397.9±16.4 ef | 321.7±72.3 ab | 40.6±0.3 efgh | -9.2±1.1 cdef | 21.3±0.7 ghij |
| 7 | 419.6±38.3 ef | 334.8± 28.9 a | 38.6±0.5 ijk | -5.2±3.7 efghi | 19.6±1.8 ijk |
| 8 | 432.0±15.0 cdef | 217.2±28.7 cdef | 39.9±1.2 ghij | -7.4±3.0 cdefg | 22.7±1.2 defgh |
| 10 | 462.5±31.2 abcde | 296.8±15.2 abc | 44.3±1.7 a | -5.6±2.4 efghi | 25.2±2.4 bcd |
| 11 | 408.3±26.2 ef | 276.3±18.6 abcde | 40.1±0.5 fghi | -8.7±1.7 cdefg | 19.5±0.4 ijk |
| 13 | 424.8±30.4 def | 199.1±29.5 f | 40.1±1.4 fghi | -7.5±2.1 defgh | 23.9±1.7 cdef |
| 14 | 415.3±25.2 ef | 214.1±9.6 cdef | 39.9±0.5 ghij | -2.8±2.7 fghi | 21.7±1.3 fghi |
| 15 | 455.7±66.2 bcdef | 211.8±23.9 ef | 37.8±0.6 k | -4.7±1.3 ghi | 21.6±1.0 fghi |
| 16 | 538.5±11.4 a | 324.5±51.5 ab | 38.2±0.8 jk | -6.4±1.3 efghi | 18.8±0.4 jk |
| 17 | 429.4±37.7 cdef | 275.6±49.4 abcdef | 43.7±0.7 ab | -13.4±1.3 a | 27.9±1.3 a |
| 19 | 375.4±30.6 f | 211.0±14.6 def | 39.6±1.9 ghij | -4.2±3.5 efghi | 20.8±3.7 hij |
| 24 | 479.2±43.7 abcde | 298.8±36.5 abcd | 40.6±0.4 defgh | -10.7±1.8 ab | 24.0±0.9 bcde |
| 28 | 521.6±16.7 abcd | 232.4±25.6 bcdef | 43.2±1.6 abcd | -11.0±2.6 abc | 27.6±1.6 ab |
| 30 | 375.9±18.8 f | 194.0±16.2 f | 41.7±0.9 cdef | -2.4±3.1 fghi | 23.6±1.2 cdefg |
| 31 | 517.6±19.0 abc | 354.1±47.4 a | 38.6±0.3 ijk | -5.8±1.1 efghi | 17.7±0.6 k |
| 33 | 375.7±26.6 f | 229.9±24.2 bcdef | 35.7±0.9 l | -1.6±3.2 hi | 14.7±2.7 l |
| 34 | 409.1±28.5 ef | 218.8±38.2 ef | 41.2±0.9 defgh | -5.9±1.0 efghi | 21.6±1.1 fghi |
| 37 | 529.8±26.0 ab | 266.1±27.1 abcdef | 43.6±0.8 ab | -7.0±2.2 efghi | 26.7±2.1 ab |
| 38 | 398.2±20.0 ef | 235.5±30.7 bcdef | 39.4±0.4 hijk | -9.3±1.7 c | 22.3±1.0 efgh |
| 39 | 422.6±66.4 ef | 268.1±31.7 abcdef | 35.6±0.7 l | 0.8±1.8 i | 15.1±1.0 l |
| 41 | 546.6±23.6 a | 324.0±68.3 ab | 40.0±1.2 fghi | -5.6±2.8 efghi | 20.9±1.5 hij |

Means with the same letter are not significantly different at the p=0.05 level

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# CHAPTER 5

# EVALUATION OF INSECTICIDES FOR SUPPRESSION OF JAPANESE BEETLE, *POPILLIA JAPONICA* NEWMAN, AND CRAPEMYRTLE APHID, *TINOCALLIS KAHAWALUOKALANI* KIRKALDY[1]

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[1]Gretchen V. Pettis, S. Kristine Braman, L. Paul Guillebeau, Beverly Sparks. To be submitted to *Journal of Environmental Horticulture*.

**Abstract**

Crapemyrtle aphid, *Tinocallis kahawaluokalani* (Kirkaldy), and Japanese beetle, *Popillia japonica* Newman, cause extensive damage to crapemyrtle, *Lagerstroemia* spp., in both the landscape and the nursery. We evaluated foliar and systemic insecticides for control of these two important pests in a field trial. Aphid control was also evaluated in a separate screenhouse trial on five cultivars of crapemyrtle. Talstar GH (bifenthrin), Scimitar GC (lambda-cyhalothrin), Merit 75WP (imidacloprid) and Flagship (thiamethoxam) were the most effective among eleven insecticides tested in the field trial for suppression of concurrent populations of aphids and beetles. Greatest reduction in Japanese beetle damage alone was evident with bifenthrin and lambda-cyhalothrin. Aphid numbers were lowest on plants treated with Orthene TTO (acephate) and Flagship in the field trial and Flagship, Talstar GH and Scimitar GC in the screenhouse trial. Aphid numbers, among the five cultivars included in the screenhouse evaluations, were highest on 'Hopi' and lowest on 'Acoma'.

**Index words:** crapemyrtle aphid, Japanese beetle, insecticides, pest management

**Species used in this study**: Crapemyrtle (*Lagerstroemia* spp.), 'Muskogee', 'Dwarf Pink', 'Dwarf White', 'Pecos', 'Acoma', and 'Hopi'

**Chemicals used in this study:** Azatin XL (azadirachtin), Dursban 50W (chlorpyrifos), 0,0-diethyl 0-(3,5,6-trichloro-2-pyridinyl); Flagship (thiamethoxam), 4H-1,3,5-oxadiazin-4-imine, 3-[(2-chloro-5-thiazolyl) methyl] tetrahydro-5-methyl-N-nitro; Merit 75 WP, (imidacloprid), 1-6[(6-chloro-3-pyridiyl)methyl]-N-nitro-2-imidazolidinimine; Orthene TTO (acephate), O,S-dimethylacetylphosphoroamidothioate; Scimitar (lambda-cyhalothrin), [1α(S*), 3α(Z)]-(±) –cyano(3-phenoxyphenyl) methyl-3-(2-chloro-3,3,3-

trifluoro-1propenyl)-2,2- dimethylcyclopropanecarboxylate; Sevin SL, Sevin 80 WSP, (carbaryl) 1-naphthyl N-methylcarbamate); Talstar GH (bifenthrin), ((2-methyl [1,1'-biphenyl]-3-yl) methyl-3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropane carboxylate); Tame 2.4 EC (fenpropathrin), alpha-cyano-3-phenoxybenzyl 2,2,3,3-tetramethylcyclopro-panecarboxylate; Tempo 20 WP (cyfluthrin), cyano(4-fluoro-3-phenoxyphenyl) methyl 3-(2,2-dichloroethenyl)-2,2- dimethylcyclopropanecarboxylate; Horticultural oil; Insecticidal soap

**Significance to the Nursery Industry**

Crapemyrtle aphid, *Tinocallis kahawaluokalani* (Kirkaldy), with its associated sooty mold, *Capnodium* spp., is one of the most significant pests of crapemyrtle, *Lagerstroemia* spp. (3). Japanese beetle, *Popillia japonica* Newman, another important crapemyrtle pest, annually causes extensive defoliation (7). Because of the popularity of this woody ornamental in the nursery industry and in the landscape, it is often necessary to manage these key pests to avoid significant economic or aesthetic injury. This study provides the nursery and landscape industries with information on the most efficacious insecticides for suppressing crapemyrtle aphid and Japanese beetle adults on crapemyrtle.

**Introduction**

Beautiful and abundant summer flowers and interesting growth characteristics make crapemyrtle one of the most popular ornamental plants in the southern U.S. (USDA hardiness zones 7-10). Crapemyrtle is a widely used woody ornamental in southern landscapes because it is easy to propagate and grows under a wide range of site and soil conditions, with sizes ranging from dwarf shrubs to small trees (6). While few other insects cause problems on this exotic flowering plant, two pests, Japanese beetle and crapemyrtle aphid, can cause significant aesthetic and economic damage.

Crapemyrtle aphid is host specific to crapemyrtle in the U.S. and was apparently introduced to the U.S. mainland along with the plant (3). It was first described from the Hawaiian Islands, but can be found throughout the entire range of its host (2). The aphid, which has a tremendous reproductive capacity (1), produces a prodigious amount of honeydew while feeding. The honeydew, in turn provides a substrate on the crapemyrtle leaves for the growth of sooty mold (3). This black mold covers all parts of the plant, potentially inhibiting photosynthesis and causing premature foliage drop and may render plants unsalable by mid summer.

Eleven insecticides were evaluated in a field trial for the suppression of naturally occurring Japanese beetle and crapemyrtle aphid populations on containerized 'Muskogee' crapemyrtles. Plants were visually rated for Japanese beetle damage. In addition, seven insecticides were evaluated in a screenhouse trial on five cultivars of crapemyrtle ('Dwarf Pink', 'Dwarf White', 'Pecos', 'Acoma', and 'Hopi'). In both the field trial and the screenhouse trial, numbers of crapemyrtle aphids present on two terminal leaves were counted.

## Materials and Methods

### *Experiment 1 – Field trial:*

One-year-old rooted cuttings of 'Muskogee' crapemyrtle were planted in 11.36 L (3 gal.) pots and arranged on 0.91m (3 ft.) centers on black weed barrier on May 9, 2000 in Griffin, Georgia. 'Muskogee' crapemyrtles were chosen based on previous trials which showed them to be highly susceptible host plants for Japanese beetles (unpublished data), in hopes of inducing maximum beetle pressure from endemic populations. Plants were of uniform size (approximately 2 ft. tall at the beginning of the study) and were arranged in a randomized complete block design with six replications of 12 treatments. They were containerized in MetroMix 300 potting soil with starter fertilizer (Scotts-Sierra Horticulture, Marysville, OH). No additional fertilizer was applied to the plants during the period of the study. Plants were watered as needed with drip irrigation to prevent wilt symptoms. Six Japanese beetle floral lures (SureFire™ Products Japanese Beetle Trap, Consep, Inc., Bend, OR) were placed at regular intervals on 1.07 meter (3.5 ft.) tall wooden stakes along the periphery of the experimental plot. Crapemyrtle aphids were allowed to develop from natural infestations.

Insecticide treatments were applied on Day 0 (May 9$^{th}$) and Day 14 (May 23$^{rd}$) at the recommended label rates (Table 1). The insecticides used were: Azatin XL (azadirachtin), Dursban 50W (chlorpyrifos), Flagship (thiamethoxam), Merit 75 WP, (imidacloprid), Orthene TTO (acephate), Scimitar (lambda-cyhalothrin), Sevin SL, Sevin 80 WSP (carbaryl), Talstar GH (bifenthrin), Tame 2.4 EC (fenpropathrin), Tempo 20 WP (cyfluthrin). Plants receiving the same treatment were removed from the blocks and insecticides were applied to plants until total leaf wetness (approx. 0.1L/plant) at a rate of 378.54 L/acre (100 gal./acre). A $CO_2$ pressurized backpack sprayer with a fan-type nozzle was used for all applications at a pressure of 30 psi. Treated plants were then placed back into the randomized complete block design. Insecticides were applied on Day 0 (May 9$^{th}$) and Day 14 (May 23$^{rd}$) at the recommended label rates (Table 1).

Crapemyrtles were evaluated weekly from the date of the initial insecticide treatment for Japanese beetle damage. Two evaluators made visual ratings based on percent defoliation. Ratings were averaged for subsequent analysis. Crapemyrtle aphid populations, which developed from natural infestations, were evaluated at the conclusion of the experiment. Two fully expanded leaves were taken from the terminal end of each plant and placed in 0.12 L (4oz.) plastic cups with lids and taken back to the lab. Total numbers of aphids per leaf were counted under 10X magnification. Aphids that had migrated off of the leaves and into the container during transport were also counted. Data on Japanese beetle damage were arcsine transformed and subjected to analysis of variance using the general linear models (GLM) procedure of SAS (8). Mean separation was by Fisher's protected least significant difference test (Fisher's LSD). Untransformed means are presented here. Data for crapemyrtle aphid populations were also analyzed using the GLM procedure and means separated by Fisher's protected LSD.

***Experiment 2- Screenhouse trial:***

Five cultivars of one-year-old rooted cuttings of crapemyrtle (approximately 2 ft. tall at the beginning of the experiment) infested with naturally occurring crapemyrtle aphid populations were planted in 11.36 L (3 gal.) pots. The varieties used were 'Dwarf Pink', 'Dwarf White', 'Pecos', 'Acoma' and 'Hopi'. Plants were containerized with MetroMix 300 potting soil with starter fertilizer and watered as needed to prevent wilt symptoms. No additional fertilizer was applied to the plants during the period of the study. Plants were maintained on black shade cloth in a screenhouse in Griffin, Georgia at the UGA Experiment Station. Insecticide treatments were applied on Day 0 (June 14, 2000) and Day 7 (June 21, 2000) to the point of total leaf wetness as in Experiment 1. The insecticides used were 2% Horticultural oil, 2% Insecticidal soap, Orthene TTO, Sevin 80WSP, Talstar GH, Scimitar GC, Flagship and a water control. Plants were arranged in a randomized complete block with five replications. One plant of each variety counted as a replication. Each of five adjoining rooms of the screenhouse containing the seven treatments was considered a block.

Aphid counts were taken before the application of insecticide treatments on Day 0 using the same method as in Experiment 1 and were counted on Days 5, 7, 12 and 14 after the initial insecticide treatment. Data were subjected to analysis of variance using the GLM procedure of SAS (8). Mean separation was by Fisher's protected LSD test.

Results and Discussion

***Experiment 1- Field trial:***

Scimitar and Talstar provided the greatest reduction in Japanese beetle damage (Table 1). Thirty-one days after the initial insecticide treatment, crapemyrtles treated with Scimitar and Talstar averaged 11 and 15% defoliation, respectively, the lowest defoliation rates of all the treatments. Defoliation in the untreated controls averaged 43%. Application of Orthene, Flagship or Merit resulted in the greatest suppression of crapemyrtle aphids. These three insecticides were not significantly different in their management of aphid populations, with mean aphid numbers ranging from 1-21 aphids/sample in comparison with a mean of 241 aphids/sample in the water control. Talstar, Scimitar, Merit and Flagship were among the most effective treatments for Japanese beetle and crapemyrtle aphid, each providing good to excellent control of both pests concurrently in this trial. Tame reduced beetle damage in our study and in previous work (12). Neem based material (azatin) in our study and others (12) were not different from the control for beetle damage at the conclusion of the study.

***Experiment 2- Screenhouse trial:***

Aphid density was high during this trial. Pretreatment numbers of aphids were not statistically different (Table 2) and averaged between approximately 200 and 400 aphids per two leaf sample. All insecticides applied during this experiment significantly reduced the number of crapemyrtle aphids relative to the untreated control by five days after treatment (Table 2). All products provided statistically similar levels of control on day 5 and day 7 post-treatment. Treatments could not be statistically separated during the second week post application because of a substantial decline in aphid numbers, due to unknown causes, on the untreated controls, although the lowest numbers of aphids were still observed on plants treated with Scimitar and Flagship as in Experiment 1. Among the five cultivars used in this trial, Hopi had the most aphids and Acoma had the fewest but were not statistically different.

A number of reasons may explain why some of the chemical treatments, such as Sevin and insecticidal soap, were more prone to subsequent aphid populations. These factors include weather, systemic and residual activity of the pesticide and degeneration of the chemical by sunlight. Individual treatments may also have disrupted beneficial insect populations.

Although beneficial arthropods were not directly evaluated, lady beetles (Coleoptera: Coccinellidae) and green lacewings (Neuroptera: Chrysopidae) were observed during the study. It has been shown that chemical sprays, particularly broad-spectrum insecticides, can have a negative impact on insect biodiversity (10). Often a rapid rebound of the target pest insect population results when pesticides used to 'control' the pest kill its predators and parasites, which as a result releases the herbivorous pest from its biological control.

**Conclusions**

Several insecticide chemistries were evaluated for their relative efficacy in controlling natural populations of Japanese beetle, as indicated by plant damage, and crapemyrtle aphid, indicated by numbers of aphids on a two leaf sample, on containerized crapemyrtles in this study. Results from the two experiments demonstrated that Azatin, a neem extract, showed relatively low effectiveness for either Japanese beetle or aphid control when compared to the other products for management of these two crapemyrtle pests. Greatest reduction in Japanese beetle damage was evident with Talstar (bifenthrin) and Scimitar (lambda-cyhalothrin). Tame (fenpropathrin), a synthetic pyrethroid, displayed moderate to good control of both pests.

Flagship, (thiomethoxam) and Merit (imidacloprid) belong to the relatively new neonicotinoid class of insecticides. These showed excellent potential in our trials for inclusion in Integrated Pest Management programs for crapemyrtle because of their low mammalian toxicity, low use rates, systemic action and excellent control of both aphids and Japanese beetles. These two materials have also been shown to provide effective control of a new beetle pest of viburnums (11) and other insect pests (3, 4, 9, 13).

Opportunities to develop and implement Integrated Pest Management (IPM) for nursery production and landscape plants increase with the identification of pest-resistant plants (5,7) and availability of effective alternative chemistries. Evaluation of emerging chemistries against older products is important for informed decision making by the pest management practitioner.

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**Table 1**. Mean ± S.E. % Japanese beetle damage or number of crapemyrtle aphids after application of products for insect control on crapemyrtle

| Product | Active ingredient | Rate (as per label) | Japanese beetle damage | | | | No. aphids |
|---|---|---|---|---|---|---|---|
| | | | week 1 | week 2 | week 3 | week 4 | |
| Flagship | thiamethoxam | 0.32 L/1000 L (4 fl oz/100 gal) | 11.7 ±7.2 | 15.7 ± 5.3 | 14.5 ± 6.1 | 17.7 ± 4.5 | 5.0 ± 2.6 |
| Sevin SL | carbaryl | 2.55 L/1000 L (32.67 fl oz/100 gal) | 4.7 ± 2.6 | 24.5 ± 6.8 | 19.3 ± 4.9 | 22.5 ± 3.6 | 183.0 ± 54.8 |
| Sevin 80WSP | carbaryl | 1.45 kg/1000 L (1.25 lb/100 gal) | 4.7 ± 1.5 | 24.0 ± 6.7 | 22.2 ± 5.6 | 23.2 ± 6.5 | 99.5 ± 19.3 |
| Azatin XL | azadirachtin | 1.25 L/1000 L (16 fl oz/100 gal) | 6.2 ± 2.4 | 19.5 ± 5.5 | 22.5 ± 2.8 | 27.5 ± 3.1 | 202.2 ± 96.4 |
| Talstar GH | bifenthrin | 23.44 mL/1000 L (0.3 fl oz/100 gal) | 2.2 ± 1.6 | 11.5 ± 5.6 | 13.8 ± 5.4 | 15.0 ± 4.2 | 75.5 ± 24.1 |
| Dursban 50W | chlorpyrifos | 1.80 kg/1000 L (1.5 lb/100 gal) | 12.7 ± 5.2 | 16.5 ± 4.8 | 30.0 ± 4.8 | 36.8 ± 6.2 | 108.0 ± 56.9 |
| Tempo 20WP | cyfluthrin | 145.30 g/1000 L (0.12 lb/100 gal) | 15.1 ± 7.2 | 20.2 ± 7.9 | 18.2 ± 6.6 | 25.3 ± 6.6 | 171.0 ± 63.9 |
| Scimitar GC | lambda-cyhalothrin | 117.19 mL/1000 L (1.5 fl oz/100 gal) | 3.8 ± 2.4 | 6.3 ± 1.2 | 6.8 ± 1.5 | 11.2 ± 2.2 | 66.0 ± 33.8 |
| Tame 2.4 EC Spray | fenpropathrin | 832.82 mL/1000L (10.66 fl oz/100 gal) | 6.0 ± 2.3 | 12.2 ± 5.2 | 11.8 ± 3.5 | 18.3 ± 6.1 | 90.8 ± 24.1 |
| Orthene TTO | acephate | 1.66 L/1000 L (21.3 fl oz/100 gal) | 3.1 ± 1.9 | 12.5 ± 5.0 | 21.7 ± 5.1 | 23.0 ± 3.4 | 1.2 ± 0.8 |
| Merit 75WP | imidacloprid | 36.98 g/1000 L (0.03 lb/100 gal) | 1.1 ± 0.3 | 6.6 ± 2.5 | 16.7 ± 4.0 | 19.2 ± 2.1 | 20.7 ± 10.4 |
| Water | N/A | N/A | 23.3 ±6.0 | 25.0 ± 3.4 | 39.2 ± 5.2 | 43.3 ± 3.6 | 241.3 ± 102.1 |
| $F_{5,11}$ | | | 2.8 | 1.5 | 3.0 | 3.2 | 2.4 |
| P | | | 0.01 | 0.2 | 0.003 | 0.002 | 0.02 |
| LSD | | | 11.2 | ------ | 13.9 | 13.3 | 146.52 |

**Table 2.** Mean $\pm$ S.E. number of crapemyrtle aphids on crapemyrtle after application of insecticides

| Chemical common name | Active ingredient | Rate | Number of aphids on X day post treatment (dpt) | | | | |
|---|---|---|---|---|---|---|---|
| | | | pretreatment | 5dpt | 7dpt | 12dpt | 14dpt |
| Horticultural oil | horticultural oil | 20 L/1000 L (2 gal/100 gal) | 275.8 $\pm$ 73.2 | 19.4 $\pm$ 15.4 | 49.8 $\pm$ 38.1 | 39.8 $\pm$ 20.1 | 53.2 $\pm$ 43.8 |
| Insecticidal soap | insecticidal soap | 20 L/1000 L (2 gal/100 gal) | 394.0 $\pm$ 135.6 | 46.0 $\pm$ 28.5 | 21.6 $\pm$ 18.1 | 78.0 $\pm$ 53.9 | 74.4 $\pm$ 39.3 |
| Flagship | thiamethoxam | 0.32 L/1000 L (4 fl oz/100 gal) | 214.8 $\pm$ 91.5 | 0.8 $\pm$ 0.4 | 0.8 $\pm$ 0.6 | 0.8 $\pm$ 0.8 | 0 |
| Sevin 80WSP | carbaryl | 1.45 kg/1000 L (1.25 lb/100 gal) | 317.0 $\pm$ 102.1 | 21.6 $\pm$ 11.9 | 23.0 $\pm$ 9.1 | 70.2 $\pm$ 57.3 | 43.6 $\pm$ 31.6 |
| Talstar GH | bifenthrin | 23.44 mL/1000 L (0.3 fl oz/100 gal) | 295.6 $\pm$ 45.8 | 0 | 0 | 0.8 $\pm$ 0.4 | 8.2 $\pm$ 7.2 |
| Scimitar GC | lambda-cyhalothrin | 117.19 mL/1000 L (1.5 fl oz/100 gal) | 227.2 $\pm$ 80.3 | 0 | 0 | 0.6 $\pm$ 0.6 | 0.2 $\pm$ 0.2 |
| Orthene TTO | acephate | 1.66 L/1000 L (21.3 fl oz/100 gal) | 255.8 $\pm$ 119.1 | 0 | 0.6 $\pm$ 0.4 | 1.6 $\pm$ 0.7 | 15.6 $\pm$ 14.8 |
| Water | N/A | N/A | 315.8 $\pm$ 74.1 | 349.8 $\pm$81.7 | 149.4 $\pm$ 33.2 | 22.6 $\pm$ 5.9 | 24.6 $\pm$ 8.3 |
| $F_{5,11}$ | | | 0.8 | 14.5 | 6.7 | 0.2 | 0.1 |
| P | | | -- | 0.0001 | 0.0001 | -- | --- |
| LSD | | | -- | 91.6 | 57.8 | -- | --- |

# CHAPTER 6

# CONCLUSIONS

Accessions of *Lagerstroemia* spp. (crapemyrtle) are among the most widely cultivated woody ornamentals in USDA hardiness zones 7-10. In the past decade a metallic flea beetle in the genus *Altica* has become an economic pest of commercial crapemyrtle (Lagerstroemia spp.: Lythraceae) production as well as the production of other ornamental plants in the Lythraceae and Onagraceae plant families. Japanese beetle, crapemyrtle aphid and most recently, *Altica litigata*, cause the majority of damage to crapemyrtles in commercial production.

This dissertation provides, through a series of basic and applied studies, information for the development of integrated tactics to manage these arthropods. Short and long term management goals of the producer are addressed, particularly in light of a previously unknown insect pest. Through the application of the management recommendations from these studies, commercial loss due to insect feeding and aesthetic damage is mitigated.

Short term management goals of controlling the two primary arthropod pests of *Lagerstroemia* spp., Japanese beetle and crapemyrtle aphid, were addressed through the evaluation of older products and novel chemical classes of insecticides. Flagship (thiomethoxam) and Merit (imidacloprid), from the relatively new neonicotinoid chemical family, showed the most promise for use in an IPM program. Both of these chemicals have low mammalian toxicity and use rates, systemic activity, and provided excellent control, while most likely minimizing the effects on beneficial insects.

The cultivar evaluations performed in the lab and field also give the pest manager another management option. Targeted scouting, decisions on which stock to grow and the need for chemical applications are all affected by the knowledge of the intrinsic resistance to important arthropod pests. Additionally, a spectrum of resistance to the two major beetle pests of crapemyrtle, Japanese beetle and *Altica litigata*, indicates plasticity of the Lagerstroemia genome and promise for future breeding efforts.

The most susceptible cultivars were those of pure Lagerstroemia indica lineage, such as ‘Carolina Beauty’, ‘Country Red’ and ‘Twilight’. Conversely, both beetle species were resistant to plants with *Lagerstroemia faurei* parentage. The most resistant cultivars were, ‘Natchez’, ‘Tonto’, and ‘Muskogee’. Literature suggests that *L. faurei* interspecific crosses confer resistance to the two fungal pathogens of most concern, Cercospora leaf spot and powdery mildew, as well. However, the inverse is true of crapemyrtle aphid resistance. The cultivars ‘Miami’, ‘Natchez’, ‘Pecos’, ‘Sioux’ and ‘Tuskegee’, contain the L. faurei parentage, but sustained lower aphid populations and, therefore show the most promise for breeding programs geared toward resistance to all three arthropod pests as well as fungal diseases of concern.

A basic phenological study revealed that *Altica* differentially develop on various potential ‘host plants’, as well as provided degree day accumulations for the respective developmental stages of this chrysomelid. Degree day calculations, heretofore unknown for *Altica* spp., can be used to predict potential outbreaks of beetles in the nursery when combined with scouting of potential host plants. This is important because of the unpredictable nature of these outbreaks. Degree days could also potentially be extrapolated to other *Altica* pests of economic importance. Host effect differences may indicate the ‘preferred’ host of the beetle, since arthropods are most likely to choose a host on which rate of development is maximized.

Reductions in pesticide applications directed toward pests of crapemyrtle can be realized through improved knowledge of the biology and ecology of the pests and their host plants. Decreasing pesticide usage saves on costs directly (chemicals, application equipment, safety equipment, etc.) and indirectly (environmental contamination and human risk). Widespread adoption of info-intensive IPM, which allows for informed and rigorous management decisions, should become more widespread as the value of ornamental crops continues its upward trend. Studies such as the one’s conducted in this dissertation will supply needed information for this bank of knowledge.