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HUNTING BILLBUG (COLEOPTERA: CURCULIONIDAE) RESISTANCE AMONG ZOYSIAGRASS (ZOYSIA SPP.) CULTIVARS

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ABSTRACT

Hunting billbugs (Sphenophorus venatus vestitus Chittenden) cause damage to zoysiagrass (Zoysia spp.) and bermudagrass (Cynodon spp), which is often misdiagnosed as the effects of drought, disease, or another soil insect. Populations have increased over the past several decades and are causing extensive damage on grasses in lawns, golf courses and other landscapes. Nine cultivars of Zoysia were evaluated for resistance to S. venatus vestitus in a field cage choice test in a paired cage split-plot experiment. Leaf-firing of plant canopy was considered an above ground expression of root feeding damage by billbug larvae. ‘Diamond’ and ‘Zorro’ exhibited significantly less leaf firing damage (a reduction of 6.1 and 9.8%, respectively). In contrast, ‘Palisades’, ‘Meyer’, and ‘Crowne’ showed >40% canopy damage. When root, shoot, and total plant dry weights were compared, ‘Diamond’, ‘Zorro’, ‘Cavalier’, and ‘Royal’ [all Z. matrella (L.) Merr.] sustained less dry weight reduction (<53%) than ‘Palisades’, ‘Meyer’, and ‘El Toro’ (all Z. japonica Steud.) with 76, 74, and 70% total dry weight reductions, respectively. Cultivars of Z. matrella appear to be more resistant as a group than the Z. japonica cultivars.

Key Words: Zoysia matrella, Zoysia japonica, Sphenophorus venatus vestitus, host plant resistance, turfgrass, lawns, Curculionidae

RESUMEN

Los billbugs cazadores (Sphenophorus venatus vestitus Chittenden) afectan cultivares de zoysiagrass (Zoysia spp.) y bermudagrass (Cynodon spp). Con frecuencia, el daño es confundido como sequía, enfermedad u otra plaga del suelo. Las poblaciones del insecto se han incrementado en las últimas dos décadas causando un extensivo daño de pastos en céspedes y campos de golf. La resistencia a S. venatus vestitus en nueve cultivares de Zoysia fueron evaluados con jaulas en el campo, con una prueba de “opción múltiple” en un experimento de parcelas divididas. El “quemado” del follaje del pasto fue considerado como una expresión del daño de la larva del insecto, al alimentarse en las raíces. ‘Diamond’ y ‘Zorro’ presentaron menor daño del follaje significativamente (con una reducción del 6.1 y 9.8%, respectivamente). Por lo contrario, ‘Palisades’, ‘Meyer’, y ‘Crowne’ mostraron >40% daño foliar. En la comparación de pesos secos de la raíz, estolón, y peso total de la planta, ‘Diamond’, ‘Zorro’, ‘Cavalier’, y ‘Royal’ [todos Z. matrella (L.) Merr.] mostraron menos reducción del peso seco (<53%) en comparación con ‘Palisades’, ‘Meyer’, y ‘El Toro’ (Todas Z. japonica Steud.) con 76, 74, y 70% del peso total, respectivamente. Los cultivares de Z matrella como grupo parecen ser que son más resistentes que el grupo de cultivares de Z. japonica.

Translation of the abstract was provided by Carlos Campos.

The genus Sphenophorus (Coleoptera: Curculionidae) contains 71 species of which 64 occur in the North America (Niemczyk & Shetlar 2000; Vaurie 1951). At least 9 of these species are known to be pests of turfgrass, causing damage to both cool- and warm-season grasses (Morrill & Suber 1976; Johnson-Cicalese et al. 1990; Vaurie 1951; Vittum et al. 1999).

The hunting billbug (HBB) (Sphenophorus venatus vestitus Chittenden) has been listed as a damaging pest of turfgrass from New Jersey (Johnson-Cicalese & Funk 1990), south to Georgia (Morrill & Suber 1976) and Florida (Kelsheimer 1956); west to Kansas (Brissell & Clark 1968), Texas, California, and Hawaii (Davis & Krauss 1964; LaPlante 1966) and throughout the Caribbean Islands (Vaurie 1951; Vittum et al. 1999). It has been identified in Arizona and Idaho, but its total range of distribution across the Western United States is not fully established (K. Umeda, Univ. of Arizona; D. J. Shetlar, Ohio State Univ.; T. Salaiz, Univ. of Idaho, personal communication). Also it is listed as a serious turf pest in Japan (Hatsukade 1997).
Hunting billbug damage is often misidentified as the effect of drought, dormancy, disease, or another root-feeding insect. Only 1 generation per year was reported in northern Florida (Kovitvadhi & Kerr 1968), Louisiana (Oliver 1984) and Arkansas (Young 2002), but Huang (2008) and Huang & Buss (2009) suggest that it may have at least 2 or 3 overlapping generations per year in Florida. The adult HBB feeds by notching the leaves of both Zoysia and Cynodon (Huang 2008), and it then lays its eggs in a small feeding scar usually in the crown of the plant. Larvae pass through 5 stadia (Hatsuakde 1997; Huang 2008) with the early instars feeding within the crown, larger rhizomes, and stolons before the later instars emerge and continue feeding on the whole root system. Initial larval damage appears as small pockets of yellowing and dying grass, resembling dollar spot disease infections, which increase in size and later coalesce as the larvae continue feeding (Vittum et al. 1999). Infested sod fields often cannot be harvested since many of the roots and rhizomes have been severed and the cut sod will not hold together.

Populations of this billbug have increased over the past 10 to 15 years and it is responsible for extensive turf damage in lawns, golf courses and other landscapes, and a loss of sod production by its primary host grasses. Satterwhite (1932) and Woodruff (1966) provide an extensive host list that includes other commonly used turfgrasses: St. Augustinegrass (Stenotaphrum secundatum Walt. Kuntze), centipedegrass [Eremochloa ophiuroides (Monro) Hack], and bahiagrass (Paspalum notatum Flugge).

Several studies have identified resistance to a related species, the bluegrass billbug (Sphenophorus parvulus Gyllenhal) in cultivars of Kentucky bluegrass (Poa pratensis L.) (Lindgren et al. 1981; Ahmad & Funk 1982; Kindler et al. 1982; Shearman et al. 1983; Johnson-Cicalese et al. 1989, 1997; Bonos & Smith 1994; Westerholt 1994). Additionally, resistance to the bluegrass billbug was documented in ‘Reveille’ and other hybrids between Kentucky bluegrass (P. pratensis) × Texas bluegrass (P. arachnifera L.) (Reinert et al. 2005). The documented resistance to insect and mite pests in turfgrass has been summarized (Reinert et al. 2004).

Resistance to several other insect and mite pests has been identified in Zoysia spp. ‘Emerald’, ‘Diamond’, ‘Zorro’, ‘Cavalier’, and ‘El Toro’ exhibit moderate to high resistance to the fall armyworm (Spodoptera frugiperda J. E. Smith) (Reinert & Engelke 2010) and these cultivars (except ‘Diamond’) along with ‘Royal’, ‘Crown’, and ‘Palisades’ also provide moderate to high resistance to the tropical sod webworm (Herpetogramma phaeopteralis Guenée). ‘Emerald’, ‘Diamond’, ‘Cavalier’, and ‘Palisades’ provided moderate resistance to the tarny mole cricket (Scapteriscus vicinus Scudder) (Braman et al. 1994). ‘Emerald’ was the most resistant to Rhodesgrass mealybug (Antonina graminis Maskel) among 5 cultivars of Zoysia (Reinert & Vinson 2010), while ‘Emerald’ and ‘Royal’ were the most resistant to the zoysiagrass mite (Eriophyes zoysiae Baker, Kona and O’Neill) (Reinert et al. 1993). ‘Cavalier’ was resistant to the differential grasshopper [Melanoplus differentialis (Thomas)] (Reinert et al. 2011). In all of these studies, ‘Meyer’ was highly susceptible to each of the respective pests.

Our experiment was designed to evaluate cultivars of Zoysia for resistance to HBB and to identify potential mechanisms of resistance. When the present experiment was initiated in 2000, no resistance had been identified to HBB in either Bermudagrass or zoysiagrass; however, more recent studies in Florida have also shown differences in susceptibility among genotypes of these 2 grasses (Huang 2008).

**MATERIALS AND METHODS**

An experiment was established to evaluate 9 Zoysia cultivars that were selected for their varying resistance to other turf pests and to compare the resistance potential between the 2 Zoysia spp. (listed in Tables 1 and 2) (including 4 Z. matrella (L.) Merr. and 5 Z. japonica Steud.) for resistance to the HBB. Metal livestock water tanks (0.76 m high and 2.44 m diam) were used as evaluation cages. Each cage was positioned above ground level on several concrete blocks, and set at a slight slant toward a 2.5 cm drain hole to eliminate any excessive water accumulating in the soil profile in the bottom of the cage. Each cage was filled to a depth of ca. 45 cm with 100% sand root zone media to facilitate uniform growth and to provide an easy medium to excavate and separate the root systems. The top of each cage was fitted with a screen (allowing 70% light transmission) to prevent movement into or out of the cages by either billbugs or other insects. A similar confined field cage has been used for the bluegrass billbug (Reinert et al. 2005) and mole cricket studies (Reinert and Busey 2001, 2005).

The Zoysia cultivars used in this experiment were produced in the greenhouse in 18-cell trays (each cell measuring 7.5 × 7.5 cm and 4 cm deep) and fertilized bi-weekly with Jack’s Classic (formerly Peter’s) 20-20-20 (NPK) + B (0.02%) Cu (0.05%), Fe (0.10%), Mn (0.05%), Mo (0.0009%), and Zn (0.05%) (J. R. Peters, Inc., Allentown, Pennsylvania) at ca. 170 ppm until transferred to the field cages. Plants were watered and fertilized as needed throughout the test period to maintain good plant growth.

For physical arrangement of the cages and plants within the cages, a modified randomized complete split-split plot design with 4 replicates was used. The main plot was billbug treatment
(e.g., cage), the subplot was location within the
cage (north vs. south), and the sub-subplot was
Zoysia cultivar. Within each replicate (consisting of
2 cages, one with and the other without bill-
bugs), 2 plants from each cultivar were paired by
total size and 1 plant was assigned to the north
half of each cage. An analogous assignment of va-
rieties was used for the south section of each cage,
except that the location of variety was re-random-
ized. The matched arrangement based on plant
size minimized the effect of the leaf area and root
mass on the treated vs. untreated comparison.
Likewise, the use of the same randomized place-
cment of cultivars for the north side of each cage
helped to minimize any effects due to plants being
closer or further from the edge of the cage than its
paired-partner in the other cage (e.g., such as
shading). Because the north vs. south effect (sub-
plot) was statistically inconsequential for all
traits measured in our study, and grass plants re-
ponded the same regardless of their location in the
cages, the average of the 2 plants of each cul-
tivar per cage was used in the statistical analysis.
Using the average of the 2 plants per cage, the
data were subjected to analysis of variance
(ANOVA) with the PROC GLM procedure of SAS
(SAS Institute 2005).

Plants were transplanted on 23-24 Jun 2000
and allowed to establish for 5 d in the cages before
HBB adults were introduced into the cages.
Plants were planted in 2 concentric circles of 3
and 6 m circumference with 7 plants in the 3 m
and 11 in the 6 m circle. Plants were spaced ca. 21
cm apart in each quadrant and a minimum of 20
cm from the side of the cage.

Treatment cages were infested at a similar
rate of adults and manner of introduction to an-
other experiment with Poa spp. vs. bluegrass bill-
bug (Reinert et al. 2005). One cage of each pair
was infested on 26 June 2000 at a rate of 30 fe-
male and 15 male HBB adults. The adult billbugs
were released between the 2 concentric rows of
plants (ca. 50 cm from the center of the cage), and
allowed to migrate to the Zoysia plants they pre-
ferred as acceptable host. The open area between
plants allowed the adult HBB to move freely from
one plant to another to choose preferred hosts for
oviposition. All HBB adults used in this study
were field collected from a bermudagrass field at
a sod farm. Collected HBB adults were held for <
1 wk in moist soil under refrigeration until re-
leased in the study tanks.

On 21 Sep 2000, “leaf firing” of the plant can-
opy (dead or dying leaf and shoot tissue in the
surface growth of the plant) for each of the Zoysia
cultivars both with and without HBB damage
was estimated by rating each plant on a scale of 1
to 9, with 1 = 90% leaf firing or a dead plant, 9 =
no leaf firing, with plants rated between the 2 ex-
tremes falling on a graduated scale between 1 and
9 (a modification of the procedure used by the Na-
tional Turfgrass Evaluation Program, Morris
2011). Observations were recorded by 2 individu-
als. Whole plants were then excavated from the
sand medium in the tanks and bagged from 22-29
Sep 2000 (after an evaluation period of about 13-
14 weeks after adult infestation of the plants) by
excavating the entire plant from the sand.

All plants from 1 replicate were dug and held
under refrigeration until they were processed be-
fore the next replicate was harvested. In the lab-
oratory, all tillers were cut at the soil line,
ashed, and counted. Roots and rhizomes were
also washed before measurements were made.

### Table 1. Resistance, measured as leaf-firing of plant canopy, among Zoysia grass cultivars to larval feeding by hunting billbug larvae (Jun-Sep 2000), Dallas, TX (four reps of paired plants).

<table>
<thead>
<tr>
<th>Zoysiagrass</th>
<th>Cultivar</th>
<th>Rating of plants with billbug feeding</th>
<th>Difference Ck - treat</th>
<th>Damage %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diamond</td>
<td>7.88 a*</td>
<td>0.50 a</td>
<td>6.08 a</td>
</tr>
<tr>
<td></td>
<td>Zorro</td>
<td>6.17 b</td>
<td>0.87 ab</td>
<td>9.76 ab</td>
</tr>
<tr>
<td></td>
<td>De Anza</td>
<td>4.83 cde</td>
<td>1.88 bc</td>
<td>21.91 abc</td>
</tr>
<tr>
<td></td>
<td>El Toro</td>
<td>5.63 bc</td>
<td>1.88 bc</td>
<td>24.93 abc</td>
</tr>
<tr>
<td></td>
<td>Cavalier</td>
<td>5.88 bc</td>
<td>2.25 cd</td>
<td>27.58 bc</td>
</tr>
<tr>
<td></td>
<td>Royal</td>
<td>5.13 bcd</td>
<td>3.38 cd</td>
<td>30.95 cd</td>
</tr>
<tr>
<td></td>
<td>Crowne</td>
<td>4.25 de</td>
<td>2.88 ed</td>
<td>40.55 cd</td>
</tr>
<tr>
<td></td>
<td>Meyer</td>
<td>3.57 e</td>
<td>3.38 d</td>
<td>44.38 d</td>
</tr>
<tr>
<td></td>
<td>Palisades</td>
<td>4.25 de</td>
<td>3.50 d</td>
<td>45.49 d</td>
</tr>
</tbody>
</table>

*Means in a column followed by the same letter are not significantly different at *P* < 0.01 using Fisher’s protected LSD test.

Zm = Zoysia matrella; Zj = Z. japonica.

Leaf firing was considered a measure of the above-ground symptom expression of the root feeding damage caused by billbug larvae.

Plants were ranked on a scale of 1-9, 1 = severe leaf firing, 9 = no leaf firing.

\[ \text{Damage} = \left( \frac{\text{check} - \text{treatment}}{\text{check}} \right) \times 100 \]

(Ck = check, treat = treatment).

\[ \text{Difference} = (\text{check} - \text{treatment}) \]

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TABLE 2. RESISTANCE AMONG ZOYSIAGRASS CULTIVARS TO LARVAL FEEDING BY HUNTING BILLBUG (JUN-SEP 2000), DALLAS, TX (FOUR REPS OF PAIRED PLANTS).

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Spp.</th>
<th>Rhizome length&lt;sup&gt;b&lt;/sup&gt;</th>
<th>No of rooted nodes&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Root mass&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Shoot mass&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Plant mass&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>diff (cm)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>% diff&lt;sup&gt;d&lt;/sup&gt;</td>
<td>diff&lt;sup&gt;c&lt;/sup&gt;</td>
<td>% diff&lt;sup&gt;d&lt;/sup&gt;</td>
<td>diff (mg)&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diamond</td>
<td>Zm</td>
<td>203.3 a&lt;sup&gt;e&lt;/sup&gt;</td>
<td>27.76 a</td>
<td>85.3 a</td>
<td>18.89 a</td>
<td>4.68 a</td>
</tr>
<tr>
<td>Zorro</td>
<td>Zm</td>
<td>437.5 ab</td>
<td>33.87 ab</td>
<td>188.9 bcd</td>
<td>34.63 ab</td>
<td>12.77 abc</td>
</tr>
<tr>
<td>Cavalier</td>
<td>Zm</td>
<td>448.8 ab</td>
<td>49.97 bc</td>
<td>162.1 abc</td>
<td>44.71 bcd</td>
<td>13.51 abc</td>
</tr>
<tr>
<td>Royal</td>
<td>Zm</td>
<td>625.1 bc</td>
<td>68.52 de</td>
<td>267.5 d</td>
<td>62.56 cde</td>
<td>11.66 ab</td>
</tr>
<tr>
<td>Crowne</td>
<td>Zj</td>
<td>551.2 bc</td>
<td>54.02 cd</td>
<td>143.5 abc</td>
<td>43.38 bc</td>
<td>29.09 d</td>
</tr>
<tr>
<td>De Anza</td>
<td>Zj</td>
<td>762.0 c</td>
<td>70.29 de</td>
<td>232.9 cd</td>
<td>65.3 e</td>
<td>17.51 bc</td>
</tr>
<tr>
<td>El Toro</td>
<td>Zj</td>
<td>551.2 bc</td>
<td>62.94 cde</td>
<td>132.0 abc</td>
<td>48.9 bcd</td>
<td>32.55 d</td>
</tr>
<tr>
<td>Meyer</td>
<td>Zj</td>
<td>421.2 ab</td>
<td>71.26 e</td>
<td>138.3 abc</td>
<td>60.46 de</td>
<td>22.51 cd</td>
</tr>
<tr>
<td>Palisades</td>
<td>Zj</td>
<td>497.6 bc</td>
<td>59.60 cde</td>
<td>109.5 ab</td>
<td>37.68 ab</td>
<td>30.63 d</td>
</tr>
</tbody>
</table>

<sup>a</sup>Zm = Zoysia matrella; Zj = Z. japonica.

<sup>b</sup>Length of rhizomes per plant, number of rooted nodes per plant, root, shoot and total mass for each treatment and each check plant.

<sup>c</sup>Difference = (amount in check) - (amount in treatment).

<sup>d</sup>% difference = [(amount in check) - (amount in treatment)] / (amount in check) × 100.

<sup>e</sup>Means in a column followed by the same letter are not significantly different at P < 0.01 using Fisher's protected LSD test.
Traits measured were: total rhizome length, longest rhizome, number of rooted nodes on rhizomes, and total plant biomass. Shoot and root biomass were collected separately, oven dried (72 hr at 70°C) and weighed. Stolons and rhizomes from each plant were also examined for larval feeding damage.

Zoysiagrass cultivars were all treated as equal entries and no nesting was considered. Two statistical analysis models were used. First, variations in plant traits among genotypes from untreated cages only were analyzed. Second, the percentage reduction of rhizome lengths, number of rooted nodes, shoots, root and whole plant dry weights was calculated as: [(check plant – infested plant) / (check plant)] × (100) (Abbott 1925). To analyze these differences, we used a traditional RCBD analysis with only replicate and cultivar as sources of variation. The actual difference data and percentage reduction data exhibited heterogeneity of variance but a square root transformation (for actual difference) and an arcsine transformation (for percentage reduction) resulted in homogeneity of variance. For both analyses (untreated plants only and difference between treatments), F-tests were made using cultivar mean square error as the numerator and residual (error mean square) as denominator. Treatment (billbug vs. no billbug) was excluded as a source of variation. Comparisons of means for weights and lengths and transformed percent difference in traits between uninested and infested plants for each genotype were performed using Fisher’s protected least significant differences (LSD). All values presented in the tables are untransformed means (percent difference between check and HBB damaged) with accompanying letters derived from the mean separation attained in the analysis of transformed values.

RESULTS AND DISCUSSION

The percentage of leaf-firing or canopy damage for each of the Zoysia cultivars is presented in Table 1. Leaf-firing was considered as an above ground symptom expression of the root feeding damage by the billbug larvae. ‘Diamond’, ‘Zorro’, ‘Cavalier’, ‘Royal’, and ‘El Toro’ exhibited the least visual damage and were ranked highest when plants were exposed to billbugs. ‘Meyer’, a cultivar which has been the industry standard for years, exhibited the most leaf-firing and ranked lowest followed by ‘Palisades’ = ‘Crown’ > ‘De Anza’. Using a modification of Abbott’s formula (1925), where the treatments are adjusted to the untreated check, ‘Diamond’ and ‘Zorro’ exhibited significantly less leaf firing damage (6.1 and 9.8% reduction, respectively) with all other cultivars showing >22% damage. ‘Palisades’, ‘Meyer’, and ‘Crown’ showed the highest leaf firing (>40%) as a result of billbugs feeding on the roots. ‘Diamond’ and ‘Zorro’ sustained only 27.8 and 33.9%, respectively, reduction in total rhizome length, followed by ‘Cavalier’ with <50% reduction while ‘Meyer’ and ‘De Anza’ each exhibit >70% reduction. Another measure of feeding was the number of rooted nodes on the rhizomes. ‘Diamond’ and ‘Zorro’ showed the least reduction in total rooted nodes (18.9 and 34.6%, respectively). By contrast, ‘Meyer’ and ‘De Anza’ each sustained >70% reduction in total rhizome lengths (Table 2). Also, when the number of rooted nodes on the rhizomes was compared, ‘Diamond’ and ‘Zorro’ showed the least reduction with 18.9 and 34.6% difference, respectively, while ‘Meyer’ and ‘De Anza’ each produced >60% reduction in rooting.

Differences in root mass were very small in absolute terms (<13.5 mg) for ‘Diamond’, ‘Zorro’, ‘Cavalier’, and ‘Royal’ although the percentage differences were more apparent with 33.6, 44.9, 60.8, and 68.1% differences, respectively. Root weight differences exceeded 22.5 mg for ‘Crowne’, ‘El Toro’, ‘Meyer’, and ‘Palisade’ with percent differences of 70-80% being very prominent for these grasses. A similar trend was recorded for shoot weights with ≤3 mg difference for ‘Diamond’, ‘Zorro’, and ‘Cavalier’ followed with 5.7 mg difference for ‘Royal’. The percentage loss in shoot mass was <33.0% for these same cultivars. By comparison, the loss in root mass was >63% for ‘Meyer’ and ‘Palisades’. When the combined shoot and root dry weight or total dry plant mass was compared, differences ranged from 6.2 mg for ‘Diamond’ to >39 mg for ‘Palisades’ and ‘El Toro’. Percentage differences between treatment and check plants ranged from 26.3 for ‘Diamond’ to >65% difference for ‘Palisades’, ‘Meyer’, ‘El Toro’, ‘De Anza’, and ‘Crowne’.

These cultivars exhibited marked differences in impact of HBB feeding on the total growth potential of the test plants. ‘Diamond’ (Z. matrella), was the most resistant (26.3% loss in total plant dry weight) while ‘Meyer’ (Z. japonica) was highly susceptible and exhibited substantial larval feeding damage (73.9% loss in total plant dry weight) (Fig. 1). The assays for shoot dry weight and total plant dry weight show that all 4 cultivars of Z. matrella sustained the least impact from HBB feeding while all 5 cultivars of Z. japonica sustained greater than 46 and 65% difference in weights for shoot and total plant mass, respectively. Experiments by Huang (2008) confirm the highest resistance in ‘Diamond’, ‘Zorro’, ‘Cavalier’, and ‘Royal’ based upon density and quality ratings and that ‘El Toro’ and ‘Palisades’ provided the lesser quality and density. Additionally, Huang (2008) found no oviposition of eggs on ‘Diamond’ and ‘Zorro’, and only an average of 0.2 and 0.4 eggs per plant on ‘Royal’ and ‘Cavalier’, respectively, within 1 month of adult confinement on these cultivars. In contrast, the adult HBB had oviposited 1.0, 1.8, 2.6, and 3.0
Fig. 1. (A) Example of *Z. matrella* cultivar with hunting billbug resistance: 'Diamond' zoysiagrass plant only sustained ca. 26% reduction in growth potential due to billbug larval damage. (B) Example of reduction in growth potential due to hunting billbug larval feeding on susceptible cultivar of *Z. japonica*. 'Meyer' zoysiagrass plants sustained a 76% average loss in total plant weight. (Billbug damaged plant on left, plant without exposure to billbugs on right).
eggs per plant on ‘Palisades’, ‘El Toro’, ‘Crowne’, and ‘Meyer’, respectively, in their greenhouse study. Although different parameters were evaluated in our study than in the Huang’s (2008) study, the 2 studies provided very similar results for the cultivars that were common to both studies.

Two growth factors associated with Z. matrella may be responsible for its resistance to feeding damage by HBB. First, rhizomes developing on Z. matrella appear to have much shorter internodes and almost every internode will develop a shoot and it is rooted (Fig. 2A). Therefore, when the rhizome is severed by larval feeding, the isolated section of the rhizome with existing shoots and roots will continue to grow, independently of the parent plant, with only minimal loss of growth potential. This also results in a much denser root system with many more intertwined rhizomes (Fig. 1A).

A second mechanism of resistance is the ability of the cultivars of Z. matrella to exhibit apical dominance; when the rhizome is severed, it responds by developing new growth points—new stolons and rhizomes with roots and shoots. In this study, when a rhizome was severed, new lateral branch rhizomes were initiated just before the point of larval feeding damage. Fig. 2B shows a rhizome of ‘Diamond’ that was severed by billbug feeding and the plant’s response by generating 6 lateral branches just before the damaged area. It was common to observe 3 or 4, and up to 6 lateral branches on the billbug infested plants of any of the Z. matrella cultivars.

Among plants of the Z. japonica cultivars, it was common to see no lateral branching, occasionally only 1 branch, and rarely 2 lateral branches just before the point of injury. A damaged rhizome of ‘Meyer’, with the production of only 1 lateral branch produced just before the point where the rhizome was severed is shown in Fig. 2C. Both the higher number of shoots and roots developed and the ability of the Z. matrella cultivars to compensate for feeding damage to the rhizome by developing lateral branching are forms of tolerance.

Granted, there is a range of resistance among the 4 cultivars of Z. matrella, and also a range of susceptibility among the 5 Z. japonica cultivars, but there appears to be a difference in response to this pest and its damage between the 2 species of Zoysia. There will always be exceptions, but one may speculate that other cultivars of Z. matrella may also carry levels of resistance to this primary pest. The study in Florida by Huang (2008) supports this conclusion since several other cultivars of both Zoysia species were evaluated, and based upon density, quality, and egg deposition results, these cultivars tend to also follow species separations for resistance vs. susceptibility as well.

It is interesting to note that several of these cultivars of Z. matrella have also exhibited good resistance to other insect and mite pests. ‘Cavalier’, for example has good levels of resistance to fall armyworm, tropical sod webworm, tawny mole cricket, Rhodesgrass mealybug, and differential grasshopper. ‘Royal’ has resistance to the zoysiagrass mite, tropical sod webworm, and Rhodesgrass mealybug; ‘Diamond’ is resistant to fall armyworm, tawny mole cricket, and Rhodesgrass mealybug; while ‘Zorro’ is resistant to fall
armyworm, tropical sod webworm, and Rhodesgrass mealybug (Reinert & Vinson 2010). The host resistance responses of these various Z. matrella cultivars have been summarized by Reinert et al. (2004).

This experiment provides a controlled study to assay a group of Zoysia cultivars for resistance to the HBB, one of the primary limiting pests of Zoysia. Zoysia cultivars are used worldwide for lawns, other landscapes, and on golf courses. The experiment included 4 cultivars of Z. matrella ('Cavalier', 'Diamond', 'Royal', and 'Zorro') and 5 cultivars of Z. japonica (Crowne, 'De Anza', 'El Toro', 'Meyer', and 'Palisades'). Based on these results, when the surface damage was assayed as leaf-firing of the plant canopy, 'Diamond' and 'Zorro' (both Z. matrella), were resistant and sustained minimal loss in plant canopy appearance. The visual appearance of the plant canopy appears to strongly reflect the associated health or damage to the root system. When rhizome length and number of rooted nodes on the rhizome were compared, the plants sustaining the least damage were, again, all Z. matrella cultivars, including 'Diamond', 'Zorro', and 'Cavalier'. Assays of the dry plant mass also showed that the Z. matrella cultivars were resistant while the Z. japonica cultivars were highly susceptible to damage.

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