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University of Georgia researchers are evaluating the potential for resistance to multiple insect pests among turfgrasses for the southeastern United States including armyworm (adult shown above). Genetic resistance to major insect pests can reduce pesticide use and simplify management of turfgrass cultivars. (Photo courtesy of H. Tashiro)

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 290 projects at a cost of $25 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Resistant Turf: Front Line Defense for Insect Pests

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SUMMARY

University of Georgia researchers are evaluating the potential for resistance to multiple insect pests among turfgrasses for the southeastern United States. Genetic resistance to major insect pests can reduce pesticide use and simplify management of turfgrass cultivars.

- Laboratory, greenhouse and field studies were conducted to identify resistance among bermudagrass, zoysiagrass, centipedegrass and seashore paspalum selections to the fall armyworm, twolined spittlebug, and tawny and southern mole crickets.
- Among warm-season grasses, fall armyworm larval weight gain and survival were greatly reduced on several zoysiagrasses. Development of surviving larvae on these grasses averaged as much as 44% longer than on susceptible grasses. Cavalier demonstrated high levels of resistance. Palisades was moderately resistant to the armyworm. Seashore paspalums were very susceptible. TifSport and an experimental 97-8 bermudagrass demonstrated improved resistance to this pest.
- All centipedegrasses tested were highly susceptible to twolined spittlebug followed by bermudagrasses, seashore paspalums, and zoysiagrasses. Improved resistance to the spittlebug among paspalums was observed on Sea Isle 2000, Mauna Kea, HI-1 and 561-79. In field tests Emerald zoysiagrass was tolerant of spittlebug injury.
- None of the tested genotypes were highly resistant to tawny mole cricket injury. TifSport and 561-79 (Argentine) seashore paspalum were most tolerant.

Insects cause significant economic damage to turf each year. These pests are expensive to manage. You have to consider not only the cost of replacing dead or severely damaged turf, but also the costs of scouting and monitoring pests and of treating infestations. Integrated pest management (IPM) is an accepted standard approach for dealing with pests. One key component of IPM, the use of pest-resistant plants, is greatly underutilized. New alternatives to traditional forms of pest management are constantly being sought. An alternative to the use of pesticides is to incorporate naturally resistant grasses into management plans.

Today we have new opportunities to deploy pest-resistant turfgrasses as a foundational management strategy for common turfgrass insect pests. Why spend time and resources combating pest problems when we can simply avoid them instead? This article is about resistance that has been identified to the fall armyworm (*Spodoptera frugiperda*) and the twolined spittlebug (*Prosapia bicincta*). Gradients in susceptibility to tawny (*Scapteriscus vicinus*) and southern (*Scapteriscus borellii*) mole crickets have also been identified.

How Resistance Works

There are several categories of plant resistance to insects. Resistance is a term that describes heritable characteristics of a plant that determine the degree of damage certain insect species will cause. Degree of resistance may be classified as:

Immunity- an immune plant variety will never be injured by a certain species of insect.

High resistance- a variety that is rarely injured by a specific insect.

Low resistance- a variety that shows less dam-

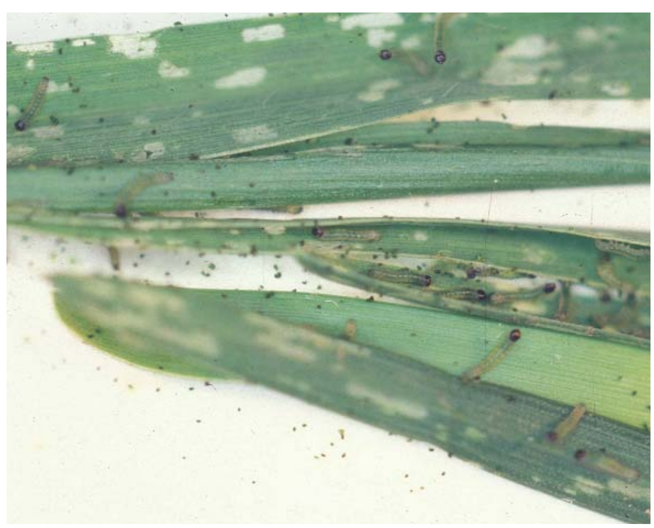

Figure 1. Newly hatched fall armyworm larvae skeletonizing turf leaf tissue. (Photo courtesy of H. Tashiro)

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Figure 2. Full grown fall armyworm larva showing characteristic inverted "Y" on the head

age by a specific insect than would be average for other similar varieties.

Susceptible- a susceptible variety shows average or more than average damage.

Highly susceptible- a variety is highly susceptible when it shows much more than average damage by a certain insect.

Plants exhibiting an intermediate level of resistance are sometimes referred to as moderately resistant. The basis for pest resistance that we observe in turf involves one (or a combination) of three mechanisms:

nonpreference on the part of the pest insect for egg laying sites, food or shelter

antibiosis or an adverse effect of the plant on the biology of the insect

tolerance of a plant that is able to repair, recover from or outgrow damage by a specific insect pest.

Plant resistance to insects and mites can be based on physical or chemical characteristics of the plant. Physical traits such as tough leaves and hairs can make feeding difficult. Chemical traits are based on compounds in plant tissues. These compounds may act as toxins, feeding deterrents, or digestibility reducers that reduce growth of pests. Some insects even use plant chemistry to locate and select their host plants. Therefore, lack of such attractants may result in 'resistance'. Sometimes resistant plants may simply be able to tolerate damage or be able to quickly grow out of susceptible stages or rapidly outgrow injury.

The Insects: Fall Armyworm (*Spodoptera frugiperda*), Twolined Spittlebug (*Prosapia bicincta*), and Mole Crickets (*Scapteriscus spp.)*

Fall armyworm migrates northward each year from over-wintering areas in Central and South America, Texas, Florida, and Mexico (8). Larvae, the immature stage, are the damaging life stage and feed on all above-ground plant parts. Fall armyworms have a broad host range, but prefer grasses.

Younger larvae skeletonize new leaf tissue (Figure 1). Older larvae can consume remaining plant parts down to the ground before moving as a group to an area of new food resources (Figures 2 and 3). Stoloniferous grasses are more likely to recover from injury than cool-season grasses. The larva may appear green, brown, or almost black, with longitudinal black stripes on each side of the body and four black dots on each abdominal segment. A distinctive light-colored inverted "Y" on the dark head is characteristic for this species. Several generations occur annually, with damage being most severe in late summer and fall.

The twolined spittlebug is a widely distributed North American species (1). Wedge-shaped adults (0.4 in or 9.5 mm) are dark brown to black with reddish orange stripes across the wings and and red thorax, eyes, legs, and upper abdomen. Nymphs (the immature stage) are cream colored with brown heads and red eyes. They produce a spittlemass that provides the high moisture environment needed for survival.

Figure 3. Fall armyworm damage where grass is eaten to the ground and larvae have moved on in a mass, hence the name "armyworm"

Figure 4. Twolined spittlebug adult

Heavily infested turf develops a "squishy" feel because of spittle masses. The oblong, cream to bright yellow-orange eggs are deposited in leaf sheaths, thatch or at ground level (Figures 4, 5, 6).

The spittlebug, long a sporadic pest of bermudagrass pastures in the Southeast, has more recently become a pest of warm-season turfgrasses. Two generations occur in much of the Southeast with a possible partial third generation present in some areas. Overwintering eggs hatch in the spring; nymphs insert needle-like mouthparts into the crown of the plant and extract plant fluids. Nymphs feed only on low-growing herbaceous plants; adults also feed on woody ornamentals such as susceptible hollies (2). A combination

Figure 5. Twolined spittlebug spittlemass

of susceptible turf and susceptible hollies becomes a spittlebug "magnet". Adults inject a toxin that results in streaking or chlorotic stippling of the leaves.

Where they occur, *Scapteriscus spp.* mole crickets are the most serious pests of turf and pasture grasses (9). Tawny and southern mole crickets, *Scapteriscus vicinus* and *S. borellii*, respectively, were introduced into the United States from South America around 1900. Southern mole cricket is primarily a predator, but will also feed on plant material and damages turf with its tunneling activities (Figure 7).

Tawny mole cricket is the more damaging of the two because it is strictly a plant feeder.

Figure 6. Twolined spittlebug eggs (Photo courtesy of H. Tashiro)

Tawny and southern mole crickets produce one generation per year. Mating and dispersal flights occur in the spring with smaller flights in the fall. Eggs (Figure 8) are deposited in the spring; nymphs (Figure 9) develop through the summer months. The majority of the population spends the winter as adults; about 15% overwinter as nymphs.

Looking for Resistance

USGA helped to fund a project that sought to identify grasses with good resistance potential to multiple insect pests. Identifying resistance to a single insect pest is one step forward, but that selection could be highly susceptible to other pests. Turf selections that demonstrate cross resistance to multiple pests are preferred. A combination of laboratory, greenhouse, and field trials allowed us to characterize the resistance potential of more than 100 commercial and experimental grass selections. We were interested not only in identifying resistant selections, but also in gaining insight into the mechanism that conferred resistance to promising grass selections.

Selections from the turfgrass breeding programs in Georgia (Dr. Ronny Duncan and Dr. Wayne Hanna) and Texas (Dr. Milt Engelke) were incorporated into the project and gave a good diversity of bermudagrass, centipedegrass, zoysiagrass, and seashore paspalum varieties. Some experiments with fall armyworm also included endophyte-infected or endophyte-free cool-season grasses. Many grasses are infected with fungal endophytes that grow intercellularly within leaves, stems, and seeds and may confer enhanced fitness to their hosts. Benefits conferred by endophytes include enhanced drought tolerance, disease resistance, and deterrence of insect and mammalian herbivory. This resistance is mediated by toxic alkaloids that are produced by the fungi. While beneficial in turfgrasses, it can be detrimental in forage grasses resulting in fescue toxicosis and ryegrass staggers in livestock.

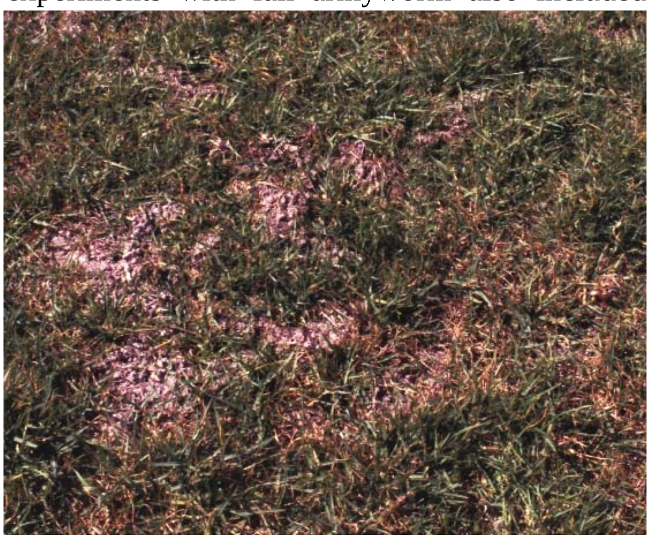

Figure 7. Tunneling damage caused by mole crickets on turf plots

Experiments evaluated insect response to turfgrass selections using both choice and no-choice assays. To evaluate for resistance and determine if antibiosis was a factor contributing to observed resistance, newly hatched fall armyworm larvae, twolined spittlebug nymphs, or tawny mole crickets were confined with plant material in environmental chambers or in a greenhouse, and insect growth and survival were monitored. Choice or preference tests with fall armyworms and twolined spittlebugs were conducted to identify any behavioral component important in resistance. Ability of turf to tolerate mole cricket feeding was evaluated in laboratory and greenhouse tests. Field studies confirmed observations and conclusions made on the basis of lab and

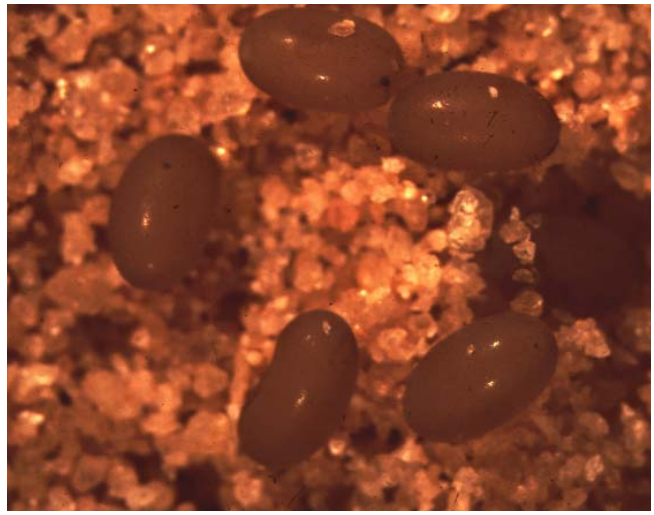

Figure 8. Mole cricket eggs

Figure 9. Young mole cricket nymph

Genus	10-Day Larval weight (mg)	Pupal weight (mg)	Days to pupation	% survival to pupal stage
Zoysia	6.5 e	145.7 d	34.8 a	19.5 c
Cynodon	35.9 d	182.7 bc	23.9 b	46.4 abc
Paspalum	56.1 c	165.9 cd	22.2 c	72.7 ab
Festuca	71.5 b	205.2 b	22.6 bc	60.0 ab
Artificial diet	102.2 a	277.1 a	21.2 c	85.0 a

Means within a column followed by the same letter are not significantly different (Bonferroni test %=0.05)

Table 1. Mean ± SE growth of *Spodoptera frugiperda* among turfgrass genera compared with artificial diet in the laboratory (24BC)

greenhouse assays for all armyworms, spittlebugs, and mole crickets.

Resistance to Fall Armyworm

Compared to a susceptible cool-season grass,' Tulsa' tall fescue and an artificial diet control, larval weight gain at day ten was most often reduced by feeding on zoysiagrasses (6). I n fact, a fifteen-fold difference in larval weight between zoysiagrass and artificial diet was observed. Larval weight gain also was lower on many of the bermudagrasses compared to when larvae were fed fescue or an artificial diet control (Table 1). Pupal weights were greatest on artificial diet, followed by fescue. Zoysia and paspalum, when fed to fall armyworms, resulted in the lowest pupal weights. Duration of development, from egg hatch to prepupation, was greatly extended when larvae were fed zoysiagrasses. Larvae feeding on artificial diet, fescue, or paspalum were similar in their development times, requiring 21.2-22.6 days to pupate.

Among individual turfgrass genotypes, larval weights were greatly reduced by feeding on any of the zoysiagrasses (5, 6). Bermudagrasses resulting in the lowest larval weights included several experimental lines. Pupal weights among genotypes were least on 'Crowne' and an experimental zoysiagrasses and greatest on 'Tulsa' tall fescue. Duration of larval development was greatly extended by feeding on the zoysiagrasses 'Cavalier', 'Crowne', 'Diamond', 'Palisades', and several experimental lines. Development on these grasses averaged as much as 44% longer than on more susceptible grasses. Three experimental bermudagrasses also extended developmental times for fall armyworms to reach the pupal stage in at least two trials. Duration of development on all seashore paspalum was similar to that on 'Tulsa' tall fescue.

Larval survival was greatly reduced by feeding on zoysiagrasses where average survival among all zoysiagrass entries was 19.5% (Table 1). Larval survival on most seashore paspalums was equivalent to that on an optimal artificial diet. Survival on bermudagrasses was least on one experimental line, 97-8, with an average survival of 24% after three trials. Survival averaged among all bermudagrasses was 46.4%, substantially less than that on paspalums, tall fescue, and artificial diet.

Resistance to Twolined Spittlebug

Potential resistance to the twolined spittlebug, *Prosapia bicincta* (Say), was evaluated among 56 turfgrass genotypes (12). All centipedegrasses demonstrated high levels of susceptibility, followed by bermudagrasses, seashore paspalums and zoysiagrasses (Table 2). Average nymphal survival to the adult stage ranged from 1.5-78.1%. Development required 38.1 to 62.0 days depending on plant taxa under greenhouse

Type of Grass	Genotype	No. adults/ pot	Days to develop
Centipede	'TifBlair'	6.2 a	39.0 g
Centipede	'Tennessee Tuff'	5.5 a	38.1 g
Centipede	TC201 (common)	3.2 b	40.5 fg
Centipede	TC178	2.7 bc	39.9 fg
Centipede	TC540 (new common)	1.6 cd	41.9 efg
Zoysia	'Crowne'	3.5 b	42.0 efg
Zoysia	'El Toro'	1.6 cd	47.3 bcde
Zoysia	'Palisades'	1.5 cde	49.0 bc
Zoysia	'Emerald'	1.4 cde	49.6 b
St. Augustine	Common	1.4 cde	49.5 b
Bermuda	'Primavera'	0.9 de	42.5 defg
Bermuda	'Tifway'	0.1 de	ND
Paspalum	AP-14	0.9 de	44.7 bcdef
Paspalum	PI509023	0.9 de	44.0 bcdefg
Paspalum	'Sea Isle 1'	0.6 de	48.8 bcd
Paspalum	561-79	0.4 de	ND
Paspalum	'Mauna Kea'	0.4 de	60.5 a
Paspalum	'Sea Isle 2000'	0.4 de	56.3 a
Paspalum	'Glenn Oaks Adalayd'	0.1 de	ND

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

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

Table 2. Mean 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

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 'Tifway' bermudagrass. 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 (Table 3). 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 (Table 4). 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).

Resistance to Mole Crickets

Previous studies (3) demonstrated a range in tolerance to tawny mole cricket feeding among zoysiagrass cultivars. USGA-funded work evaluated 21 seashore paspalum selections in the laboratory. ‘Glenn Oaks Adalayd’ was least tolerant, while HI-1, 561-79 and ‘Excalibur’ were most tolerant of *Scapteriscus spp*. feeding injury (4). Nymphal survival was not influenced by plant

Type of Grass	Genotype	Mean no. of adults	Mean Proportion of live stems
Bermudagrass	Tifway	0.4 defg	0.7 ab
Bermudagrass	Primavera	0.9 a	0.1 fg
Centipedegrass	TC201	0.6 abcde	0 g
Festuca	Kentucky 31	0.3 fg	0.4 bcdef
Paspalum	Sea Isle 1	0.7 abcd	0.6 abcd
Paspalum	HI-1	0.7 abc	0.3 defg
Paspalum	561-79	0.8 ab	0.3 cdef
Paspalum	Mauna Kea	0.7 abc	0.4 bcdef
Paspalum	AP-14	0.5 bcdef	0.3 efg
Paspalum	PI509023	0.4 cdefg	0.5 abcde
Paspalum	Adalayd	0.2 g	0.7 abc
Paspalum	Sea Isle 2000	0.3 fg	0.7 ab
St. Augustine	Common	0.5 bcdefg	0.3 cdef
Zoysia	Palisades	0.7 abc	0.2 efg
Zoysia	Emerald	0.3 efg	0.1 fg

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

Table 3. First generation twolined spittlebug preference for various grasses

type. Among the turf selections included in a greenhouse trial, those that maintained the best growth while infested with tawny mole crickets were the paspalums 561-79, HI-1, HI-2, ‘Excalibur’, ‘Sea Isle 1’ and ‘TifSport’ bermudagrass. None of the selections have been highly resistant, but ‘TifSport’ bermudagrass and 561-79 (an Argentine selection of paspalum) have been the most tolerant.

Putting it all Together

Potential cross resistance to multiple pests also has been shown among combined studies. 'Cavalier' zoysiagrass, for example, is apparently resistant to fall armyworm (5), moderately resistant to mole crickets (3), susceptible to zoysiagrass mite, *Eriophyes zoysiae* Baker, Kono and O'Neill (11), and moderately resistant to twolined spittlebugs (12). 'Crowne' is moderately resistant to zoysiagrass mite and fall armyworm, but is relatively susceptible to tawny mole cricket and twolined spittlebug. 'Diamond' which demonstrated moderate resistance to fall armyworm and tawny mole cricket is also moderately resistant to twolined spittlebug.

Paspalum selections that demonstrated some antibiotic effects on fall armyworms compared to all paspalum selections in previous studies included 561-79, PI-509021 and PI 509022 although all were susceptible to this pest (5). 'Glenn Oaks Adalayd' paspalum was least tolerant of tawny mole cricket, *Scapteriscus vicinus* (Scudder), injury, while 561-79 and HI-1 were more tolerant although none of these were highly resistant to mole crickets (4).

Insects cause major economic damage to turf bermudagrasses each year. Significant progress has been made in incorporating tawny mole cricket resistance in 'TifSport' (4, 8). Among bermudagrasses, our research showed that armyworm survival was lowest on 'TifSport' compared to other commercial cultivars in the experiment. New experimental cultivars show significantly improved resistance to tawny mole crickets (4). Such genetic resistance to major insects in turfgrass can reduce pesticide use and simplify management of these cultivars.

Type of Grasses	Genotype	Mean Proportion of live stems
Bermudagrass	'Primavera'	0.5 abc
Bermudagrass	'Tifway'	0.3 bcd
Centipedegrass	TC201	0.1 d
Festuca	'Kentucky 31'	0.5 abc
Paspalum	'Sea Isle 2000'	0.5 ab
Paspalum	561-79	0.6 a
Paspalum	'Mauna Kea'	0.5 abc
Paspalum	'Sea Isle 1'	0.1 1 d
Paspalum	HI-1	0.4 abc
Paspalum	AP-14	0.3 bcd
Paspalum	'Adalayd'	0.2 cd
St. Augustine	Common	0.4 abc
Zoysia	'Emerald'	0.6 ab
Zoysia	'Palisades'	0.3 abcd

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

Table 4. Second generation twolined spittlebug preference for various grasses

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