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Classical Biological Control of Brazilian Peppertree (*Schinus terebinthifolius*) in Florida[1]

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Brazilian peppertree, *Schinus terebinthifolius* Raddi (Anacardiaceae), also known as Christmasberry, Florida Holly, and aroeira (Brazil), is an aggressive, rapidly colonizing invasive weed of disturbed habitats, natural communities and conservation areas in peninsular Florida (Ferriter 1997). Native to Argentina, Paraguay and Brazil, Brazilian peppertree was introduced into Florida as a landscape ornamental in the late 19th century (http://edis.ifas.ufl.edu/TOPIC_BOOK_Florida_Weeds). The popularity of BP as an ornamental plant can be attributed to the numerous bright red drupes (fruits) produced during the October to December holiday season (Figure 1). Grown as a substitute for the more traditional English holly (*Ilex aquifolium* L.), Brazilian peppertree was common in cultivation in Florida during the first half of 20th century. However, this relative of poison ivy was a rare component of the native flora until the late 1950s when the first naturalized plants were discovered in Monroe County.

Brazilian peppertree currently dominates entire ecosystems in southcentral Florida (Ferriter 1997). It is considered an important invader of the Everglades National Park, and poses a significant threat to ongoing Evergladess restoration efforts. Once established, Brazilian peppertree quickly displaces the native vegetation, often forming dense monocultures that reduce the biological diversity of plants and animals in the invaded area. Herbicides (http://edis.ifas.ufl.edu/AA219) and mechanical or physical control practices (e.g., cutting, burning and flooding) are routinely used often in combination for controlling existing stands, but these conventional

Figure 1. Leaves and fruit of Brazilian peppertree. Credits: A. Murray, University of Florida, Center for Aquatic and Invasive Plants (used with permission).

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methods are expensive, labor intensive and provide only temporary control due to the plant's regenerative capacity. Furthermore, non-selective chemical and mechanical controls are unsuitable for sensitive natural areas (e.g., coastal mangrove forests) because they can have negative effects on non-target species and increase water pollution. Minimizing the use of herbicides and other non-selective control practices is needed to maintain the integrity of Florida's fragile environment and natural resources. The introduction of host-specific natural enemies of Brazilian peppertree into Florida that are capable of selectively damaging the plant will accomplish this goal.

In the 1980s, Brazilian peppertree was identified as a suitable target for introductory or classical biological control (Habeck et al. 1994). Biological control is an appropriate management tactic because the invasive characteristics exhibited by Brazilian peppertree are consistent with the enemy escape hypothesis (Williams 1954). The key elements of this hypothesis are that (a) native host specific enemies strongly control the abundance and distribution of native plants; (b) escape from host specific enemies is a key contributor to exotic plant success; and (c) enemy escape benefits exotic plants because they gain a competitive advantage over native plants as a result of being liberated from their herbivores. Also, because no close relatives of Brazilian peppertree occur in the US, the potential for non-target damage by approved biological control agents would be low.

Several insects were identified from exploratory surveys conducted in Brazil as potential biological control agents of Brazilian peppertree (Habeck et al. 1994, Hight et al. 2002, Cuda et al. 2004). Two insect species, the thrips *Pseudophilothrips ichini* Hood (= *Liothrips ichini*) (Thysanoptera: Phlaeothripidae) and the sawfly *Heteroperreyia hubrichi* Malaise (Hymenoptera: Pergidae), were initially selected as candidates for further study because they visibly damage the plant in its native range and are probably host specific. The leaf roller *Episimus utilis* Zimmerman (Lepidoptera: Tortricidae) that was introduced into Hawaii for classical biological control of Brazilian peppertree in the 1950s (Krauss 1963), is another promising insect that is undergoing evaluation.

Brazilian Peppertree Thrips, *Pseudophilothrips ichini*

The biology and field host range of *P. ichini* were studied in southeastern Brazil (Garcia 1977). *Pseudophilothrips ichini* has not been observed feeding on plants other than Brazilian peppertree in its native range (Garcia 1977, J. H. Pedrosa, pers. observ.). Because this thrips was found attacking only Brazilian peppertree in field surveys, Garcia (1977) suggested that *P. ichini* might be a good candidate for biological control of Brazilian peppertree.

The life cycle of *P. ichini* begins when the female deposits her eggs on the leaves of the plant. After hatching, the immature thrips undergo two larval instars that are the active feeding stages. The wingless larvae are mostly red but occasionally orange in color (Figure 2). As soon as the larval feeding phase is completed on the host plant, the remainder of the life cycle occurs in or on the soil. Unlike other families of the Thysanoptera that have only two pupal instars (the propupa and pupa), thrips belonging to the family Phlaeothripidae that includes *P. ichini* are unique in that they undergo three non-feeding pupal instars (the propupa, pupa I and pupa II) instead of two (Mound and Marullo 1996). While these developmental phases are not true larvae or pupae, these terms are commonly used to describe the immature stages in a thrips life cycle.

Figure 2. *Pseudophilothrips ichini*, a thrips that kills the shoot tips of Brazilian peppertree. Adult female (left); larvae on young stem (right). Credits: (adult) M. Vitorino; (larvae) D. H. Habeck.

The immature stages vary in length, depending on climate and other factors. Adults of *P. ichini* are

black, winged, and relatively small (3-6 mm) (Figure 2), but have a high reproductive rate. *Pseudophilothrips ichini* is polyvoltine; up to four generations per year have been observed in Curitiba, Brazil, and it is considered a common species in its native range (Garcia 1977). Mating is not required to produce offspring. Unmated females deposit eggs that develop only into males whereas mated females produce eggs that develop into females (Mound and Marullo 1996). This form of parthenogenetic reproduction is called arrhenotoky.

In Brazil, the adults overwinter on Brazilian peppertree. In early spring (September), females start laying eggs singly or in small groups on the leaflet pedicels and blades, or on the new tender shoot growth. The larvae hatch from the eggs in 7-8 days at 24°C. The first and second instars last 6 days and 11-12 days, respectively. The three-nonfeeding prepupal and pupal stages require ~ 8 days to complete their development. After transformation to the adult stage, females undergo a 5 to 15 day preoviposition period, and can oviposit up to 220 eggs during their lifetime (45-78 days). Duration of the complete life cycle for *P. ichini* is temperature dependent. According to Garcia (1977), the life cycle from egg to egg was completed in 76 days at 18°C, and 38 days at 24°C. Under laboratory conditions, females lived on average 78 days at 23.1°C when maintained in vials provided with food.

Both the larval and adult stages damage the plant. Larvae of *P. ichini* usually are found clustered around the stem of a tender shoot (Figure 2). They feed by rasping and sucking the plant sap, which frequently kills the growing tip. Adults are usually found on the new unfolding leaves where they feed, mate, and oviposit. Although they can be more randomly distributed on the plant, adults usually are found aggregated with the developing larvae. Adults also will feed on the flowers, causing them to abort. This type of feeding damage can inhibit seed production in mature plants and growth rate of younger plants. In addition, there is anecdotal evidence suggesting that feeding damage by *P. ichini* promotes infection by plant pathogens that contributes to shoot death (R. Barreto, pers. comm.).

The laboratory host range of *P. ichini* was investigated in Florida quarantine. A petition to release the insect from quarantine was prepared and submitted to the federal interagency Technical Advisory Group for the Introduction of Biological Weed Control Agents, or TAG (http://edis.ifas.ufl.edu/IN607) in November 1996. Request for release from quarantine was denied because the biological and host range testing data presented in the original petition did not adequately address the risk to native plant species and to the closely related California peppertree, *Schinus molle* L., a common introduced ornamental in southern California. A new petition to release the thrips in Florida was prepared and resubmitted to the TAG in October 2002 (Cuda et al. 2002). Although the revised petition addressed virtually all of the concerns raised by reviewers in the earlier petition, the TAG recommended testing of some additional plant species. These tests have been completed, and an addendum to the 2002 petition will be submitted to the TAG in 2005.

Brazilian Peppertree Sawfly, *Heteroperreyia hubrichi*

Heteroperreyia hubrichi is a primitive non-stinging wasp native to northern Argentina and southeastern Brazil. The biology, ecology and host range of the sawfly *H. hubrichi* were investigated in Brazil, Florida, and Hawaii (Vitorino et al. 2000, Medal et al. 1999, Hight et al. 2002, Cuda et al. 2005). The adults are black with yellow legs (Figure 3), and the sexes can be separated on the basis of size (females are larger), the presence of the ovipositor in females, and also antennal morphology. Field data collected in Brazil indicate this species is bivoltine (two generations per year). Sex ratio of the adults is approximately 1:1 (males to females) when reproduction is bisexual, but the sawfly also exhibits arrhenotoky; unmated females produce only males. In Brazil, a pupal diapause period occurs in the summer (December to February) and winter (June to August).

Upon emergence from the pupal stage, females mate and/or oviposit in young woody branches that are adjacent to the more tender terminal shoots. This behavior enables the sawfly to avoid the toxic resin

Figure 3. *Heteroperreyia hubrichi*, a defoliating sawfly of Brazilian peppertree. Adult female guarding egg mass inserted into stem (left); gregarious larvae feeding on leaflet (right). Credits: J. C. Medal, University of Florida.

common in the Brazilian peppertree's terminal growth. The female uses her saw-like ovipositor to cut the stem tissue and insert her eggs between the thin bark and the phloem (Figure 3). The eggs are elliptical in shape, and are deposited side by side in long rows of variable length and number. Females exhibit maternal behavior by guarding the egg masses during the incubation period, but die as soon as the first larvae hatch.

The period of egg maturation is about 15 days. The number of eggs is directly linked to the size of egg mass. The average number of eggs per mass is ~ 100. Females prefer to oviposit on plants that are < 3 m in height, and select young branches with a diameter between 2.5 to 5 mm for oviposition. In Brazil, the majority of sawfly egg masses (76.5%) occurred on plants with hairy leaves (varieties *pohlianus* and *rhoifolius*). However, in laboratory and greenhouse studies, sawflies readily accepted var. *raddianus*, the smooth variety of Brazilian peppertree that commonly occurs in Florida.

The larvae are bright green with a black head capsule (Figure 3), and have red areas at the end of abdomen and adjacent to the head capsule in the last two instars. The larval stage has seven instars in females and six in males. The duration of the larval stage (from emergence of the neonate larvae to pupation) is 45 days. The pre-pupal phase is characterized by the change in the size of the last instar larvae (25% smaller), and cessation of feeding. In this phase, the larvae burrow in the soil to a depth ranging from 3 to 4 cm to pupate. The pupation chamber acquires the color of the surrounding soil, and is ~ 1 cm in length, and ~ 0.5 cm in width. The pupal stage lasts from 1 to 5 months, with an average of 4 months.

The larva of *H. hubrichi* is the damaging stage. Developing larvae are voracious leaf feeders, and can cause complete defoliation of Brazilian peppertrees depending on the size of the plant and quantity of larvae present. This type of feeding damage could severely injure or kill young plants and prevent older plants from reproducing, thereby reducing the competitive advantage that Brazilian peppertree currently holds over native vegetation. In Brazil, it is not uncommon to find Brazilian peppertree shrubs and more rarely trees completely defoliated by the sawfly. Larvae are gregarious in the early instars (Figure 3), and feed in groups on tender leaflets mainly on new shoots. When the larvae reach the third instar, they disperse over the plant and attack leaflets of all age classes.

Since the entire life cycle from adult to adult can be completed in less than 4 months under ideal conditions, this insect may be capable of producing two or three generations per year in central and south Florida where Brazilian peppertree is a severe problem. Simulated herbivory studies conducted under field conditions in south Florida over a 2-year period have shown that growth and reproduction of Brazilian peppertrees are severely impacted when the plants are subjected to multiple defoliations within the same growing season (L.W. Treadwell and J.P. Cuda, unpublished data).

The TAG recommended the release of the defoliating sawfly *H. hubrichi* in Florida in 1997. A release permit has been delayed due to concerns about toxins present in the larvae. This candidate biological control agent currently is undergoing risk assessment as required by the National Environmental Policy Act (http://edis.ifas.ufl.edu/IN607).

Brazilian Peppertree Leafroller, *Episimus utilis*

Martin et al. (2004) investigated the biology of the leafrolling tortricid moth *E. utilis* in quarantine in the process of establishing a laboratory colony for conducting host range tests. Adults (Figure 4) are small, grayish brown moths with distinctive markings on the forewings. When at rest, the adults are cryptically colored, resembling either tree bark or bird droppings. Sexes can be readily separated without magnification by examining the wing pattern. Average life span for the adult moths is 8 to 9 days, and development from egg to adult stage occurs in about 42 days.

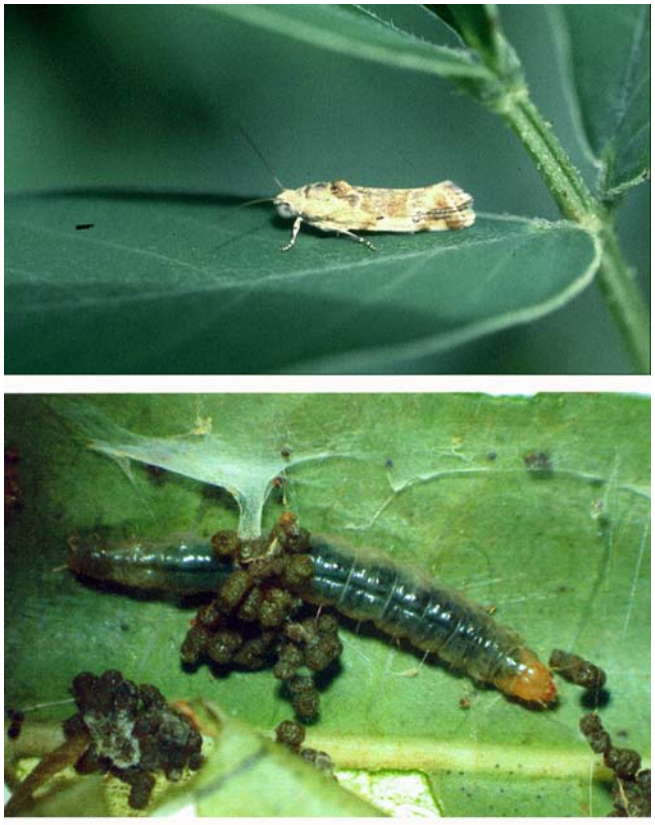

Figure 4. Adult (top) and mature larva (bottom) of *Episimus utilis*, a leafrolling moth introduced into Hawaii for biological control of Brazilian peppertree. Currently undergoing host range testing in quarantine laboratory in Gainesville, Florida. Credits: Photo of larva by M. Fukada, Hawaii Department of Agriculture. (Used with permission).

Females can deposit up to 172 eggs during their lives. Eggs are usually deposited singly but occasionally in groups of up to six eggs on the upper and lower surfaces of Brazilian peppertree leaflets. The eggs, which are glued to the leaflet, are compressed, ovoid, and light green in color with a smooth shell when first deposited but darken as they develop. The thin, scale like shape and transparency of freshly deposited eggs probably afford them some protection from predation and possibly parasitism.

The caterpillar (or larval stage) of *E. utilis* (Figure 4) attacks the foliage of Brazilian peppertree. Early instars are tan to light green in color but as they reach maturity, the larvae turn bright red before pupating and are approximately 15 mm long. The larval stage has five instars although a sixth instar may occur on occasion.

Feeding habits of the larvae vary depending upon their age. Newly hatched larvae and early instars feed by scraping the surface of the leaflets. Early instars are leaflet tiers, and normally feed between young and expanding leaflets that have been tied together with silk. Older larvae bind single leaflets into the characteristic cylindrical roll that is usually associated with *E. utilis* in nature. A cohort of approximately 35 larvae is capable of completely defoliating a 0.5 m tall Brazilian peppertree potted plant in less than 3 weeks (Martin et al. 2004).

Unlike the sawfly *H. hubrichi* that pupates in the soil and is vulnerable to flooding and possibly ant predation, mature larvae of *E. utilis* pupate in the tree canopy inside rolled leaflets attached to the plant. Pupae are brown in color with the head, appendages and wings darker than the abdomen.

In Hawaii, where it was released in the 1950s, *E. utilis* is widely distributed on Brazilian peppertree, but the insect apparently is not sufficiently abundant to severely damage the plant (Yoshioka and Markin 1991, J.P. Cuda 2002, personal observation). The ineffectiveness of *E. utilis* as a biological control agent in the Hawaiian Islands may be due in part to biotic mortality factors unique to that environment. For example, two wasps that were introduced into Hawaii for classical biological control of the sugar cane leafroller *Hedylepta* (=*Omiodes*) *accepta* (Butler) were discovered attacking *E. utilis* soon after it was released against Brazilian peppertree (Krauss 1963).

Although satisfactory biological control of Brazilian peppertree by *E. utilis* was not achieved in the Hawaiian archipelago, this failure should not preclude the introduction of the insect into Florida. *Episimus utilis* could be a more effective biological control agent of Brazilian peppertree in Florida because it would be introduced into a new environment where biotic mortality from introduced and native parasitoids and predators may be less severe compared to Hawaii.

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