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Damage caused by *Conotrachelus psidii* (Coleoptera: Curculionidae) to the fruits of feijoa (*Acca sellowiana*)

Daños causados por *Conotrachelus psidii* (Coleoptera: Curculionidae) en frutos de feijoa (*Acca sellowiana*)

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Abstract: The feijoa, *Acca sellowiana*, is a native fruit species from Southern Brazil. In this work, we study the occurrence and damage caused by a weevil species to the fruits of feijoa. The study was conducted during two seasons in orchards and the natural forests of *A. sellowiana* at two locations in the States of Santa Catarina (SC) and Rio Grande do Sul, Brazil. In the feijoa orchard in Lages, SC, fruits were sampled to typify the injury. The fruit size, incidence, and severity of damage to the fruits were measured. Fifteen plants were randomly selected in which 30 fruits were measured weekly and the number of weevil injuries per fruit was counted. The taxonomic expertise confirmed the species as *Conotrachelus psidii* (Coleoptera: Curculionidae). The incidence and severity of weevil damage was higher on fruits from monoculture orchards than on fruits from native forests. Both unripe and ripe fruits were damaged by weevils through epidermis disruption resulting in blackened holes. The larvae damage the pulp and seeds, there by causing rotten fruits. Weevils are able to damage the feijoa fruits immediately after the onset of fruiting. In feijoa monoculture, 100% of the fruits evaluated until harvest were damaged by *C. psidii*. The severity of the weevil damage increased proportionately to the increase of fruit size.

Keywords: Damaged fruits. Insect-plant interaction. Taxonomy. Weevils.

Resumen: Feijoa, *Acca sellowiana* es un frutal nativo del sur de Brasil. Se estudió la ocurrencia y se caracterizaron los daños causados por el gorgojo en frutos de *A. sellowiana*. Se realizó el trabajo durante dos ciclos de cosecha, en cultivo y ambientes naturales localizados en diferentes municipios de los estados de Santa Catarina (SC) y Rio Grande do Sul, Brasil. En cultivo de feijoa en Lages, SC, fueron monitoreados semanalmente 30 frutos por planta de quince plantas seleccionadas aleatoriamente en el cultivo para la descripción de daños, medición del diámetro, y presencia y severidad del ataque causado por el gorgojo. La identificación taxonómica confirmó la presencia de *Conotrachelus psidii* (Coleoptera: Curculionidae). La mayor incidencia de los daños y de la severidad del ataque ocurrió en monocultivo de feijoa. Tanto los frutos verdes como los maduros sufren daños por el gorgojo, los cuales causan rompimiento de la epidermis del fruto resultando en orificios ennegrecidos. Las larvas dañan la pulpa y las semillas de los frutos causando podredumbre. Los gorgojos poseen capacidad de dañar los frutos de feijoa inmediatamente después del fructificación. En el monocultivo de feijoa, 100% de los frutos evaluados hasta la cosecha sufrieron daños por *C. psidii*. La severidad del ataque aumentó proporcionalmente con el incremento del tamaño de los frutos.

Palabras clave: Frutos dañados. Interacción insecto-planta. Taxonomía. Gorgojo.

Introduction

The feijoa (*Acca sellowiana* (Berg) Burret) or pineapple guava in English is a fruit tree that belongs to the family Myrtaceae. It is distributed throughout the Brazilian Southern Plateau, from Parana to Rio Grande do Sul States, and in North-Eastern Uruguay, occurring in *Araucaria* forests and natural grasslands (Mattos 1990). It is commonly known in Brazil as "goiaba serrana", "goiabeira-da-serra"or "feijoa" (Mattos 1990).

Ducroquet *et al.* (2000) pointed out that their fruits have a distinctive flavor and aroma and contain bioactive components that, according to Weston (2010), may be sold as nutraceutical products. The anti-oxidant and immunological properties of feijoa fruits are attributed to bioflavonoids/polyphenols such as catequins, leucoantocianins, proantocianidins, andnaftoquinones (Ebrahimzadeh *et al*. 2008). According to Quintero (2012), the processed fruits are used in more than 15 commercial products such as juice, brandy, icecream, and jam. In New Zealand, the fruit pulp is used to make juices, wines, liqueurs, and chocolates among other products (Thorp and Bieleski 2002).

The species *A. sellowiana* has been considered, by the Brazilian Ministry of Environment, as a high promising domesticated plant for the future, suitable for small family farm production systems in Brazil (MMA 2007). Although it is cultivated in Southern Brazil, feijoa is also commercially cultivated in several regions of the United States, Colombia, New Zealand, and Australia among others (Thorp and Bieleski 2002). In China, it was introduced as an ornamental plant and nowadays it is cultivated in orchards for fruit production (Zhang *et al*. 2010).

The success of cultivating feijoa on a commercial scale depends on the domestication process by natural selection within productive populations and on their breeding without losing their rusticity and natural resistance to diseases and pest. According to Hickel and Ducroquet (1994), the first record of feijoa cropping in Brazil dates from the beginning of 90's. Two major insects' infestations were observed, the fruit fly, *Anastrepha* spp. and an unusual weevil of the genus *Conotrachelus*.

Belonging to the Coleopteran order the *Conotrachelus* Dejean is one of the largest genera in the world. According

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to O'Brien and Couturier (1995), there are more than 1,100 *Conotrachelus* species that are concentrated in the Neotropical region and they report two new species *Conotrachelus eugeniae* O'Brienand *C. dubiae* O'Brien that are economically important due to their attack on commercially and grown fruits in the Amazonian basin. In the Peruvian Amazon, the species *C. eugeniae* was found damaging fruits of *Eugenia stipitata* Me Vaughn (Myrtaceae), and *C. dubiae* on *Myrciaria dubia* Mark Vaughn (Myrtaceae) fruits (O'Brien and Couturier 1995; Couturier *et al*. 1996; Delgado and Couturier 2004). In addition, Delgado and Couturier (2014) studied the major pests of cashew (*Anacardium occidentale* L.) in the Peruvian Amazon and found that *Conotrachelus* sp. was one of the five insect species that causes significant pseudo fruit damage. On the other hand, the species *Conotrachelus psidii* Marshall, 1922 is reported mostly due to its damaging "guava fruits" *Psidium guajava* L. (Myrtaceae). This species in which the larva feeds on the pulp and seeds of guava is present in Bolivia, Brazil, Paraguay, and Venezuela (Costa Lima 1956, Couturier *et al*. 1996; Vasquez and Delgado 2002; Bailez *et al*. 2003, Delgado and Couturier 2004; Salas-Araiza and Romero-Nápoles 2012).

In southern Brazil, weevils of the *Conotrachelus* were observed causing damage to feijoa (*A. sellowiana)* fruits in high lands, whereas fruit fly was more frequent at low altitude (Ducroquet *et al*. 2000, Hickel and Ducroquet 2006). According to Ducroquet *et al*. (2007: 2008) most of the work done for breeding feijoa was to improve yield and fruit quality. Thereby the control of insect pests is dependent on the use of synthetic chemical products. Moreover, regarding the regional condition in the Santa Catarina State, we observed that the improvement of the crop system has not taken into account the sustainable management strategies of major pests occurring in feijoa.

The few farmers in South Brazil who already started growing feijoa adopted conventional systems that include the use of pesticides that are recommended for apple orchards but are not registered for feijoa cultivation. This brings us to legal problems and, besides that, growers need information about the level of damage caused by the feijoa weevil and what the restrictions are in order to avoid *Conotrachelus* infestations (Luckmann *et al.* 2009). It was also argued that in case no chemicals were registered for the cultivated species, it would be better to select a plant from natural feijoa populations that occur in natural ecosystems. Cultivation under ecological principles was also claimed by organic farming that can use home-made preparations to protect the crop.

The objectives of this study were to identify the species of *Conotrachelus* weevil occurring in feijoa orchards in Southern Brazil, to characterize fruit injuries, and to evaluate the intensity of the damage caused by this insect. The description of the injury and the infestation by *Conotrachelus* will show basic information that will help to design a suitable program for sustainable management of the weevil in feijoa orchards. This native fruit species has high potential as commercial crop in Southern Brazil.

Material and methods

The study was carried out from November 2008 until April 2010 in the regions of "Planalto Serrano Catarinense", in Santa Catarina State and "Campos de Cima da Serra" in Rio Grande do Sul State, both in Southern Brazil. The samples of insects were collected in native feijoa plants in Araucaria forest ecosystem and in orchards of feijoa.

Species identification. Samples of adult weevils were collected from feijoa plants. A white cloth was stretched out on the canopy projection and the stirring of the branches was performed. Immediately after collection, the weevils were killed in mortal glass containing ethyl acetate. Then, the insects were assembled and placed in an oven at 38 degrees for 48 hours for drying, labeled, and sent to a specialist. The taxonomic identification of the specimens was confirmed by the weevil specialist Dr. Germano Henrique Rosado-Neto, Federal University of Paraná (UFPR), by means of dichotomous keys and by comparison with insects of the entomological collection at UFPR. The identified specimens were deposited in the collections of the Museum of Entomology of UDESC/CAV, Lages, SC and the Pe. J. S. Moure Entomology Collection of Zoology Department at UFPR, PR, Brazil.

Characterization of weevil's injuries on feijoa fruits. Fruits of feijoa were collected in trees of the Municipalities of Capão Alto (27°57'S 50º00'W), Painel (27º53'S 50º06'W), and Vacaria (28º29'S 50º58'W). The fruits were put into thermo-box and brought to Laboratory of Homeopathy and Plant Health at EPAGRI Experimental Station, Lages, SC. The typical weevil damages were characterized through the description of external and internal symptoms of the fruits. Cuts in the fruit pericarp were done to observe the oviposition site, as well the disposition of eggs. Then, destructive analysis was done by a transverse cut in the equatorial region of the fruit for description of internal damage and larvae characterization.

Incidence and severity of weevil on feijoa fruits. The study was conducted from the end of flowering (November 2009) until the fruit maturation (April 2010). Fruits were collected from orchards located at EPAGRI Experimental Station located in Lages, SC (27°48'S 50°19'W) 904 m high. According to Köeppen, the climate of this region is subtropical Cfb, humid and summer. Winter time is cool with an annual temperature average of approx. 16 °C (Peel *et al*. 2007; Epagri/Ciram 2011). The orchard from where the fruits were collected had 1.5 ha, under ecological management, with spacing of 1 m among plants and 5 m among rows. The orchard was surrounded by native pastures, conifer plantation and a segment of *Araucaria* forest belonging to Atlantic biome. Thirty fruits at the height of 1.5 to 2.0 m in each 15 randomized plants were labeled. Every week, the number of typical weevil holes per fruit was counted and the diameter of each fruit was measured. The incidence of damage was considered as the proportion of fruits that had at least one typical hole caused by *C. psidii* in relation to the total fruits. The severity was estimated by counting the number of holes per fruit. Pearson's correlation analysis was done to study the relation between incidence (proportion of damaged fruits) and severity (number of holes per fruit) with fruit diameter through SAS® statistical program version 9.2.

Results and discussion

Species identification and damage characterization of the feijoa weevil. The sampled weevils were all identified

Table 1. Intensity of damages by weevil *Conotrachelus psidii* on feijoa fruits, according to location of growing trees (orchard and native forests). Crop cycle 2009/2010.

Location	Nº of fruits	Incidence (% of injured fruits)	Severity (Nº of holes per fruit ± SE)[3]
Lages, SC[1]	40	75	11.2 ± 1.22 a
Painel, SC[2]	40	55	6.1 ± 1.19 b
Vacaria, RS[2]	40	40	2.1 ± 0.53 c
Capão Alto SC[2]	40	64	1.35 ± 0.23 c
V.C (%)	-	-	51.5

[1] Experimental orchard of feijoa managed without chemicals. [2] Native forests. SC: Santa Catarina State; RS: Rio Grande doSul State; [3] SE: Standard error of mean. Means followed by the same letters in the column do not differ by Tukey's test ($P < 0.05$).

as *Conotrachelus psidii* (Curculionidae: Molytinae). This insect in its adult form is a small beetle about six mm long by four mm wide, dark-brown, with mouthparts shaped snout and elongated shape. Their elytra show longitudinal strial covered by yellow and white thinner and short setae which corroborates with Monroy and Insuasty (2006). Salas-Araiza and Romero-Nápoles (2012) report that adults of *C. psidii* presents mesosternum plane between the middle coxae, the metasternum has the surface densely covered with coarse and deep punctures, the carina in the interval five disappears in the basal third and the humeri are rounded.

It was observed that *C. psidii* caused damage on unripe, as well as, on ripe feijoa fruits. The damaged fruit showed deformation and presented dry black spots hollow and pierced with many holes and the small ones (± 2 cm in diameter) drop soon after the weevil attack. The holes in the feijoa fruits were made by the mouthparts (placed at the distal end of the long and thin snout) due to feeding and oviposition behaviors. In both cases, the mandibles allow epidermis scraping and perforations of fruit bark (Fig. 1A). Boscán de Martinez and Casares (1980) reported that the adults and larvae of *C. psidii* can also feed from flower buds and small fruits of *P. guajava* distributed in the Neotropical Region.

The *C. psidii* eggs (1 mm long) are deposited about 3-4 mm beneath the fruit epidermis only one egg per hole, however it was found more than one oviposition site per fruit (Fig. 1B) and consequently it was found more than one larvae in a fruit as was observed by Monroy and Insuasty (2006) in *P. guajava* fruits. Our observations contrast with those of Rodríguez and Cásares (2003) that found three eggs of *Conotrachelus* sp. per hole in fruits of *Manilkara achras* L. (Sapotaceae). The fruit tissue around the oviposition hole died and became dark and hardened, causing fruit deformation (Fig. 1C). According to Souza *et al*. (2003) if fruits of feijoa are superficially damaged by *C. psidii* they present physiological disturbance showing abnormal and anticipated maturation and are considered unsuitable for natural consumption and industrialization. Monroy and Insuasty (2006) also observed that *P. guajava* fruits damaged by *C. psidii* lose their commercial value. Ducroquet *et al.* (2000) reported that perforations done by the weevil on feijoa fruits also facilitate the infection of pathogenic diseases such as anthracnose (*Colletotrichum* sp.).

The larvae of *C. psidii* hatch in approximately four days following the oviposition with white color and feed of the inner fruit part, building galleries throughout pulp and eventually reaching the seeds. The fruit pulp became dark and rotten (Fig. 1D), which anticipate the fruit drop. These observations are similar those reported by Bailez *et al*. (2003) about damage and biological cycle of *C. psidii* on fruits of *P. guajava*, a related species to feijoa.

According to Bailez *et al*. (2003) and Valente and Benassi (2014) the life cycle of *C. psidii* on *P. guajava* in the laboratory conditions is about 360 ± 144 and 302,59 days, respectively. However Monroy and Insuasty (2006) working at natural conditions observed that the total *C. psidii* life cycle lasted 199 days. The daily annual average of temperature in the area where *C. psidii* was sampled is 16 ºC and the wintertime is relatively cold with minimum temperatures reaching -10 ºC. This temperature is probably not optimal for the development of *C. psidii*, but the presence of feijoa could facilitate the establishment of this insect (Ducroquet 2000).

Fruit infestation by *Conotrachelus psidii*. Mature fruits harvested from native growing feijoa trees exhibited less infestation (40, 55 and 64% of the total fruits) and reduced number of holes per fruit (2.1, 6.1, and 1.35 holes/ fruit) than those collected from conventional orchard (75% of fruit infestation and 11.2 holes/fruit) (Table 1). According to Sá and Silva (2011) fruit sampling from the feijoa plants is considered a suitable method to assess the level of infestation of weevil in the orchards. This method is also recommended

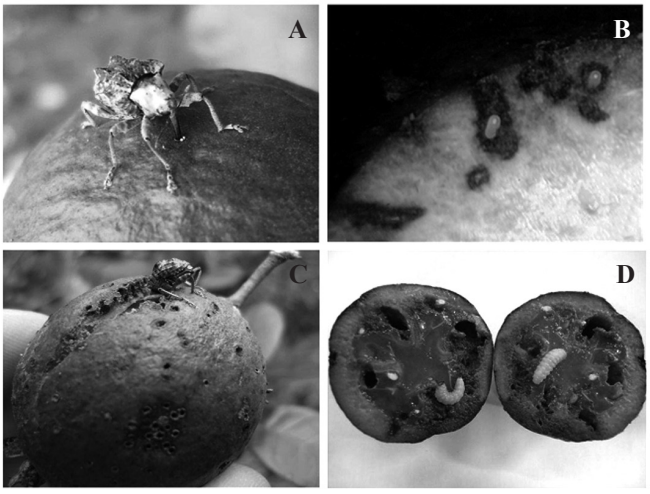

Figure 1. A. Adult of *Conotrachelus psidii* on fruits of *Acca sellowiana*. **B.** Transversal section of *A. sellowiana* fruit showing the presence of *C. psidii* eggs. **C.** Holes and perforation of *A. sellowiana* caused by *C. psidii* at early stage of fruit maturation. **D.** Eggs and larvae feeding the fruit pulp and consequent rotten fruit caused by *C. psidii* infestation.

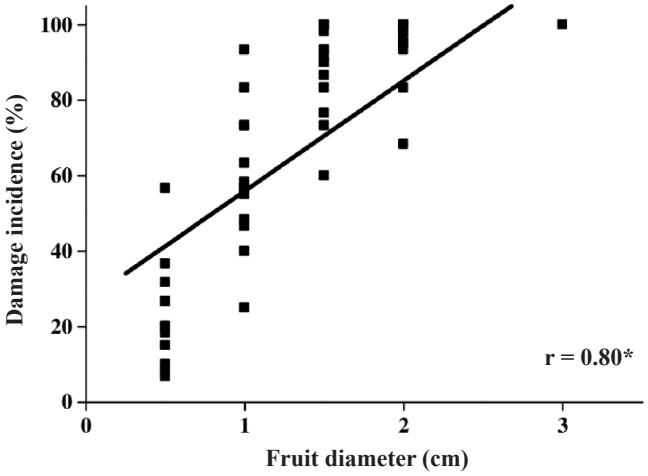

Figure 2. Damage incidence of the weevil *Conotrachelus psidii* on fruit of *Acca sellowiana*. Crop cycle 2009/2010, Lages, SC.

* Significant at 1% probability.

for larval control of weevil on *P. guajava*. Sá and Silva (2011) reported that a high infestation of *C. psidii* occurred in monoculture where there was a high density of guava plants in comparison to diversified areas where plants were dispersed. It seems that higher food availability attracts more insects for oviposition and increase reproductive rate. In agreement with that, Luckmann *et al*. (2009) observed the fruits of feijoa from the monoculture system but managed under ecological principle presented more damage from weevil than fruits sampled from plant natural growing in the forest. According to Altieri (2003) diversified crop systems mislead insect to found the proper host plant. At the same time gives the stability of low population density due to the greater food availability and the presence of phytophagous insects will provide a smooth fluctuation of pest enemies.

Size of fruits and infestation of weevil. The diameter of fruit was positively correlated with the number of fruits damaged (incidence) by weevil in every plant ($r = 0.80$, $P \leq 0.001$) (Fig. 2).

The injury by breaking the epidermis and attempting to make holes throughout cork feijoa fruit cause deformation in the early stage of fruit development. Ferreira *et al*. (2003) in studying the infestation of the weevil *Conotrachelus dubiae* on the fruits of *Myrciaria dubia* under Amazon conditions found positive correlation between fruit damage and fruit ripeness. In fact, injuries on fruits stimulate ethylene production, which speeds up fruit maturation (Kluge *et al*. 2002).

Bailez *et al*. (2003) reported the studies of *C. psidii* on *P. guajava* and found larvae damaging fruits from the size of 4 cm diameter. These species grow in warmer conditions than feijoa and a single hole per fruit is enough to start putrefaction. In most studies, the losses are estimated by counting the damaged fruits regardless the number of holes per fruit (Moore 1983; Haji *et al*. 1995). In our study, 20% of feijoa fruits at 0.5 cm diameter showed perforations and at 3.0 cm diameter all fruit were damaged by the weevil. Luckmann *et al.* (2009) verified that fruits from monoculture orchard located at Lages reached 98% of damage by *Conotrachelus* sp. (probably *C. psidii*). In Venezuela, *C. psidii* could affect more than 60% of the fruits of *P. guajava* (Boscán de Martinez and Casares 1980).

Injury severity of *C. psidii* on fruits of feijoa. The number of holes per fruit are correlated with the diameter of the fruit ($r = 0.83$, $P \leq 0.001$) (Fig. 3). Fruits with more than 3.0 cm diameter had an average of 15 holes per fruit.

Conotrachelus psidii occurs in feijoa orchards before the late flowering time. The high frequency of fruit infestation and damage severity by *C. psidii* justify the development of sustainable management in feijoa orchards. In *Theobroma grandiflorum* ("cupuaçu"), according to Aguilar and Gasparotto (1999), the success of chemical control of *Conotrachelus* sp. is difficult due to development of the larval stage inside the fruits. The pupae develop in the soil. Bagging fruits would be a good option to get high quality fruits, free of insect damage (Teixeira *et al*. 2011). This practice was already suggested by Hickel and Ducroquet (1994) to manage fruit fly on feijoa. For that insect, the authors recommended to bag fruits until 22 mm diameter and before 45 days of harvest. Because the weevil can damage the early stage of fruit development, it is necessary to start fruit bagging at the beginning of the feijoa fruit formation.

Additionally, Silva-Filho *et al*. (2012) found an attractive effect of feijoa bud flowers and weevil excrement on the adults of other weevils. The sugary and fleshy characteristics of feijoa flower petals match the taste and feeding of weevil (Sazima and Sazima 2007). This could be used as traps to manage weevil populations in the feijoa orchards.

In conclusion, the weevil species that occur in native plants and orchards of *Acca sellowiana* in the Southern Brazil region is *Conotrachelus psidii* (Coleoptera: Curculionidae). The damage caused by the feijoa weevil can start from the beginning of fruit formation. Injuries of feijoa weevil on fruits cause deformation and anticipate maturation and make it unsuitable for consumption. High infestation and losses are more expected under monoculture conditions.

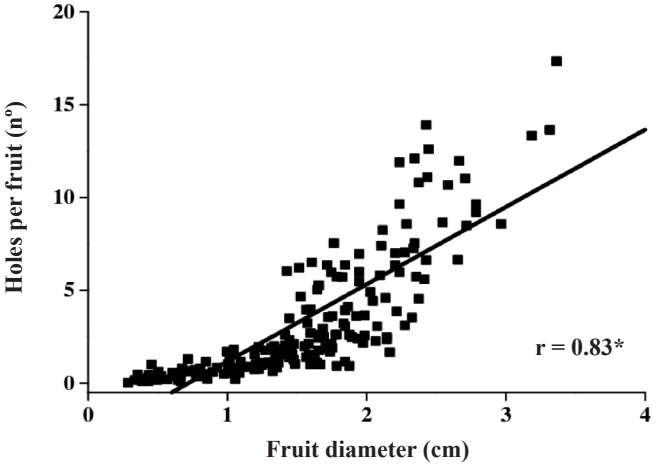

Figure 3. Severity of *Conotrachelus psidii* on fruits of *Acca sellowiana* measured by the number of perforation per fruit size. Crop cycle 2009/2010, Lages, SC.

* Significant at 1% probability.

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