Development of a training program to identify invasive weevils in the Caribbean basin and the United States

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Abstract
Numerous weevil species are serious pests on agricultural crops in the Caribbean basin and the USA. These pests include native and exotic weevil (Coleoptera: Curculionoidea) species. Among them, some weevil species are easy to identify, and others need training and expertise in taxonomy in order to identify them properly. Commodity-based identification and training tools are extremely important and critical. For example, the citrus root weevil, Diaprepes abbreviatus (L.) (Coleoptera: Curculionidae) was established in the US nearly 50 yr ago, and costs millions of dollars annually in control attempts in Florida alone. Other species such as the red palm weevil, Rhynchophorus ferrugineus (Olivier) (Coleoptera: Dryophthoridae), the South American palm weevil, Rhynchophorus palmarum (L.) (Coleoptera: Dryophthoridae); and the Jamaican weevil, Exophthalmus vittatus L. (Coleoptera: Curculionidae), are potential threats to fruits, vegetables, and ornamental crops. Adults of these weevils display various coloration, and patterns of red, blue, black, green, yellow, orange, and white. Some species have more than 2 color forms; male and female weevils may show major variations in their morphological characters. Regulatory agencies at the local, regional, and international levels are strengthening collaboration on offshore mitigation of these pests. Strict enforcement of regulatory guidelines and procedures is being adopted at the ports of entry into the US. Indeed, training on the identification and screening of these species, and other potential crop pests, is critically important for food security in the region. Training and capacity building to design, develop, and deploy keys, tools, and resources are major components of successful implementation of digital identification tools. The team at the Center for Biological Control is part of the digital resource consortium building tools on invasive beetles on economically important crops. To build capacity in digital insect identification, we have not only modified the contents of graduate and undergraduate insect systematics curriculum, but also have trained numerous students in these new skills.

Key Words: Curculionoidea; training; identification; agriculture; commodities; mitigation

Resumen
Numerosas especies de gorgojos son plagas importantes en cultivos agrícolas en la cuenca del Caribe y los Estados Unidos. Estas plagas incluyen especies de gorgojos nativos y exóticos (Coleoptera: Curculionoidea). Entre ellas, algunas especies de gorgojo son fáciles de identificar y otras necesitan capacitación y experiencia en taxonomía para poder identificarlas adecuadamente. Las herramientas de identificación y capacitación basadas sobre la clase de hospedero son extremadamente importantes y críticas. Por ejemplo, el gorgojo de la raíz de los cítricos, Diaprepes abbreviatus (L.) (Coleoptera: Curculionidae), se estableció en los EE. UU. hace casi 50 años y ha costado millones de dólares cada año en esfuerzos para controlarlo solamente en la Florida. Otras especies, como el gorgojo de la palma roja, Rhynchophorus ferrugineus (Olivier) (Coleoptera: Dryophthoridae); el gorgojo de la palma de América del Sur, Rhynchophorus palmarum (L.) (Coleoptera: Dryophthoridae); y el gorgojo jamaicano, Exophthalmus vittatus L. (Coleoptera: Curculionidae), son amenazas potenciales para las frutas, los vegetales y las plantas ornamentales. Los adultos de estos gorgojos muestran varios colores y patrones de rojo, azul, negro, verde, amarillo, naranja y blanco. Algunas especies tienen más de 2 formas de color; los machos y las hembras de estos gorgojos pueden mostrar grandes variaciones en sus caracteres morfológicos. Las agencias reguladoras a nivel local, regional e internacional están fortaleciendo la colaboración en la mitigación de estas plagas en alta mar. La aplicación estricta de las pautas y procedimientos reglamentarios se está adoptando en los puertos de entrada a los EE. UU. De hecho, la capacitación en la identificación y detección de estas especies y otras posibles plagas de los cultivos es de importancia crítica para la seguridad de alimentos en la región. La capacitación y el desarrollo de capacidades para diseñar, desarrollar e implementar claves, herramientas y recursos son componentes principales de la implementación exitosa de las herramientas de identificación digital. El equipo del Centro para el Control Biológico es parte del consorcio de recursos digitales que construye herramientas sobre escarabajos invasores en cultivos económicamente importantes. Para desarrollar capacidad en la identificación digital de insectos, no solo hemos modificado los contenidos del plan de estudios de sistemática de insectos para graduados y no graduados, sino que también hemos capacitado a numerosos estudiantes en estas nuevas habilidades.

Palabras Clave: Curculionoidea; formación; identificación; agricultura; productos básicos mitigación

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Table 1. Weevil pests of economically important crops in the Caribbean basin and the United States.

| Host plant                  | Common name                        | Scientific name                      | Distribution***                                                                 |
|-----------------------------|------------------------------------|--------------------------------------|---------------------------------------------------------------------------------|
| Citrus                      | citrus root weevils                | *Diaprepes abbreviatus* (Linnaeus) 1758 | Widespread - Greater and Lesser Antilles, *Florida, *Texas (O’Brien & Wibmer 1982) |
|                            |                                    | *Diaprepes ballolai* Marshall 1916   | Dominica (O’Brien & Wibmer 1982)                                              |
|                            |                                    | *Diaprepes doublieii* Guérin 1847    | Haiti (O’Brien & Wibmer 1982)                                                  |
|                            |                                    | *Diaprepes comma* Boheman 1834       | “Americas meridionali,“ Dominica, Grenada (O’Brien & Wibmer 1982)               |
|                            |                                    | *Diaprepes famelicus* (Olivier) 1790 | Dominica, Guadeloupe, Martinique, Nevis                                         |
|                            |                                    | *Diaprepes marginatus* (Fabricius) 1775 | Guadeloupe, St. Thomas (Virgin Islands)                                        |
|                            |                                    | *Diaprepes rohrii* (Fabricius) 1775  | “West Indies,” St. Croix                                                        |
|                            |                                    | [Actually prefers sugar cane]        |                                                                                  |
|                            |                                    | *Diaprepes spangleri* (Linnaeus) 1767 | Puerto Rico                                                                     |
|                            |                                    | *Pachnaeus citri* Marshall 1916      | Jamaica                                                                         |
|                            |                                    | *Pachnaeus marmoratus* Marshall 1916 | Jamaica                                                                         |
|                            |                                    | *Pachnaeus psittacus* (Olivier) 1807 | Cuba, Puerto Rico                                                               |
|                            |                                    | *Pachnaeus litus* (Germar) 1824      | Florida, Mexico [Cuba, Jamaica, both believed to be misidentifications of other species] |
|                            |                                    | *Exophthalmus vittatus* (Linnaeus) 1758 | Jamaica                                                                        |
|                            |                                    | *Exophthalmus similis* (Drury) 1773 | Jamaica                                                                         |
| Sugar cane, also attack banana and palms | West Indian cane weevil | **Metamasius hemipterus** (Linnaeus) 1758 | *Lesser Antilles and South America                                              |
|                            | silky cane weevil                  | **Metamasius seriaceus** (Olivier) 1807 | *Greater Antilles, Central and South America                                    |
| Sweet potato                | Sweet potato weevils                | *Cylas formicarius* (Fabricius) 1798 | Old World, *southern USA, *Greater Antilles, *Central America, *Hawaii         |
|                            | El Piche de la Batata              | *Euscepes postfasciatus* (Fairmaire) 1849 | South America, Greater and Lesser Antilles, *California, *Hawaii, *Tahiti, *Old World |
|                            | The “Scarabee”                     | *Palaeopus costicolis* Marshall 1918 | Jamaica, (Florida in quarantine)                                                |
| Rice                        | rice water weevils                 | *Rhysomatus nigerinus* Fahraeus 1837 | St. Vincent, Central America                                                    |
| Coconut palm and other palms | South American palm weevil         | *Lissorhoptrus isthmicus* Kuschel 1952 | Panama, *Dominican Republic, *Haiti, *Puerto Rico, *Colombia, *Venezuela       |
|                            | red palm weevil                    | *Lissorhoptrus brevirostris* (Suffrian) 1871 | Cuba                                                                         |
| Cultivated palms            |                                     | *Lissorhoptrus oryzophilus* Kuschel 1952 | USA, East Coast to California, southern Canada to Texas, Mexico, Cuba, *Japan, *Korea, *China [mainland], *Taiwan, *Italy |
| Stored grains               | rice weevil                        | *Rhynchophorus palmarum* (Linnaeus) 1758 | Neotropical, Greater and Lesser Antilles                                       |
|                            | maize weevil                       | **Rhynchophorus ferrugineus** (Olivier) 1790 | India, Pakistan, Middle East, China, Japan, Aruba, Curacao, etc.               |
|                            | broad-nosed grain weevil           | *Siphotus oryzae* (Linnaeus) 1763     | Cosmopolitan                                                                  |
|                            |                                    | *Siphotus zeamae* Motschusky 1855    | Cosmopolitan                                                                  |
| Coffee                      | Lachnopus coffeae* Marshall 1922   | *Caulophilus oryzae* (Gyllenhal) 1838 | Southern US, California, Baja, Central America, Cuba, Jamaica, Puerto Rico, Hawaii, Madeira, Europe |
| Beans (legumes)             |                                      |                                      |                                                                                 |
|                            | *Chalcodermus angulicollis* Fahraeus 1837 | Central America, Barbados, Dominican Republic, South America                  |
|                            |                                     | *Styracopus phaseoli* Marshall 1916  | Dominica, Guadeloupe, St. Vincent, South America                              |

*Countries or the US states into which species have been introduced. **Species introduced in Caribbean countries. ***Native and introduced ranges.
### Table 1. (Continued) Weevil pests of economically important crops in the Caribbean basin and the United States.

| Host plant | Common name | Scientific name | Distribution*** |
|-------------|-------------|-----------------|-----------------|
| Cassava     | Pappista armipes (Boheman) 1837 | Dominican Republic, Puerto Rico, Guadeloupe, St. Vincent | Formerly and Coelosternus Sternocoelus. |
| Pineapple   | Metamasius ritchiei Marshall 1916 | Hawaii (in quarantine) | **Species introduced in Caribbean countries.** |
| Mango       | Conotrachelus sapotae (Barber) 1924 | Greater and Lesser Antilles, Florida, Louisiana, South America, Old World | **Countries or the US states into which species have been introduced.** |
| Sapodilla   | Anthonomus fraxipennicornis Kirkaldy 1913 | Greater and Lesser Antilles, Florida, Louisiana, South America, Old World | **Countries or the US states into which species have been introduced.** |

### Material and Methods

This study was conducted in the Caribbean and other parts of the world, relying on weevil collection, loan of material, and specimen exchange(s). Lists of economically important weevils were developed from the existing literature (O’Brien & Wibmer 1982; Wibmer & O’Brien 1986), including the electronic resources available. Survey and collection were carried out in Trinidad and Tobago in summer 2009, and Aruba and Curacao in summer 2013. All specimens were identified before any imaging and digital identification work. For imaging, we have been relying exclusively on museum specimens and Auto-Montage imaging systems (Syncroscopy, http://www.directindustry.com/prod/syncroscopy/product-14153-357875.html) in the Center for Biological Control, College of Agriculture and Food Sciences, Florida A&M University, Tallahassee, Florida, USA. The weevil damage images and plant information were captured with a Nikon SLR camera and software. For identification and diagnostics,
Figs. 1-6. Red palm weevil (1), and South American palm weevil (2), South American palm weevil damage (3, 4, 5), and red ring disease symptom (6). Arrows 3 and 4 show early and late infestation of South American palm weevil, arrow 5 shows a full-grown larva and its damage, arrow 6 shows the cross section of coconut palm with red ring disease.

Figs. 7-10. Hands-on student training (7), and weevil identification process (8 and 9), image-based selection of diagnostic characters that leads to species identification in question (10), spreadsheet on a species with embedded brief introduction, distribution, hosts, damage, biological and ecological notes, and bibliography.
we used Lucid nutshell (http://www.lucidcentral.com/). The software is unique to design, develop, and deploy web- and compact disc (CD)-based insect identification keys.

**Results**

A list (Table 1) of 38 weevil species within 20 genera which included the introduced 3 species in Caribbean countries or the US, and introduced into Caribbean countries (10 species), and 25 species native to the Caribbean region is provided. However, most of these weevil species may not be from the Caribbean countries, because of intensive tourism and trade around the world. Central and South America are especially vulnerable, and serve as a hub for further spread of these exotic species to North America. Some of these species are monophagous, others are oligophagous and have narrow host plant range(s), and some are polyphagous. A web-based tool for the identification of these species was developed, and CDs were developed for users who do not have access to the internet. In this digital tool, images of dorsal and lateral habitus of these species were developed and embedded in spreadsheets. Notes on brief introduction, hosts, distribution, biology, and ecology of each species were included. The digital identification tools we have developed are based on simple distinguishing characters of weevils (25 genera and 40 species) linked with images for end-users to properly identify invasive weevil pests on economically important crops. Herein, we have provided examples of 2 exotic species: the red palm weevil, *R. ferrugineus*, and the South American palm weevil, *R. palmarum*; both are serious pests of cultivated palms, and also feed on other hosts (Figs. 1–6). Their appearance, and signs and symptoms of infestation are provided. Common and diagnostic characters of both species are provided in Table 2. Our efforts focused on providing necessary skills and hands-on training to graduate and undergraduate students to develop and deploy such digital identification tools and user-friendly identification processes (Figs. 7–10). Since spring 2009, we have trained 19 graduate and 14 undergraduate students to develop and identify insect pests, including weevil pests, based on the Lucid nutshell. Currently, these digital tools are part of the Systematic Entomology class at Florida Agricultural and Mechanical University to further train incoming students. We have organized symposia and workshops for end-users, including port of entry pest identifiers, pest managers, pest survey experts, and those involved in biodiversity and ecological studies who rely on correct identification of invasive pest species to analyze problems.

**Discussion**

Agricultural production needs to increase considerably in the foreseeable future to meet food demands of a growing human population.
Productivity of crops grown for human consumption is at risk due to the incidence of economically important crop pests. In the Caribbean, several serious weevil pest species exist that feed on economically important crops. A number of these pest species are native to the region, whereas others are exotic. Several of these species are polyphagous, and others have narrow host ranges. Because several Caribbean countries are important trade partners of the US and play a very significant role in tourism, monitoring the movements of these species in several conventional and non-conventional pathways in the Caribbean is critical to successful mitigation of these pest species. Keys to successful implementation of regionally coordinated strategies, including the development of rapid identification and detection of potential crop pests, are data exchange and joint response strategies.

Insect identifiers confront the challenge of identifying new, existing, and potentially invasive pest species. Accurate identification of insects is required before action can be determined. In the past, end-users used various approaches to identity insects, including matching with type specimens, dichotomous keys, pathway keys, matrices, and multiple entry keys (computer assisted), tabular keys (taxa vs. diagnostic characters), and punch card keys. Currently, computer-based taxonomic programs (Walter & Winterton 2007) comprising taxonomic keys, tools, and resources have become increasingly popular. Therefore, the Entomology program at Florida Agricultural and Mechanical University has been developing and training graduate and undergraduate students in this national need area.

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