Red palm weevil (*Rhynchophorus ferrugineus*), an invasive pest recently found in the Caribbean that threatens the region

A. Roda[1], M. Kairo[2], T. Damian[3], F. Franken[3], K. Heidweiller[4], C. Johanns[4] and R. Mankin[5]

[1]*United States Department of Agriculture, Animal Plant Health Inspections Service, Center for Plant Health Science and Technology, Miami, FL (USA)*

[2]*Center for Biological Control, College of Engineering Sciences, Technology and Agriculture, Florida Mechanical and Agricultural University, Tallahassee, FL (USA)*

[3]*Department of Agriculture, Husbandry and Fisheries, Oranjestad (Aruba)*

[4]*Department of Agriculture, Husbandry and Fisheries, Willemstad (Curacao)*

[5]*United States Department of Agriculture, Agriculture Research Service, Gainesville, FL (USA); e-mail: amy.l.roda@aphis.usda.gov*

Rhynchophorus ferrugineus, an important palm pest, was accidentally introduced into the Caribbean. A monitoring programme was established to determine the population level and distribution of infestations on Aruba and Curacao through the use of commercially available pheromone traps. Due to the small size of the islands and limited distribution of palms, eradication may be feasible using a combination of trapping, timely disposal of infested palms and curative and prophylactic chemical treatments. These studies on the pest in the Caribbean were used to help design a USDA plant health emergency response through the development of Animal Plant Health Inspection Service, Plant Protection and Quarantine New Pest Response Guidelines and provide an effective emergency response programme for other Caribbean Islands and the Americas.

Introduction

In tropical and subtropical regions, palms are an important component of the native landscape. Often, they are also economically important plants for agriculture, landscaping and tourism. In 2009, *Rhynchophorus ferrugineus* (red palm weevil), was detected in the Caribbean (Borchert, 2009). The pest originates from tropical Asia, but has spread through the Middle East and the Mediterranean where it has severely damaged commercial and ornamental palm trees (Faleiro, 2006; EPPO, 2008). Damage to palms is mainly caused by the larvae and only becomes visible long after infection. By the time the first symptoms of the pest appear, the infected palms are so seriously injured that they frequently die (Faleiro, 2006).

In both Curacao and Aruba, palms are principally grown for aesthetic purposes and are therefore a prominent feature in the landscape around tourist development, residential and other business areas. In many instances, fully grown palms, which are very expensive (3500–7000 EUR per palm), are used for new plantings in order to give a mature finish to a property. Red palm weevil was probably brought into the region with large *Phoenix* spp. date palms (>5 m tall) imported from Egypt. Due to the lack of phytosanitary regulations, similar *Phoenix* palms continue to enter Curacao for use primarily in housing developments and hotel landscaping. The pest was probably imported into Aruba from infested nursery stock obtained from Curacao. As in Curacao, Aruba does not have phytosanitary regulations in place to prohibit the importation of infested plant material nor regulatory measures to prevent movement within the country. In addition, the limited Agriculture, Husbandry and Fisheries (DLVV) staffing resources have prevented any wide scale mitigation program.

Due to the possibility of *R. ferrugineus* spreading through the New World, studies were conducted to determine the extent of red palm weevil infestation, to assess the approaches that government and private entities were taking to manage the pest, to optimize surveillance strategies and protocols, and to develop mitigation strategies that would minimize the pest's impact in the region.

Materials and methods

Host range

For potential new and known red palm weevil host plants, the presence of larvae and adults was verified by dissecting the infested trunk (stipe) and fronds to locate tunnelling. Palm species were documented through collection or photos of the identifying characters (e.g. frond, flowers, and fruit). The collected specimens and pictures were provided to local palm experts for identification through use of standard keys or comparison to herbarium collections.

Population monitoring

A major objective of the study was to develop a standardized, easily implemented trapping protocol for collecting information on red palm weevil distribution, density and population changes.

Preliminary trapping was done using red palm weevil lures (4-methyl-5-nonanol/4-methyl-5-nonanone and ethyl acetate) (Hallett *et al.*, 1993) purchased from Chemtica, Costa Rica. Traps constructed from white, 13.25-L plastic buckets (Freund Container, Chicago, USA) were baited with the lures as well as food attractants (cut apples) placed in a 4-L solution of 50/50 water/ethylene glycol, as recommended by the lure manufacture. Four 64-mm holes were cut into the upper 1/4 of the bucket and the surface was roughened to facilitate the beetle's entry into the trap. In September 2009, 16 traps were placed using a grid system throughout the known infested area in Willemstad, Curacao. During January 2010, 3 additional traps were added to 3 urban sites distributed across the island. In Aruba, 7 traps were distributed throughout the hotel and residential portion of the island at the beginning of September 2009. The traps were serviced every 2 weeks; all weevils were counted and removed and the food attractant and water/coolant mixture was changed. In January 2010, molasses was substituted for cut apples as the food attractant. Lures were replaced every 6 weeks or as needed. Initially, the traps were placed at 1.5-m height on *Phoenix* spp. palms. In January 2010, the traps were moved to telephone poles or non-host species 25–50 m away from host trees to reduce the risk of the tree being attacked by beetles not caught in the trap.

Acoustic detection

The potential of utilizing acoustic technology to detect larvae in trees not yet showing visual symptoms was studied under the actual conditions encountered in Aruba and Curacao, such as very tall trees and a noisy background environment. Acoustic recordings were obtained using methods described in Mankin & Moore (2010) from individual palm trees of several species, including *Phoenix dactylifera,* L., *Phoenix canariensis* Chabaud, and *Bismarckia nobilis* Hildebrand & Wendl, that either showed clear evidence of infestation or were asymptomatic. The signals were monitored aurally with headphones to determine the presence or absence of infestation (Mankin & Moore, 2010; Mankin *et al.*, 2011). A truck with an aerial work platform was used during 1 day to record larval sounds systematically over the height of the stipe of several palm trees. The recorded signals were subsequently analysed by computer software. Red palm weevil signals were discriminated from background noise and customized signal analysis programs were used for automated assessment of the likelihood of infestation (Mankin *et al.*, 2008, 2011).

Results and discussion

Host range

Previously documented hosts

On both islands, *R. ferrugineus* were found to attack primarily *Phoenix* spp. In Aruba, these plants were found mostly at hotels and resorts and were not widely distributed in the landscape. This was in contrast to the situation in Curacao where date palms were more widespread.

Table 1 Potential new *Rhynchophorus ferrugineus* host palms found with larvae or expressing typical symptoms of infestation

Species	Adult	Larvae	Symptoms
Bismarckia nobilis	?	?	Death, exudates
Dictyosperma album	?	Many, all stages	Death, tunnelling
Pritchardia pacifica	?	Reported larvae*	Death
Washingtonia robusta	?	Reported larvae*	Death

*Photographs or collections of larvae not made.

New host species

Several new palm host species were reported in both islands (Table 1). Fiji Fan Palm (*Pritchardia pacifica*) was also documented as being attacked and killed by palm weevil larvae (*Rhynchophorus* sp.) in Aruba. However, no adults were collected to confirm the identification of the species. Liquid exudates, a typical sign of *Rhynchophorus* infestation, were seen on Bismarck Palms (*Bismarckia nobilis*) in Aruba but no larvae or adults could be detected. There were also unconfirmed reports of this species dying in Curacao. Although these observations suggest that Bismarck palm may be a new host for red palm weevil, further work is needed to confirm this. It should be noted that although not known to be present on these islands, *Rhynchophorus cruentatus* is a common pest of Bismarck palms in southern USA and causes similar symptoms. Washington Palm (*Washingtonia robusta*), and Hurricane Palm (*Dictyosperma album*) were also reported to be dying from red palm weevil infestations in both islands. The increase in the number of host species reported may indicate the host range is broader than previously thought or that as the populations of the weevil increase they are spreading to less preferred hosts. Fiji Fan, Bismarck and Hurricane palms are important landscape palms used widely in housing developments and tourist resorts. The addition of new host palms could have major economic implications particularly if area wide pesticide treatment programs are implemented or restrictions on the movement of host plant materials are established. Therefore, care must be taken in reporting additional palm species as hosts of the red palm weevil as other factors such as diseases and/or mechanical damage can lead to symptoms that resemble red palm weevil damage.

Application of acoustic detection devices

Being able to detect larvae in palms which are not yet expressing symptoms would greatly aid mitigation efforts by nursery and landscape managers. For instance, the technology would facilitate decisions on whether nursery stock is uninfested and could be moved to new locations or if application of particular management strategies are needed. The technology would also help determine whether or not particular chemical treatments or other management strategies were effective. The gnawing sound made by feeding larvae has been used to detect infested palms (Abraham *et al.*, 1989; Soroker *et al.*, 2004; Mankin *et al.*, 2008). The sounds can be detected by trained individuals using endoscopes and acoustic devices to amplify *R. ferrugineus* larval sounds inside palm stipes. Recent advances using software to select frequencies specific to red palm weevil have shown promising results in the laboratory (Pinhas *et al.*, 2008) and the field (Siriwardena *et al.*, 2010). Under field conditions in Aruba and Curacao, the larvae produced signals that had greater energy than the background levels at frequencies above the peak frequency of the background noise (Mankin *et al.*, 2011). At the crown of the palm, where larvae were found, the sounds were louder and more diverse compared to lower locations, suggesting that sounds of different frequency do not transmit uniformly through the stipe. Lower frequency signals travelled with less attenuation than higher frequency signals. In addition, the amplitude of sound decreased as the detection equipment was moved away from the source of the infestation. Larvae were difficult to hear >3 m away from the infestations and the exact distance from which sound could be heard is likely to be dependent on the level of infestation. The acoustic detection devices also indicated that infestations occurred in both the crown and at the base of palm trees, which was substantiated with visual symptoms. Red palm weevil larvae were detected in date palms (*Phoenix* spp.), but distinctive larval sounds were not detected on Bismarck palms that were expressing red palm weevil symptoms, which suggests that additional suspected Bismarck palm infestations may be needed to verify whether as the species is really a red palm weevil host. Overall, the acoustic detection devices appear to be a feasible method for detecting the presence of larvae in the urban environments of Aruba and Curacao, and would provide a higher level of detection than simple visual inspection. Nevertheless, additional studies are needed to determine the correlations between the population, age and size of larvae and sound detection. Also, studies are needed to determine how larval feeding sounds are affected by the health of the tree and species of palm.

Population monitoring

The Departments of Agriculture (DLVV) in both Curacao and Aruba continued to service and record data from the monitoring traps placed in September 2009–January 2010 (Figs 1 and 2). In Aruba, regular bimonthly servicing of and data collection from monitoring traps was maintained until January 2011. In Curacao traps were serviced sporadically due to limited availability of staff. There were more red palm weevils caught in the traps placed in Curacao (maximum 28 weevils per trap per 2 weeks) than Aruba (maximum 6 weevils per trap per 2 weeks). Many factors could have influenced the difference in numbers, including the date of initial infestation, the amount of host material available, and the management and sanitation efforts. In Curacao, high numbers of weevils were found in Willemstad during all dates, indicating that this entire area was highly infested. In January 2010, traps were placed across the island of Curacao. This included residential and resort developments located approximately (40 km) from Willemstad that were separated by large stretches of palm-free, cacti-dominated landscapes. Red palm weevils were found in all traps indicating that they had spread across the entire island. In Aruba, the trap catches were consistently low, suggesting that efforts in the area to suppress populations were effective. However, red palm weevil infestations appeared to be problematic in residential areas according to local pest management companies. The Department of Agriculture in Aruba plans to expand their trapping efforts to include the residential areas.

Palm trees on which pheromone traps had been placed, frequently showed visual damage from red palm weevil attack. This suggested that some of the weevils attracted to the traps ended up attacking the trees. The problem was likely to be more serious if the traps were not serviced regularly, as the weevils could escape from traps that had dried out. Also, the health of a palm where the trap was placed must be monitored carefully and either prophylactic or curative applications of insecticides be made to the palm tree. It was therefore decided that when monitoring for changes in populations over time, traps should no longer be placed on host palms.

The group worked with Curacao DLVV cooperators and a local geographic information systems (GIS) firm to explore ways to use the trapping data to map the distribution of the weevil and areas with the highest concentrations of the pest. Through interpolation of the September 2009–January 2010 trapping data, the areas with the highest concentration of red palm weevil were located. In the future, GIS mapping systems could be used to map all the locations where susceptible hosts are present, the current location and populations of weevils based on trapping information, and the current control efforts. Mitigation efforts (mass trapping, chemical control and sanitation) could then be targeted on high risk areas, e.g., those with high weevil populations, large number of hosts, and minimal management in order to maximize limited resources. Continuous updating of the maps with new trapping data could aid in assessment of the effectiveness of management strategies and any need to refocus mitigation efforts.

Private pest control companies and governmental agencies are using several different trap types. All designs caught weevils to some extent. However, all designs were frequently observed to dry out, indicating a need to modify the design to decrease evaporation of the trap liquid or to use other means to prevent the escape of adults. The traps also need to be optimized for use in specific situations (e.g. hotel pest management vs. government detection/monitoring programmes) to maintain the highest attractiveness to adult weevils, to retain all individuals entering the trap, and to avoid contact with the public and non-target animals. Further studies are needed to evaluate the various trap designs being used to determine the most effective position, colour, container and method for reducing evaporation of the trap liquid.

Management recommendations

Both Curacao and Aruba are small islands and the distribution of palms is limited primarily to hotel, housing developments and roadways. Eradication of red palm weevil may be feasible using a combination of trapping, curative and prophylactic chemical treatments, and timely removal of infested palms. The high value of the palms is prompting hotels and high-end residential

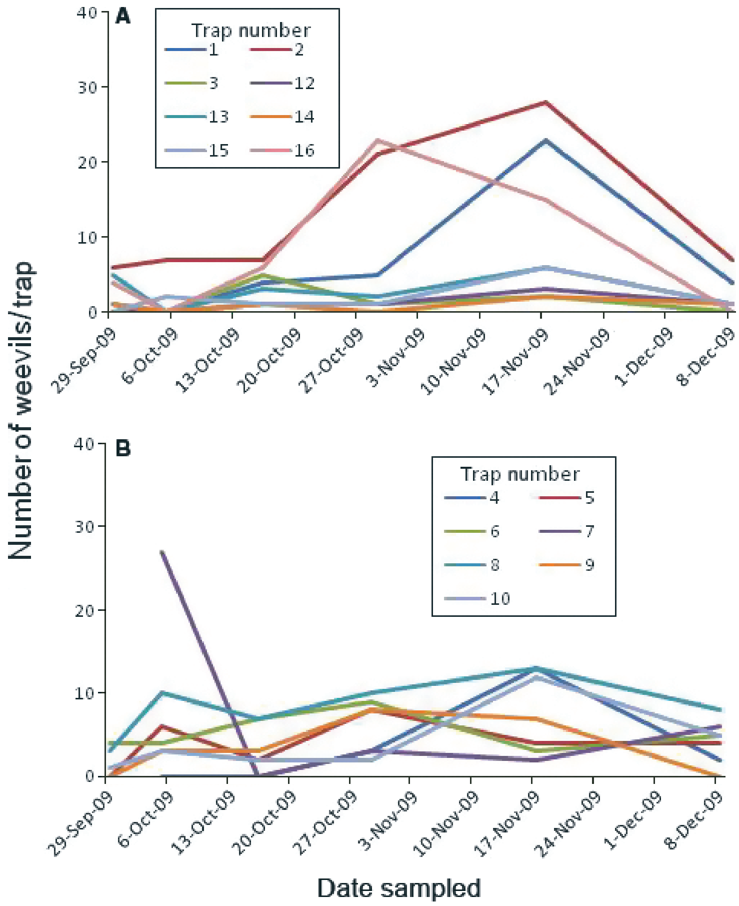

Fig. 1 The number of adult red palm weevils caught in 8 traps placed east of St. Annabaai (A) and 7 traps placed west of St. Annabaai, (B) Williamstad, Curacao from September 2009 to January 2010. Colours designate different trap locations.

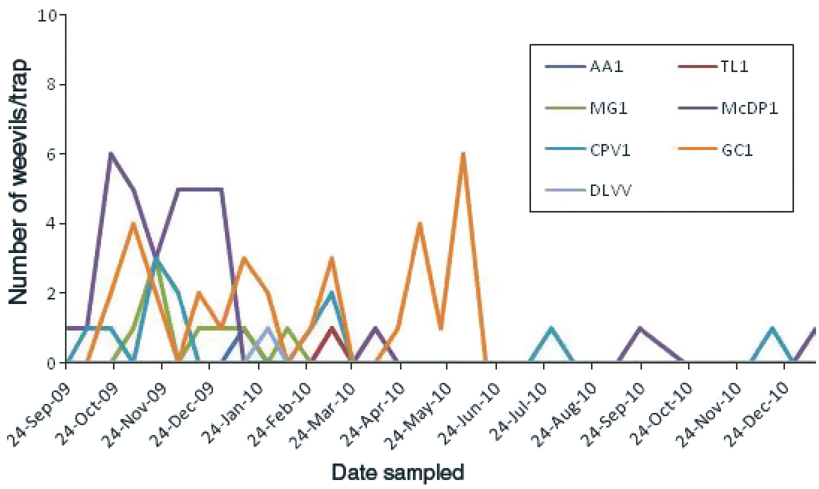

Fig. 2 The number of red palm weevil adults caught in 7 traps placed in Aruba from September 2009 to January 2011. Colours designate different trap locations.

developments to invest in pest management strategies. For example, Curacao Hospitality and Tourism Association (CHATA) developed a plan to focus their resources to manage the pest. The CHATA strategy included an intensive mass trapping and monitoring program in 7 major tourism areas. The idea is to operate a ring of traps to attract the weevils away from the tourism area as well as to reduce migration from the adjacent residential areas. CHATA approached Curacao DLVV to help with management particularly in public and residential areas. On both islands, the hotel associations also agreed to support DLVV in the development of phytosanitary and other regulations. It was also proposed that a task force comprising Curacao DLVV and CHATA representatives be established to oversee implementation of mitigation efforts. If these collaborative and coordinated efforts are carried out as planned, red palm weevil may be controlled before the pest spreads to other areas in the region. However, regulatory and management measures must be established.

Timely disposal of dead palm trees by chipping, incineration or deep burial at a landfill is critical to the management of red palm weevil (Faleiro, 2006). However, due to the cost of disposal, many dead palms were left standing. Additionally, the Aruba DLVV cooperators also found dead infested palms being dumped along the roadside some distance from known infestations. Unfortunately, this allows larvae and pupae to develop and infest new palms. Regulations that require a timely and proper disposal of dead palms would minimize further spread of infestations.

Finally, the development of phytosanitary legislation such as those identified under International Standards for Phytosanitary Measures to stop unrestricted importation of plant material from countries where red palm weevil is present, would be useful to prevent re-infestation of the islands. This would be applicable as long as measures are taken to officially control or eradicate the pest. Additionally, other local regulatory mechanisms that would prevent unrestricted movement of infested host material within the country may also help limit the spread of the beetle and assist in current control efforts.

Conclusions

Rhynchophorus ferrugineus has devastated palms and date production throughout Europe, the Mediterranean, the Middle East and Asia (Faleiro, 2006; Malumphy & Moran, 2007). A concerted effort should be made to contain and possibly eradicate the pest from Aruba and Curacao to avoid similar economic and environmental damage in the region. A real threat exists that the red palm weevil will spread to other islands and South America. For example, small boats travel to and from Venezuela daily to sell fruits, spices and produce at Curacao's Floating Market. With very high populations of red palm weevil in Curacao, the possibility exists that the pest could be transported to Venezuela. Additionally, the transport of nursery stock from one island to another, as was seen with the Aruba infestation, could rapidly spread the pest though out the Caribbean Basin into the rest of the New World. Groups such as the Caribbean Invasive Species Working Group, Food and Agricultural Organization could partner private and government institutions to fund an eradication program that would benefit the entire region.

Acknowledgements

The authors thank L Bradshaw, W DeChi, V Defeo, J Lemly, J Leon, J Shaw, G van Buurt, and S Weihman for their assistance in this project and the members of AHATA, CHATA, Fantastic Gardens, and Professional Pest Control for providing critical information. This work was partly supported through U.S. Farm Bill Section 10201 funding.

Le charançon rouge du palmier (*Rhynchophorus ferrugineus*), un ravageur envahissant récemment trouvé dans les Caraïbes et qui menace cette région

Rhynchophorus ferrugineus, un important ravageur des palmiers, a été accidentellement introduit aux Caraïbes. Un programme de suivi a été établi pour déterminer les populations et la répartition des infestations sur Aruba et Curaçao grâce à l'utilisation de pièges à phéromone commerciaux. Etant donné la petite taille des îles et la répartition limitée des palmiers, l'éradication peut être faisable en combinant le piégeage, la destruction rapide des palmiers infestés et les traitements chimiques curatifs et prophylactiques. Ces études sur le ravageur dans les Caraïbes ont été utilisées pour aider à élaborer le plan d'urgence phytosanitaire de l'USDA à travers le développement des Directives sur les nouveaux organismes nuisibles de l'APHIS-PPQ et donnent un programme de réponse en urgence pour les autres îles des Caraïbes.

Обнаруженный недавно в Карибском бассейне красный пальмовый долгоносик (*Rhynchophorus ferrugineus*), инвазивный вредитель, угрожает всему региону

Rhynchophorus ferrugineus, важный вредитель пальм, был интродуцирован в бассейн Карибского моря случайно. Для оценки популяции и распространенности заражения на островах Аруба и Кюрасао с помощью находящихся в свободной продаже феромонных ловушек была предпринята программа мониторинга. В силу небольшого размера островов и ограниченной распространенности пальмовых деревьев, ликвидация может быть вполне выполнима путем сочетания отлова, своевременного уничтожения зараженных пальм, а также истребительных и профилактических химических обработок. Эти исследования вредителя в бассейне Карибского моря использовались Департаментом сельского хозяйства США при создании экстренного фитосанитарного реагирования по линии Инспекционной службы здоровья растений и животных в виде Руководящих принципов ответной реакции на появление инвазии и создание эффективной программы экстренного реагирования для других островов Карибского бассейна.

References

Abraham VA, Koya KMA & Kurian C (1989) Integrated management of *Rhynchophorusferrugineus*in coconut gardens. *Journal of Plantation Crops* **16**(Suppl.), 159–162.

Borchert DM (2009) New Pest Advisory Group Report on *Rhynchophorus ferrugineus*(Olivier): red palm weevil. USDA-APHIS-PPQ-CPSHT-PERAL.

EPPO (2008) Data sheets on quarantine pest, *Rhynchophorus ferrugineus*. *EPPO Bulletin* **38**, 55–59.

Faleiro JR (2006) A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus*(Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years. *International Journal of Tropical Insect Science* **26**, 135–154.

Hallett RH, Gries G, Gries R, Borden JH, Czyzewska E, Oehlschlager AC, Pierce Jr HD, Angerilli NPD & Rauf A (1993) Aggregation pheromones of two Asian palm weevils, *Rhynchophorus ferrugineus* and *R. vulneratus*. *Naturwissenschaften* **80**, 328–331.

Malumphy C & Moran H (2007) Red palm weevil *Rhynchophorus ferrugineus*. *Plant Pest Notice, Central Science Laboratory* **50**, 1–3.

Mankin RW, Hagstrum DW, Smith MT, Roda AL & Kairo MTK (2011) Perspective and promise: a century of insect acoustic detection and monitoring. *American Entomologist* **57**, 30–44.

Mankin RW & Moore A (2010) Acoustic detection of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae: Dynastinae) and *Nasutitermes luzonicus* (Isoptera: Termitidae) in palm trees in urban Guam. *Journal of Economic Entomology* **103**, 1135–1143.

Mankin RW, Mizrach A, Hetzroni A, Levsky S, Nakache Y & Soroker V (2008) Temporal and spectral features of sounds of wood-boring beetle larvae: identifiable patterns of activity enable improved discrimination from background noise. *Florida Entomologist* **91**, 241–248.

Pinhas J, Soroker V, Hetzroni A, Mizrach A, Teicher M & Goldberger J (2008) Automatic acoustic detection of the red palm weevil. *Computers and Electronics in Agriculture* **63**, 131–139.

Soroker V, Nakache Y, Landau U, Mizrach A, Hetzroni A & Gerling D (2004) Utilization of sounding methodology to detect infestation by *Rhynchophorus ferrugineus*on palm offshoots. *Phytoparasitica* **32**, 6–8.

Siriwardena KAP, Fernando LCP, Nanayakkara N, Perera KFG, Kumara ADNT & Nanayakkara T (2010) Portable acoustic device for detection of coconut palms infested by *Rhynchophorus ferrugineus*(Coleoptera: Curculionidae). *Crop Protection* **29**, 25–29.