Woody Host Plants of the Sugarcane Root Weevil (Coleoptera: Curculionidae) in Florida Sugarcane[1]

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Abstract Studies were conducted to evaluate adult sugarcane root weevil (*Diaprepes abbreviatus* (L.) (Coleoptera: Curculionidae) survival, residence (location), feeding damage, and oviposition on sugarcane and woody plant species proximal to sugarcane grown in Florida. Adults survived longer feeding on lime (*Citrus aurantifolia* (Christm.) Swingle) and Brazilian peppertree (*Schinus terebinthifolius* Raddi) foliage compared to sugarcane in a laboratory no-choice feeding test. Four sugarcane varieties and three woody plant species (Brazilian peppertree, castorbean (*Ricinus communis* L.), US-942 citrus (*Citrus reticulata* Blanco 'Sunki' × *Poncirus trifoliate* L. 'Flying Dragon')) were evaluated in a greenhouse free-choice test. Adult residence and feeding damage were highest on Brazilian peppertree compared to the other species, although the feeding damage was not significantly different from US-942 citrus. There was little feeding damage on castorbean and sugarcane. Oviposition was observed on all sugarcane and woody plant species with exception of castorbean. Brazilian peppertree had the highest number of egg masses followed by US-942 citrus. Leaf tissue analysis showed that feeding preference of adults for Brazilian peppertree and US-942 citrus may be due to higher tissue concentration of plant nutrients compared to those of sugarcane. Woody plant surveys showed that Brazilian peppertree and castorbean had the highest frequency around Florida sugarcane. These results show that Brazilian peppertree is a preferred food source and oviposition site for adult weevils. Adults oviposit on sugarcane, but it is not a preferred food source since adult survival is reduced. Therefore, reduction of Brazilian peppertree near sugarcane fields is important in controlling the weevil in Florida sugarcane.

Key Words sugarcane root weevil, sugarcane, woody plant species, Florida, *Diaprepes*

The sugarcane root weevil (*Diaprepes abbreviatus* (L.)) (Coleoptera: Curculionidae), occurs naturally in the Lesser and Greater Antilles where it is considered an important pest of sugarcane (*Saccharum* spp.) hybrids and citrus (*Citrus* spp.) in the Caribbean (Woodruff 1968). The sugarcane root weevil is native in the Caribbean and was first reported in a citrus nursery in Apopka, Florida, in 1964 (Woodruff 1964, Schroeder and Jones 1983). It subsequently expanded its range across southern and central Florida, although secondary introductions from the Caribbean may have occurred (Hall 1995). Regarded to be a poor flier that disperses slowly

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and locally (Nigg et al. 2001), the spread of the sugarcane root weevil is usually attributed to the movement of infested plants. The sugarcane root weevil is now considered an important pest of citrus and ornamental plants in Florida (Simpson et al. 1996, Knapp et al. 2000).

The sugar industry was alarmed by the presence and spread of the sugarcane root weevil in Florida during the 1970s and 1980s, even though no infestation in sugarcane had been reported. Adult weevils were found in the vicinity of sugarcane fields in association with weed species and other plants growing near sugarcane fields in the late 1990s and early 2000s, but no larval infestations or signs of damage to sugarcane were found. However, Cherry et al. (2011) observed the first sugarcane root weevil larval damage in Florida sugarcane in 2010 at two distinctly separate locations 50 km apart near Clewiston (Hendry Co.) on sandy muck soil and Pahokee (Palm Beach Co.) on muck soil. The occurrence of sugarcane root weevil damage in Florida sugarcane (Cherry et al. 2011) presents a potential major pest problem for >163,000 ha of commercial sugarcane grown in Florida (USDA 2012).

The sugarcane root weevil has a wide host range, including 270 species in 157 genera in 59 plant families, with associations ranging from adult and larval feeding to oviposition of egg masses (Simpson et al. 1996, Knapp et al. 2000). Weed species associated with Florida sugarcane include common lambsquarters (*Chenopodium album* L.), spiny amaranth (*Amaranthus spinosus* L.), common purslane (*Portulaca oleracea* L.), sicklepod (*Senna obtusifolia* (L.) H.S. Irwin & Barneby), and coffee senna (*Senna occidentalis* (L.) Link) and are preferred residence and feeding hosts for adult sugarcane root weevils (Odero et al. 2013). Although sugarcane is a poor adult residence and feeding host, it is an excellent host for oviposition (Odero et al. 2013) and for the larvae (Simpson et al. 1996) that burrow through the soil and cause root damage, resulting in fields with stunted, lodged, and upturned plants (Schroeder et al. 1979, Cherry et al. 2011). Injury inflicted by larvae on roots of susceptible plants can lead to plant decline or death (Griffith 1975).

There are several weedy species, including woody plants, that grow adjacent to sugarcane fields in Florida. Woody plants are species with self-supporting stems, secondary growth, and a diameter >2.5 cm at breast height (Bovey 2001, Macía 2008). The objective of this study was to compare adult root weevil survival, residence, feeding, and oviposition on Florida sugarcane varieties versus woody plants. The concentrations of foliage tissue macronutrients and micronutrients of the plant species also were investigated. In addition, a survey of woody plant species associated with Florida sugarcane was conducted.

Materials and Methods

Field collections. Adult sugarcane root weevils were collected by picking adults by hand from sicklepod located inside a commercial sugarcane field. This weed species has been shown to be an important host plant in Florida sugarcane (Odero et al. 2013). After collection, adults were stored at 18°C in covered plastic pans (30 × 25 × 10 cm [length × width × depth]). Pans had moistened paper towels on the bottom to provide humidity and absorb excretory products. Adults were fed fresh guava (*Psidium guajava* L.) leaves, and pans were aired every 3 to 4 d. Guava is a host plant for the sugarcane root weevil (Simpson et al. 1996, Knapp et al. 2000) and was used as a food source because it is in a different family (Myrtaceae) from other plants used in this study, thereby eliminating any preconditioning for subsequent testing.

No-choice feeding test. A no-choice feeding test was conducted to determine adult weevil survival on three host plants: Brazilian peppertree (*Schinus terebinthifolius* Raddi), lime (*Citrus aurantifolia* (Christm.) Swingle), and sugarcane (variety CP 04–1252). No-choice experiments are considered necessary to maximize the identification and measurement of plant resistance to insects (Smith et al. 1994). Brazilian peppertree was chosen because it is the most common woody plant species (see Results and Discussion) around Florida sugarcane fields, and there was grower concern about its suitability as a host plant for the root weevil. Lime and sugarcane were chosen because *Citrus* spp. and sugarcane are by far the two major host plants of economic concern in Florida (Simpson et al. 1996, Hall et al. 2001, Odero et al. 2013).

For testing, adult weevils were kept in plastic boxes (30 × 17 × 10 cm [length × width × depth]), with one host plant per box. The bottoms of the boxes were lined with moistened towels to provide humidity and absorb excretory products. Boxes were stored at 26°C and were maintained on 12-h dark/12-h light regimen. Fresh leaves (young and old) of host plants were added to boxes; the boxes were aired every 3 to 4 d. Ten adult weevils (five males, five females) were randomly selected from field-collected adults and placed in each box. One replication consisted of one box of each of the three host plants, and six replications were tested. Tests were initiated 5 October 2012 and terminated after 10 d when it was apparent that few adults were still surviving in the sugarcane treatment. Adult survival data were subjected to analysis of variance using the GLM procedure in SAS (SAS Institute 2008), and means were separated using the least significant difference (LSD) test ($\alpha = 0.05$).

Free-choice test. A free-choice test was conducted using four sugarcane varieties and three woody plant species to determine host plant preference of the adult weevils for residence (location), oviposition, and feeding. Sugarcane varieties tested were CP 89–2143, CP 88–1762, CP 80–1743, and CP 78–1628. These varieties account for 81 and 61% of Florida sugarcane acreages grown on muck and sand soils, respectively (Rice et al. 2010). Woody plant species evaluated were Brazilian peppertree, castorbean (*Ricinus communis* L.), and US-942 citrus. Citrus variety US-942 is a cross of mandarin (*Citrus reticulata* Blanco 'Sunki') × trifoliate orange (*Poncirus trifoliate* L. 'Flying Dragon') commonly used as a rootstock in Florida (Anonymous 2010). Brazilian peppertree and castorbean were chosen for testing because they are the two most common woody plant species around Florida sugarcane (see Results and Discussion). Citrus was included because of the proximity of some citrus groves to sugarcane fields, in addition to being an important host of the root weevil in Florida.

Sugarcane stalk cuttings (10–15 cm in length, with a single bud) of each variety were planted (one per pot) in 15-liter (28-cm-diameter) pots filled with Dania muck soil in August 2012. Brazilian peppertree and castorbean seedlings were collected near Belle Glade, Florida, and transplanted into similar-sized pots with Dania muck soil in August 2012. Greenhouse-raised US-942 citrus plants with a history of no insecticide application were used in the study. Plants were grown under natural light at a maximum temperature of 27°C and watered as needed. Plants were allowed to establish for >1 mo before release of adult weevils.

Plants with no visible chewing insect damage were selected and moved to a completely sealed greenhouse maintained under similar growing conditions. Wooden slats were placed between plants so that, besides flying, adults could easily walk between plants, thus making this a free-choice test. Eight adult weevils (four males, four females) were again randomly selected from field-collected adults and placed at the base of each plant on 25 October 2012. Sugarcane varieties and woody plant species were 43–59 and 32–99 cm in height, respectively. The experimental design was a randomized complete block with five replications of each sugarcane variety and woody plant species.

Adult sugarcane root weevil residence, feeding, and oviposition were determined 1 and 2 weeks later. For adult residence, the number of live adults present on above-ground portions of plants was recorded. Host plant feeding damage was visually estimated on a scale of 0 to 10, with 0 being no damage and 10 being complete plant defoliation. Plant foliage was considered damaged when characteristic notches along leaf margins were observed. Other herbivorous insects with chewing mouthparts were not observed or removed, thus ensuring that the damage was caused by adult weevils. Plants with characteristically cemented leaves were assessed for egg masses. Oviposition was determined by counting egg masses because individual eggs could not be counted easily due to small size, hatching, predation, or a combination. Egg masses counted at week 1 were left on plants, but marked so as not to be recounted. The test was terminated after 2 weeks due to declining numbers of surviving adults. Data were subjected to statistical analysis as described previously.

Leaf tissue analysis. At the end of the test, leaf tissue samples were collected from all plants and analyzed for total N, P, K, Ca, Mg, Mn, Fe, Cu, and Zn. N, P, K, Ca, and Mg are macronutrients, whereas Mn, Fe, Cu, and Zn are micronutrients. Leaves were collected, rinsed in distilled water to remove surface residues and contaminants, and dried at 70°C for 3 d. Leaf tissue was then ground and subjected to high-temperature acid digestion (Wright 2009, Ye and Wright 2010) for analysis of all nutrients. Two milliliters of sulfuric acid and 2 ml of 30% hydrogen peroxide were used to digest 0.3 g of ground leaf tissue for 2 h at 350°C. Digestates were diluted to 50 ml final volume and then analyzed colorimetrically for N and P as described in Ye and Wright (2010) and for other nutrients using Inductively coupled plasma methods described in Wright and Mylavarapu (2010). Data were subjected to statistical analysis as described previously.

Woody plant surveys. Surveys of woody plant species growing around sugarcane fields were conducted between December 2012 and February 2013 by using the method described by McAvoy et al. (2012). Woody plant species up to 10 m outward from the edge of sugarcane fields were counted and recorded in five 161-m-long segments along 60 sugarcane fields. The frequency of detection of each woody plant species was calculated as a percentage of the total number of sampling segments in which a species occurred.

Results and Discussion

No-choice feeding test. Survival of adult weevils varied among the three host plants. The number (mean ± SD) of adults that survived feeding on lime, Brazilian

Table 1. Number of adult root weevil residence (location) on sugarcane and woody plant species.

Species	Weeks After Adult Release* 1	Weeks After Adult Release* 2	Total†
Sugarcane variety			
CP 78-1628	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b
CP 80-1743	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b
CP 88-1762	0.0 ± 0.0 b	0.0 ± 0.0 b	0.0 ± 0.0 b
CP 89-2143	0.4 ± 0.2 b	0.2 ± 0.2 b	0.6 ± 0.4 b
Woody plant			
Brazilian peppertree	5.6 ± 3.1 a	1.2 ± 0.0 a	6.8 ± 3.8 a
Citrus§	0.2 ± 0.2 b	0.0 ± 0.0 b	0.2 ± 0.2 b
Castorbean	0.4 ± 0.4 b	0.0 ± 0.0 b	0.4 ± 0.4 b

* Means ± SE followed by the same letter in a column are not significantly different ($\alpha = 0.05$) using an LSD test (SAS Institute 2008).
† Combined total number of adult observations after 2 weeks.
§ Citrus variety US-942.

peppertree, and sugarcane was 6.6 ± 2.4, 6.0 ± 3.2, and 2.5 ± 2.3, respectively, 10 d after release. Significantly more adults survived feeding on lime and Brazilian peppertree foliage compared to sugarcane. There was no significant difference in weevil survival between lime and Brazilian peppertree hosts. Simpson et al. (1996) reported adult root weevil feeding on Brazilian peppertree based on a report by Cassani (1986). However, Cassini (1986) did not state that it was adult weevil feeding in a survey of arthropods on Brazilian peppertree. In contrast, sugarcane has been shown to be a poor adult weevil feeding host (Odero et al. 2013), but it is suitable for the development of larvae (Schroeder et al. 1979). All weevils used in this test were collected at the same time and provided with guava leaves as a food source before use in the test. Therefore, there were probably no extrinsic factors that would have influenced the outcome of the test.

Adult residence. Brazilian peppertree had significantly higher number of resident weevils compared to the other species 1 and 2 weeks after release (Table 1). Few to no adults were observed on sugarcane varieties, US-942 citrus, and castorbean. Adult residence was not significantly different among sugarcane varieties on any observation date. The number of adult residents on all species declined 2 weeks after release; this decline was attributed to declining numbers of surviving adults after 2 weeks. Overall, adult residence was clearly highest on Brazilian peppertree.

Feeding damage. Weevil feeding damage on host plants was characterized by a pattern of notches around leaf margins. Brazilian peppertree was the preferred adult feeding choice at 1 and 2 weeks after release compared to the other species, although the damage was not significantly different from US-942 citrus at 2 weeks

Table 2. Adult root weevil feeding damage rating* on sugarcane and woody plant species.†

	Weeks After Adult Release	
Species	**1**	**2**
Sugarcane variety		
CP 78-1628	0.4 ± 0.4 b	0.4 ± 0.4 b
CP 80-1743	0.3 ± 0.2 b	0.3 ± 0.2 b
CP 88-1762	0.2 ± 0.2 b	0.3 ± 0.2 b
CP 89-2143	0.4 ± 0.2 b	0.6 ± 0.2 bcd
Woody plant		
Brazilian peppertree	2.0 ± 0.7 a	2.1 ± 0.6 a
Citrus§	0.6 ± 0.4 b	1.2 ± 0.6 abc
Castorbean	0.3 ± 0.2 b	0.3 ± 0.2 b

* Damage rating is on a scale of 0 to 10, with 0 being no damage and 10 being complete plant defoliation.
† Means ± SE followed by the same letter in a column are not significantly different ($\alpha = 0.05$) using an LSD test (SAS Institute 2008).
§ Citrus variety US-942.

(Table 2). There was little feeding damage on sugarcane cultivars; similarly, little damage was observed on castorbean. Damage was not significantly different among the sugarcane varieties at both evaluation dates. Among woody plant species, castorbean had the least feeding damage, indicating that it was not a preferred adult feeding choice, even though it is listed as a root weevil host (Knapp et al. 2000).

These results show that feeding damage was closely related to adult residence. Greatest feeding damage occurred in Brazilian peppertree that had highest adult residence, which is not surprising. Adults were also previously shown to survive on Brazilian peppertree and lime, a *Citrus* species, as a food source in the no-choice feeding test. Sugarcane has been previously reported as a host known to support the entire life cycle of sugarcane root weevils, including adult feeding (Fennah 1942, Simpson et al. 1996). Our study shows that the primary Florida sugarcane varieties are not preferred adult feeding choices compared to Brazilian peppertree. Castorbean, an important woody plant species around Florida sugarcane, was not a preferred food source, despite being listed by Knapp et al. (2000) as a host plant.

Oviposition choice. There were significant differences in oviposition between plant species at 1 and 2 weeks after release (Table 3). Brazilian peppertree had the highest number of egg masses 1 and 2 weeks after release followed by US-942 citrus. No egg masses were found on the foliage of castorbean. Although adult residence and feeding damage to sugarcane were minimal, females oviposited on all sugarcane varieties. These data show that Brazilian peppertree was preferred for

Table 3. Number of egg masses of root weevils on sugarcane and woody plant species.

Species	Weeks After Adult Release* 1	2	Total†
Sugarcane variety			
CP 78-1628	0.4 ± 0.2 cd	0.4 ± 0.4 b	0.8 ± 0.4 bc
CP 80-1743	1.0 ± 0.5 bcd	0.8 ± 0.4 b	1.8 ± 0.7 bc
CP 88-1762	1.6 ± 0.2 abc	1.0 ± 0.5 ab	2.6 ± 0.5 bc
CP 89-2143	1.2 ± 0.6 bcd	0.8 ± 0.4 b	2.0 ± 0.9 bc
Woody plant			
Brazilian peppertree	2.6 ± 0.7 a	3.0 ± 1.4 a	5.6 ± 2.0 a
Citrus§	2.0 ± 0.7 ab	1.2 ± 0.8 ab	3.2 ± 0.6 ab
Castorbean	0.0 ± 0.0 d	0.0 ± 0.0 b	0.0 ± 0.0 c

* Means ± SE followed by the same letter in a column are not significantly different ($\alpha = 0.05$) using an LSD test (SAS Institute 2008).
† Combined total number of egg masses after 2 weeks.
§ Citrus variety US-942.

oviposition compared to other species and that preference for oviposition was related to adult residence and feeding.

Leaf tissue analysis. Trends in tissue nutrient concentrations were apparent (Table 4). Plant macronutrients N, Ca, and Mg were significantly higher for all three woody plants than for the four varieties of sugarcane. P, K, and micronutrients showed no clear differences between the sugarcane varieties and woody plant species.

Adult weevil preference of Brazilian peppertree for feeding compared to sugarcane may be due to higher leaf tissue nutrient concentrations, especially N. The important role of N in insect herbivory was previously reviewed by McNeil and Southwood (1978). For example, Cagampang et al. (1974) reported that rice (*Oryza sativa* L.) varieties resistant to planthopper *Nilaparvata lugens* Stål had low levels of amino acids (N is an important constituent of amino acids), especially asparagine, that significantly affected rate of weight gain and fecundity of this planthopper. Hogendorp et al. (2006) reported that high leaf N in citrus increased egg masses and female body size and decreased developmental times of citrus mealybug (*Planococcus citri* (Risso)). More recently, Price et al. (2011) noted that there are many examples showing that phytophagous insects, in general, survive better, grow faster, molt into larger adults, and are more fecund if they develop on N-rich host plants. There is limited information on the role of other plant nutrients in host plant selection by insect herbivores. Joern et al. (2012) measured foliar concentrations of 12 elements (N, P, S, B, Ca, Mg, Na, K, Zn, Fe, Mn, and Cu) in grasses and forbs from grassland habitats and correlated them with grasshopper *Schistocerca*

Table 4. Leaf tissue analysis of sugarcane and woody plant species for plant nutrients.

Species	Macronutrient*					Micronutrient*			
	N	P	K	Ca	Mg	Mn	Fe	Cu	Zn
	g/kg					mg/kg			
Sugarcane variety									
CP 78-1628	19.0 cd	1.9 c	13.0 e	3.0 d	1.7 c	3.8 b	54.5 ab	4.0 a	5.4 cd
CP 80-1743	22.0 c	2.2 bc	16.0 cde	4.0 c	1.7 c	3.2 b	43.8 ab	3.6 a	12.9 abc
CP 88-1762	22.0 c	2.0 bc	24.0 a	3.0 d	1.6 c	0.6 c	43.4 b	2.0 abc	8.3 bc
CP 89-2143	18.0 d	2.1 ab	15.0 de	2.0 e	1.5 c	0.2 d	47.1 b	1.6 bcd	4.5 d
Woody plant									
Brazilian peppertree	29.0 b	2.4 ab	17.0 bcd	10.0 b	2.7 b	5.2 b	36.9 b	1.6 cd	3.2 d
Citrus†	36.0 a	2.1 bc	19.0 bcd	15.0 a	2.4 b	48.7 a	48.4 ab	0.8 d	26.8 ab
Castorbean	42.0 a	2.6 ab	19.0 bcd	15.0 a	4.1 a	4.3 b	59.8 a	3.1 a	23.0 a

* Means followed by the same letter in a column are not significantly different ($\alpha = 0.05$) using an LSD test (SAS Institute 2008).
† Citrus variety US-942.

Table 5. Frequency of detection of woody plant species in Florida sugarcane fields.*

Family	Common Name	Scientific Name	Frequency (Mean ± SE)
Anacardiaceae	Brazilian peppertree	*Schinus terebinthifolius* Raddi	21.0 ± 4.3
Euphorbiaceae	Castorbean	*Ricinus communis* L.	12.3 ± 3.0
Verbanaceae	Lantana	*Lantana camara* L.	2.1 ± 1.2
Caprifoliaceae	Elderberry	*Sambucus nigra* L. ssp. canadensis (L.) R. Bolli	6.0 ± 2.3

* Survey of woody plant species was conducted between December 2012 and February 2013.

americana (Drury) population density. In their study, grasshopper population density was associated with N, P, Mg, and Na in grasses and only N and P in forbs. Overall, there was a positive correlation of grasshopper population density with N and P, and there was also a potential role of Mg, Na, and K in influencing population density. Similar to these previous studies, our data suggest that feeding preference of adult root weevils for Brazilian peppertree was due to higher leaf tissue concentration of N, Ca, and Mg. This is consistent with the conclusion of Price et al. (2011) that N limitation is a pivotal factor directing the feeding strategies of insect herbivores.

Woody plants field survey. In total, 48 km in length along sugarcane fields was surveyed. Four woody plant species from four different plant families were identified in this survey (Table 5). Brazilian peppertree had the highest frequency of detection followed by castorbean. Brazilian peppertree was most frequently found in clusters compared to the other species. Size of these clusters varied from a few plants up to $\geq$20 plants per cluster. Brazilian peppertree and castorbean have been previously reported to be host plants of the root weevils (Simpson et al. 1996, Knapp et al. 2000). In contrast, lantana (*Lantana camara* L.) and elderberry (*Sambucus nigra* L. ssp. *canadensis* (L.) R. Bolli) are woody plants that have not previously been reported as hosts of root weevils. Therefore, the suitability of lantana and elderberry as host plants of root weevils is not known.

Foliar sprays of contact insecticides against adult citrus weevils and granular insecticides applied to kill neonatal larvae can be used for management of infestations in citrus (Duncan et al. 2011). Furthermore, biocontrol of root weevils may be enhanced by entomopathogenic nematodes (Duncan et al. 2011) and insect parasitoids (Jacas et al. 2005, Castillo et al. 2006) that specifically attack larvae. However, there is no information on control of the root weevil in sugarcane by using insecticides or biocontrol agents. Flooding, a common cultural practice in Florida sugarcane, has been shown to be an effective control measure against root weevil larvae under laboratory conditions, depending on temperature (Shapiro et al. 1997). However, no research on flooding has been conducted in the field, where floodwaters might not reach all larvae boring into a sugarcane stool. Disking an infested sugarcane field to kill root weevils and replanting are expensive options. Odero et al. (2013) have shown the importance of controlling smaller herbaceous weeds in and around sugarcane fields to reduce root weevil infestations. In this study, we have shown that the most abundant larger woody invasive weed species around Florida sugarcane is Brazilian peppertree, an excellent host for adult root weevils. Shapiro et al. (1997) and Odero et al. (2013) are consistent in showing that weed control is probably the single most important factor in preventing infestations of the sugarcane root weevil.

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