Screening Newly Developed Bermudagrasses for Host Plant Resistance against Fall Armyworm (Lepidoptera: Noctuidae)

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Abstract. The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is an important pest of warm-season turfgrass species, including bermudagrass (*Cynodon* spp.). Bermudagrass is a popular turfgrass that is widely planted on golf courses, athletic grounds, and ornamental landscapes across the country and throughout the world. *Spodoptera frugiperda* infestation is often sporadic; however, when it does occur, damage can be severe. Host plant resistance against *S. frugiperda* can be a valuable tool for reducing or preventing the use of insecticides. Therefore, the objective of this study was to determine resistance against *S. frugiperda* in a few promising bermudagrasses. Fourteen experimental bermudagrass genotypes plus two control cultivars, ‘Zeon’ zoysiagrass (resistant control) and ‘TifTuf’ bermudagrass (susceptible control), were evaluated against *S. frugiperda* to determine host plant resistance in the laboratory. The results showed that the resistant control, ‘Zeon’ zoysiagrass, was more resistant than the other genotypes to *S. frugiperda* larvae. To determine the response of the experimental lines to *S. frugiperda* as compared with that of the controls, three indices were developed based on survival, development, and overall susceptibility. According to the susceptibility index, ‘13-T-1032’, ‘T-822’, ‘11-T-510’, ‘12-T-192’, ‘11-T-56’, ‘09-T-31’, ‘11-T-483’, and ‘13-T-1067’ were the top-ranked bermudagrasses. Among these, the responses of ‘13-T-1032’, ‘T-822’, ‘11-T-510’, ‘11-T-56’, ‘09-T-31’, and ‘11-T-483’ were comparable to that of ‘TifTuf’, and antibiosis was the underlying mechanism of resistance. Additionally, larval length, head capsule width, and weight were negatively associated with the days of pupation and adult emergence and positively associated with pupal length, thorax width, and weight. These results will help refine future breeding and with investigations of resistance against the fall armyworm.

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a sporadic but serious pest of various warm-season turfgrass species in the mid-southern and southeastern United States (Braman et al., 2000; Reinert and Engelke, 2010). In Georgia, the turfgrass industry is

worth US\$7.8 billion (Kane and Wolfe, 2012). This pest affects various sectors of the turfgrass industry. From July to late November, landscape maintenance companies and homeowners often must apply insecticides to protect residential and public lawns in urban and suburban areas. *S. frugiperda* also threatens golf courses and sod farms, where insecticides are intensively used to maintain vast stretches of turfgrass. Currently, sod producers and golf course superintendents use pyrethroid insecticides, such as bifenthrin, for fall armyworm control on the turfgrass starting in July (Buss and Dale, 2017; Waltz and McCullough, 2017).

The early larval stages of *S. frugiperda* usually go undetected because they remain hidden within the turfgrass canopy during the daytime until the larvae reach the fourth or fifth instar. The young larvae feed on the grass blades, whereas the late instar larvae consume both the stems and grass blades. Severely affected turfgrass appears brown be-

cause most of the grass blades are consumed. Compared with young instars, late instar larvae are more tolerant of insecticides (Hardke et al., 2011; Mink and Luttrell, 1989).

S. frugiperda is a polyphagous pest that is known to damage more than 50 plant species, including corn, sorghum, cotton, rice, and bermudagrass (Luginbill, 1928). Multiple overlapping generations of *S. frugiperda* occur within 1 year and infest several host species. Resistance to older insecticide formulations, such as carbamates, pyrethroids, and organophosphates, has been reported for corn (Carvalho et al., 2013; Diez-Rodríguez and Omoto, 2001; Nascimento et al., 2016; Young, 1979). Because most of the insecticides used in row crops, such as corn, are also used in the turfgrass industry to control *S. frugiperda*, insecticide resistance by *S. frugiperda* in turfgrass is a real threat. This suggests that there is a need to develop alternate management options for *S. frugiperda* control in turfgrass.

Turfgrass breeding programs have always emphasized the improvement of aesthetic characteristics and tolerance to abiotic factors, such as drought and foot traffic (Baxter and Schwartz, 2018; Patton et al., 2017). Because insecticide resistance and nontarget effects of insecticide applications pose serious concerns to the turfgrass industry, alternative control options, such as the development of *S. frugiperda*-resistant genotypes, have been recently emphasized by turfgrass breeding programs (Reinert and Engelke, 2010). In pastures, *S. frugiperda* is a major pest of bermudagrass, and severe infestation critically affects grass quality and yield (Croughan and Quisenberry, 1989). Bermudagrass genotypes used for pastures can grow densely and up to 60 cm tall. Previously, *S. frugiperda*-resistant ‘Tifton 292’ and ‘Tifton 296’ bermudagrass cultivars were developed for pasture production (Leuck et al., 1968), and antibiosis was identified as an underlying resistance mechanism (Lynch et al., 1983). In turfgrass, the zoysiagrass cultivars Cavalier, Emerald, DALZ8501, DALZ8508, Royal, Palisades, Belair, and Zeon were found to exhibit high levels of resistance to neonates of *S. frugiperda* (Anderson et al., 2007; Braman et al., 2000; Reinert and Engelke, 2010). There are no known *S. frugiperda*-resistant bermudagrass cultivars available to the turfgrass industry. Therefore, the objectives of the current study were to test 14 promising experimental bermudagrass genotypes for resistance against *S. frugiperda* and to compare their performance to that of the emerging standard bermudagrass ‘TifTuf’. These experimental genotypes are considered “elite” because of their superior turfgrass quality, drought tolerance, shade persistence, rapid growth, and resistance to foot traffic during multiple years of field testing.

Materials and Methods

Turfgrass and insects. All the turfgrass genotypes were maintained in a greenhouse

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at the University of Georgia, Griffin Campus, GA. The bermudagrass genotypes used in this study were '12-TG-101', '12-T-192', '13-T-1032', '11-T-483', 'KBUF-UF-1326', '97-45', '13-T-1067', 'T-822', 'B16-8', '11-T-510', 'T-789', 'FROST 1', '09-T-31', and '11-T-56'. A bermudagrass cultivar ('TifTuf') and a zoysiagrass cultivar ('Zeon') were used as susceptible and resistant controls, respectively. 'Zeon' zoysiagrass is resistant to the fall armyworm (Anderson et al., 2007), whereas the bermudagrass 'TifTuf' is an emerging standard and its response to *S. frugiperda* has never been tested before. The turfgrasses were maintained at 25 °C and ~60% relative humidity in the greenhouse. There were 14 bermudagrass experimental lines plus two control cultivars planted in 7.8 × 5.6 × 5.9-cm pots. The soil medium used was sand. The turfgrasses were irrigated every day and fertilized with 20:20:20 N:P:K in 5.9 g·L⁻¹ water (100 mL/pot) at weekly intervals. Lateral shoot growth was trimmed to prevent their spread into nearby pots. Vertical shoot growth was never completely trimmed off to ensure that there was enough leaf material to feed the *S. frugiperda* larvae. The neonate larvae of *S. frugiperda* used in this study were purchased from Benzon Research Inc. (Carlisle, PA). When the *S. frugiperda* larvae were received from the rearing facility, they were temporarily maintained at room temperature (21 °C) and ~40% relative humidity in the laboratory. The *S. frugiperda* larvae were used in the experiment within 2 to 4 h after arrival.

Experimental procedure. The 14 bermudagrass experimental lines and the two controls were arranged in a completely randomized block design. The experiment was conducted in 29.6-mL clear plastic containers (product #9051; Frontier Agricultural Sciences, Newark, DE). The grass clippings from mostly newly emerged grass blades were cut from the treatment pots using a pair of scissors and transferred to clear plastic containers. The containers with grass clippings were placed inside a refrigerator for 2 to 3 h before introduction. The three first instar *S. frugiperda* larvae were introduced into each container with freshly cut grass clippings from the corresponding treatments. After every 2-d interval, 15 g of fresh turfgrass clippings were added to each container. The cups with larvae and grass clippings were randomly placed in cup holders and maintained in an environmentally controlled chamber at 28 °C, ~40% relative humidity, and a 16:8 h (light:dark) cycle.

This experiment was conducted in multiple groups so that the data collection could be managed. Six to seven treatments were evaluated in each group, making a total of three groups. Each of the treatments within every group was replicated 10 times. Evaluations of treatments from the same group were repeated in time. Ultimately, the bermudagrass genotypes were replicated 20 times in total, whereas the control cultivars were replicated 60 times in total because the control cultivars, 'TifTuf' and 'Zeon', were included in all the

groups. The test of the first group was initiated on 2 Aug. 2019 and repeated on 25 Sept. 2019. The test of the second group was initiated on 28 Aug. 2019 and repeated on 20 Oct. 2019. The test of the third group was initiated on 10 Dec. 2019 and repeated on 8 Jan. 2020. The same treatments were used in the tests of each group and were combined for analysis purposes.

Evaluation and data analysis. Larval survival and development were recorded at 2-d intervals. To document larval development, larval length from the head to the tip of the abdomen, head capsule width, and larval weight were recorded. The larval length and head capsule width were measured using a Vernier caliper (model #1468417; General UltraTech, Friendswood, TX). The measurements for all the surviving larvae in a container were averaged and recorded. When those larvae pupated, the length, width (of the thoracic region), and weight were recorded at 2-d intervals. The day of pupation and day of moth emergence were also noted when the evaluations were conducted at 2-d intervals. To determine if the survival of *S. frugiperda* was affected when exposed to the different bermudagrasses, the numbers of live *S. frugiperda* larvae at 2, 6, 10, and 14 d after introduction were subjected to one-way analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) in SAS (SAS Institute, 2012) after log-transformation ($\ln[x + 1]$). After 14 d, *S. frugiperda* larvae started pupating in certain bermudagrass treatments. The rate of larval development after consuming various bermudagrasses was determined by calculating the change in larval length, head capsule width, and weight between 8 and 6 d, 10 and 8 d, and 12 and 10 d after introduction. The data were log-transformed ($\ln[x + 1]$) and a one-way ANOVA was performed using the general linear model procedure (PROC GLM) in SAS. A one-way ANOVA was also performed for larval length, head capsule width, and weight at 6 d to determine the effects of bermudagrass lines on *S. frugiperda* larval feeding. Similarly, the pupal and adult data, such as day of pupation and day of adult emergence, were subjected to a one-way ANOVA using the general linear model procedure (PROC GLM) in SAS after log-transformation ($\ln[x + 1]$). The means were separated using the Tukey-Kramer least square method ($\alpha = 0.05$). The means and SE of the variables were calculated using the PROC MEANS procedure in SAS (SAS Institute, 2012). Pearson's correlations between larval parameters, such as larval length, head capsule width, and weight at 6, 8, and 10 d after introduction, and pupal plus adult parameters, such as day of pupation, pupal length, thorax width, and weight as well as day of adult emergence, were performed using the PROC CORR procedure in SAS (SAS Institute, 2012). The mean larval length, head capsule width, and weight as well as the day of pupation and day of adult emergence data were calculated for the correlation analysis. The mean pupal length,

thorax width, and weight were calculated after averaging the pupal parameters by treatment and replication across the observation dates.

To determine the performance of the bermudagrasses relative to the controls, survival, development, and overall susceptibility indices were developed. To develop the survival index, the mean *S. frugiperda* larval survival data generated using the Tukey-Kramer test for the treatments (bermudagrass genotypes and controls) were ranked from 1 to 16, with 1 indicating the fewest survivors and 16 indicating the most survivors. The rank data were calculated at 2, 4, 6, 8, 10, 12, and 14 d after introduction. The rank data were subjected to an ANOVA using the general linear model procedure (PROC GLM) in SAS after log-transformation ($\ln[x + 1]$), where the bermudagrass genotypes and controls and postintroduction dates were the treatment and replication, respectively. Using the mean ranks generated by the Tukey-Kramer test, the treatments were further ranked from 1 to 16, with 1 indicating the lowest mean rank and 16 indicating the highest mean rank.

To determine the development index, the larval length, width, and weight at 6, 8, and 10 d after introduction as well as the day of pupation and day of adult emergence were individually ranked from 1 to 16, with 1 indicating the lowest value and 16 indicating the highest value, using the means generated by the Tukey-Kramer test. The rank data for each parameter were combined, log-transformed ($\ln[x + 1]$), and analyzed using the general linear model procedure (PROC GLM) in SAS. The treatments were further ordered by their rank means (separated by the Tukey-Kramer test) by assigning each a value from 1 to 16, with 1 indicating the lowest mean rank and 16 indicating the highest mean rank. To determine the overall resistance index, both survival and developmental rank data were combined and analyzed using the general linear model procedure (PROC GLM) in SAS after log-transformation ($\ln[x + 1]$). The rank means separated by the Tukey-Kramer test were further ranked from 1 to 16, with 1 indicating the most resistant and 16 indicating the least resistant to *S. frugiperda* larvae.

A criterion was developed to compare and contrast the performance of the bermudagrasses with the commercial standard, 'TifTuf'. Fulfillment of the criterion was "high" if the genotype was more resistant than 'TifTuf', "comparable" if either one of the survival or developmental ranks was ≤5, "medium" if either one of the survival or developmental ranks was between 5 and 16, and "low" if both the survival and developmental ranks were between 10 and 16. The assumption was that 'TifTuf' is ranked lower than 5 in all indices.

Results

Larval survival. At 2 d after introduction, the survival of *S. frugiperda* larvae on the 'Zeon' treatment was significantly lower than

Fig. 1. Mean ($\pm$ SE) numbers of *S. frugiperda* larvae that survived at (A) 2, (B) 6, (C) 10, and (D) 14 d after the introduction of the neonates at 28 °C and $\approx$ 40% relative humidity. Three neonates were initially released per cup. The bars within a figure with the same letters are not significantly different (Tukey-Kramer test, $P < 0.05$).

Fig. 2. Mean ($\pm$ SE) *S. frugiperda* larval length (A), head capsule width (B), and weight (C) at 6 d. The bars with the same letters are not significantly different (Tukey-Kramer test, $P < 0.05$).

that on the '12-TG-101', '11-T-483', 'KBUF-UF-1326', 'T-789' and 'Frost 1' treatments ($F_{15, 325} = 2.7$; $P < 0.001$) (Fig. 1). At 6 d after introduction, a significantly lower number of larvae survived on 'Zeon' than on the rest of the treatments except 'T-822' ($F_{15, 325} = 7.2$; $P < 0.001$). At 10 d after introduction, the number of larvae that survived on the 'Zeon'

treatment was not significantly different from that on the 'T-822' and '11-T-483' treatments, although larval survival on 'Zeon' was significantly lower than that on the rest of the treatments ($F_{15, 325} = 6.2$; $P < 0.001$) (Fig. 1). At 14 d after introduction, the number of larvae that survived on 'Zeon' was significantly lower than that on the rest of the treatments except 'T-822' and '11-T-483' ($F_{15, 325} = 8.1$; $P < 0.001$).

Larval development. At 6 d after introduction, the length of the *S. frugiperda* larvae was significantly lower for those feeding on 'Zeon' than for the rest of the treatments ($F_{15, 264} = 9.4$; $P < 0.001$) (Fig. 2A). The larval length was not significantly different between 'TifTuf' and '12-T-192', '13-T-1032', '11-T-483', '11-T-483', '97-45', '13-T-1067', '11-T-510', 'T-789', 'Frost 1', '09-T-31', and '11-T-56' treatments. Similarly, there was no significant difference in the larval head capsule widths of 'TifTuf' and '13-T-1032', 'Zeon', '11-T-510', 'T-789', 'Frost 1', and '11-T-56' treatments ($F_{15, 264} = 11.4$; $P < 0.001$) (Fig. 2B). The larval weight was significantly lower on 'Zeon' than on the rest of the treatments except for '13-T-1032'; however, the larval weight on 'TifTuf' was similar to that on '13-T-1032' and the rest of the treatments except for '12-TG-101' ($F_{15, 264} = 10.1$; $P < 0.001$) (Fig. 2C).

Thereafter, the rate of larval development was assessed at 2-d intervals, beginning at 6 d and for up to 10 d after introduction, when the larvae started pupating in more than two treatments. From 6 to 8 d after introduction, the change in larval length was not significantly different between treatments ($F_{15, 263} = 1.5$; $P = 0.099$) (Fig. 3A). The change in head capsule width was significantly lower on the '12-T-192' treatment than on the '12-TG-101', '13-T-1032', 'KBUF-UF-1326', '97-45', '13-T-1067', 'Frost 1', and '11-T-56' treatments ($F_{15, 266} = 5.1$; $P < 0.001$) (Fig. 3B). Compared with that on 'Zeon' and 'TifTuf', the head capsule width on the '12-T-192' treatment was not significantly different. The change in larval weight was significantly lower on 'Zeon' than on the rest of the treatments; however, there was no significant difference in larval weights on the 'TifTuf', '12-T-192', '13-T-1032', '11-T-483', 'T-822', '11-T-510', '09-T-31', and '11-T-56' treatments ($F_{15, 263} = 8.9$; $P < 0.001$) (Fig. 4A). Between 8 and 10 d after introduction, a significantly lower change in larval length was observed on the '12-TG-101', '12-T-192', 'T-822', and 'Zeon' treatments than on the 'Frost 1' treatment, whereas other treatments ('13-T-1032', '11-T-483', 'KBUF-UF-1326', '97-45', '13-T-1067', 'B16-8', '11-T-510', 'T-789', '09-T-31', and '11-T-56') had larval length changes similar to that on the 'TifTuf' treatment ($F_{15, 245} = 3.2$; $P < 0.001$) (Fig. 3C). For most of the treatments, the change in larval width was not significantly different from that on the 'TifTuf' treatment, but it was significantly higher than that on the '12-TG-101' treatment ($F_{15, 233} = 3.2$; $P < 0.001$) (Fig. 3D). The change in larval weight was significantly lower on the 'Zeon' treatment

than on the 'KBUF-UF-1326', '97-45', 'B16-8', and 'Frost 1' treatments; however, none of the treatments was significantly different from 'TifTuf' ($F_{15, 255} = 4.4$; $P < 0.001$) (Fig. 4B). Between 10 and 12 d after introduction, the change in larval length was significantly lower on the 'KBUF-UF-1326' treatment than on the '11-T-56' treatment ($F_{15, 183} = 2.5$; $P = 0.002$) (Fig. 3E). There was no significant difference in the change in larval weight on 'TifTuf' and the rest of the treatments. The changes in both the larval head capsule width ($F_{15, 231} = 0.9$; $P = 0.544$) (Fig. 3F) and weight ($F_{15, 194} = 1.2$; $P = 0.244$) (Fig. 4C) were not significantly different from each other.

Pupal and adult parameters. *S. frugiperda* larvae pupated significantly later on 'Zeon' than on the rest of the treatments ($F_{15, 253} = 13.1$; $P < 0.001$) (Fig. 5A). The larvae on '12-T-192', '13-T-1032', '11-T-510', '09-T-31', and '11-T-56' treatments required similar time to pupate compared with the pupation time of the larvae on the 'TifTuf' treatment. Similarly, the emergence of adults was significantly more delayed on 'Zeon' than on the rest of the treatments ($F_{15, 228} = 11.3$; $P < 0.001$) (Fig. 5B). The moth emergence time was not significantly different on the '12-T-192', '13-T-1032', and '11-T-510' treatments compared with that on the 'TifTuf' treatment.

Although there was no significant positive association between the larval length, larval width, or larval weight and pupal length, pupal width, or pupal weight at 6 d after introduction, at 10 d after introduction, both the larval length or weight and pupal length, width, or weight had positive and significant associations (Table 1). At 12 d after introduction, there were positive and significant associations between the larval and pupal widths and larval and pupal weights. At 6 and 8 d after introduction, there were significant negative associations between the larval length, width, or weight and days of pupation and adult emergence. At 10 d after introduction, there was a significant negative association between the larval width or weight and days of pupation and adult emergence (Table 1).

Susceptibility indices. Based on the susceptibility index, the top-ranked bermudagrasses in this study were 13-T-1032', 'T-822', '11-T-510', '12-T-192', '11-T-56', '09-T-31', '11-T-483', and '13-T-1067' ($F_{15, 255} = 33.5$; $P < 0.001$) (Table 2). However, there were some differences in the order of the top genotypes when ranked by larval survival ($F_{15, 90} = 14.6$; $P < 0.001$) and development ($F_{15, 150} = 85.1$; $P < 0.001$). Based on the larval survival and developmental rankings, the top genotypes compared with 'TifTuf' bermudagrass were '13-T-1032', 'T-822', '11-T-510', '11-T-56', '09-T-31', and '11-T-483'; the other lines were categorized as medium and low (Table 2).

Discussion

The results show that the bermudagrasses '13-T-1032', 'T-822', '11-T-510', '11-T-56',

Fig. 3. Mean ($\pm$ SE) changes in *S. frugiperda* larval length and head capsule width between 8 and 6 d (A and B, respectively), 10 and 8 d (C and D, respectively), and 12 and 10 d (E and F, respectively). The bars with the same letters are not significantly different (Tukey-Kramer test, $P < 0.05$). When no differences were observed, no letters are given.

Fig. 4. Mean ($\pm$ SE) changes in *S. frugiperda* larval weight between 8 and 6 d (A), 10 and 8 d (B), and 12 and 10 d (C). The bars with the same letters are not significantly different (Tukey-Kramer test, $P < 0.05$). When no differences were observed, no letters are given.

'09-T-31', and '11-T-483' were comparable to 'TifTuf' when resistance against *S. frugiperda* was evaluated in the laboratory. These genotypes were deemed comparable to 'TifTuf' after carefully evaluating both the survival and development indices (Table 2). Currently, 'TifTuf' bermudagrass and 'Zeon' zoysiagrass are emerging standards, with each increasingly being planted across the United States (Schwartz, personal communication). Previous studies showed that zoysia-

grass cultivars were resistant to young larvae of *S. frugiperda* (Braman et al., 2000; Reinert and Engelke, 2010). In the current study, 'Zeon' was the least susceptible treatment, followed by 'TifTuf'. Because 'TifTuf' is an emerging bermudagrass standard, the emphasis of the current study was on determining where the experimental bermudagrasses rank relative to this cultivar. Based on the susceptibility index, which incorporated the ranks of both the survival data and developmental data, the '13-T-1032', 'T-822', '11-T-510', '12-T-192', '11-T-56', '09-T-31', '11-T-483', and '13-T-1067' bermudagrasses were among the top 10 treatments. When the least susceptible genotypes (based on the susceptibility index) were compared with 'TifTuf', they all elicited susceptibility comparable to that of 'TifTuf'. The bermudagrasses tested in the current study were not bred specifically for *S. frugiperda* resistance; however, they were previously tested for desirable turfgrass performance traits such as visual quality, drought tolerance, shade persistence, and adaptation to lower mowing heights. These *S. frugiperda* susceptibility results are important for understanding where these genetically novel genotypes rank relative to popular commercial cultivars, thus providing direction for future breeding research.

Based on the survival index, the bermudagrasses 'T-822', '09-T-31', and '11-T-483' were within the top five treatments, along with the 'TifTuf' and 'Zeon' cultivars. Because young larvae of the fall armyworm are vulnerable to food deprivation, they constantly consume grass tissue starting from the neonate stage. When fall armyworm moths invade a landscape, their egg masses are found on human-made structures adjacent to turfgrass so that emerging larvae have

Fig. 5. Mean ($\pm$ SE) *S. frugiperda* day of pupation (A) and day of adult emergence (B). The bars with the same letters are not significantly different (Tukey-Kramer test, $P < 0.05$).

immediate and constant access to the food source. In the current study, the survival of young larvae was affected when they were placed on certain bermudagrasses, suggesting that these genotypes prevented access to the vital nutrients and moisture in the grass tissue. The physical characteristics of grass cells, such as thick cell walls, or biochemical compositions of the cells, such as secondary metabolites toxic to larvae, can interfere with the ability of young larvae to access these vital resources (Braman et al., 2000, 2002; Reinert and Engelke, 2010). Therefore, the survival index can be an indicator of resistance or tolerance mechanisms, as evidenced by the survival of *S. frugiperda* exposed to certain bermudagrasses.

The development of larval stages of *S. frugiperda* was affected when the larvae consumed certain bermudagrass genotypes. The results show that '13-T-1032', '11-T-56', and '11-T-510' were among the top five bermudagrasses, in addition to 'TifTuf' and 'Zeon', based on the development index (Table 2). The underlying mechanism for delayed development is antibiosis, which has been reported previously for turfgrass genotypes and cultivars (Braman et al., 2000, 2002; Reinert and Engelke, 2010). In the current study, the *S. frugiperda* larvae developed more quickly on certain bermudagrasses than on other less susceptible genotypes and cultivars (Figs. 3–5). This suggests that the biochemical compositions of certain bermudagrasses affect normal larval growth and development. The longer the *S. frugiperda* remains in the larval stages, the greater is their chance of succumbing to predation, pathogens, or severe weather. Previous studies have shown that the days to pupation and days to adult emergence decreased with the increased susceptibility of turfgrass genotypes (Lynch et al., 1983; Reinert and Engelke, 2010).

The data show that the larval development parameters, such as length, head capsule width, and weight, were negatively associated with the day of pupation or day of adult

Table 1. Pearson's correlation coefficients of larval and pupal or adult parameters of *S. frugiperda*.

Larval parameter	Pupal length	Pupal width	Pupal wt	Day of pupation	Day of adult emergence
6 d after introduction					
Larval length				-0.85***	-0.85***
Larval width				0.75***	-0.72**
Larval weight				-0.78***	-0.79***
10 d after introduction					
Larval length	0.50*	0.62*	0.51*	-0.94***	-0.92***
Larval width				-0.95***	-0.93***
Larval weight	0.60*	0.67**	0.58*	-0.92***	-0.91***
12 d after introduction					
Larval length					
Larval width		0.50*		-0.92***	-0.89***
Larval weight			0.48 ^a	-0.66**	-0.68**

The notations indicate significant correlations (^a, *, **, ***significant at $P \leq 0.1$, 0.05, 0.01, or 0.001, respectively) between the larval and pupal or adult parameters.

Table 2. Rankings based on the indices.

Treatment ^z	Survival rank ^y	Development rank ^x	Resistance status relative to 'TifTuf' ^w	Susceptibility index ^v	Overall rank ^u
'Zeon'	1	1	High	1.0 ± 0.0 g	1
'TifTuf'	3	2	—	3.2 ± 0.4 f	2
'13-T-1032'	9	3	Comparable	5.4 ± 1.0 ef	3
'T-822'	2	9	Comparable	7.2 ± 1.2 de	4
'11-T-510'	7	5	Comparable	6.6 ± 0.5 c-e	5
'12-T-192'	8	6	Medium	6.9 ± 0.6 c-e	6
'11-T-56'	13	4	Comparable	7.5 ± 0.9 c-e	7
'09-T-31'	4	7	Comparable	7.7 ± 0.8 b-e	8
'11-T-483'	5	10	Comparable	8.3 ± 0.7 b-d	9
'13-T-1067'	6	12	Medium	9.5 ± 0.8 a-d	10
'T-789'	15	8	Medium	10.1 ± 0.7 abc	11
'Frost 1'	7	11	Medium	10.0 ± 0.6 abc	12
'97-45'	12	13	Low	11.3 ± 0.5 ab	13
'B16-8'	14	15	Low	13.0 ± 0.5 a	14
'12-TG-101'	11	16	Low	13.6 ± 0.9 a	15
'KBUF-UF-1326'	13	14	Low	14.1 ± 0.4 a	16

^zBermudagrass genotypes and control cultivars arranged by the overall rank.

^yRanks based on the survival index (mean survival ranks arranged in decreasing order).

^xRanks based on the developmental index (mean developmental ranks arranged in decreasing order).

^wHigh = more resistant than 'TifTuf'. Comparable = either one of the survival or one of the developmental rankings is ≤ 5 . Medium = either one of the survival or one of the developmental rankings is between 5 and 16. Low = both the survival and developmental rankings are between 10 and 16.

^vBased on the mean value of the susceptibility index.

^uRanks based on the susceptibility index (mean combined survival and developmental ranks arranged in decreasing order).

emergence (Table 1). Additionally, the results show that the *S. frugiperda* larvae that fed on the less susceptible bermudagrass genotypes and cultivars spent more time pupating and emerging into adults than those that fed on the susceptible bermudagrasses. This suggests that the *S. frugiperda* larvae that develop on relatively less susceptible bermudagrass genotypes tend to be smaller and lighter than the *S. frugiperda* larvae that develop on more susceptible bermudagrasses. Perhaps the fitness of the *S. frugiperda* adults developed on the less susceptible genotypes was compromised. More studies involving parameters such as the longevity of adults, fecundity, and viability of eggs evaluated as secondary effects for *S. frugiperda* adults developed on less susceptible genotypes are warranted. The results also show that the larval length, head capsule width, and weight are positively associated with the pupal length, thorax width, and weight (Table 1). This suggests that measurements of the length, thorax width, and weight of *S. frugiperda* pupae can be used for evaluating resistance or susceptibility (Braman et al., 2000; Reinert and Engelke 2010).

In summary, this study identified a few bermudagrasses comparable to the bermudagrass 'TifTuf' in terms of their susceptibility

to *S. frugiperda*. Some genotypes were less susceptible to neonates of *S. frugiperda*, whereas a few other bermudagrasses led to reduced development rates, potentially exposing the larvae to severe weather and predation. The results also show that resistance or susceptibility screening can be achieved by evaluating pupal parameters, which will be especially useful when breeders screen for *S. frugiperda* resistance or susceptibility using several genotypes at one time. Because the current study only focused on evaluating the resistance or susceptibility against *S. frugiperda* through antibiosis mechanisms, other mechanisms, such as antixenosis (nonpreference) and tolerance, were not evaluated and merit further investigation. Although this study identifies few promising experimental genotypes, more studies are warranted to understand the consistency of their performance in field conditions because host plant resistance continues to be a valuable tactic for managing *S. frugiperda* in turfgrass.

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