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Resistance and susceptibility among turfgrasses and potential weedy hosts to twolined spittlebug (*Prosapia bicincta* (Say)) (Hemiptera: Cercopidae)
(Under the Direction of S.K. BRAMAN.)

Potential resistance to the twolined spittlebug, *Prosapia bicincta* (Say), was evaluated among 56 turfgrass genotypes. All centipedegrasses demonstrated high levels of susceptibility, followed by bermudagrasses, seashore paspalums, and zoysiagrasses. Among seashore paspalums, nymphal survival to the adult stage was lowest and duration of development was longest on HI-1, 'Sea Isle 2000', 561-79, and 'Mauna Kea'. Reduced spittlebug survival and increased developmental times were also observed on the bermudagrasses BERPC 91-15 and 'Tifway'. Although zoysiagrasses supported spittlebug development and survival to the adult stage, developmental times were extended on the zoysiagrass cultivars 'Emerald' and 'El Toro'. Among taxa included in field trials, HI-1, 'Mauna Kea', 'Sea Isle 2000' and AP-14 paspalums, 'Tifway' bermudagrass, and 'Emerald' zoysiagrass were most tolerant of twolined spittlebug feeding. Of eight grasses and eight broadleaf weeds tested among seven plant families, *P. bicincta* successfully developed on seven Gramineae, one Compositae, and one Euphorbiaceae.

INDEX WORDS: twolined spittlebug, *Prosapia bicincta* (Say), host plant resistance, turfgrass, bermudagrass, centipedegrass, seashore paspalum, zoysiagrass, Cercopidae, froghoppers, weeds, Homoptera, Hemiptera.

RESISTANCE AND SUSCEPTIBILITY AMONG TURFGRASSES AND POTENTIAL WEEDY HOSTS TO TWOLINED SPITTLEBUG (*PROSAPIA BICINCTA* (SAY) (HEMIPTERA: CERCOPIDAE)

by

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Taxonomy, Biology, and Management Review of *Prosapia bicincta* (Say) (Hemiptera: Cercopidae)

Prosapia bicincta (Say), the twolined spittlebug (TLS), has long been recognized as an economic pest on Coastal bermudagrass, a cultivar of *Cynodon dactylon* (L.) Pers. (Byers and Wells 1966), and other bermudagrass cultivars (Taliaferro et al. 1969). Damage has been reported on other grasses such as pangolagrass, *Digitaria decumbens* Stent., and St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntze (Genung et al. 1954). Sweet corn, *Zea mays* L., sustains damage by adult twolined spittlebugs (Janes 1971). Lately, economic damage has been reported on ornamental hollies, *Ilex opaca* L. and *I. cornuta Burfordii* De France (Pass and Reed 1965, Braman and Ruter 1997.) used in the landscape trade, and on southern lawns planted with centipede, *Eremochloa ophiuroides* (Munro) Hack., and bermudagrass (Potter and Braman 1991, Braman 1995).

Originally, the TLS was described as *Cercopis bicincta* by Say in 1830. The current valid name is *Prosapia bicincta* (Say). In the interim, the species has been placed in the genera *Thomaspis* and *Monecephora*. Worldwide, in the subfamily Cercopinae, in the tribe Cercopini, there are 14 genera with six subspecies (Metcalf 1961). According to Arnett, Jr. (1993), in North America the subfamily Cercopinae, tribe Cercopini, consists of two genera, *Prosapia* and *Philaenus*. Arnett, Jr. (1993) lists *Prosapia bicincta* as having four named subspecies: *P.b. bicincta* S. Str., *P. b.angustata* Walker, *P.b. bifascia* Walker, and *P.b. ignipecta* Fitch. Hamilton (1977) recognized no subspecies since the geographical variation in genitalia features could not be precisely defined. Scanning electron microscopy has revealed the morphology of the antennal sensilla in *P. bicincta.* This has allowed for comparisons of basiconic, coeloconic, campaniform, and trichord sensilla among taxa that are phylogenetically informative (Liang 2001).

The spittlebug genus, *Prosapia* Fennah, occurs in North America. Most species are found in Mexico and Central America (Hamilton 1977). TLS has been reported from Florida to Maine (Byers 1965) and as far west as Texas and Arkansas in the US. Both Cuba and Jamaica have reported TLS.

Recently, *Prosapia*, without a species designation, and *Prosapia* nr. *bicincta* (Peck 1998) have been reported in the literature from Brazil as a pest on grasses of the genus *Brachiaria* Griseb. (Lapointe et al. 1992). These grasses are widely grown throughout Central and South America as a major component of the Centro Internacional de Agricultura Tropical (CIAT) program to provide suitable, productive, and sustainable forage on the acid, infertile lowlands of these areas. To date, these grasses have been reported to be susceptible to damage from eight native species of spittlebugs and intensive breeding programs for resistance are underway. TLS may be one of the species involved.

The twolined spittlebug is apparently an opportunistic xylem feeder as a nymph and as an adult, with reports of more than forty hosts (Fagin and Kuitert 1969). The TLS can survive on almost any host providing a sufficient amount of fluid to meet its feeding demands (Pass and Reed 1965). Thompson (1994) reports that the Cercopoidea are preferentially associated with nitrogen-fixing angiosperms, and Cercopidae show a preference for nitrogen-fixing grasses. Spittlebugs demonstrate a preferential association with nitrogen-fixing hosts that transport fixed nitrogen as amino acids and amides rather than as urides.

Much of the basic biology of the twolined spittlebug has already been investigated (Byers 1965). Eggs are deposited at, near, or below the soil line. Occasionally, they have been reported as inserted into the stem of the host plant (Fagin and Kuitert 1969). After hatching, the mobile nymphs make their way to suitable hosts and immediately begin to feed. Spittle is produced within five minutes of the initiation of feeding (Fagan and Kuitert 1969; Pass and Reed 1965). Five instars occur before the adult stage. Total development time varies with temperature. In the field in Clemson, South Carolina, from March 1960 to March 1962, the nymphal period ranged from 34 to 60 days (Pass and Reed 1965).

Peak times of adult emergence were in late July and early August in Clemson, S.C. (Pass and Reed 1965), while in Tift Co., Georgia, three peaks were observed (Byers 1965). Two peaks occurred in June and early July, and were associated with the first generation. The third peak, representing the second generation, occurred in August. Adults have been collected from March until late November with two generations per year reported (Byers 1965). Overwintering usually occurs in the egg stage, although an occasional overwintering adult has been reported in Tift Co., Georgia (Beck and Skinner 1972).

Females release a mate-attracting perfume-like pheromone. Females first mate when they are five to nine days old (Byers 1965), and continue to mate throughout the growing season. They mate both before and after the beginning of oviposition. Egg laying begins when adult females are seven days old, and the average oviposition period is 14 days (Fagan and Kuitert 1969).

Diapause studies were conducted by Byers (1965) at Tifton, Georgia to determine the induction and termination of diapause. He concluded that soil temperature (9.5-28°C) as well as moisture (45-100%) affect diapause and hatching, but that photoperiod (e.g., 0L:24D vs. 14L:10D) has little or no effect. He also determined that eggs laid in the field were not initially in diapause, and if moisture conditions were right, such as those found in the spring and summer, the eggs would hatch. If conditions were too dry, as they were in the fall, eggs would diapause, or exhibit "long periodism" and would not hatch despite environmental conditions.

Since TLS experiments usually start with field-collected specimens, trapping techniques were investigated by Beck and Skinner (1972). Research proved that black light (BL) traps captured significantly greater numbers of adults. High traps (157-274cm above ground) collected almost four times as many males as females, but as the trap height was lowered to 15.2 cm above the ground, ratios of males to females were more equal, and the number of TLS captured increased. The amount of damage to the bermudagrass host was related to number and proportion of females collected, with areas of the highest damage yielding both the greatest numbers and highest percentages. Timing of trapping was also investigated (Beck and Skinner 1972). The peak of flight activity occurred between 9 and 10 PM.

Rearing techniques have also been greatly improved (McWilliam and Cook 1975; Lapointe et al. 1989). McWilliam and Cook (1975) took TLS eggs in the advanced eyespot stage and placed them into the vermiculite substrate of pots of pearl millet, *Pennisetum americanum* (L.) K. Schum., close to the crowns of the plants. Each 15.2 cm pot was infested with about thirty-five eggs. A sixteen-hour photoperiod was maintained to prevent diapause. Hatching occurred about two days later. Approximately one week post hatch, spittle masses were observed, and adults emerged in about seven weeks. Adults were removed after emergence, and placed on different pots of millet for the 10-day preoviposition period. They were then transferred to oviposition cages constructed from cardboard ice cream containers, cut down to 10.2cm, with cellophane tops and mesh bottoms secured by lid rims. Ovipositing females were fed on leaf bouquets composed of millet, sorghum, *Sorghum bicolor* (L.) Moench, sugarcane, *Saccharum officianarum* L., corn, and rye, *Secale cereale* L., with their proximal end(s) wrapped in Cellucotton® and placed into a vial containing 5% (by vol.) corn syrup in water solution. The cotton acted as a wick to allow for feeding by the spittlebugs, and to seal the vial. Oviposition sites were constructed from the Cellucotton® wrapped around a toothpick. When moistened, the females found this to be a satisfactory oviposition site. Each cage contained six oviposition sites and twelve food bouquets. These were replaced every two days. About one hundred females were supported in each cage.

Egg recovery was accomplished by removing the Cellucotton® from the toothpick, adding enough water to make a pulp, and with air bubbling through a separatory funnel, collecting and draining the eggs that had accumulated on the bottom of the funnel. The eggs were then placed on moist filter paper and incubated.

Lapointe et al. (1989) reported spittlebug-rearing techniques refined from the McWilliams and Cook (1975) method. Trays of clay soil imprinted with a reticulate pattern to increase oviposition and obtain a more uniform distribution of eggs were used. The top of the soil in the pots was sealed with an aluminum cover as a means to increase humidity around the base of the plant, and to encourage superficial rooting of the plants due to reduced light levels.

A fascinating aspect of the insect's ecology is the production of its characteristic spittle mass. Some spittlebugs create semi-liquid bubble nests by adding bubbles and a mucopolysaccharide to xylem fluid as it is excreted (Thompson 1997). The need for a spittle nest as a shelter for the nymph during development has been researched in other Cercopidae, even though theories for its existence have yet to be proven. The conventional view is that the spittle provides protection against desiccation for the nymph (Weigert 1964a,b, Wigglesworth 1972, Kuenzi and Coppel 1985), but due to the energetic cost of making and maintaining such a nest, this may be erroneous. Another explanation for the nest is that it may function as an osmoregulatory device, such as a plastron would for an aquatic insect (Turner 1994). Protection from predation and bacterial and fungal pathogens has also been proposed as a function of the spittle nest (Guilbeau 1908, Weaver and King 1954, William and Ananthasubramanian 1989).

Niche partitioning for several spittlebugs has been researched, but not for *P. bicincta.* McEvoy (1986) showed that density-dependent effects were absent regarding growth and development even when nymphs of different species shared the same axil. Axil width greater than the width of the spittlebug was a factor in host suitability.

Damage has been shown to occur from the feeding of nymphs (Pass and Reed 1965) and adults (Byers and Wells 1966; Byers and Taliaferro 1967). Age and sex were shown to be unimportant in the ability of adults over one day of age to produce damage.

A plant growth promoter in the salivary glands may be responsible for the damage (Cutler and Stimmann 1971), however the identity of this substance remains unknown. A toxin is injected into the xylem as the insects feed, and damage begins within 24 hours. Symptoms include stippling, streaking and browning. Necrosis of the host can result. Recovery from spittlebug damage can occur if the plant is not too severely damaged, but the recovery time is much longer than would be expected, indicating a residual effect of the phytotoxin (Meyer 1993; Meyer and Root 1993; Meyer and Whitlow 1992; Karban and Strauss 1993).

Attempted control of TLS has included mechanical, biological, and chemical measures. Overwintering insects were controlled by burning all refuse from the previous year in early April in Tifton, Georgia (Beck 1963). Mowing heights on lawn grasses are being investigated as management options (Cobb, personal communication, 1997). The first documented biological control was a report of crop contents of the southern meadowlark, *Sturnella magna argutulla* (Bangs). Included in the crop contents were a significant number of twolined spittlebugs (Genung and Green, Jr. 1974).

Tropical American forage grasses in the genus *Brachiaria* (Trin.) Griseb. have been utilized in screenings for resistance to spittlebug with the conclusion that a breeding program for resistance is feasible (Miles et al. 1995, Lapointe et al. 1992). Potential for resistance of forage bermudagrasses to two-lined spittlebug phytotoxins was evaluated in the hope that breeding methods could increase the resistance of bermudagrass cultivars to spittlebug damage (Taliaferro et al. 1969, Stimmann and Taliaferro 1969).

Non-significant chemical control was reported on second-generation nymphs using granular formulations of Zinophos 10%, Diazinon 5%, Phorate 10%, and

Endosulfan 4% (Beck 1963). However, residual soil samples of Endosulfan indicated that significant control of second-generation nymphs was obtained by one isomer of this chemical seventy-five days after application (Byers et al. 1965). In Florida Everglades pastures, chemical control was obtained using 1.362 kg wettable Toxaphene in 380 l water per 0.405 ha (Mead 1962). Scouting for spittle nests and chemical control of TLS has become a routine part of landscape companies' maintenance procedures.

Turfgrass Taxonomy and Plant Improvement Efforts

All grasses belong to the Gramineae (or Poaceae) family. Within this family, all turfgrasses are members of three primary subfamilies: Festucoideae, Panicoideae, Eragrostoideae. Cool-season turfgrasses belong to the festucoids. Warm-season turfgrasses belong to the other two subfamilies. Eragrostoideae include the bermudagrasses in the Chlorideae tribe and the zoysias (*Zoysia* Willd.) in the Zoysieae tribe. The Panicoideae subfamily contains two tribes, the Paniceae and Andropogoneae. St. Augustine and paspalum (*Paspalum vaginatum* Swartz.) grasses are members of the Paniceae tribe. Centipede belongs to the Andropogoneae tribe (Turgeon 1980). In the southeastern US, bermudagrass, centipede, zoysia, St. Augustinegrass, and seashore paspalum are cultivated as warm season turfgrasses. A tall fescue, ‘Kentucky 31’, (*Festuca arundinacea* Schreb.) is representative of cool-season turfgrasses used in the same geographic area.

Traditionally, breeding programs for plant improvement have included efforts to increase desirable aesthetic characteristics. More recently, additional emphasis has been placed on screening for host plant resistance (HPR) to disease and insect problems due to efforts to reduce chemical control applications, both for cost and environmental reasons. Screenings have been conducted for herbicide tolerance. The incorporation of host plant resistance into breeding programs has become a standard practice.

Host plant resistance is an important management tool as it incorporates specificity, cumulative effectiveness, persistence, harmony with the environment, and ease of adoption. Resistance can occur as a result of physical or chemical factors. Plant resistance characteristics can be environmentally triggered, genetically controlled but triggered by environmental factors (induced resistance), or genetic and always expressed regardless of any external stimulus (constitutive resistance). Induced and constitutive resistance result from antibiosis or antixenosis, both of which have an effect on the behavior or physiology of the insect. Tolerance is defined as a mechanism of resistance that allows for the normal growth and reproduction of a plant while acting as a host to an insect population that would severely impair the ability of a susceptible plant to flourish (Painter 1951). Comparison of the yield, or plant biomass, in insect-infested to non-infested plants of the same cultivar generates a measure of the ability of a plant to tolerate the insect population (Smith 1989 in N'Guessan et al. 1994).

Breeding programs for turfgrass improvement have included the incorporation of desirable growth and aesthetic characteristics with a focus on adaptability and environmental compatibility. The ongoing breeding program for seashore paspalum at the University of Georgia exemplifies this multidimensional approach (Duncan and Carrow 2000). Approximately 300 ecotypes have undergone evaluation for canopy density and turf quality at various mowing heights, fertilization requirements, cold hardiness, soil pH tolerance, salinity tolerance, water requirements, and drought resistance. To create additional diversity and to identify genetic differences, tissue culture techniques and genetic analyses have been employed. Additionally, screenings have been conducted for herbicide tolerance and disease resistance. Insect resistance screening has been conducted for a limited number of pests. This study and others currently underway at the University of Georgia will add to that body of knowledge.

Plant improvement efforts to include characteristics yielding resistance to disease and insect damage have intensified (Quisenberry 1990). Reinert (1982) and Quisenberry (1990) provided reviews of resistance in turfgrass and forage grasses to insects and mites. Reinert and Engelke (2000) presented a display on host resistance to insects and mites in Zoysia turf species. They reported resistance to fall armyworm (*Spodoptera frugiperda*) in ‘Cavalier’ and DALZ8501, resistance to tropical sod webworm (*Herpetogramma phaeopteralis*) in ‘Cavalier’, DALZ8501, ‘El Toro’, and ‘Korean Common’, and high resistance to the differential grasshopper (*Melanoplus differentialis*) in ‘Cavalier’. ‘Cavalier’ and ‘Diamond’ exhibited resistance to tawny mole crickets (*Scapteriscus vicinus*). Multiple resistance to insect pests was evident in ‘Diamond’, ‘Cavalier’, ‘Crowne’, and ‘Palisades’, new releases to the turf industry. Zoysiagrass mite (*Eriophyes zoysiae*) resistance was high for DALZ9006, DALZ8516, DALZ8508, and ‘Emerald’.

The fall armyworm is a primary pest of turfgrass all across the United States. Reinert et al. (1994) examined resistance in cultivars and genotypes of Zoysiagrass to the fall armyworm. Their research demonstrated neonate larval survival of less than 5% after four days on DALZ8507, ‘Emerald’, and ‘Belair’. DALZ8502 produced the largest larvae, and produced pupae and adults faster than any other selection even though it had only a 15% larval survival rate. Larvae reared on susceptible DALZ8516 and transferred to selected genotypes at the four-day old larval stage continued to develop with much less mortality although lower larval weights were observed. DALZ8507 had no larvae survive for 17 days in either experiment.

High levels of antibiosis were found in cool season grasses *Poa pratensis* L. cvs. 'Baron' and 'Delwood', *P. arachnifera* Torr. cvs. 'SYN1' and 'SYN2' and among *P. arachnifera* x *P. pratensis* hybrids. Resistance occurred on *Festuca arundinacea* Schreb. cvs. 'Rebel II' and 'Rebel Jr.'. On warm season grasses, thirteen tetraploid cultivars of *Buchloe dactyloides* (Nutt.) Engalm., and *Zoysia matrella* (L.) Merr. cv. 'Cavalier' demonstrated resistance, but no resistance was found in diploid *B. d.* cvs. 'Stampede' and 'UCR-95', or among cultivars of *Z. matrella*, *Z. japonica* Steud, *Cynodon dactylon* (L.) Pers., *C. dactylon x C. transvaalensis* (Burtt-Davy), and *Stenotaphrum secondatum* (Walt.) Kuntze (Reinert et al. 1998).

Braman et al. (2000a) assessed antibiosis and nonpreference among more than 30 turfgrass selections to first and third instar fall armyworms. High degrees of antibiosis were exhibited by the Zoysiagrasses 'Cavalier', 'Emerald', DALZ8501, DALZ8508, 'Royal', and 'Palisades'. Lengthened development times, or reduced larval or pupal weights were reported on paspalum selections 561-79, Temple-2, PI-509020, and PI-509022.

Eighty-one Plant Introduction *Paspalum* spp., including the turfgrass 'Tropic Shore', were evaluated for resistance to larvae of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Wiseman and Duncan 1996). Antibiosis was demonstrated on *Paspalum modestum* and *Paspalum scrobiculatum*. *Paspalum vaginatum* selections demonstrated reduced larval weights and extended development times in comparison to controls.

Plant improvement efforts have included screenings of turfgrasses for resistance to tawny mole cricket (*Scapteriscus vicinus* Scudder) and southern mole cricket (*Scapteriscus borellii* Giglio-tos) (Braman et al. 2000b). Environmental chamber testing of seashore paspalum selections demonstrated the greatest tolerance to cricket injury in 561-79, HI-1 and ‘Excalibur’. Glenn Oaks ‘Adalayd’ was the least tolerant. HI-1, HI-2, 561-79, PI-509018 (Sea Isle 1), ‘Excalibur’, SIPV-1 paspalums, and ‘Tifeagle’, and ‘Tifsport’ bermudagrasses evidenced the greatest tolerance to feeding by tawny mole cricket over a four week period in three greenhouse trials.

Twolined spittlebug injury, although well documented on forage and turf grasses, has not been included in evaluations of turfgrasses for tolerance or resistance. An improved resistance screening methodology for cercopid damage to forage grasses of *Brachiaria* spp. genotypes was recently reported (Cardona et al. 1999) that could lead to faster screening of turfgrass genotypes. This research attempts to evaluate turfgrass selections for their potential to withstand damage by this pest in laboratory, greenhouse and field conditions.

Additionally, testing of common weeds found in close association with turf for potential as twolined spittlebug hosts will be conducted. These weeds are found in turf as well as along transitional zones bordering turf areas. If they prove capable of providing refugia for these spittlebugs, or an advantage in recolonization of treated areas, they would be important components of an integrated pest management program.

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CHAPTER 2

EVALUATION OF TURFGRASS SPECIES AND CULTIVARS FOR POTENTIAL RESISTANCE TO TWOLINED SPITTLEBUG, *PROSAPIA BICINCTA* (SAY) (HEMIPTERA: CERCOPIDAE)[1]

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ABSTRACT Potential resistance to the twolined spittlebug, *Prosapia bicincta* (Say), was evaluated among 56 turfgrass genotypes. Greenhouse, laboratory, and field bioassays identified differences in spittlebug survival and development, host preference and damage levels, and turfgrass tolerance to and ability to recover from pest-induced injury. All centipedegrasses demonstrated high levels of susceptibility, followed by bermudagrasses, seashore paspalums, and zoysiagrasses. Average nymphal survival to the adult stage ranged from 1.5-78.1%. Development required 38.1 to 62.0 d depending on plant taxa under greenhouse conditions. Among seashore paspalums, nymphal survival to the adult stage was lowest and duration of development was longest on HI-1, 'Sea Isle 2000', 561-79, and 'Mauna Kea'. Reduced spittlebug survival and increased developmental times were also observed on the bermudagrasses BERPC 91-15 and 'Tifway'. Although zoysiagrasses supported spittlebug development and survival to the adult stage, developmental times were extended on the zoysiagrass cultivars 'Emerald' and 'El Toro'. Spittlebug preference varied with generation evaluated. First generation spittlebugs inflicted the greatest damage on TC201 (centipedegrass), 'Primavera' (bermudagrass), and 'Emerald' (zoysiagrass) in choice tests. In the fall, second-generation spittlebugs damaged TC201 (centipedegrass) and 'Sea Isle 1' (paspalum) most severely, while 561-79 (paspalum) and 'Emerald' (zoysiagrass) were less severely affected. Among taxa included in field trials, HI-1, 'Mauna Kea', 'Sea Isle 2000' and AP-14 paspalums, 'Tifway' bermudagrass, and 'Emerald' zoysiagrass were most tolerant of twolined spittlebug feeding.

KEY WORDS twolined spittlebug, *Prosapia bicincta* (Say), host plant resistance, turfgrass, bermudagrass, centipedegrass, seashore paspalum, zoysiagrass, Hemiptera, Homoptera.

The spittlebug genus, *Prosapia* Fennah, occurs throughout the Americas, with most species occurring in Mexico and Central America (Hamilton 1977). Twolined spittlebug, *Prosapia bicincta* (Say), has been reported from Florida to Maine (Byers 1965) and as far west as Texas and Arkansas in the United States. *Prosapia*, without a species designation, has been reported in Brazil as a pest on grasses of the genus *Brachiaria* Griseb. (LaPointe et al. 1992). Cercopids (at least eight species) limit the establishment of *Brachiaria* spp. grasses in the South and Central American rangeland. Intensive breeding programs for resistance are underway (LaPointe et al. 1992, Peck 1998). In the Monteverde region of Costa Rica, *Prosapia* nr. *bicincta*, distinct from *P. bicincta*, is the dominant pest of forage grasses (Peck 1998).

Nymphal and adult twolined spittlebugs are opportunistic xylem feeders, with reports of more than forty hosts (Fagan and Kuitert 1969). Twolined spittlebug is a recognized pest of bermudagrass, *Cynodon* spp., pastures (Byers 1965, Pass and Reed 1965, Byers and Wells 1966, Fagan and Kuitert 1969, Taliaferro et al. 1969). Damage also has been reported on other grasses such as Pangola grass, *Digitaria decumbens* Stent., and St. Augustinegrass, *Stenotaphrum secundatum* (Walt.) Kuntze (Genung and Green 1974). Economic damage has also been reported on ornamental hollies, *Ilex opaca* L., *I. cornuta burfordii* De France, and *I. cassine* L. (Braman and Ruter 1997), and on southern lawns planted with centipedegrass, *Eremochloa ophiuroides* (Munro) Hack. or bermudagrass (Potter and Braman 1991).

Turfgrass adaptability and aesthetic traits have traditionally been emphasized in turfgrass breeding programs. Recent efforts in plant improvement have incorporated insect and disease resistance (Quisenberry 1990). Reinert (1982) and Quisenberry (1990) provided reviews of resistance in turfgrass and forage grasses to insects and mites. While forage grass response to various spittlebugs has been investigated (Stimman and Taliaferro 1969, Miles et al. 1995, Cardona et al. 1999, LaPointe et al. 1992), there have been no evaluations of turfgrass for potential resistance to twolined spittlebug. Here, we report the relative resistance of 56 turfgrass entries to twolined spittlebug.

Materials and Methods

Insects and Plants. Adult twolined spittlebugs were field collected from local residential and commercial landscapes, and on a golf course from June to September, 1996-1998. Spittlebugs were maintained on turfgrass in 0.5 liter glass cages ventilated with 32-mesh screens. Adults were placed in environmental chambers (Percival Scientific, Inc.; Perry, Iowa) and maintained at 24°C, 85% RH and on a 15:9 (L:D) h. Adults were provided with moistened filter paper as oviposition sites. Eggs were collected daily, placed on moistened filter paper in 10-cm petri dishes and maintained in environmental chambers.

Experimental grasses included selections of seashore paspalum (*Paspalum vaginatum* Swartz.), bermudagrass *(Cynodon* L.C. Rich), zoysiagrass (*Zoysia* Willd.), centipedegrass (*Eremochloa ophiuroides* (Munro) Hack.), St. Augustinegrass (*Stenotaphrum secundatum* (Walt.) Kuntze), and tall fescue (*Festuca arundinacea* Schreb.).

No-choice Greenhouse Evaluations. *Year 1*: The ability of the twolined spittlebug to complete its life cycle on centipedegrass, bermudagrass, zoysiagrass, and seashore paspalum under greenhouse conditions was assessed. Fifty-one selections from four genera of turf and forage grasses were planted in Metro Mix 300 potting media

(Scotts-Sierra Horticultural, Marysville, OH) in15.2-cm plastic pots and allowed to acclimate in a greenhouse for several weeks. Five eggs were placed on filter paper in each pot close to the crowns of the plants. Each pot was placed in a fiber plant sleeve (Kleentest Products, Milwaukee, WI) that was rolled down from the top and secured with a wire paper clip to insure that all nymphs and adults remained on the designated pot. Four replications, arranged in a randomized complete block design, were grown under natural daylength and temperature conditions in Griffin, GA, with a weekly fertilization program using a 20-20-20 plus micronutrients water soluble fertilizer at 100 ppm and misting three times per day. Plants were observed daily for the presence of twolined spittlebug spittle masses, nymphs, and adults. Adults were removed within 48 hours of emergence to prevent excessive feeding damage to the plants. Number of spittlebugs surviving to the adult stage among plant species and cultivars was compared using SAS General Linear Models Procedure (GLM) with mean separation by LSD (SAS Institute 1985).

Year 2: Twenty-four plant taxa were selected from the 51 entries evaluated during the first year and included centipedegrass selections not previously available. St. Augustinegrass also was added to this trial. Accessions showing no signs of twolined spittlebug growth in the first year trial were reevaluated the second year to determine the degree of potential antibiosis. Grasses were grown in the greenhouse in the same manner as described previously. Eight replications were placed on a bench in a randomized complete block design. Eight eggs per pot were used rather than five to increase the number of nymphs for the test. Eggs were placed on the pots two days before expected hatch dates.

In a separate evaluation to assess potential antibiosis, the same 24 grass taxa were used to measure development times of twolined spittlebug from day-old nymphs to teneral adults. Five, 1d-old nymphs were placed on each host plant with a camel's-hair brush and allowed to complete their life cycle. Four replications of the 24 selections were arranged in a randomized complete block design on greenhouse benches.

Data, including number of individuals completing development and duration of development, were subjected to ANOVA using SAS GLM procedure (SAS Institute 1985). Mean separation was accomplished using Fisher's protected least significant difference (LSD) test.

No-choice Field Evaluations: *Year 1*: Eighteen of the grasses used in the greenhouse evaluations were selected for inclusion in field studies for assessment of twolined spittlebug damage the following year. Field plots, located on the Georgia Experiment Station, Griffin GA, were established in a randomized complete block design with four replications, consisting of one 3.2 m^2 plot for each of the 18 selections (Table 2.3). Plots were irrigated and maintained according to University of Georgia Extension Service recommendations.

Year 2: The established field plots were infested with three mating pairs of field-collected first-generation adults. Each plot had two centrally located, 15.2-cm plastic PVC tubes inserted 10-cm deep into the soil with at least an equal height above ground. One tube was used to confine the twolined spittlebugs to the designated area. The other tube contained grass with no spittlebugs and was used as a control. To minimize the effect of shading on plant growth, both tubes were covered by a mesh screen. Spittlebug damage and grass recovery data were collected weekly, and included a visual estimate of plant density recorded as percent cover within the cage area, grass height, and weight of clippings placed in paper bags and dried at 43°C for one week. Grass was maintained at a height of 5 cm by weekly cutting after the death of adult spittlebugs.

Year 3: Eight selections of turfgrass that survived the previous winter were infested with field-collected second-generation adults. Four PVC tubes (infested, control, control, infested) were placed in each plot in a counterclockwise direction. The infested tubes contained two male and two female adult twolined spittlebugs. The tubes were screened until the death of all adults, and data were recorded for turfgrass recovery response to twolined spittlebug presence. The same data parameters were observed as in the previous year. Each grass has its own inherent growth rate and characteristics. To accurately compare the response of the grasses to spittlebug injury independent of normal variation in growth among cultivars, analysis of covariance was used. This allowed the normal variation in growth among cultivars to be quantified and effectively separated from that due to feeding by the spittlebug (Gomez and Gomez 1984). Data for both years were subjected to analysis of covariance, with performance of noninfested control plots of each cultivar of turfgrass as the covariate (SAS Institute 1985). A SAS macro, PDMIX612, was then applied to convert the mean separation output to letter groupings (Saxton 1998).

Choice Evaluations. In three separate evaluations, the host preference of either first- or second-generation adult twolined spittlebugs for selected grass accessions placed in a circle within 1 m^3, wooden cages covered with 32 mesh nylon screen was compared in September, 1997 and June and August, 1998. Grasses, in sand media, were handwatered daily and held at a 14:10 (L:D) h photoperiod and 27°C. Twenty spittlebugs were released into the center of the circle of each cage in September, 1997, with the 16 plant selections. Plants were arranged in a randomized complete block design with four replications (cages). Similarly, 12 females and six males were introduced with 15 plant taxa in June, 1998. Nineteen females and five males were introduced into the cages in August, 1998. Location of adults was noted at morning and afternoon observations. Feeding damage was assessed by counting the number of live stems at the conclusion of the experiment. Data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute 1985). Mean separation was by LSD.

Results

No-choice Greenhouse Evaluations. *Year 1.* Among the grass species tested, mean survival of two-lined spittlebug was greatest on centipedegrass (2.5 adults), followed by bermudagrass (1.4), seashore paspalum (0.7), and zoysiagrass (0.5) (F=1.63; df=3,50; P<0.05). Among the 51 individual taxa tested (Table 2.1), common centipedegrass yielded the highest number of adult twolined spittlebugs. During year 1, five of the selections failed to support spittlebug development to the adult stage, although nymphal masses were initially observed.

Year 2. The centipedegrass selections ‘TifBlair’, ‘Tennessee Tuff’, and TC316 BGBP (broad gene base population) were all capable of supporting twolined spittlebug development (means ranging from 5.5 to 6.25 adults per pot) (Table 2.2). Significant differences among turfgrass selections were determined for adult emergence (F=8.37; df=3,23; P<0.05). Twolined spittlebug development times, ranging from 38-42 days, were shortest on the centipedegrasses (Table 2.2). While ‘Crowne’ zoysiagrass produced no survivors the first year, spittlebugs did complete development on this cultivar with development times similar to common centipede during year two. A wide range in survival and development times was observed among seashore paspalum. ‘Glenn Oaks Adalayd’ produced a low number of adults during both years and failed to support any twolined spittlebug to adulthood in the development study. The longest developmental periods (days) occurred on the paspalums HI-1 (62.0), ‘Mauna Kea’ (60.5), and ‘Sea Isle 2000’ (56.3) (F=6.48; df=3,18; P<0.05).

During year two, in the no-choice trial, 91-15, a bermudagrass selection, and St. Augustinegrass failed to produce adult twolined spittlebug, but in development studies conducted with the same grasses, adults were produced on St. Augustinegrass. In the previous year’s trial, 91-15 was capable of supporting development. The remaining three cultivars that produced no adult twolined spittlebug in year 1 were all capable of supporting development in year 2.

No-choice Field Evaluations: During 1997, all selections were affected by twolined spittlebug feeding. All selections also demonstrated the ability to recover from injury, although to varying degrees (Tables 2.3-2.5). Average season-long plant density, measured as a visual estimate of percent cover of infested grasses ranged from 8.1 to 71.5% (Table 2.3). This represented a range in percentage of the noninfested turfgrass counterpart plots of 23.6 to 244.3. Covariate analysis revealed significant differences in turfgrass response to spittlebug injury (F=93.39; df=1; P<0.0001). Two selections, ‘Mauna Kea’ and HI-1, demonstrated average percentages of noninfested controls that exceeded 100%, indicating that spittlebug-infested plots actually covered in excess of their noninfested counterparts, although considerable plot to plot variation was observed (Table 2.3). This indicates that some infested plants grew more with, or compensated for, spittlebug induced injury. Two paspalum grasses, AP-14 and 'Mauna Kea', also demonstrated season-long improvement in percent cover compared to common centipedegrass, a grass previously observed to be susceptible. Spittlebugs also reduced turfgrass height (Table 2.4) (F=328.67; df=1; P<0.0001), although to a lesser extent than their impact on percent cover and plant dry weight. Average weekly plant dry weights ranged from 0.06 to 0.44 gm per plot (Table 2.5) (F=265.1; df=1; P<0.0001). AP-14 was least affected by spittlebug injury during 1997 as measured by plant dry weight. The zoysiagrasses 'Crowne', 'Emerald' and 'Palisades', and the paspalum grasses AP-14, AP-10 ('Sea Isle 2000'), and 561-79 all demonstrated significantly higher plant weights compared with common centipedegrass (Table 2.5).

Winter survival among turfgrasses was consistently high for the eight selections included in evaluations during 1998. Although the seashore paspalum 'Sea Isle 1' and the bermudagrass 91-15 had been severely injured by spittlebugs during 1997, plots containing these selections survived the winter and were evaluated during 1998. Differences among plant taxa for plant density (F=22.5; df=1; P<0.0001), plant dry weights (F=275.39; df=1; P<0.0001), and height (F=156.5; df=1; P<0.0001) were significant (Table 2.6). Among the eight turfgrass selections included in the 1998 trials, AP-14 demonstrated the best growth when subjected to spittlebug feeding. During 1998, fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) larvae were observed in experimental plot areas. Number of larvae was included as a covariate in analysis and determined not to be a significant influence on relative plant performance (F=1.16; df=1; P=0.2820).

Choice Evaluations. During 1997, percent live stems remaining after exposure to adult spittlebugs ranged from 6 to 61% (Table 2.7) (F=2.25; df=3,15; P=0.0182). The most extensive damage was sustained by centipedegrass and the seashore paspalum 'Sea Isle 1'. Selections retaining at least 50% of their normal growth were 'Kentucky 31' tall fescue, 'Mauna Kea', 'Sea Isle 2000', and 561-79 seashore paspalum. Preferred resting location, for spittlebugs in the June, 1998, choice test included 'Primavera' bermudagrass; the paspalums 561-79, HI-1, 'Mauna Kea', Palisades, 'Sea Isle-1'; and the centipedegrass TC201 (Table 2.8) (F= 3.04; df=3,14; P=0.0023). No live stems were evident on TC201 after exposure to spittlebugs, while 'Tifway' bermudagrass maintained 75% of its original live stems during the June, 98 evaluation. Second-generation spittlebugs preferred to rest on the 'Kentucky 31' tall fescue, although little damage was observed on this turf species (Table 2.9). 'Tifway' bermudagrass and 'Sea Isle 2000' seashore paspalum sustained little damage in either June or August choice tests (Tables 2.8 and 2.9). 'Sea Isle 1' was less severely damaged in the June evaluation compared with August evaluation with second generation spittlebugs.

Discussion

All grass species evaluated were capable of supporting twolined spittlebug survival and development. All the grasses fed on by adult twolined spittlebug showed typical feeding damage, which included yellowing, purple streaking, browning and death of the above-ground plant parts. Once adults were removed, plants began to recover. In the Southeast, centipedegrasses are considered to be preferred hosts of twolined spittlebugs (Braman 1995). In these evaluations, all centipedegrasses were highly susceptible to spittlebugs. Survival was high, developmental times were short, and turfgrass response to injury was pronounced. Centipedegrasses also were less able to tolerate spittlebug injury than other selections included in this study. Historically, zoysiagrasses have not been regarded as particularly susceptible to twolined spittlebug, but these evaluations demonstrated that this genus has the potential to support spittlebug survival and development and to sustain damage by this pest. In the greenhouse, spittle masses were often not readily apparent in zoysia, perhaps because most spittlebug development takes place in the thatch or below the soil line. As a genus, zoysiagrasses proved least susceptible to twolined spittlebugs in greenhouse, laboratory, and field assessments. They retained more of their typical growth, had limited spittlebug survival, and increased spittlebug development times.

Seashore paspalums are relatively new to the turf industry, although they are grown as forage on saline soils in tropic and subtropical climates. In these evaluations, all paspalums (32 selections) were capable of supporting spittlebug survival and development. Most were moderately to highly susceptible to spittlebug injury. Exceptions included 561-79, HI-1, AP-14, and 'Mauna Kea', which demonstrated reduced spittlebug survival, superior growth of infested field plots, and/or lengthened spittlebug development times in no-choice tests.

High levels of resistance to fall armyworms have been identified among certain zoysiagrass cultivars (Braman et al. 2000b, Reinert et al. 1994, 1997, 1998). 'Cavalier' is apparently resistant to fall armyworm (Braman et al. 2000b), moderately resistant to mole crickets (Braman et al. 1994), susceptible to zoysiagrass mite, *Eriophyes zoysiae* Baker, Kono and O'Neill (Reinert et al. 1993), and was moderately resistant to twolined spittlebug in this study. 'Crowne' is moderately resistant to zoysiagrass mite and fall armyworm, but is relatively susceptible to tawny mole cricket and twolined spittlebug. ‘Diamond’, which demonstrated resistance to twolined spittlebug in the present study, is also moderately resistant to the fall armyworm and tawny mole cricket. Paspalum selections that demonstrated reduced fall armyworm larval or pupal weights, or prolonged developmental times when compared to all paspalum selections, included 561-79, PI-509021 and PI-509022, although all paspalums were susceptible to this pest (Braman et al. 2000a). ‘Glenn Oaks Adalayd’ paspalum was least tolerant of injury by the tawny mole cricket, *Scapteriscus vicinus* (Scudder), while 561-79 and HI-1 were more tolerant, although none of these were highly resistant (Braman et al.1994).

Several turfgrass genotypes with resistance to twolined spittlebug have been identified in the present study. Those with demonstrated cross resistance to other turfgrass-infesting insect or mite species may play an especially important role in integrated pest management for residential and recreational turf in the future. Experiments conducted to compare effectiveness of intensity and type of landscape management (Braman et al. 2000c) demonstrated that twolined spittlebugs and other landscape pests were most effectively suppressed in landscapes designed with resistant plant species of woody ornamentals and turf. These studies highlight the opportunities for development of arthropod resistant grasses. Impediments to implementation of host resistance as a foundation pest management strategy include difficulties in identifying the underlying mechanisms contributing to resistance and the ability to transfer resistance to plants with suitable agronomic or horticultural characteristics. These represent fertile areas for future research focus.

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Table 2.1. Mean (± SE) number of twolined spittlebugs surviving to the adult stage on *Cynodon*, *Eremochloa*, *Paspalum,* and *Zoysia* spp. genotypes in a no-choice greenhouse trial (1996).

Type of Grasses	Genus Species	Genotype	Adults per pot
Centipede	*E. ophiuroides*	Common	2.5 ± 0.6 a
Bermuda	*C. dactylon*	BERPC 91-4	2.2 ± 1.0 ab
Bermuda	*C. dactylon*	BERPC 91-2	2.0 ± 0.7 abc
Bermuda	*C. transvaalensis*	BERPC 91-15	2.0 ± 1.2 abc
Bermuda	*C. dactylon*	‘Primavera’	1.7 ± 0.8 abcd
Bermuda	*C. dactylon*	B-12	1.7 ± 0.5 abcd
Bermuda	*C. dactylon*	20SI	1.5 ± 0.9 abcde
Bermuda	*C. dactylon*	B-14	1.0 ± 0.7 abcde
Bermuda	*C. dactylon*	BERPC 91-3	1.0 ± 0.7 abcde
Bermuda	*C. dactylon*	‘Tifway’	0.7 ± 0.7 bcde
Bermuda	*C. dactylon*	B-2	0.7 ± 0.5 bcde
Paspalum	*P. vaginatum*	‘Mauna Kea’	2.2 ± 0.5 ab
Paspalum	*P. vaginatum*	SIPV-1	2.2 ± 0.5 ab
Paspalum	*P. vaginatum*	PI509023	1.2 ± 0.9 abcde
Paspalum	*P. vaginatum*	‘Tropic Shore’	1.2 ± 0.6 abcde
Paspalum	*P. vaginatum*	SIPV-2	1.0 ± 0 abcde

Paspalum	*P. vaginatum*	'Temple 2'	1.0 ± 0.4 abcde
Paspalum	*P. vaginatum*	'Taliaferro PV'	1.0 ± 0.7 abcde
Paspalum	*P. vaginatum*	HI-2	1.0 ± 0 abcde
Paspalum	*P. vaginatum*	K-6	1.0 ± 1.0 abcde
Paspalum	*P. vaginatum*	'Sea Isle 1'	1.0 ± 1.0 abcde
Paspalum	*P. vaginatum*	PI377709	0.7 ± 0.5 bcde
Paspalum	*P. vaginatum*	PI509021	0.7 ± 0.5 bcde
Paspalum	*P. vaginatum*	PI364985	0.7 ± 0.2 bcde
Paspalum	*P. vaginatum*	561-79	0.5 ± 0.3 cde
Paspalum	*P. vaginatum*	K-7	0.5 ± 0.3 cde
Paspalum	*P. vaginatum*	K-8	0.5 ± 0.5 cde
Paspalum	*P. vaginatum*	PI299042	0.5 ± 0.3 cde
Paspalum	*P. vaginatum*	PI509022	0.5 ± 0.5 cde
Paspalum	*P. vaginatum*	'Glenn Oaks Adalayd'	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	SIPV-2-1	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	'Sea Isle 2000'	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	HI-39	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	HI-1	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	AP-14	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	HI-25	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	'Temple-1'	0.2 ± 0.2 de
Paspalum	*P. vaginatum*	'Excalibur'	0 ± 0 e
Zoysia	*Z. 39*	DALZ8516	1.7 ± 0.5 abcd

Zoysia	*Z. 43*	DALZ9006	1.5 ± 0.5 abcde
Zoysia	*Z. japonica*	'Palisades'	1.2 ± 0.9 abcde
Zoysia	*Z. 33*	DALZ8701	0.2 ± 0.2 de
Zoysia	*Z. matrella*	'Cavalier'	0.2 ± 0.2 de
Zoysia	*Z. matrella*	'Diamond'	0.2 ± 0.2 de
Zoysia	*Z. japonica*	'El Toro'	0.2 ± 0.2 de
Zoysia	*Z. 42*	DALZ8506	0 ± 0 e
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	0 ± 0 e
Zoysia	*Z. japonica*	'Crowne'	0 ± 0 e
Zoysia	*Z. 40*	DALZ8501	0 ± 0 e

Means ± SE followed by the same letter are not significantly different, $LSD_{.05}$.

Table 2.2. Mean (± SE) number of twolined spittlebugs surviving to the adult stage and developmental times of *Cynodon*, *Eremochloa*, *Paspalum*, *Zoysia*, and *Stenotaphrum* genotypes in no-choice greenhouse trials (1997).

Type of Grass	*Genus Species*	Genotype	No. adults per pot	Days to develop
Centipede	*E. ophiuroides*	'TifBlair'	6.2 ± 1.6 a	39.0 ± 0.8 g
Centipede	*E. ophiuroides*	TC316 BGBP	6.0 ± 1.0 a	42.0 ± 1.3 efg
Centipede	*E. ophiuroides*	'Tennessee Tuff'	5.5 ± 0.7 a	38.1 ± 0.5 g
Centipede	*E. ophiuroides*	TC201 (common)	3.2 ± 0.5 b	40.5 ± 1.1 fg
Centipede	*E. ophiuroides*	TC178	2.7 ± 1.2 bc	39.9 ± 0.9 fg
Centipede	*E. ophiuroides*	TC540 (new common)	1.6 ± 0.6 cd	41.9 ± 1.1 efg
Zoysia	*Z. japonica*	'Crowne'	3.5 ± 0.5 b	42.0 ± 1.6 efg
Zoysia	*Z. japonica*	'El Toro'	1.6 ± 0.4 cd	47.3 ± 3.8 bcde
Zoysia	*Z. japonica*	'Palisades'	1.5 ± 0.6 cde	49.0 ± 3.7 bc
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	1.4 ± 0.4 cde	49.6 ± 2.8 b
St. Augustine	*S. secundatum*	Common	1.4 ± 0.5 cde	49.5 ± 3.5 b
Bermuda	*C. dactylon*	'Primavera'	0.9 ± 0.3 de	42.5 ± 1.0 defg
Bermuda	*C. dactylon*	BERPC 91-3	0.5 ± 0.2 de	42.8 ± 0.9 cdefg
Bermuda	*C. dactylon*	'Tifway'	0.12 ± 0.12 de	ND
Bermuda	*C. transvaalensis*	BERPC 91-15	0 ± 0 e	ND

Paspulum	*P. vaginatum*	AP-14	0.9 ± 0.6 de	44.7 ± 0.7 bcdef
Paspulum	*P. vaginatum*	PI509023	0.9 ± 0.2 de	44.0 ± 1.8 bcdefg
Paspulum	*P. vaginatum*	'Sea Isle 1'	0.6 ± 0.3 de	48.8 ± 3.9 bcd
Paspulum	*P. vaginatum*	PI299042	0.6 ± 0.4 de	ND
Paspulum	*P. vaginatum*	561-79	0.4 ± 0.3 de	ND
Paspulum	*P. vaginatum*	'Mauna Kea'	0.4 ± 0.3 de	60.5 ± 8.5 a
Paspulum	*P. vaginatum*	'Sea Isle 2000'	0.4 ± 0.3 de	56.3 ± 1.4 a
Paspulum	*P. vaginatum*	'Glenn Oaks Adalayd'	0.1 ± 0.1 de	ND
Paspulum	*P. vaginatum*	HI-1	0 ± 0 e	62.0 ±0 a

Means ± SE followed by the same letter are not significantly different $LSD_{.05}$.

ND - 561-79, 'Glenn Oaks Adalayd', 'Tifway' and BERPC91-15 were not included in developmental times because in this separate trial, no nymphs survived to the adult stage.

Table 2.3. Plant density of turfgrass (*Eremochloa*, *Zoysia*, *Paspalum*, and *Cynodon* spp.) measured as % ground cover in response to injury by adult twolined spittlebug in field plots, 1997.

Genus Species	Genotype	Least Square Means	% Cover infested	% noninfested Controls
P. vaginatum	561-79	37.45cde	43.9	74.5
P. vaginatum	'Sea Isle 1'	-7.83j	10.7	59.6
P. vaginatum	PI509023	26.30efgh	16.1	64.6
P. vaginatum	HI 1	39.02bcd	38.6	244.3
P. vaginatum	'Mauna Kea'	51.10a	49.5	100.2
P. vaginatum	PI299042	14.25hi	8.1	33.4
P. vaginatum	'Adalayd'	31.53defg	24.9	63.2
P. vaginatum	'Sea Isle 2000'	39.73bc	43.8	74.9
P. vaginatum	AP-14	54.28ab	71.5	86.2
E. ophiuroides	Common	35.23cdef	36.7	53.4
C. dactylon	'Tifway'	28.83fg	25.7	55.6
C. dactylon	'Primavera'	39.92bcd	26.2	68.9
C. dactylon	91-3	26.04gh	20.7	52.3
C. transvaalensis	91-15	7.46ij	9.4	23.6
Z. japonica x tenuifolia	'Emerald'	29.65a-i	68.3	75.3
Z. japonica	'Palisades'	36.02a-h	65.3	82.3
Z. japonica	'Crowne'	31.34cdefg	45.0	65.3
Z. japonica	'El Toro'	41.31bc	43.5	64.8

Table 2.4. Plant height of turfgrass (*Eremochloa*, *Zoysia*, *Paspalum*, and *Cynodon* spp.) in response to injury by adult twolined spittlebug in field plots, 1997.

Genus Species	Genotype	Height least square means	Height (cm) Infested plots	% Noninfested Controls
P. vaginatum	561-79	8.56fg	8.5	72.6
P. vaginatum	'Sea Isle 1'	9.85cdef	9.9	81.1
P. vaginatum	PI509023	8.27g	8.6	64.7
P. vaginatum	HI 1	11.48ab	9.8	98.0
P. vaginatum	'Mauna Kea'	8.75efg	7.9	85.9
P. vaginatum	PI299042	10.27abcde	12.1	74.2
P. vaginatum	'Adalayd'	11.40a	11.1	97.4
P. vaginatum	'Sea Isle 2000'	10.91abc	9.7	96.0
P. vaginatum	AP-14	10.73abc	10.0	90.0
E. ophiuroides	Common	10.36a-d	10.7	84.3
C. dactylon	'Tifway'	10.66a-d	9.7	93.3
C. dactylon	'Primavera'	9.47c-g	9.5	75.4
C. dactylon	91-3	10.70abc	12.3	87.8
C. transvaalensis	91-15	8.41g	8.3	71.6
Z. japonica x tenuifolia	'Emerald'	10.82a-d	9.3	93.9
Z. japonica	'Palisades'	9.92b-f	10.9	81.9
Z. japonica	'Crowne'	11.52a	12.3	88.5
Z. japonica	'El Toro'	9.24d-g	9.4	77.0

Table 2.5. Plant dry weight of turfgrass (*Eremochloa*, *Zoysia*, *Paspalum*, and *Cynodon* spp.) in response to injury by adult twolined spittlebug in field plots, 1997.

Genus Species	Genotype	Weight Least Square	Weight (gm) Infested plots	% Noninfested Controls
P. vaginatum	561-79	0.24abc	0.23	54.0
P. vaginatum	'Sea Isle 1'	0.14ef	0.12	37.0
P. vaginatum	PI509023	0.18cde	0.17	42.7
P. vaginatum	HI 1	0.23bcd	0.21	54.6
P. vaginatum	'Mauna Kea'	0.13ef	0.13	48.0
P. vaginatum	PI299042	0.08f	0.09	16.9
P. vaginatum	'Adalayd'	0.21cde	0.19	53.3
P. vaginatum	'Sea Isle 2000'	0.24abc	0.21	71.3
P. vaginatum	AP-14	0.32a	0.44	65.2
E. ophiuroides	Common	0.14ef	0.15	31.8
C. dactylon	'Tifway'	0.19cde	0.16	47.8
C. dactylon	'Primavera'	0.14ef	0.14	31.4
C. dactylon	91-3	0.15def	0.14	39.6
C. transvaalensis	91-15	0.08f	0.06	18.3
Z. japonica x tenuifolia	'Emerald'	0.30ab	0.22	67.6
Z. japonica	'Palisades'	0.24abc	0.35	47.6
Z. japonica	'Crowne'	0.31ab	0.38	51.8
Z. japonica	'El Toro'	0.14ef	0.16	30.2

Table 2.6. Plant density, height, and dry weight of turfgrass (*Paspalum* and *Cynodon* spp.) in response to twolined spittlebug injury in field plots, 1998.

Genus Species	Genotype	% Cover Least square means	Infested plots	% Noninfested Controls
P. vaginatum	'Sea Isle 1'	22.2de	21.0	48.7
P. vaginatum	PI509023	23.3e	23.0	37.8
P. vaginatum	PI299042	44.9b	43.1	75.1
P. vaginatum	'Adalayd'	32.7c	29.6	51.7
P. vaginatum	AP-14	68.5a	77.2	90.7
C. dactylon	'Tifway'	32.3bc	33.9	59.8
C. dactylon	91-3	33.9bcd	37.1	52.6
C. transvaalensis	91-15	28.1cde	36.8	48.8

Genus Species	Genotype	Height (cm) Least square means	Infested plots	% Noninfested controls
P. vaginatum	'Sea Isle 1'	8.7ab	9.3	76.9
P. vaginatum	PI509023	8.7ab	9.5	71.4
P. vaginatum	PI299042	9.8a	10.6	73.6
P. vaginatum	'Adalayd'	8.2b	7.6	78.3
P. vaginatum	AP-14	9.0ab	7.4	90.2
C. dactylon	'Tifway'	8.2b	8.1	80.7
C. dactylon	91-3	8.4b	8.1	78.6
C. transvaalensis	91-15	9.0ab	8.6	83.5

Genus Species	Genotype	Weight (gm) Least square means	Infested plots	% Noninfested controls
P. vaginatum	'Sea Isle 1'	0.2bc	0.1	44.2
P. vaginatum	PI509023	0.1c	0.1	28.4
P. vaginatum	PI299042	0.2bc	0.2	46.9
P. vaginatum	'Adalayd'	0.1c	0.2	49.9
P. vaginatum	AP-14	0.3a	0.4	86.7
C. dactylon	'Tifway'	0.2bc	0.4	99.8
C. dactylon	91-3	0.2bc	0.2	47.4
C. transvaalensis	91-15	0.3ab	0.3	60.5

Table 2.7. Twolined spittlebug preference for *Paspalum, Eremochloa, Cynodon, Zoysia, Stenotaphrum,* and *Festuca* spp. Sept. 1997.

Species	Genotype	Proportion live stems Mean ± SE
P. vaginatum	561-79	0.6 ± 0.0 a
Z. japonica x Z. tenuifolia	'Emerald'	0.6 ± 0.1 ab
P. vaginatum	'Sea Isle 2000'	0.5 ± 0.0 ab
P. vaginatum	'Mauna Kea'	0.5 ± 0.1 abc
F. arundinacea	'Kentucky 31'	0.5 ± 0.1 abc
C. dactylon	'Primavera'	0.5 ± 0.1 abc
S. secundatum	Common	0.4 ± 0.2 abc
P. vaginatum	HI-1	0.4 ± 0.2 abc
Z. japonica	'Palisades'	0.3 ± 0.1 abcd
C. dactylon	'Tifway'	0.3 ± 0.1 bcd
P. vaginatum	AP-14	0.3 ± 0.2 bcd
P. vaginatum	PI509023	0.2 ± 0.0 cd
P. vaginatum	'Adalayd'	0.2 ± 0.1 cd
P. vaginatum	PI299042	0.2 ± 0.1 cd
E. ophiuroides	TC201	0.1 ± 0.2 d
P. vaginatum	'Sea Isle 1'	0.1 ± 0.1 d

Means ± SE followed by the same letter are not significantly different $LSD_{.05}$.

Table 2.8. Twolined spittlebug preference for *Paspalum, Eremochloa, Cynodon, Zoysia, Stenotaphrum,* and *Festuca* spp. June 1998.

Species	Genotype	Mean no. adults ± SE	Mean ± SE Proportion live stems
C. dactylon	'Primavera'	0.9 ± 0.1 a	0.1 ± 0.1 fg
P. vaginatum	561-79	0.8 ± 0.2 ab	0.3 ± 0.2 cdef
P. vaginatum	HI-1	0.7 ± 0.1abc	0.3 ± 0.2 defg
P. vaginatum	'Mauna Kea'	0.7 ± 0.1 abc	0.4 ± 0.1 bcdef
Z. japonica	'Palisades'	0.7 ± 0.1 abc	0.2 ± 0.1 efg
P. vaginatum	'Sea Isle 1'	0.7 ± 0.1 abcd	0.6 ± 0.2 abcd
E. ophiuroides	TC201	0.6 ± 0.1 abcde	0 ± 0 g
P. vaginatum	AP-14	0.5 ± 0.1 bcdef	0.3 ± 0.9 efg
S. secundatum	Common	0.5 ± 0.1 bcdefg	0.3 ± 0.1 cdef
P. vaginatum	PI509023	0.4 ± 0.1 cdefg	0.5 ± 0.1 abcde
C. dactylon	'Tifway'	0.4 ± 0.1 defg	0.7 ± 0.15
Z. japonica x Z. tenuifolia	'Emerald'	0.3 ± 0.1 efg	0.1 ± 0.1 fg
P. vaginatum	'Sea Isle 2000'	0.3 ± 0.1 fg	0.7 ± 0.1 ab
F. arundinacea	'Kentucky 31'	0.3 ± 0.1 fg	0.4 ± 0.2 bcdef
P. vaginatum	'Adalayd'	0.2 ± 0.1 g	0.7 ± 0.1 abc

Means ± SE followed by the same letter are not significantly different $LSD_{.05}$.

Table 2.9. Mean ± SE number of adult TLS per plant on *Paspalum, Eremochloa, Cynodon, Zoysia, Stenotaphrum,* and *Festuca* spp. in a rearing room caged choice test in August 1998.

Species	Genotype	Mean no. adults ± SE	Mean ± SE Proportion live stems
F. arundinacea	'Kentucky 31'	1.5 ± 0.2 a	0.9 ± 0.1 a
P. vaginatum	HI-1	1.0 ± 0.1 b	0.4 ± 0.1 bc
E. ophiuroides	TC201	0.9 ± 0.1 bc	0.3 ± 0.1 c
P. vaginatum	561-79	0.8 ± 0.1 bcd	0.5 ± 0.1 bc
P. vaginatum	'Adalayd'	0.7 ± 0.1 bcde	0.5 ± 0.1 bc
P. vaginatum	'Sea Isle 2000'	0.7 ± 0.1 cdef	0.6 ± 0.1 ab
P. vaginatum	AP-14	0.6 ± 0.1 cdefg	0.5 ± 0.2 bc
S. secundatum	Common	0.6 ± 0.1 cdefg	0.5 ± 0.2 bc
Z. japonica	'Palisades'	0.5 ± 0.1 defgh	0.6 ± 0.0 ab
P. vaginatum	'Sea Isle 1'	0.5 ± 0.1 defgh	0.3 ± 0.1 c
P. vaginatum	PI509023	0.4 ± 0.1 efgh	0.3 ± 0.1 c
P. vaginatum	'Mauna Kea'	0.4 ± 0.1 efgh	0.5 ± 0.2 bc
Z. aponica x Z. tenuifolia	'Emerald'	0.4 ± 0.1 fgh	0.5 ± 0.1 bc
C. dactylon	'Primavera'	0.4 ± 0.1 gh	0.5 ± 0.2 bc
C. dactylon	'Tifway'	0.3 ± 0.1 h	0.7 ± 0.1 ab

Means ± SE followed by the same letter are not significantly different $LSD_{.05}$.

CHAPTER 3

NOTE: SURVIVAL AND DEVELOPMENT OF TWOLINED SPITTLEBUG, *PROSAPIA BICINCTA* (SAY) (HEMIPTERA: CERCOPIDAE), ON POTENTIAL WEEDY HOSTS[1]

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[1] S.L. Shortman and S.K. Braman. To be submitted to *Journal of Entomological Science*.

Key Words Alternate hosts, Cercopidae, froghoppers, *Prosapia bicincta* (SAY), Homoptera, Hemiptera, turfgrass, weeds

The twolined spittlebug, *Prosapia bicincta* (Say), Hemiptera: Cercopidae, is a pest of turf, pasture grasses and native *Ilex* species and cultivars containing *Ilex cassine* or *Ilex opaca* parentage in the southeastern United States (Braman, 1995, ESA Handbook of Turfgrass Insect Pests, 140 pp; Braman and Ruter, 1997, J. Environ. Hort. 15: 211-214). Numerous graminaceous and broadleaf plants have been recorded as hosts for the twolined spittlebug (Byers, 1965, Georgia Agricultural Expt. Sta. Tech. Bull. N.S. 42. 26 pp.; Fagan and Kuitert, 1969, Fla. Entomol. 52: 199-206; Mead, 1962, Entomology Cir. #7 Fla. Dept. Agri. DPI; Pass and Reed, 1965, J. Econ. Entomol. 58: 275-278; Thompson, 1999, Can. J. Bot. 77, no. 9: 1387-1390). Adults have been observed to be opportunistic xylem feeders on woody and herbaceous plants. Nymphs develop on herbaceous hosts, primarily grasses. Although numerous plants have been reported as hosts, little information exists to document which plants support survival, development and oviposition by *P. bicincta*. This study reports the results of an evaluation of common weeds that occur in turf, and weedy borders as potential developmental hosts for *P. bicincta*. An understanding of which weeds potentially harbor and support development of spittlebug populations can facilitate better management of the insect pest by focusing attention on high risk weedy hosts. Our study seeks to identify true host plants, capable of supporting survival and development to the adult stage, rather than hosts that support occasional feeding by adults.

Sixteen weed species were field collected in July, 1998 in Spalding Co. GA. Roots were washed to remove field soil and plants transferred to sterile potting media in 15 cm diam. pots. Pots were arranged on greenhouse benches in a randomized complete block design with four replications. On 24 July, plants were infested with five eggs per pot for the first three replications; the fourth replication of 16 plants received eight eggs per pot. Eggs were obtained from field collected adults that were maintained in an environmental chamber at 24°C at 15:9 (L:D) photoperiod in glass rearing cages. Females were allowed to oviposit into filter paper (Whatman no. 2) and eggs were collected daily and stored in sterile petri dishes maintained in the environmental unit until just before hatch, when they were placed in the pot at the base of the plant. Before adult emergence, each pot was placed in a fiber plant sleeve (Kleentest Products, Milwaukee, WI.) that was rolled down from the top and secured with a wire paper clip to ensure that all nymphs and adults remained on the designated pot. Four reps in a randomized complete block design were grown under natural day-length and temperature conditions in Griffin, Georgia, with a weekly fertilization program utilizing a 20-20-20 plus micronutrients water soluble fertilizer at 100 ppm and misting three times a day. Plants were observed for the presence of twolined spittlebug spittle masses, nymphs, and adults at regular intervals. Total number of adults emerging from each plant and duration of development was recorded.

Of eight grasses and eight broadleaf weeds tested among seven plant families, *P. bicincta* successfully developed on seven Gramineae, one Compositae and one Euphorbiaceae (Table 3.1). In addition, spittle masses were observed on Cyperaceae, and Rubiaceae. Twolined spittlebug survival and development had been documented previously on the Gramineae genera *Paspalum*, *Cynodon*, *Zoysia*, *Stenotaphrum*, *Eremochloa*, *Pennisetum*, *Digitaria* and *Avena* (Shortman, in press, J. Econ. Entom.; Byers and Wells, 1966, Annals Entomol Soc. Am. 59: 1067-1071; Genung, 1955, Univ. Fla. Agr. Exp. Sta. Ann. Rep. 236). The range in number of individuals completing development on potential broadleaf or grass hosts was 1-6. A wide range in duration of development was observed (27 to 54 days, Table 3.1). Average duration of development on susceptible cultivated turf grasses in the greenhouse in a companion study was 39 to 62 days. On experimental Gramineae genera, twolined spittlebug development times ranged from 43 to 53 days. Development took place near the crown of the grasses until just before emergence of the adult, when the nymph moved to a higher position on the plant. It is not clear why development time on the spotted spurge, a Euphorbiaceae, was so rapid; justifying/deserving further study. Feeding attachment of the nymph was located along the stem of the plant toward the distal end although the entire stem is prostrate. The Compositae family member, shiny cudweed, supported development of a single adult spittlebug over a 54-day period. Development occurred within a tight rosette of leaves and was relatively unapparent until just before eclosion. Nymphal position did not change appreciably over time.

The invasion and rapid increase in numbers of twolined spittlebug leading to serious problems in turf quality has long been known to be moisture-dependent, but oviposition and nymphal development have been reported as occurring primarily on members of the Gramineae. This study has demonstrated the exploitative ability of the twolined spittlebug to develop on an annual Compositae and on a biennial Euphorbiaceae. Since eggs were placed at the base of plants and not directly oviposited, no conclusions may be drawn about host preference. Although these may not be the oviposition hosts of choice, nymphs moving from one host to another as they mature certainly could take advantage of having these plants present as refugia. Further study of ovipositional preference is warranted as twolined spittlebugs may be able to overwinter in untreated weedy borders including these weeds and re-infest turf the following year as conditions become favorable. Equally important was the finding that there were no adults recovered from carpetgrass. This is deserving of follow up, especially considering the implications for the incorporation of resistance, should it be genetic, into turf breeding programs.

A special thanks is given to Tim R. Murphy for his help in selecting and identifying weeds included in this study.

Table 3.1. *Prosapia bicincta* survival and duration of development on potential weed hosts common in southeastern turfgrasses in a no-choice greenhouse trial

FAMILY	SPECIES	COMMON NAME	LC*	MEAN ± SE OF ADULTS	MEAN ± SE DEV DAYS**
Gramineae	*Digitaria ischaemum* (Schreb. Ex Schweig.) Schreb. Ex Muhl	Smooth Crabgrass	SA	4.00 ± 0.41a	52.87 ± 1.85a
Gramineae	*Paspalum dilatum* Poir.	Dallisgrass	P	3.00 ± 1.35ab	51.60 ± 6.40a
Gramineae	*Eleusine indica* (L.) Gaertn.	Goosegrass	SA	2.25 ± 1.31abc	43.11 ± 1.45a
Gramineae	*Echinochloa colonum* (L.) Link	Junglerice	SA	1.75 ± 1.11bcd	47.85 ± 1.01a
Gramineae	*Cynodon dactylon* (L.) Pers.	Common Bermuda	P	1.25 ± 0.75bcd	50.60 ± 2.46a
Gramineae	*Echinochloa crusgalli* (L.) Beauvois	Barnyard grass	SA	1.25 ± 0.95bcd	52.20 ± 0.80a
Gramineae	*Digitaria ciliaris* (Retz.) Koel.	Southern crabgrass	SA	0.25 ± 0.25d	53.00 ± .a
Euphorbiaceae	*Chamaesyce maculata* (L.) Small	Spotted spurge	SA	0.25 ± 0.25d	27.00 ± .a
Compositae	*Gnaphalium spicatum* Lam.	Shiny cudweed	A, B	0.25 ± 0.25d	54.00 ± .a
Loganiaceae	*Polypremum procumbens* L.	Rustweed	P	0 ± 0d	
Aizoaceae	*Mollugo verticillata* L.	Carpetweed	SA	0 ± 0d	
Compositae	*Eupatorium capillifolium* (Lam.) Small	Dog fennel	P	0 ± 0d	
Euphorbiaceae	*Acalypha gracilens* Gray	Three-seeded Mercury	SA	0 ±0d	
Rubiaceae	*Diodia virginiana* L.	Virginia buttonweed	P	0 ± 0d	
Gramineae	*Axonopus affinis* Chase	Carpetgrass	P	0 ± 0d	

Cyperaceae	*Cyperus compressus* L.	Annual sedge	A	0 ± 0d

* LC=life cycle, SA=summer annual, A=annual, B=biennial, P=perennial

** DEVDAYS=days to development

$F_{3,16}$=3.51, P=0.004 mean number of adults

$F_{3,9}$=1.03, P>0.05 days to development

Means within a column followed by the same letter are not significantly different, P>0.05

CHAPTER 4

CONCLUSIONS

Potential resistance to the twolined spittlebug, *Prosapia bicincta* (Say), was evaluated among 56 turfgrass genotypes. Greenhouse, laboratory, and field bioassays identified differences in spittlebug survival and development rate, host preference and damage levels, and turfgrass tolerance to and ability to recover from pest induced injury. All centipedegrasses demonstrated high levels of susceptibility, followed by bermudagrasses, seashore paspalums, and zoysiagrasses. Average nymphal survival to the adult stage ranged from 1.5-78.1%. Under greenhouse conditions, development required 38.1 to 62.0 d depending on the host plant. Among seashore paspalums, nymphal survival to the adult stage was lowest and duration of development was longest on HI-1, 'Sea Isle 2000', 561-79, and 'Mauna Kea'. Reduced spittlebug survival and increased developmental times were also observed on the bermudagrasses BERPC 91-15 and 'Tifway'. Although zoysiagrasses supported spittlebug development and survival to the adult stage, developmental times were extended on the zoysiagrass cultivars 'Emerald' and 'El Toro'. Spittlebug preference varied with generation evaluated. First generation spittlebugs inflicted the greatest damage on TC201 (centipedegrass), 'Primavera' (bermudagrass) and 'Emerald' (zoysiagrass) in choice tests. In the fall, second-generation spittlebugs damaged TC201 (centipedegrass) and 'Sea Isle 1' (paspalum) most severely, while 561-79 (paspalum) and 'Emerald' (zoysiagrass) were less severely affected. Among taxa included in field trials, HI-1, 'Mauna Kea', 'Sea Isle

2000' and AP-14 paspalums, 'Tifway' bermudagrass, and 'Emerald' zoysiagrass were most tolerant of twolined spittlebug feeding.

Of eight grasses and eight broadleaf weeds tested among seven plant families, *P. bicincta* successfully developed on seven Gramineae, one Compositae, and one Euphorbiaceae. In addition, spittle masses were observed on Cyperaceae, and Rubiaceae. Twolined spittlebug survival and development had been documented previously on the Gramineae genera *Paspalum, Cynodon, Zoysia, Stenotaphrum, Eremochloa, Pennisetum, Digitaria* and *Avena.* Range in number of individuals completing development on potential broadleaf or grass hosts was 1- 6. A wide range in duration of development was observed (27 to 54 days). Average duration of development on susceptible cultivated turf grasses in the greenhouse in a companion study was 39 to 62 days. On experimental Gramineae genera, twolined spittlebug development times ranged from 43 to 53 days. Development took place near the crown of the grasses until just before emergence of the adult, when the nymph moved to a higher position on the plant. It is not clear why development time on the spotted spurge, a member of the Euphorbiaceae, was so rapid; justifying/deserving further study. Feeding attachment of the nymph was located along the stem of the plant toward the distal end although the entire stem is prostrate. The Compositae family member, shiny cudweed, supported development of a single adult spittlebug over a 54-day period. Development occurred within a tight rosette of leaves and was relatively inapparent until just before eclosion. Nymphal position did not change appreciably over time.

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