Evaluation of Turfgrass Species and Cultivars for Potential Resistance to Twolined Spittlebug (Hemiptera: Cercopidae)

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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 centipede grasses demonstrated high levels of susceptibility, followed by bermudagrasses, seashore paspalums, and zoysiagrasses. Average nymphal survival to the adult stage ranged from 1.5 to 78.1%. Development required 38.1–62.0 d under greenhouse conditions, depending on plant taxa. 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 (centipede grass), 'Primavera' (bermudagrass), and 'Emerald' (zoysiagrass) in choice tests. In the fall, second-generation spittlebugs damaged TC201 (centipedegrass) and 'Sea Isle 1' (paspalum) most severely, whereas 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 (demonstrated the best regrowth potential following twolined spittlebug feeding).

KEY WORDS twolined spittlebug, host plant resistance, turfgrass, bermudagrass, centipedegrass, seashore paspalum

The spittlebug genus *Prosapia* Fennah occurs in North America, with most species ocurring 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).

Nymphs and adult twolined spittlebug are opportunistic xylem feeders, with reports of more than 40 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. Augustine grass, *Stenotaphrum secundatum* (Walt.) Kuntz (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 centipede grass, *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. Although forage grass

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response to various spittlebugs has been investigated (Stimman and Taliaferro 1969, LaPointe et al. 1992, Miles et al. 1995, Cardona et al. 1999), 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, Perry, IA) and maintained at 24°C, 85% RH, and a photoperiod of 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. Levels of infestation used in the experiments described here were based on preliminary observations of injury.

Experimental grasses included selections of seashore paspalum (*Paspalum vaginatum* Swartz.), bermudagrass (*Cynodon* L.C. Rich), zoysiagrass (*Zoysia* Willd.), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.], St. Augustine grass [*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) in 15.2-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 ensure 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 h 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 (GLM) procedure with mean separation by least significant difference (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. Augustine grass also was added to this trial. Accessions showing no signs of supporting 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 2 d 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, 1-d-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 analysis of variance (ANOVA) using SAS GLM procedure (SAS Institute 1985). Mean separation was accomplished using Fisher protected LSD test.

No-Choice Field Evalutions. *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. Plots were irrigated and maintained according to University of Georgia Extension Service recommendations (Landry 2000).

Year 2. The established field plots were infested during August 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. The infested tubes contained two males 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. To minimize the effect of shading on plant growth, both tubes were covered by a mesh screen. Grass was cut each week to a height of 5 cm after the death of adult spittlebugs. Spittlebug damage and grass recovery data were collected weekly. These data included a visual estimate of plant density, which was recorded as percent ground cover within the cage area. Grass height was recorded in cm measured from the soil surface to the tip of the tallest plant. Grass clippings above 5 cm were placed in paper bags, dried at 43°C for 1 wk and weighed. All parameters were measured in both spittlebug infested plots and noninfested plots. Comparison of the yield, or plant biomass, in insect-infested to noninfested plants of the same cultivar generated a measure of the ability of a plant to tolerate the insect population (Smith 1989).

Year 3. Eight selections of turfgrass that survived the previous winter were infested during August with field-collected second-generation adults. Four PVC tubes (infested, control, control, infested) were placed in each plot in a counterclockwise direction. The same data parameters were measured 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 (ANCOVA) 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 ANCOVA, 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 the laboratory during September 1997 and June and August 1998. Grasses, in sand media, were handwatered daily and held at 27°C and a photoperiod of 14:10 (L:D) h. 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 after a 5-d exposure period. Data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute 1985). Mean separation was by LSD.

Table 1. Mean ± SEM 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 ± 0.6a
Bermuda	*C. dactylon*	BERPC 91-4	2.2 ± 1.0ab
Bermuda	*C. dactylon*	BERPC 91-2	2.0 ± 0.7abc
Bermuda	*C. transvaalensis*	BERPC 91-15	2.0 ± 1.2abc
Bermuda	*C. dactylon*	'Primavera'	1.7 ± 0.8abcd
Bermuda	*C. dactylon*	B-12	1.7 ± 0.5abcd
Bermuda	*C. dactylon*	20SI	1.5 ± 0.9abcde
Bermuda	*C. dactylon*	B-14	1.0 ± 0.7abcde
Bermuda	*C. dactylon*	BERPC 91-3	1.0 ± 0.7abcde
Bermuda	*C. dactylon*	'Tifway'	0.7 ± 0.7bcde
Bermuda	*C. dactylon*	B-2	0.7 ± 0.5bcde
Paspalum	*P. vaginatum*	'Mauna Kea'	2.2 ± 0.5ab
Paspalum	*P. vaginatum*	SIPV-1	2.2 ± 0.5ab
Paspalum	*P. vaginatum*	PI509023	1.2 ± 0.9abcde
Paspalum	*P. vaginatum*	'Tropic Shore'	1.2 ± 0.6abcde
Paspalum	*P. vaginatum*	SIPV-2	1.0 ± 0abcde
Paspalum	*P. vaginatum*	'Temple 2'	1.0 ± 0.4abcde
Paspalum	*P. vaginatum*	'Taliaferro PV'	1.0 ± 0.7abcde
Paspalum	*P. vaginatum*	HI-2	1.0 ± 0abcde
Paspalum	*P. vaginatum*	K-6	1.0 ± 1.0abcde
Paspalum	*P. vaginatum*	'Sea Isle 1'	1.0 ± 1.0abcde
Paspalum	*P. vaginatum*	PI377709	0.7 ± 0.5bcde
Paspalum	*P. vaginatum*	PI509021	0.7 ± 0.5bcde
Paspalum	*P. vaginatum*	PI364985	0.7 ± 0.2bcde
Paspalum	*P. vaginatum*	561-79	0.5 ± 0.3cde
Paspalum	*P. vaginatum*	K-7	0.5 ± 0.3cde
Paspalum	*P. vaginatum*	K-8	0.5 ± 0.5cde
Paspalum	*P. vaginatum*	PI299042	0.5 ± 0.3cde
Paspalum	*P. vaginatum*	PI509022	0.5 ± 0.5cde
Paspalum	*P. vaginatum*	'Glenn Oaks Adalayd'	0.2 ± 0.2de
Paspalum	*P. vaginatum*	SIPV-2-1	0.2 ± 0.2de
Paspalum	*P. vaginatum*	'Sea Isle 2000'	0.2 ± 0.2de
Paspalum	*P. vaginatum*	HI-39	0.2 ± 0.2de
Paspalum	*P. vaginatum*	HI-1	0.2 ± 0.2de
Paspalum	*P. vaginatum*	AP-14	0.2 ± 0.2de
Paspalum	*P. vaginatum*	HI-25	0.2 ± 0.2de
Paspalum	*P. vaginatum*	'Temple-1'	0.2 ± 0.2de
Paspalum	*P. vaginatum*	'Excalibur'	0 ± 0e
Zoysia	*Z. 39*	DALZ8516	1.7 ± 0.5abcd
Zoysia	*Z. 43*	DALZ9006	1.5 ± 0.5abcde
Zoysia	*Z. japonica*	'Palisades'	1.2 ± 0.9abcde
Zoysia	*Z. 33*	DALZ8701	0.2 ± 0.2de
Zoysia	*Z. matrella*	'Cavalier'	0.2 ± 0.2de
Zoysia	*Z. matrella*	'Diamond'	0.2 ± 0.2de
Zoysia	*Z. japonica*	'El Toro'	0.2 ± 0.2de
Zoysia	*Z. 42*	DALZ8506	0 ± 0e
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	0 ± 0e
Zoysia	*Z. japonica*	'Crowne'	0 ± 0e
Zoysia	*Z. 40*	DALZ8501	0 ± 0e

Means ± SE followed by the same letter are not significantly different, $LSD_{0.05}$.

Results

No-Choice Greenhouse Evaluations. *Year 1.* Averaged across all selections for each type of grass, mean survival of twolined spittlebug was greatest on centipedegrass (2.5 ± 0.6 adults per plot), followed by bermudagrass (1.4 ± 0.2), seashore paspalum (0.7 ± 0.1), and zoysiagrass (0.5 ± 0.1) ($F = 1.63$; df = 3, 50; $P < 0.05$). Among the 51 individual taxa tested (Table 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). 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 to 42 d, were shortest on the centipedegrasses (Table 2). Although 'Crowne' zoysiagrass produced no survivors the first year, spittlebugs did complete development on this cultivar and development times were similar to

Table 2. Mean ± SEM 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/pot	Days to develop
Centipede	*E. ophiuroides*	'TifBlair'	6.2 ± 1.6a	39.0 ± 0.8g
Centipede	*E. ophiuroides*	TC316 BGBP	6.0 ± 1.0a	42.0 ± 1.3efg
Centipede	*E. ophiuroides*	'Tennessee Tuff'	5.5 ± 0.7a	38.1 ± 0.5g
Centipede	*E. ophiuroides*	TC201 (common)	3.2 ± 0.5b	40.5 ± 1.1fg
Centipede	*E. ophiuroides*	TC178	2.7 ± 1.2bc	39.9 ± 0.9fg
Centipede	*E. ophiuroides*	TC540 (new common)	1.6 ± 0.6cd	41.9 ± 1.1efg
Zoysia	*Z. japonica*	'Crowne'	3.5 ± 0.5b	42.0 ± 1.6efg
Zoysia	*Z. japonica*	'El Toro'	1.6 ± 0.4cd	47.3 ± 3.8bcde
Zoysia	*Z. japonica*	'Palisades'	1.5 ± 0.6cde	49.0 ± 3.7bc
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	1.4 ± 0.4cde	49.6 ± 2.8b
St. Augustine	*S. secundatum*	Common	1.4 ± 0.5cde	49.5 ± 3.5b
Bermuda	*C. dactylon*	'Primavera'	0.9 ± 0.3de	42.5 ± 1.0defg
Bermuda	*C. dactylon*	BERPC 91-3	0.5 ± 0.2de	42.8 ± 0.9cdefg
Bermuda	*C. dactylon*	'Tifway'	0.12 ± 0.12de	ND
Bermuda	*C. transvaalensis*	BERPC 91-15	0 ± 0e	ND
Paspulum	*P. vaginatum*	AP-14	0.9 ± 0.6de	44.7 ± 0.7bcdef
Paspulum	*P. vaginatum*	PI509023	0.9 ± 0.2de	44.0 ± 1.8bcdefg
Paspulum	*P. vaginatum*	'Sea Isle 1'	0.6 ± 0.3de	48.8 ± 3.9bcd
Paspulum	*P. vaginatum*	PI299042	0.6 ± 0.4de	ND
Paspulum	*P. vaginatum*	561-79	0.4 ± 0.3de	ND
Paspulum	*P. vaginatum*	'Mauna Kea'	0.4 ± 0.3de	60.5 ± 8.5a
Paspulum	*P. vaginatum*	'Sea Isle 2000'	0.4 ± 0.3de	56.3 ± 1.4a
Paspulum	*P. vaginatum*	'Glenn Oaks Adalayd'	0.1 ± 0.1de	ND
Paspulum	*P. vaginatum*	HI-1	0 ± 0e	62.0 ± 0a

Means ± SE followed by the same letter are not significantly different $LSD_{0.05}$. 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.

common centipede during year 2. 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 2, in the no-choice trial, 91–15, a bermudagrass selection, and St. Augustine grass failed to produce adult twolined spittlebug, but in development studies conducted with the same grasses, adults were produced on St. Augustine grass. 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 3–5).

Table 3. Mean ± SEM plant density of turfgrass (*Eremochloa*, *Zoysia*, *Paspalum*, and *Cynodon* spp.) infested with twolined spittlebug and as a percentage of ground cover in non-infested plots, 1997

Genus species	Genotype	Least square means	% ground cover (infested plots)	% of non-infested controls
P. vaginatum	561-79	37.45cde	43.9 ± 4.9	74.5 ± 8.4
P. vaginatum	'Sea Isle 1'	−7.83j	10.7 ± 1.6	59.6 ± 1.4
P. vaginatum	PI509023	26.30efgh	16.1 ± 2.6	64.6 ± 3.2
P. vaginatum	HI 1	39.02bcd	38.6 ± 2.2	244.3 ± 6.4
P. vaginatum	'Mauna Kea'	51.10a	49.5 ± 3.2	100.2 ± 2.5
P. vaginatum	PI299042	14.25hi	8.1 ± 0.6	33.4 ± 2.7
P. vaginatum	'Adalayd'	31.53defg	24.9 ± 2.4	63.2 ± 7.0
P. vaginatum	'Sea Isle 2000'	39.73bc	43.8 ± 3.2	74.9 ± 3.7
P. vaginatum	AP-14	54.28ab	71.5 ± 2.3	86.2 ± 2.7
E. ophiuroides	Common	35.23cdef	36.7 ± 2.3	53.4 ± 13.1
C. dactylon	'Tifway'	28.83fg	25.7 ± 2.2	55.6 ± 4.6
C. dactylon	'Primavera'	39.92bcd	26.2 ± 4.4	68.9 ± 10.9
C. dactylon	91-3	26.04gh	20.7 ± 1.9	52.3 ± 4.4
C. transvaalensis	91-15	7.46ij	9.4 ± 1.7	23.6 ± 14.1
Z. japonica x tenuifolia	'Emerald'	29.65a-i	68.3 ± 2.5	75.3 ± 2.4
Z. japonica	'Palisades'	36.02a-h	65.3 ± 3.3	82.3 ± 3.7
Z. japonica	'Crowne'	31.34cdefg	45.0 ± 3.4	65.3 ± 4.8
Z. japonica	'El Toro'	41.31bc	43.5 ± 2.0	64.8 ± 4.0

LS means followed by the same letter are not significantly different, $P > 0.05$. Percentage of noninfested controls = parameter measured in infested plots/parameter measured in non-infested plots.

Table 4. Mean ± SEM 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	% of non-infested controls
P. vaginatum	561-79	8.56fg	8.5 ± 0.7	72.6 ± 8.4
P. vaginatum	'Sea Isle 1'	9.85cdef	9.9 ± 0.8	81.1 ± 1.3
P. vaginatum	PI509023	8.27g	8.6 ± 0.9	64.7 ± 10.8
P. vaginatum	HI 1	11.48ab	9.8 ± 0.5	98.0 ± 2.9
P. vaginatum	'Mauna Kea'	8.75efg	7.9 ± 0.5	85.9 ± 7.3
P. vaginatum	PI299042	10.27abcde	12.1 ± 0.6	74.2 ± 4.2
P. vaginatum	'Adalayd'	11.40a	11.1 ± 0.9	97.4 ± 7.0
P. vaginatum	'Sea Isle 2000'	10.91abc	9.7 ± 0.5	96.0 ± 3.7
P. vaginatum	AP-14	10.73abc	10.0 ± 0.6	90.0 ± 2.8
E. ophiuroides	Common	10.36a-d	10.7 ± 0.5	84.3 ± 13.1
C. dactylon	'Tifway'	10.66a-d	9.7 ± 0.7	93.3 ± 4.9
C. dactylon	'Primavera'	9.47c-g	9.5 ± 0.5	75.4 ± 6.3
C. dactylon	91-3	10.70abc	12.3 ± 0.6	87.8 ± 5.3
C. transvaalensis	91-15	8.41g	8.3 ± 0.6	71.6 ± 6.3
Z. japonica x tenuifolia	'Emerald'	10.82a-d	9.3 ± 0.4	93.9 ± 2.2
Z. japonica	'Palisades'	9.92b-f	10.9 ± 0.6	81.9 ± 2.4
Z. japonica	'Crowne'	11.52a	12.3 ± 0.7	88.5 ± 4.7
Z. japonica	'El Toro'	9.24d-g	9.4 ± 0.4	77.0 ± 2.4

LS means followed by the same letter are not significantly different, $P > 0.05$. Percentage of noninfested controls = parameter measured in infested plots/parameter measured in non-infested plots.

Average season-long plant density in infested plots, measured as a visual estimate of percent cover, ranged from 8.1 to 71.5% (Table 3). This represented a range in percentage of the noninfested turfgrass counterpart plots of 23.6–244.3%. Covariate analysis revealed significant differences in turfgrass response to spittlebug injury ($F = 93.39$; df = 1, 17; $P < 0.0001$). The average percentage ground cover in infested plots of two selections, 'Mauna Kea' and HI-1, exceeded that of noninfested controls, indicating that spittlebug-infested plots actually covered in excess of their noninfested counterparts, although considerable plot to plot variation was observed (Table 3). This indicates that some infested plants grew more than noninfested plots, perhaps compensating for spittlebug induced injury. Two paspalum grasses, AP-14 and 'Mauna Kea', also demonstrated season-long improvement in percent cover compared with common centipedegrass, a grass previously observed to be susceptible. 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). Spittlebugs also reduced turfgrass height (Table 4) ($F = 328.67$; df = 1, 17; $P < 0.0001$), 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 5) ($F = 265.1$; df = 1, 17; $P < 0.0001$). AP-14 was least affected by spittlebug injury during 1997 as mea-

Table 5. Mean ± SEM 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 means	Weight (gm) infested plots	% of non-infested controls
P. vaginatum	561-79	0.24abc	0.23 ± 0.03	54.0 ± 1.8
P. vaginatum	'Sea Isle 1'	0.14ef	0.12 ± 0.04	37.0 ± 4.5
P. vaginatum	PI509023	0.18cde	0.17 ± 0.05	42.7 ± 3.2
P. vaginatum	HI 1	0.23bcd	0.21 ± 0.03	54.6 ± 9.8
P. vaginatum	'Mauna Kea'	0.13ef	0.13 ± 0.02	48.0 ± 1.8
P. vaginatum	PI299042	0.08f	0.09 ± 0.02	16.9 ± 1.5
P. vaginatum	'Adalayd'	0.21cde	0.19 ± 0.03	53.3 ± 2.3
P. vaginatum	'Sea Isle 2000'	0.24abc	0.21 ± 0.03	71.3 ± 9.3
P. vaginatum	AP-14	0.32a	0.44 ± 0.08	65.2 ± 8.6
E. ophiuroides	Common	0.14ef	0.15 ± 0.04	31.8 ± 5.0
C. dactylon	'Tifway'	0.19cde	0.16 ± 0.03	47.8 ± 2.4
C. dactylon	'Primavera'	0.14ef	0.14 ± 0.03	31.4 ± 2.3
C. dactylon	91-3	0.15def	0.14 ± 0.03	39.6 ± 5.3
C. transvaalensis	91-15	0.08f	0.06 ± 0.02	18.3 ± 3.7
Z. japonica x tenuifolia	'Emerald'	0.30ab	0.22 ± 0.03	67.6 ± 6.8
Z. japonica	'Palisades'	0.24abc	0.35 ± 0.05	47.6 ± 3.7
Z. japonica	'Crowne'	0.31ab	0.38 ± 0.05	51.8 ± 4.9
Z. japonica	'El Toro'	0.14ef	0.16 ± 0.02	30.2 ± 5.8

LS means followed by the same letter are not significantly different, $P > 0.05$. Percentage of noninfested controls = parameter measured in infested plots/parameter measured in non-infested plots.

Table 6. Mean ± SEM plant density, height and dry weight of turfgrass (*Eremochloa*, *Zoysia*, *Paspalum*, and *Cynodon* spp.) in response to twolined spittlebug injury in field plots, 1998

Genus species	Genotype	Least square means	Infested plots	% of non-infested controls
		% cover		
P. vaginatum	'Sea Isle 1'	22.2de	21.0 ± 2.7	48.7 ± 11.8
P. vaginatum	PI509023	23.3e	23.0 ± 2.5	37.8 ± 7.5
P. vaginatum	PI299042	44.9b	43.1 ± 2.4	75.1 ± 4.4
P. vaginatum	'Adalayd'	32.7c	29.6 ± 3.2	51.7 ± 5.5
P. vaginatum	AP-14	68.5a	77.2 ± 1.3	90.7 ± 1.7
C. dactylon	'Tifway'	32.3bc	33.9 ± 4.4	59.8 ± 1.2
C. dactylon	91-3	33.9bcd	37.1 ± 3.5	52.6 ± 5.0
C. transvaalensis	91-15	28.1cde	36.8 ± 3.6	48.8 ± 1.5
		Height, cm		
P. vaginatum	'Sea Isle 1'	8.7ab	9.3 ± 0.6	76.9 ± 5.3
P. vaginatum	PI509023	8.7ab	9.5 ± 0.7	71.4 ± 6.5
P. vaginatum	PI299042	9.8a	10.6 ± 0.6	73.6 ± 4.3
P. vaginatum	'Adalayd'	8.2b	7.6 ± 0.4	78.3 ± 5.9
P. vaginatum	AP-14	9.0ab	7.4 ± 0.3	90.2 ± 2.4
C. dactylon	'Tifway'	8.2b	8.1 ± 0.5	80.7 ± 5.8
C. dactylon	91-3	8.4b	8.1 ± 0.5	78.6 ± 3.4
C. transvaalensis	91-15	9.0ab	8.6 ± 0.7	83.5 ± 7.3
		Weight, gm		
P. vaginatum	'Sea Isle 1'	0.2bc	0.1 ± 0	44.2 ± 1.8
P. vaginatum	PI509023	0.1c	0.1 ± 0	28.4 ± 1.1
P. vaginatum	PI299042	0.2bc	0.2 ± 0	46.9 ± 1.5
P. vaginatum	'Adalayd'	0.1c	0.2 ± 0	49.9 ± 1.0
P. vaginatum	AP-14	0.3a	0.4 ± 0.1	86.7 ± 6.4
C. dactylon	'Tifway'	0.2bc	0.4 ± 0.1	99.8 ± 1.5
C. dactylon	91-3	0.2bc	0.2 ± 0	47.4 ± 1.8
C. transvaalensis	91-15	0.3ab	0.3 ± 0.1	60.5 ± 1.5

LS means followed by the same letter are not significantly different, $P > 0.05$. Percentage of noninfested controls = parameter measured in infested plots/parameter measured in non-infested plots.

sured by plant dry weight. The zoysiagrasses 'Crowne', 'Emerald' and 'Palisades', and the paspalum grasses AP-14, AP-10, and 561-79 all demonstrated significantly higher plant weights compared with common centipedegrass (Table 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, 7; $P < 0.0001$), plant dry weights ($F = 275.39$; df = 1, 7; $P < 0.0001$) and height ($F = 156.5$; df = 1, 7; $P < 0.0001$) were significant (Table 6). Among the eight turfgrass selections included in the 1998 trials, AP-14 demonstrated the greatest 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 were included as a covariate in analysis and determined not to be a significant influence on relative plant performance ($F = 1.16$; df = 1, 7; $P = 0.2820$).

Choice Evaluations. During 1997, percent live stems remaining after exposure to adult spittlebugs ranged from 6 to 61% (Table 7) ($F = 2.25$; df = 3, 15; $P = 0.0182$). The most extensive damage was sustained by centipede grass 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 centipede grass TC201 (Table 8) ($F = 3.04$; df = 3, 14; $P = 0.0023$). No live stems were evident

Table 7. Mean ± SEM twolined spittlebug preference for *Paspalum*, *Eremochloa*, *Cynodon*, *Zoysia*, *Stenotaphrum*, and *Festuca* spp. September 1997

Type of grasses	Genus species	Genotype	Proportion live stems
Bermuda	*C. dactylon*	'Primavera'	0.5 ± 0.1abc
Bermuda	*C. dactylon*	'Tifway'	0.3 ± 0.1bcd
Centipede	*E. ophiuroides*	TC201	0.1 ± 0.2d
Festuca	*F. arundinacea*	'Kentucky 31'	0.5 ± 0.1abc
Paspalum	*P. vaginatum*	'Sea Isle 2000'	0.5 ± 0.0ab
Paspalum	*P. vaginatum*	561-79	0.6 ± 0.0a
Paspalum	*P. vaginatum*	'Mauna Kea'	0.5 ± 0.1abc
Paspalum	*P. vaginatum*	'Sea Isle 1'	0.1 ± 0.1d
Paspalum	*P. vaginatum*	HI-1	0.4 ± 0.2abc
Paspalum	*P. vaginatum*	AP-14	0.3 ± 0.2bcd
Paspalum	*P. vaginatum*	PI509023	0.2 ± 0.0cd
Paspalum	*P. vaginatum*	'Adalayd'	0.2 ± 0.1cd
Paspalum	*P. vaginatum*	PI299042	0.2 ± 0.1cd
St. Augustine	*S. secundatum*	Common	0.4 ± 0.2abc
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	0.6 ± 0.1ab
Zoysia	*Z. japonica*	'Palisades'	0.3 ± 0.1abcd

Means ± SE followed by the same letter are not significantly different $LSD_{0.05}$.

Table 8. Mean ± SEM twolined spittlebug preference for *Paspalum*, *Eremochloa*, *Cynodon*, *Zoysia*, *Stenotaphrum*, and *Festuca* spp. June 1998

Type of grasses	Genus species	Genotype	No. adults	Proportion live stems
Bermuda	*C. dactylon*	'Tifway'	0.4 ± 0.1defg	0.7 ± 0.15
Bermuda	*C. dactylon*	'Primavera'	0.9 ± 0.1a	0.1 ± 0.1fg
Centipede	*E. ophiuroides*	TC201	0.6 ± 0.1abcde	0 ± 0g
Festuca	*F. arundinacea*	'Kentucky 31'	0.3 ± 0.1fg	0.4 ± 0.2bcdef
Paspalum	*P. vaginatum*	'Sea Isle 1'	0.7 ± 0.1abcd	0.6 ± 0.2abcd
Paspalum	*P. vaginatum*	HI-1	0.7 ± 0.1abc	0.3 ± 0.2defg
Paspalum	*P. vaginatum*	561-79	0.8 ± 0.2ab	0.3 ± 0.2cdef
Paspalum	*P. vaginatum*	'Mauna Kea'	0.7 ± 0.1abc	0.4 ± 0.1bcdef
Paspalum	*P. vaginatum*	AP-14	0.5 ± 0.1bcdef	0.3 ± 0.9efg
Paspalum	*P. vaginatum*	PI509023	0.4 ± 0.1cdefg	0.5 ± 0.1abcde
Paspalum	*P. vaginatum*	'Adalayd'	0.2 ± 0.1g	0.7 ± 0.1abc
Paspalum	*P. vaginatum*	'Sea Isle 2000'	0.3 ± 0.1fg	0.7 ± 0.1ab
St. Augustine	*S. secundatum*	Common	0.5 ± 0.1bcdefg	0.3 ± 0.1cdef
Zoysia	*Z. japonica*	'Palisades'	0.7 ± 0.1abc	0.2 ± 0.1efg
Zoysia	*Z. japonica x Z. tenuifolia*	'Emerald'	0.3 ± 0.1efg	0.1 ± 0.1fg

Means ± SE followed by the same letter are not significantly different $LSD_{0.05}$.

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 9). Resting locations did not necessarily imply feeding by the insect. 'Tifway' bermudagrass and 'Sea Isle 2000' seashore paspalum sustained little damage in either June or August choice tests (Tables 8 and 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, centipede grasses 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 compared with 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 took 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

Table 9. Mean ± SEM number of adult twolined spittlebugs per plant on *Paspalum*, *Eremochloa*, *Cynodon*, *Zoysia*, *Stenotaphrum*, and *Festuca* spp. in a rearing room caged choice test in August 1998

Type of grasses	Genus species	Genotype	No. adults	Proportion live stems
Bermuda	*C. dactylon*	'Primavera'	0.4 ± 0.1gh	0.5 ± 0.2bc
Bermuda	*C. dactylon*	'Tifway'	0.3 ± 0.1h	0.7 ± 0.1ab
Centipede	*E. ophiuroides*	TC201	0.9 ± 0.1bc	0.3 ± 0.1c
Festuca	*F. arundinacea*	'Kentucky 31'	1.5 ± 0.2a	0.9 ± 0.1a
Paspalum	*P. vaginatum*	HI-1	1.0 ± 0.1b	0.4 ± 0.1bc
Paspulum	*P. vaginatum*	AP-14	0.6 ± 0.1cdefg	0.5 ± 0.2bc
Paspulum	*P. vaginatum*	'Adalayd'	0.7 ± 0.1bcde	0.5 ± 0.1bc
Paspulum	*P. vaginatum*	561-79	0.8 ± 0.1bcd	0.5 ± 0.1bc
Paspulum	*P. vaginatum*	'Sea Isle 2000'	0.7 ± 0.1cdef	0.6 ± 0.1ab
Paspulum	*P. vaginatum*	'Sea Isle 1'	0.5 ± 0.1defgh	0.3 ± 0.1c
Paspulum	*P. vaginatum*	PI509023	0.4 ± 0.1efgh	0.3 ± 0.1c
Paspulum	*P. vaginatum*	'Mauna Kea'	0.4 ± 0.1efgh	0.5 ± 0.2bc
St. Augustine	*S. secundatum*	Common	0.6 ± 0.1cdefg	0.5 ± 0.2bc
Zoysia	*Z. japonica*	'Palisades'	0.5 ± 0.1defgh	0.6 ± 0.0ab
Zoysia	*Z. japonica x Z. tenuifolia*	Emerald'	0.4 ± 0.1fgh	0.5 ± 0.1bc

Means ± SE followed by the same letter are not significantly different $LSD_{0.05}$.

survival, and increased spittlebug development times. However, although zoysiagrasses were least susceptible to spittlebugs compared with other grasses, visible damage was still incurred.

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 (Reinert et al. 1994, 1997, 1998; Braman et al. 2000b). '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 & 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 current 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 with 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), whereas 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 current 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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