

Review

# Biology and Management of Pest *Diabrotica* Species in South America

Guillermo Cabrera Walsh <sup>1,\*</sup> , Crébio J. Ávila <sup>2</sup>, Nora Cabrera <sup>3</sup>, Dori E. Nava <sup>4</sup>, Alexandre de Sene Pinto <sup>5</sup>  and Donald C. Weber <sup>6</sup>

<sup>1</sup> ARS-SABCL/FuEDEI (Foundation for the Study of Invasive Species), Hurlingham B1686EFA, Argentina

<sup>2</sup> EMBRAPA Agropecuaria Oeste, Dourados, Mato Grosso de Sul Caixa-postal 449, Brazil; crebio.avila@embrapa.br

<sup>3</sup> Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata, La Plata B1900FWA, Argentina; ncabrera@fcnym.unlp.edu.ar

<sup>4</sup> EMBRAPA Clima Temperado, Pelotas, Rio Grande do Sul Caixa-Postal 403, Brazil; dori.edson-nava@embrapa.br

<sup>5</sup> Centro Universitario Moura Lacerda, Ribeirão Preto, São Paulo 14076-510, Brazil; aspinn@uol.com.br

<sup>6</sup> USDA-ARS Invasive Insect Biocontrol & Behavior Laboratory, Baltimore Avenue, Beltsville, MD 10300, USA; don.weber@usda.gov

\* Correspondence: gcabrera@fuedei.org; Tel.: +54-11-4452-4838

Received: 27 May 2020; Accepted: 4 July 2020; Published: 8 July 2020



**Abstract:** The genus *Diabrotica* has over 400 described species, the majority of them neotropical. However, only three species of neotropical *Diabrotica* are considered agricultural pests: *D. speciosa*, *D. balteata*, and *D. viridula*. *D. speciosa* and *D. balteata* are polyphagous both as adults and during the larval stage. *D. viridula* are stenophagous during the larval stage, feeding essentially on maize roots, and polyphagous as adults. The larvae of the three species are pests on maize, but *D. speciosa* larvae also feed on potatoes and peanuts, while *D. balteata* larvae feed on beans and peanuts. None of these species express a winter/dry season egg diapause, displaying instead several continuous, latitude-mediated generations per year. This hinders the use of crop rotation as a management tool, although early planting can help in the temperate regions of the distribution of *D. speciosa*. The parasitoids of adults, *Celatoria bosqi* and *Centistes gasseni*, do not exert much control on *Diabrotica* populations, or show potential for inundative biocontrol plans. Management options are limited to insecticide applications and Bt genetically modified (GM) maize. Other techniques that show promise are products using *Beauveria bassiana* and *Heterorhabditis bacteriophora*, semiochemical attractants for monitoring purposes or as toxic baits, and plant resistance.

**Keywords:** *Diabrotica speciosa*; *Diabrotica balteata*; *Diabrotica viridula*; rootworm management; maize pests; cucurbitacins; semiochemicals

## 1. General Biology of South American Pest *Diabrotica*

The genus *Diabrotica* has over 400 described species [1], the majority of them neotropical, but only 7 species, plus six subspecies, are considered agricultural pests in the Americas [2]. Of these, only three species are considered agricultural pests in South America: *D. speciosa* (Germar) with subspecies *speciosa* and *vogens*, *D. balteata* (LeConte), and *D. viridula* (F.) (Figure 1). The genus *Diabrotica* is divided into three species groups: *virgifera*, *fucata*, and *signifera* [3,4]. However, studies on South American *virgifera* group species suggest that these groups are not as well defined as previously thought [5,6]. *D. speciosa* and *D. balteata* are in the *fucata* group, which is the group with the largest number of species. The species in this group that have been studied are polyphagous both as adults and during the larval stage. Another characteristic of the North American pest *Diabrotica* of the *fucata* species group is that

they overwinter as adults and lack resistant stages to deal with harsh climatic conditions [2]. *D. viridula* is in the *virgifera* group, the same clade of the Northern, Western, and Mexican corn rootworms (*Diabrotica barberi*, *Diabrotica virgifera virgifera*, and *Diabrotica virgifera zea*, respectively). The larvae of the North American species in the *virgifera* group feed exclusively on Poaceae [7], although the host range has been observed or tested for only a few of the species in the group [8]. The North American pest species in the *virgifera* species group are univoltine, or sometimes semivoltine, and possess diapausing eggs that allow them to overwinter in temperate climates or survive dry seasons in the subtropics [9,10], both situations during which the adult cannot find sustenance or survive the extreme conditions.



**Figure 1.** Photographs of the adult of the three species of pest *Diabrotica* from South America.

*D. speciosa* is distributed throughout South America, from agricultural patches in the temperate Patagonian steppes to the tropics, with the exception of Chile, and up to altitudes of over 2500 m above sea level [2,11] (Figure 2). It is the best studied *Diabrotica* species in South America due to its impact on many crops. The adult has over 132 recorded host species, in 24 different plant families [11, and literature therein]. Larval hosts are not as well known, but *D. speciosa* has at least five confirmed larval hosts: maize (*Zea mays* L.), wheat (*Triticum* spp.), Johnsongrass (*Sorghum halepense* Persoon), peanut (*Arachis hypogaea* L.), and potato (*Solanum tuberosum* L.). Another four plant species hosted full development in the laboratory [11–15]. However, the fact that larvae can develop on plant species in four families of three different orders suggests that there could be many more larval hosts that simply have not been discovered because of the hypogeous habit of the larva.

*D. speciosa* is documented in most crops in South America, but is considered mainly a horticultural pest as an adult, and a pest of potato, maize, and peanuts as larva [11,13,16]. Yet these generalizations are not without exceptions. In Brazil, this species is considered a pest of maize as a larva, and a minor pest as an adult as well [17,18]. It is also regarded as an important pest of potato during both the adult and larval stages, although this depends heavily on the cultivar [19]. In addition, the adult is also regarded as an important pest of seedlings and young plants of some extensive crops, such as soybeans, beans (*Phaseolus vulgaris*), cotton, sunflower, maize, tobacco, wheat, and canola [20–22], and, curiously, of table grapes [23] (Table 1).



Figure 2. Distribution of *Diabrotica speciosa* in South America (crosshatched area).

Table 1. Main crops attacked by the South American pest *Diabrotica* species, and current and potential control methods.

Host Crop	<i>D. balteata</i>		<i>D. speciosa</i>		<i>D. viridula</i>		Control Methods		Promising Control Methods	
	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae
beans	x	x	x		x		Cb, Op, Nn, Py <sup>1</sup>		intercropping plant resistance cucurbitacin baits	
cucurbits	x		x				Cb, Op, Nn, Py			
maize		x	x	x		x	Cb, Op, Nn, Py	Bt maize seed treatment (Nn, Cb, Di) <sup>1</sup>	silicon cucurbitacin baits	IGR <sup>1</sup> seed treatment with fungi, plant resistance, nematodes
peanuts		x	x	x			Cb, Op, Nn, Py			
potatoes	x		x	x			Nn		plant resistance	plant resistance, nematodes
soybeans			x				Cb, Op, Nn, Py			
tobacco			x				Cb, Op, Nn, Py			

<sup>1</sup> Cb, carbamates; Op, organophosphates; Nn, neonicotinoids; Py, phenylpyrazole; Di, diamides; IGR, insect growth regulators

*D. balteata* is found from subtropical North America through Central America and Caribbean islands including Cuba, Hispaniola, and Puerto Rico, to South America, although its distribution in South America is limited to Venezuela and Colombia [2,24], where it can occur at altitudes ranging from 0 to 2000 m [25]. However, there is insufficient data to infer species distribution patterns in either country. The adult of *D. balteata* also has an extremely wide range of host plants, as it has been documented on over 140 plant species [26]. There is a more conservative estimate of 50 species in 23 families, with a preference for plants in the Cucurbitaceae, Rosaceae, Fabaceae, and Brassicaceae [27]. The *D. balteata* adult is considered a pest on squash (*Cucurbita* spp., Cucurbitaceae), several bean species (*P. vulgaris*, *Glycine max*, *Mucuna pruriens*, and *Vigna unguiculata*, Fabaceae), lettuce (*Lactuca sativa*, Asteraceae), sugar cane (*Saccharum officinarum*, Poaceae), and potato [28]. Adults are also implicated in the transmission of the tomato brown rugose fruit virus (Tobamovirus, ToBRFV) to *P. vulgaris* [29], and other viruses of *P. vulgaris* and calapo (*Calopogonium mucunoides* Desv.) [30,31]. Larval damage is reported only from Colombia, where this species is known to attack beans, but as considered a minor problem [32], maize, on which it can be locally problematic [33,34], and peanuts,

on which it is considered among the 10–12 worst pests in Colombia [35] (Table 1). The larva has also been reported to attack sweet potato in the USA [36], although not in South America. Yet, the fact that these hosts are also from three families in three orders suggests that there could be many more larval hosts as well. In addition, phylogenetic studies indicate *D. speciosa* and *D. balteata* are sister clades [37].

*D. viridula* is distributed from Mexico to northern Argentina, and apparently absent in Uruguay and Chile, except on Easter Island, where it was introduced [2,13,38] (Figure 3). Like *D. balteata*, its distribution is primarily tropical and subtropical. The *D. viridula* adult is considered a minor pest of beans in Peru [39], while the larva is considered locally important on maize in Central America and Peru [40]. In greenhouse tests, both the larvae and the adults of this species were able to transmit maize chlorotic mottle virus (MCMV) to maize, and they are assumed to be one of its vectors in the field [41]. *D. viridula* is also assumed to be an important, albeit new, pest of maize roots in Argentina, Paraguay, and Brazil [11,42], but its damage cannot be differentiated from that of *D. speciosa*. Studies to clarify what proportion of the damage is owed to each species (e.g., collections of larvae directly in the field) have not been done. The larva has been found feeding on maize roots only, and in the laboratory, it developed successfully on wheat as well, but not on any of the species tested from outside the Poaceae, suggesting it is stenophagous during the larval stage [2,43]. As an adult it is polyphagous, albeit reduced to fewer hosts than *D. speciosa* and *D. balteata*, as it has been recorded only on 21 plant species in the Poaceae, Cucurbitaceae, and Asteraceae [11] (Table 1). Yet, similarities with the North American species in the *virgifera* group end here, as *D. viridula* eggs do not diapause. This species was reared in the laboratory for many generations, and the eggs never expressed any delay in hatching at optimal developmental temperature ( $8 \pm 1$  days at  $25 \pm 1$  °C), regardless of previous photoperiod and temperature conditions ( $0 \pm 1$ ,  $5 \pm 1$ ,  $13 \pm 1$  °C; 10:14, 12:12, 14:10 h (L:D)) [13,43,44]. Eggs from field-collected adults, including overwintering adults, expressed no delay in hatching either [44].



Figure 3. Distribution of *Diabrotica viridula* in South America (stippled area).

Evidence indicates that the three South American pest *Diabrotica* overwinter as adults, are multivoltine, and do not have diapausing eggs. A reproductive diapause has been observed for *D. speciosa*, at least for the populations from the temperate and higher subtropical areas, but the fact that it could be overridden by manipulating temperature and light hours suggests it may not exist in the lower latitudes [44].

## 2. Control of South American *Diabrotica*

As the North American corn rootworms in the *virgifera* species group overwinter as diapausing eggs, are univoltine, and have a narrow larval host range limited to maize and a few grasses, their life cycle is tightly coupled to the phenology of one or very few annual host species. This provides opportunities for the use of different management strategies to reduce damage levels on susceptible crops, such as crop rotation and manipulation of sowing dates [45,46], expected density functions based on preceding density data [47], and anticipation of adult appearance through degree-day models [48]. Also, as the eggs are found anywhere in the soil from before the crop is planted, different tillage techniques could be applied to hinder the larvae from reaching the roots, for instance, compacting the soil between rows, thus affecting neonate larval movement [49]. Furthermore, factors behind the recommencement and completion of embryonic development after winter in univoltine *Diabrotica* are fairly well understood, so it is possible to estimate a “fixed point” (or interval) for the conclusion of embryonic development of the egg bank laid during the previous season in any given area [50]. However, none of these options have been developed for multivoltine species.

The field biology of the multivoltine species of the North American pest *Diabrotica* is also relatively well understood. Yet, in contrast to the univoltine species, predicting the incidence of the multivoltine species is not easily achieved. The only predictive tool of which the authors are aware has been used to calculate the probable damage of *Diabrotica undecimpunctata howardi* Barber on peanuts. This index used data such as soil texture, soil drainage class, planting date, cultivar resistance, and field history of rootworm damage to determine when to apply soil insecticides. Although the index recommended insecticide applications for 98.5% of the fields that actually needed insecticide treatment, it also recommended treatment for over 50% of fields that did not need it [51].

Although it is certain that the South American pest *Diabrotica* are multivoltine, seasonal reproductive patterns are not well known for these species. Soil and air temperatures were used in a linear degree-day model in laboratory and greenhouse experiments, to predict the occurrence of adults of *D. speciosa* [52]. The authors found that soil and air temperatures provided a significantly different prediction of insect occurrence than those observed experimentally. However, the prediction of occurrence based on soil temperature was more accurate than when the air temperature was used. One study in Argentina based on teneral collections in different regions suggests that the single most important determinant for the emergence of *D. speciosa* adults was weekly average temperatures above 13 °C. Due to this, in the temperate distribution areas of *D. speciosa*, there could be around three generations a year, and in subtropical regions, no fewer than five. However, no obvious or discrete voltinism pattern could be observed, expressing, to all practical effects, continuous generations [53]. What is known of the reproductive biology of the other two pest species suggests the same may be expected for them. Under the circumstances, it may be feasible to predict the appearance of a first generation after winter, in the areas where larval development might be temperature-limited, but such prediction may not be accurate enough to calculate planting dates, and certainly not apt to determine predictable cohorts. The practical implications of this study were that the life history pattern of this pest seems to leave few management alternatives. In the temperate regions of this species' distribution, early planting of maize could ensure that the first generations of larvae encounter more mature, and thus less susceptible stages of the crop. Other than this, the seasonal dispersion and unpredictability of *D. speciosa* outbreaks suggest that the only pre-emptive action available to protect maize crops from this pest is to plant Bt maize [53].

As mentioned above, the damage on maize from *D. speciosa* larval feeding cannot be differentiated from that of *D. viridula*, so control measures implemented for the control of *D. speciosa* larvae apply to *D. viridula* as well (Figure 4). In addition, the vast majority of references to research on *Diabrotica* spp. control in South America apply to *D. speciosa*, or are general for several agricultural pests.



**Figure 4.** Top, typical damage on maize roots and lodging caused by *D. speciosa* and *D. viridula* larvae. (photos by Dirceu N. Gassen); below, *D. speciosa* larva on potato with typical pinprick damage (photo by Pablo Lanzetta).

### 2.1. Chemical Control

Most control efforts in agriculture in South America are aimed at foliar pests and stem borers. There are published recommendations for treatment thresholds based on adult *Diabrotica* sampling protocols and foliar damage rates for beans and soybeans, respectively [54,55]. Yet, some control measures for root-feeders have been attempted, mainly seed treatments, in-furrow spraying, and granular pesticide applications [56,57]. There are no published calculations of the input of pesticides used for maize, beans, and potato, but they are generally considered to be high [58]. In Brazil there are 129 pesticides registered for *D. speciosa* in maize, potatoes, and beans, including foliar sprays, in-furrow, seed treatments, and four biological products based on *Beauveria bassiana* and one based on *Heterorhabditis bacteriophora* [58] (Table 1).

References for chemical control of *Diabrotica* in Argentina, Peru, and Uruguay follow more or less the same tendency of recommending several broad spectrum pesticides for adult control: chlorpyrifos, methomyl, other carbamates, fenitrothion, and several pyrethroids [59,60]. We have not found references to chemical control of larvae, and in fact concern for larval damage from *Diabrotica* is relatively recent, and all root-damaging insects are combined insofar as treatment actions are concerned. Their control has been trusted essentially to seed treatments with carbamates, neonicotinoids such as clothianidin, thiamethoxam, and imidacloprid, recently combined with diamides (cyantraniliprole and chlorantraniliprole), and genetically modified (GM) maize [61,62] (Table 1). However, seed treatments have been reported to be inefficient ways of controlling *D. speciosa* larvae on maize in Brazil [63]. Several authors reported that the most effective treatments are liquid in-furrow applications

with organophosphates and phenylpyrazole insecticides in maize [64,65], and neonicotinoids for potatoes [66]. Granular applications also showed promise, but are not recommended due to technical limitations related to the cost and efficiency of granular applicators, and toxicity risks [67]. Finally, silicon applications have been reported to help decrease adult damage from *D. speciosa* and *Liriomyza* spp. (Diptera: Agromyzidae), leaf miners in organic potatoes [68].

Insecticides that interfere with the development of immature forms of insects (insect growth regulators (IGR)) can also cause a sterilizing effect on adult Coleoptera, affecting their fecundity and egg viability [69,70]. *D. speciosa* adults fed bean leaves treated with the IGR lufenuron showed a significant reduction in fertility and egg viability [71,72]. This deleterious effect on the progeny might reduce their biotic potential in the field, without using soil treatments (Table 1), although this has yet to be confirmed.

References to the evolution of insecticide resistance in South American *Diabrotica* are absent in the literature. However, this does not mean that it does not occur, but perhaps that it has not been studied.

## 2.2. Genetically Modified Crops

GM crops are one of the most widespread options for insect management in South America. GM maize, cotton, and soya are widely planted in Brazil and Argentina, the second and third countries with the largest productions of GM crops in the world, respectively, after the USA [73]. GM maize containing the Cry3Bb1 gene has been available in both countries since 2010 [57]. Up to 90% of the maize sown in Brazil is GM [57], and 96% in Argentina [73], mostly for control of Lepidoptera. Field tests showed that root damage levels were, without exception, lower than economic threshold, while yield was 2 to 5% higher than that of susceptible maize of the same variety [57]. Several lines of maize containing the Cry3Bb1 and the Cry1Ab genes were tested in greenhouse feeding tests with *D. speciosa* in Argentina in 2004. A 15-stage rating system was applied, which revealed that both events afforded some protection from larval damage compared to that seen in their conventional near-isolines. In the tests, however, the lines with the Cry3Bb1 gene suffered significantly lower damage levels (Cabrera Walsh, unpublished). Other countries in South America show a similar pattern, such as Paraguay (virtually 100% of its maize, [74]), and Uruguay, where there are no official data, but the area cultivated with GM maize is estimated at 86% [75]. This situation is not observed in Colombia, with only 31% of its maize crop being GM [76], Peru, where there is a moratorium on GM crops until 2021 [77], or Bolivia, where GM maize has recently been approved for planting, but its level of adoption remains unreported [78] (Table 1).

A new Bt protein, aimed especially for the control of *D. speciosa* larvae, was made available to maize growers during the 2013–2014 season, especially in south-central Brazil. This transgenic cultivar contained two Bt proteins expressed in the aerial parts aimed at caterpillars, and another specific protein (Cry3Bb1) for the control of *D. speciosa* larvae. Silva et al. [79] evaluated the efficiency of the Cry3Bb1 protein present in maize for the control of *D. speciosa* larvae, confirming higher productivity than that of the susceptible maize, and fewer larvae in the rhizosphere. Gallo [80] also evaluated the efficacy of corn genotypes that express the Cry3Bb1 protein for the control of *D. speciosa* larvae, and reported that both genotypes tested were effective in reducing corn root damage compared to that of other genotypes free of this toxin.

Potatoes expressing both the Cry3A and Cry1Ia1 genes were developed, field tested, and deemed to be effective to control *D. speciosa* [81]. However, these potato varieties were never commercialized.

## 2.3. Plant Resistance

Damage of *D. speciosa* on potatoes can be locally severe, both from adult damage to the aerial parts, and larval damage to the roots and tubers [82]. Work has been done to promote natural resistance in potato. This can come from chemical defenses, such as leptins (which are insecticidal peptides) and natural glycoalkaloids, which can confer resistance to both adults and larvae. Furthermore, the density and type of trichomes expressed by the plant can influence adult feeding behavior. These

defense mechanisms can be selected from different cultivars, or incorporated from different species of wild potatoes [82–84].

In South Carolina (USA), sweet potatoes have been evaluated for *D. balteata* resistance [85]. In Florida (USA), where *D. balteata* is a key pest of lettuce, resistance has been evaluated based on the effective expression of latex upon injury [86,87]. Beans can also be selected for trichome expression to confer defoliation resistance to many pests, not only *Diabrotica* spp. [88,89].

Native resistance in maize to South American *Diabrotica* has not been tested, but it should be explored given the high number of native maize varieties in South America. Experiments in the US indicate that some maize genotypes expressed native antibiosis that reduced *D. virgifera virgifera* feeding significantly, as compared to that in the more susceptible genotypes. Damage was still higher than for a control GM maize, but larval development was not significantly different between the GM control and the more resistant maize genotypes [90] (Table 1).

Although not actually a form of plant resistance, intercropping shows some promise as a management option as well. There is some evidence of reduced incidence and damage from several bean pests, including *Diabrotica* sp., on *P. vulgaris*, based on intercropping with sugar cane in Colombia [91]. Intercropping beans with banana, maize, and other crops has shown mixed, although often favorable results in Central America [92,93] (Table 1).

#### 2.4. Biological Control

In spite of the large number of species in the *Diabrotica* genus, and how widespread several of them are, only five species of parasitoids are known for the whole genus [94,95]. This is not the result of a lack of survey efforts, since many entomologists have surveyed for parasitoids and pathogens for many years throughout the Americas, and only one new species was detected in 60 years ([94], and literature therein). The scarcity of parasitoids of adults in the genus has been hypothesized to be due to the accumulation of cucurbitacins in fatty tissues [96,97]. These triterpenes are frequent in the Cucurbitaceae, common feeding hosts of adults in the genus, and are known to have antifeedant properties, but act as feeding stimulants for *Diabrotica* spp. [98,99]. There are no references of predators or parasitoids of larvae of South American species of *Diabrotica* [94]. However, based on the wide range of predators detected for *D. virgifera virgifera* in North America [100,101], it is to be expected that there are egg and larval predators of South American *Diabrotica* as well, which are yet to be discovered. *Diabrotica virgifera virgifera* larvae were found to have potent hemolymph defenses against predators [102,103], which may also be present in other *Diabrotica* spp.

Two adult parasitoid species, *Centistes gasseni* (Hymenoptera: Braconidae) and *Celatoria bosqi* (Diptera: Tachinidae), are known to parasitize *D. speciosa* and *D. viridula*, but with extremely low incidences in the latter. *Celatoria compressa* (Diptera: Tachinidae) is known to parasitize *D. balteata* in North and Central America, with no records for South America [104–107]. Other than these, at least 10 generalist predators have been recorded for adult *D. speciosa* [108].

Natural parasitism levels in *D. speciosa* have been reported between 1 and 28%, and on rare occasions over 30% [105,106]. Furthermore, the higher levels of parasitoidism are always recorded toward the end of the growing season, when most of the crop damage is done, suggesting that natural control levels are of minor importance to pest management [108]. It seems unlikely that biological control with macro-organisms will provide any significant relief to agriculture, or to have much potential at this stage for inundative biocontrol plans, given their low reproductive rate, comparatively long development, and dependence on laboratory-reared adults. However, new advances in parasitoid rearing could change this situation in the future [109].

Biological control with pathogens and nematodes offers a different outlook, with several promising laboratory and greenhouse results. Several strains of *Beauveria bassiana*, *B. brongniartii* (Hypocreales: Cordycipitaceae), and *Metarhizium anisopliae* (Hypocreales: Clavicipitaceae) were effective in controlling *Diabrotica virgifera virgifera* larvae for up to 21 days after application [110]. Similar results have been obtained for South American species. In Brazil, the microbial control of *D. speciosa* larvae with

entomopathogenic fungi or nematodes is considered to have great potential because the soil is a relatively stable environment in terms of temperature and humidity, especially in no-till farming [111]. Argentine strains of *M. anisopliae* and *B. bassiana* killed third instars of *D. speciosa* in the laboratory [112]. Brazilian strains of *Isaria fumosorosea* (Hypocreales: Clavicipitaceae) and *Purpureocillium lilacinum* (Hypocreales: Ophiocordycipitaceae) killed eggs of these species, also in the laboratory [113]. Twenty strains of entomopathogenic fungi (*B. bassiana*, *M. anisopliae*, and *P. lilacinum*) were colonized as endophytes in tobacco from northern Argentina. However, feeding tests on *D. speciosa* adults with the treated plants showed no significant differences with endophyte-free plants [114] (Table 1).

A few studies have also been translated to field conditions for biological control of *D. speciosa* in production systems [113,115]. Promising results were obtained with the strain of *B. bassiana* ESALQ PL63, used in seed treatments, which decreased the defoliation caused by *D. speciosa* adults in beans for more than three weeks after seeding [116]. Similar results were obtained in maize when the soil was treated with *Pseudomonas* (Pseudomonadales: Pseudomonadaceae) [117] and *Bacillus pumilus* [118].

Rhabditid nematodes (Steinernematidae and Heterorhabditidae) have been studied to control corn rootworms for decades, often with promising results. In the field, *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae) was as effective as tefluthrin in controlling *Diabrotica virgifera virgifera* in corn crop [119] and with a long residual action in the soil [120,121]. Seventeen native and exotic entomopathogenic nematode isolates (Steinernematidae and Heterorhabditidae) were tested against *D. speciosa* under laboratory and greenhouse conditions in Brazil on eggs, third (last) instars, and pupae. High mortality rates were obtained with *Heterorhabditis* sp. RSC01 and JPM04, *Steinernema glaseri*, and *Heterorhabditis amazonensis* on larvae and pupae, while eggs were unaffected [121]. These nematodes are considered to have great potential to control *D. speciosa* in irrigated maize and potatoes [122] (Table 1).

Maize roots attract entomopathogenic nematodes with (E)- $\beta$ -caryophyllene when fed upon by *D. balteata* and other *Diabrotica*, and production of this chemical is enhanced by certain root-colonizing bacteria [123]. Furthermore, Jaffuel et al. [120] have shown that *Heterorhabditis bacteriophora*, encapsulated in durable alginate-based beads, effectively controlled *D. balteata* larvae in greenhouse tests.

Mermithidae have been cited quite often from *D. speciosa* adults [95,124,125] as well as *D. balteata* [126], but they are generally considered to be too difficult to mass rear, so are probably not feasible biocontrol agents [122].

## 2.5. Semiochemicals

*D. speciosa* females exhibited calling behavior similar to that described for *Diabrotica virgifera virgifera* [127,128]. Nardi [129] studied the sexual behavior of *D. speciosa*, observing mating from the third day after the emergence of the females. Mating was concentrated from 6 p.m. to midnight. Based on these studies, it became evident that the sexual behavior of *D. speciosa* was well defined, and that sexual attraction was probably mediated by a sexual pheromone produced by females. Yellow plastic cups coated with an adhesive and baited with females, especially virgin females, attracted males. Males of different age or reproductive state enclosed in the same cups did not attract females nor males [130]. Y-tube olfactometer and GC-EAG tests showed that males of *D. speciosa* were attracted by volatile compounds emitted by females. However, this compound has not been identified yet. Male volatiles were not attractive to either sex [128].

The female-produced sex pheromone for *D. balteata* is (R,R) 6,12-dimethylpentadecan-2-one [131,132]. Although stereospecific syntheses have been published [133–135], the racemic mixture is attractive, based on the single active stereoisomer [132]. It was attractive to males in the field in South Carolina (USA) and potentially useful for monitoring and management [136], and is commercially available in the USA [137].

The floral compound 1,2-dimethoxybenzene, one of the main floral volatiles of *Cucurbita maxima*, was found attractive to *D. speciosa* adults. Traps baited with TIC (1,2,4-trimethoxybenzene + indole + trans-cinnamaldehyde) and VIP (veratrole + indole + phenylacetaldehyde) also attracted *D. speciosa* adults, but less effectively [138]. Although 1,2-dimethoxybenzene is a very abundant and well-known floral

component, it had not been reported as an attractant for *Diabrotica* spp. before, suggesting *D. speciosa* has a unique response pattern for floral volatiles [130]. Ensuing studies showed that the attractiveness of this compound was quite specific, as none of the analogs tested were attractive to adults [139].

Olfactometer tests with seedlings have shown that CO<sub>2</sub> and unidentified host specific root compounds from maize and oat seedlings were attractive to *D. speciosa* larvae. Wheat, beans, and soybean seedlings also elicited a response, albeit less vigorous [140]. Johnson and Gregory [141] reported that CO<sub>2</sub> is involved in general orientation, while specific compounds are involved in fine orientation toward the host plant roots. In any case, Nardi [129] argued that *D. speciosa* larvae have a very limited capacity for movement and host location, and it is the gravid female that chooses the host plants, suggesting there may not be much of a future for *D. speciosa* management in larval attractants. Regardless, this information could be useful in future research on chemical communication and development of management techniques for this species [142], but to date, no pheromones or floral attractants have been synthesized for practical uses.

As mentioned above, there are many references to the attractant and/or arrestant effects of cucurbitacins to adult *Diabrotica* spp. Several pest management tactics have been implemented based on the phagostimulatory effect of cucurbitacins on diabroticine beetles. These include lacing bitter cucurbit roots or fruit with an insecticide [128,143,144], using the roots or fruits in traps for monitoring and collecting Luperini [10,145–148], bitter cucurbit juice formulations combined with fungal pathogens [149], and in toxic baits [150–155]. Cucurbitacins have also been included as baits in traps for monitoring purposes [10,145,147,156,157].

Although it is clear that cucurbitacins are phagostimulants, there were contradictory reports as to them being volatile kairomones as well (see [147] for a full discussion on the subject). The difference is that volatile kairomones have the power to attract the recipient from a distance, whereas arrestants cause the recipient to remain only after the individual has made contact with the compound. These characteristics potentially provide different applications, because whereas an arrestant in a toxic bait can drive the target insect to ingest the insecticide, it will not attract it from a distance, precluding its use in traps. Kairomones, on the other hand can serve both purposes if they are phagostimulants as well, as is the case with cucurbitacins. Field experiments in Argentina showed that only males of *D. speciosa* were attracted from a distance to cucurbitacins (ca. 20 m), whereas for females these compounds acted only as arrestants, and to a lesser degree than for males [11,148]. This indicates that control or monitoring devices reliant on distance attraction to bitter cucurbit extracts would function exclusively on *D. speciosa* males. However, the wide dispersal of a toxic bait based on cucurbitacins promoted encounters and control of both sexes within the treated area, without any significant non-target effects [155,158] (Table 1).

### 3. Conclusions

*Diabrotica* management in South America has been stagnated for several years. Apart from insecticide applications, the major innovation of applicable use of the last 30 years has been the introduction of GM maize. However, other techniques that show promise must continue to be explored, such as the use of toxic baits with semiochemical attractants to suppress adult populations and for monitoring purposes, IGR insecticides aimed at adults to reduce their progeny, development of plant resistance, and biological control using *Heterorhabditis* nematodes and entomopathogenic fungus against larvae. Insecticide + cucurbitacin baits also deserve a special mention, because this combination has proved to be an effective technique that probably warrants further development.

Pest *Diabrotica* in South America are widely regarded as important, but usually are not differentiated from other foliar pests or root-feeders when it comes to management. Farmers do not identify them among the worst pests, and seldom deploy specific control measures for these beetles, except for potatoes in Brazil, where producers consider *D. speciosa* to be the main pest. Yet, the actual impact of the larvae of *D. speciosa* and *D. viridula*, especially on maize, may not be properly assessed, and until that is done, we cannot be sure of the real importance of these pests.

**Author Contributions:** Writing—original draft preparation and conceptualization, G.C.W.; validation, investigation, data curation, writing—review and editing, G.C.W., C.J.Á., N.C., D.E.N., A.d.S.P. and D.C.W. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** We wish to thank Joseph Spencer and Lance Meinke for inviting us to prepare this review and Paulo Lanzetta, Dirceu Gassen, and Stephen Cresswell for letting us use their photographs.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

- Derunkov, A.; Konstantinov, A. Taxonomic changes in the genus *Diabrotica* Chevrolat (Coleoptera: Chrysomelidae: Galerucinae): Results of a synopsis of North and Central America *Diabrotica* species. *Zootaxa* **2013**, *3686*, 301–325. [[CrossRef](#)]
- Krysan, J.L. Introduction: Biology, distribution, and identification of pest *Diabrotica*. In *Methods for the Study of Pest Diabrotica*, 1st ed.; Krysan, J.L., Miller, T.A., Eds.; Springer: New York, NY, USA, 1986; pp. 1–23.
- Wilcox, J.A. Chrysomelidae: Galerucinae: Luperini: Diabroticina; Pars. 78, Fasc. 2. In *Coleopterum Catalogus Supplementa*, 1st ed.; Wilcox, J.A., Ed.; Uitgeverij Dr. W. Junk's: Gravenhage, The Netherlands, 1972; pp. 296–343.
- Krysan, J.L.; Smith, R.F. Systematics of the *virgifera* species group of *Diabrotica* (Coleoptera: Chrysomelidae: Galerucinae). *Entomography* **1987**, *5*, 375–484.
- Cabrera, N.; Sosa Gómez, D.; Micheli, A. A morphological and molecular characterization of a new species of *Diabrotica* (Coleoptera: Chrysomelidae: Galerucinae). *Zootaxa* **2008**, *1922*, 33–46. [[CrossRef](#)]
- Cabrera, N.; Cabrera Walsh, G. *Diabrotica collicola* (Coleoptera: Chrysomelidae), a new species of leaf beetle from Argentina. Discussion and key to some similar species of the *Diabrotica virgifera* group. *Zootaxa* **2010**, *2683*, 45–55. [[CrossRef](#)]
- Branson, T.F.; Krysan, J.L. Feeding and oviposition behavior and life cycle strategies of *Diabrotica*: An evolutionary view with implications for pest management. *Environ. Entomol.* **1981**, *10*, 826–831. [[CrossRef](#)]
- Clark, T.L.; Hibbard, B.E. Comparison of nonmaize hosts to support western corn rootworm (Coleoptera: Chrysomelidae) larval biology. *Environ. Entomol.* **2004**, *33*, 681–689. [[CrossRef](#)]
- Krysan, J.L. Diapause in the nearctic species of the *virgifera* group of *Diabrotica*: Evidence for tropical origin and temperate adaptations. *Ann. Entomol. Soc. Am.* **1982**, *75*, 136–142. [[CrossRef](#)]
- Krysan, J.L.; Branson, T.F.; Díaz Castro, G. Diapause in *Diabrotica virgifera* (Coleoptera: Chrysomelidae): A comparison of eggs from temperate and subtropical climates. *Entomol. Exp. Appl.* **1977**, *22*, 81–89. [[CrossRef](#)]
- Cabrera Walsh, G.; Cabrera, N. Distribution and hosts of the pestiferous and other common Diabroticites from Argentina and Southern South America: A geographic and systematic view. In *New Developments in the Biology of Chrysomelidae*; Jolivet, P.H., Santiago-Blay, J.A., Schmitt, M., Eds.; SPB Academic Publishers: The Hague, The Netherlands, 2004; pp. 333–350.
- Ávila, C.J.; Parra, J.R.P. Desenvolvimento de *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) em diferentes hospedeiros. *Cienc. Rural* **2002**, *32*, 739–743. [[CrossRef](#)]
- Cabrera Walsh, G. Host range and reproductive traits of *Diabrotica speciosa* (Germar) and *Diabrotica viridula* (F.) (Coleoptera: Chrysomelidae), two species of South American pest rootworms, with notes on other species of Diabroticina. *Environ. Entomol.* **2003**, *32*, 276–285. [[CrossRef](#)]
- Cabrera Walsh, G. Sorghum halepense (L.) Persoon (Poaceae), a new larval host for the South American corn rootworm *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae). *Coleopt. Bull.* **2007**, *61*, 83–84. [[CrossRef](#)]
- Ávila, C.J.; Bitencourt, D.R.; Silva, I.F. Biology, reproductive capacity, and foliar consumption of *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) in different host plants. *J. Agric. Sci.* **2019**, *11*, 1–9. [[CrossRef](#)]
- Marques, G.B.C.; Ávila, C.J.; Parra, J.R.P. Danos causados por larvas e adultos de *Diabrotica speciosa* (Coleoptera: Chrysomelidae) em milho. *Pesqui. Agropecu. Bras.* **1999**, *34*, 1983–1986. [[CrossRef](#)]
- Gassen, D.N. *Insetos Subterrâneos Perjudiciais às Culturas no Sul de Brasil Documentos*, 13; Embrapa-CNPT: Passo Fundo, Brazil, 1989; pp. 32–33.

18. Ávila, C.J.; Milanez, J.M. Larva alfinete. In *Pragas de Solo no Brasil*; Salvadori, J.R., Ávila, C.J., Silva, M.T.B., Eds.; Fundacep-Fecotriro: Passo Fundo/Dourados/Cruz Alta, Brazil, 2004; pp. 345–378.
19. Salles, L.A. Incidência de danos de *Diabrotica speciosa* en cultivares e linhagens de batata. *Cienc. Rural* **2000**, *30*, 205–209. [[CrossRef](#)]
20. Haji, N.F.P. Biología, dano e controle do adulto de *Diabrotica speciosa* (Germar, 1824) (Coleoptera: Chrysomelidae na cultura da batatinha (*Solanum tuberosum* L.). Ph.D. Thesis, Escola Superior de Agricultura “Luiz de Queiroz”, Piracicaba, Brazil, 1981.
21. Ávila, C.J. Principais pragas e seu controle. In *A Cultura do Feijoeiro em Mato Grosso do Sul, Circular Técnica 17*; Embrapa-UEPAE: Dourados, Brazil, 1990; pp. 54–56.
22. Ávila, C.J.; Santana, A.G. Cap. 4: Danos causados às culturas por adultos e larvas de *Diabrotica speciosa*. In *Diabrotica speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 59–67.
23. Roberto, S.R.; Genta, W.; Ventura, M.U. *Diabrotica speciosa* (Ger.) (Coleoptera: Chrysomelidae): New pest in table grape orchards. *Neotrop. Entomol.* **2001**, *30*, 721–722. [[CrossRef](#)]
24. Segarra-Carmona, A.E.; Flores-López, L.; Cabrera-Asencio, I. New report of a leaf beetle pest from North America in Puerto Rico: *Diabrotica balteata* Le Conte (Coleoptera: Chrysomelidae) and its chemical control. *J. Agric. Univ. Puerto Rico* **2008**, *92*, 119–122.
25. Gonzalez, R.; Cardona, C.; Schoonhoven, A.V. Morfología y biología de los crisomélidos *Diabrotica balteata* LeConte y *Cerotoma facialis* Erickson como plagas del frijol común. *Turrialba* **1982**, *32*, 257–264.
26. Clark, S.M.; LeDoux, D.G.; Seeno, T.N.; Riley, E.G.; Gilbert, A.J.; Sullivan, J.M. *Host Plants of Leaf Beetle Species Occurring in the United States and Canada* (Coleoptera: Megalopodidae, Orsodacnidae, Chrysomelidae, Excluding Bruchinae), *Special Publication No. 2*; Coleopterists Society: Sacramento, CA, USA, 2004; pp. 86–87.
27. Saba, F. Host plant spectrum and temperature limitations of *Diabrotica balteata*. *Can. Entomol.* **1970**, *102*, 684–691. [[CrossRef](#)]
28. Agrosavia. Available online: <https://www.agrosavia.co/ctni/ctc/coleoptera/chrysomelidae/diabrotica/diabrotica-balteata> (accessed on 16 April 2020).
29. Morales, F.; Gámez, R. Beetle-transmitted viruses. In *Bean Production Problems in the Tropics*, 2nd ed.; Schwartz, H.F., Pastor Corrales, M.A., Eds.; CIAT: Cali, Colombia, 1989; pp. 363–378.
30. Cano Piedrahíta, C.A. Evaluación de tres Extractos Vegetales para el Control de Plagas en el Cultivo de Frijol Arbustivo *Phaseolus vulgaris* L. Master’s Thesis, Universidad de Manizales, Caldas, Colombia, 2016.
31. Morales, F.J.; Castano, M.; Arroyave, J.A.; Ospina, M.D.; Calvert, L.A. A sobemovirus hindering the utilization of *Calopogonium mucunoides* as a forage legume in the lowland tropics. *Plant Dis.* **1995**, *79*, 1220–1224. [[CrossRef](#)]
32. Cardona, C.; Gonzalez, R.; Schoonhoven, A.V. Evaluation of damage to common beans by larvae and adults of *Diabrotica balteata* and *Cerotoma facialis*. *J. Econ. Entomol.* **1982**, *75*, 324–327. [[CrossRef](#)]
33. Bandas, L.D.C.; Corredor, D.; Corredor, S. Efecto de la asociación patilla (*Citrullus lanatus*) con maíz (*Zea mays*) sobre la población y daño causado por tres insectos plaga y el rendimiento de estos cultivos en la Ciénaga Grande de Lorica, Córdoba. *Rev. Colomb. Entomol.* **2004**, *30*, 161–169.
34. Rodríguez Chalarca, J.; Valencia, S.J. Daño por larvas de *Diabrotica balteata* (Coleoptera: Chrysomelidae) en raíces de maíz en condiciones controladas. In Proceedings of the 39 Congreso de la Sociedad Colombiana de Entomología, Ibagué, Universidad Cooperativa de Colombia, Bogota, Colombia, 11–13 June 2012; p. 93.
35. Tobar, J.A. *Manejo Integrado de Insectos Plaga en el Cultivo de la Mani (Arachis hypogaea L.)*; Facultad de Ciencias Agrícolas, Universidad de Nariño: Nariño, Colombia, 1990; p. 21.
36. Pitre, H.N., Jr.; Kantack, E.J. Biology of the banded cucumber beetle, *Diabrotica balteata*, in Louisiana. *J. Econ. Entomol.* **1962**, *55*, 904–906. [[CrossRef](#)]
37. Clark, T.L.; Meinke, L.J.; Foster, J.E. Molecular phylogeny of *Diabrotica* beetles (Coleoptera: Chrysomelidae) inferred from analysis of combined mitochondrial and nuclear DNA sequences. *Insect Mol. Biol.* **2001**, *10*, 303–314. [[CrossRef](#)] [[PubMed](#)]
38. Olalquiaga, F.G. Aspectos fitosanitarios de la Isla de Pascua. *Rev. Chil. Entomol.* **1980**, *10*, 101–102.
39. Anteparra, M.; Velásquez, J. Revisión de la familia Chrysomelidae asociada a leguminosas de grano en el trópico sudamericano. *Invest. Amazonía* **2015**, *4*, 62–69.
40. King, A.B.S.; Saunders, J.L. *The Invertebrate Pests of Annual Food Crops in Central America*, 1st ed.; Overseas Development Administration: London, UK, 1984; pp. 44–45.

41. Reyes, H.E.; Castillo, L.J. Transmisión del virus del moteado clorótico del maíz (maize chlorotic mottle virus -MCMV) por dos especies del género *Diabrotica*, familia Chrysomelidae. *Fitopatología* **1988**, *23*, 65–73.
42. Waquil, J.M.; Mendes, S.M.; Marucci, R.C. *Comunicado Técnico 178: Ocorrência de Espécies de Diabrotica em milho no Brasil: Qual a Predominante, Diabrotica Speciosa ou Diabrotica Viridula*; Embrapa Milho e Sorgo: Sete Lagoas/Minas Gerais, Brazil, 2010; pp. 1–6.
43. Cabrera Walsh, G. Laboratory rearing and vital statistics of *Diabrotica speciosa* (Germar) and *Diabrotica viridula* (F.) (Coleoptera: Chrysomelidae), two species of South American pest rootworms. *Rev. Soc. Entomol. Argent.* **2001**, *60*, 239–248.
44. Cabrera Walsh, G. *Crisomélidos Diabroticinos Americanos: Hospederos y Enemigos Naturales. Biología y Factibilidad de Manejo de las Especies Plaga*, 1st ed.; Lap Lambert Academic Publishing GmbH & Co.: Saarbrücken, Germany, 2012; pp. 42–60.
45. Levine, E.; Oloumi-Sadeghi, H. Management of diabroticite rootworms in corn. *Annu. Rev. Entomol.* **1991**, *36*, 229–255. [[CrossRef](#)]
46. Spencer, J.L.; Hibbard, B.E.; Moeser, J.; Onstad, D.W. Behaviour and ecology of the western corn rootworm (*Diabrotica virgifera virgifera* LeConte). *Agric. For. Entomol.* **2009**, *11*, 9–27. [[CrossRef](#)]
47. Schaafsma, A.W.; Whitfield, G.H.; Ellis, C.R. A temperature-dependent model of egg development of the western corn rootworm, *Diabrotica virgifera virgifera* Leconte (Coleoptera: Chrysomelidae). *Can. Entomol.* **1991**, *123*, 1183–1197. [[CrossRef](#)]
48. Stevenson, D.E.; Michels, G.J.; Bible, J.B.; Jackman, J.A.; Harris, M.K. Physiological time model for predicting adult emergence of western corn rootworm (Coleoptera: Chrysomelidae) in the Texas High Plains. *J. Econ. Entomol.* **2008**, *101*, 1584–1593. [[CrossRef](#)]
49. Park, Y.; Tollefson, J.J. Spatial prediction of corn rootworm (Coleoptera: Chrysomelidae) adult emergence in Iowa cornfields. *J. Econ. Entomol.* **2005**, *98*, 121–128. [[CrossRef](#)]
50. Meinke, L.J.; Sappington, T.W.; Onstad, D.W.; Guillemaud, T.; Miller, N.J.; Komáromi, J.; Levay, N.; Furlan, L.; Kiss, J.; Toth, F. Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) population dynamics. *Agric. For. Entomol.* **2009**, *11*, 29–46. [[CrossRef](#)]
51. Herbert, D.A., Jr.; Malone, S.; Brandenburg, R.L.; Royals, B.M. Evaluation of the peanut southern corn rootworm advisory. *Peanut Sci.* **2004**, *31*, 28–32. [[CrossRef](#)]
52. Ávila, C.J.; Milanez, J.M.; Parra, J.R.P. Previsão de ocorrência de *Diabrotica speciosa* utilizando o modelo de graus-dia de laboratório. *Pesqui. Agropecu. Bras.* **2002**, *37*, 427–432. [[CrossRef](#)]
53. Cabrera Walsh, G.; Sacco, J.; Mattioli, F. Voltinism of *Diabrotica speciosa* (Coleoptera: Chrysomelidae) in Argentina: Latitudinal clines and implications for damage anticipation. *Pest Manag. Sci.* **2013**, *69*, 1272–1279.
54. Hoffmann-Campo, C.B.; Moscardi, F.; Corrêa-Ferreira, B.S.; Oliveira, L.J.; Sosa-Gómez, D.R.; Panizzi, A.R.; Corso, I.C.; Gazzoni, D.L.; Oliveira, E.B. *Pragas da Soja no Brasil e seu Manejo Integrado, Circular Técnica 30*; Embrapa Soja: Londrina, Brazil, 2000; pp. 16–17.
55. Silva, C.C.; Peloso, M.J.D. *Informações técnica para o cultivo do feijoeiro comum na região central-brasileira 2005–2007*; Embrapa arroz e feijão: Santo Antônio de Goiás, Brazil, 2006; pp. 124–136.
56. Ávila, C.J. Eficiência do inseticida terbufós no controle de larvas de vaquinha (*Diabrotica speciosa*) em milho (*Zea mays* L.). In Proceedings of the 15 Congresso Brasileiro de Entomologia, Universidade Federal de Lavras, Lavras, Brazil, 12–17 March 1995; p. 467.
57. Carvalho, R.A.; Dourado, P.M.; Oliveira Junio, J.A.; Martinelli, S. Cap. 6: Plants transgênicas no controle de *Diabrotica* spp. In *Diabrotica Speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 85–103.
58. Ávila, C.J.; Santana, A.G. Cap. 9: Controle químico de *Diabrotica speciosa*. In *Diabrotica speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 139–149.
59. AGROFIT. Available online: [http://agrofit.agricultura.gov.br/agrofit\\_cons/principal\\_agrofit\\_cons](http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons) (accessed on 6 May 2020).
60. Programa de Hortalizas. 2020. Available online: <http://www.lamolina.edu.pe/hortalizas> (accessed on 30 March 2020).
61. INTA. Manejo de Plagas de Maíz. Available online: [https://inta.gob.ar/sites/default/files/script-tmp-inta-manejo\\_de\\_plagas\\_en\\_el\\_cultivo\\_de\\_maz.pdf](https://inta.gob.ar/sites/default/files/script-tmp-inta-manejo_de_plagas_en_el_cultivo_de_maz.pdf) (accessed on 22 April 2020).
62. On24. Available online: <https://www.on24.com.ar/negocios/agro/a-la-vanguardia-en-tratamientos-de-semillas/> (accessed on 22 April 2020).

63. Ávila, C.J.; Gomez, S.A. Diagnóstico de pragas de solo no Estado de Mato Grosso do Sul. In Proceedings of the 9 Reunião Sul-Brasileira de Pragas de solo, EPAGRI, Estação Experimental de Itajaí, Camboriú, Brazil, 3–5 September 2005; pp. 30–34.
64. Ávila, C.J.; Gomez, S.A. Controle químico de larvas de *Diabrotica speciosa* Coleoptera: Chrysomelidae) na cultura do milho. In Proceedings of the 8 Reunião sul Brasileira de Pragas do Solo, Londrina, Brazil, 26–27 September 2001; Embrapa Soja: Londrina, Brazil, 2001; pp. 254–257.
65. Viana, P.A.; Marochi, A.I. Controle químico da larva de *Diabrotica* spp. na cultura do milho em sistema de plantio direto. *Rev. Bras. Milho Sorgo* **2002**, *1*, 1–11. [[CrossRef](#)]
66. Salles, L.A. Eficiência do inseticida thiamethoxam (actara) no controle das pragas de solo da batata, *Diabrotica speciosa* (Col., Chrysomelidae) e *Heteroderes* spp. (Col., Elateridae). *Rev. Bras. Agrociencia* **2000**, *6*, 149–151.
67. Ávila, C.J.; Botton, M. *Aplicação de Inseticidas no Solo*; FEALQ: Piracicaba, Brazil, 2000; pp. 24–26.
68. Gomes, F.B.; Moraes, J.C.; Ner, D.K.P. Adubação com silício como fator de resistência a insetos-praga e promotor de produtividade em cultura de batata inglesa em sistema orgânico. *Cienc. Agrotec.* **2009**, *33*, 18–23. [[CrossRef](#)]
69. Lovestrang, S.G.; Beavers, J.B. Effect of diflubenzuron on four species of weevil attacking citrus in Florida. *Fla. Entomol.* **1980**, *63*, 112–115. [[CrossRef](#)]
70. Elek, J.A.; Longstaff, B.C. Effect of chitin-synthesis inhibitors on stored-products beetles. *Pestic. Sci.* **1994**, *40*, 225–230. [[CrossRef](#)]
71. Ávila, C.J.; Nakano, O.; Chagas, M.C.M. Efeito do regulador de crescimento de insetos lufenuron na fecundidade e viabilidade dos ovos de *Diabrotica speciosa* (Germar), 1924 (Coleoptera: Chrysomelidae). *Rev. Agric.* **1998**, *73*, 69–78.
72. Ávila, C.J.; Nakano, O. Efeito do regulador de crescimento de insetos lufenuron na reprodução de *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae). *An. Soc. Entomol. Bras.* **1999**, *28*, 293–299. [[CrossRef](#)]
73. ArgenBio. Available online: <http://www.argenbio.org/cultivos-transgenicos> (accessed on 22 April 2020).
74. INBIO. Available online: <https://inbio.org.py/wp-content/uploads/maiz-soja-zafri%C3%B1a-2019-INBIO-para-web-1-1.pdf> (accessed on 22 April 2020).
75. ISAAA. ISAAA Brief No. 53: *Global Status of Commercialized Biotech/GM Crops in 2017: Biotech Crop Adoption Surges as Economic Benefits Accumulate in 22 Years*; ISAAA: Ithaca, NY, USA, 2017; pp. 53–55.
76. Cultivos Transgênicos en Colombia. Available online: [https://www.semillas.org.co/apc-aa-files/5d99b14191c59782eab3da99d8f95126/informe-pais-ogm-2018\\_web.pdf](https://www.semillas.org.co/apc-aa-files/5d99b14191c59782eab3da99d8f95126/informe-pais-ogm-2018_web.pdf) (accessed on 15 April 2020).
77. Delgado Gutiérrez, D. *Regulación de los transgénicos en el Perú*; Sociedad Peruana de Derecho Ambiental: Lima, Peru, 2015; pp. 56–61.
78. Hernández, X. Bolivia abandona su política anti transgénicos y se suma al mercado de los OGM. Available online: <https://www.infocampo.com.ar/bolivia-abandona-su-politica-anti-transgenicos-y-se-suma-al-mercado-de-los-ogm/> (accessed on 16 April 2020).
79. Silva, J.R.; Feldmann, N.A.; Muhl, F.R.; Rhoden, A.C.; Blabinot, M.; Asolin, L.; Pava, D. Avaliação da eficiência da biotecnologia no controle da larva-alfinete (*Diabrotica speciosa*) na cultura do milho. *Rev. Cienc. Agrovet. Aliment.* **2016**, *1*, 1–11.
80. Gallo, P. Avaliação da eficácia do evento MON88017 (Cry3bb1) na redução do dano da larva de *Diabrotica speciosa* (Germar, 1824) (Coleoptera: Chrysomelidae) na raiz do milho. Master's Thesis, Universidade Estadual de Ponta Grossa, Ponta Grossa, Brazil, 2012.
81. Afonso da Rosa, A.P.S.; Castro, C.M.; Pereira, A.S.; Lourenção, A.L. Cap. 5. Resistência de plantas a *Diabrotica speciosa*. In *Diabrotica speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 71–82.
82. Lara, F.M.; Scaranello, A.L.; Baldin, E.L.L.; Bolça Junior, A.L.; Lourenção, A.L. Resistência de genótipos de batata a larvas e adultos de *Diabrotica speciosa*. *Hortic. Bras.* **2004**, *22*, 761–765. [[CrossRef](#)]
83. Lara, F.M.; Poletti, M.; Barbosa, J.C. Resistência de genótipos de batata (*Solanum* spp.) a *Diabrotica speciosa* (Germar, 1824) (Coleoptera: Chrysomelidae). *Cienc. Rural* **2000**, *30*, 927–931. [[CrossRef](#)]
84. Teodoro, J.S.; Martins, J.F.S.; Rosa, A.P.; Castro, C.M. Characterization of potato genotypes for resistance to *Diabrotica speciosa*. *Hortic. Bras.* **2014**, *32*, 440–445. [[CrossRef](#)]
85. Jackson, D.M.; Bohac, J.R. Resistance of sweetpotato genotypes to adult *Diabrotica* beetles. *J. Econ. Entomol.* **2014**, *100*, 566–572. [[CrossRef](#)]

86. Lu, H.; Wright, A.L.; Sui, D. Responses of lettuce cultivars to insect pests in southern Florida. *Horttechnology* **2011**, *21*, 773–778. [[CrossRef](#)]
87. Sethi, A.; Alborn, H.T.; McAuslane, H.J.; Nuessly, G.S.; Nagata, R.T. Banded cucumber beetle (Coleoptera: Chrysomelidae) resistance in romaine lettuce: Understanding latex chemistry. *Arthropod Plant Interact.* **2012**, *6*, 269–281. [[CrossRef](#)]
88. Heyer, W.; Cruz, B.; Chiang-Lok, M.L. Comportamiento y preferencia de los adultos de *Diabrotica balteata*, *Andrector ruficornis*, *Systema basalis* (Coleoptera: Chrysomelidae) y *Empoasca fabae* (Homoptera: Cicadellidae), en frijol. *Cienc. Agric.* **1986**, *27*, 61–76.
89. Vieira, C.; Borém, A.; Ramalho, M.A.P. Melhoramento do feijão. In *Melhoramento de Espécies Cultivadas*; Borém, A., Ed.; UFV: Viçosa, Brazil, 2005; pp. 301–391.
90. El Khishen, A.A.; Bohn, M.O.; Prischmann-Voldseth, D.A.; Dashiell, K.E.; French, B.W.; Hibbard, B.E. Native resistance to western corn rootworm (Coleoptera: Chrysomelidae) larval feeding: Characterization and mechanisms. *J. Econ. Entomol.* **2009**, *102*, 2350–2359. [[CrossRef](#)]
91. García, J.; Cardona, C.; Raigosa, J. Evaluación de poblaciones de insectos plaga en la asociación caña de azúcar–frijol y su relación con los rendimientos. *Rev. Colomb. Entomol.* **1979**, *5*, 17–24.
92. Risch, S. The population dynamics of several herbivorous beetles in a tropical agroecosystem: The effect of intercropping corn, beans and squash in Costa Rica. *J. Appl. Ecol.* **1980**, *17*, 593–611. [[CrossRef](#)]
93. Cardona, C. Effect of intercropping on insect populations: The case of beans. In *Proceedings, Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa (Lilongwe, Malawi)*; Waddington, S.R., Palmer, A.F.E., Edje, O.T., Eds.; CIMMYT: Mexico City, Mexico, 1989; pp. 56–61.
94. Toepfer, S.; Cabrera-Walsh, G.; Eben, A.; Alvarez Zagoya, R.; Haye, T.; Zhang, F.; Kuhlmann, U. A critical evaluation of host ranges of parasitoids of the subtribe Diabroticina (Coleoptera: Chrysomelidae: Galerucinae: Luperini) using field and laboratory host records. *Biocontrol Sci. Technol.* **2008**, *18*, 485–508. [[CrossRef](#)]
95. Toepfer, S.; Haye, T.; Erlandson, M.; Goettel, M.; Lundgren, J.G.; Kleespies, R.G.; Weber, D.C.; Cabrera Walsh, G.; Peters, A.; Ehlers, R.-U.; et al. A review of the natural enemies of beetles in the subtribe Diabroticina (Coleoptera: Chrysomelidae): Implications for sustainable pest management. *Biocontrol Sci. Technol.* **2009**, *19*, 1–65. [[CrossRef](#)]
96. Metcalf, R.L. Chemical ecology of Diabroticites. In *Novel Aspects of the Biology of Chrysomelidae, Series Entomologica*, 1st ed.; Jolivet, P.H., Cox, M.L., Petitpierre, E., Eds.; Springer: Dordrecht, The Netherlands, 1994; Volume 50, pp. 153–169.
97. Tallamy, D.W.; Stull, J.; Ehresman, N.P.; Gorski, P.M.; Mason, C.E. Cucurbitacins as feeding and oviposition deterrents to insects. *Environ. Entomol.* **1997**, *26*, 678–683. [[CrossRef](#)]
98. Contardi, H.G. Estudios genéticos en *Cucurbita* y consideraciones agronómicas. *Physis* **1939**, *18*, 332–347.
99. Howe, W.L.; Sanborn, J.R.; Rhodes, A.M. Western corn rootworms and spotted cucumber beetle associations with *Cucurbita* and cucurbitacin. *Environ. Entomol.* **1976**, *5*, 1043–1048. [[CrossRef](#)]
100. Lundgren, J.G.; Fergen, J.K. Predator community structure and trophic linkage strength to a focal prey. *Mol. Ecol.* **2014**, *23*, 3790–3798. [[CrossRef](#)]
101. Lundgren, J.G.; McDonald, T.; Rand, T.A.; Fausti, S.W. Spatial and numerical relationships of arthropod communities associated with key pests of maize. *J. Appl. Entomol.* **2015**, *139*, 446–456. [[CrossRef](#)]
102. Lundgren, J.G.; Haye, T.; Toepfer, S.; Kuhlmann, U. A multifaceted hemolymph defense against predation in *Diabrotica virgifera virgifera* larvae. *Biocontrol Sci. Technol.* **2009**, *19*, 871–880. [[CrossRef](#)]
103. Lundgren, J.G.; Toepfer, S.; Haye, T.; Kuhlmann, U. Haemolymph defence of an invasive herbivore: Its breadth of effectiveness against predators. *J. Appl. Entomol.* **2010**, *134*, 439–448. [[CrossRef](#)]
104. Eben, A.; Barbercheck, M.E. Field observations on host plant associations enemies of diabroticite beetles (Chrysomelidae: Luperini) in Veracruz, Mexico. *Acta Zool. Mex.* **1996**, *67*, 47–65.
105. Heineck-Leonel, M.A.; Salles, L.A.B. Incidência de parasitóides e patógenos em adultos de *Diabrotica speciosa* (Germar, 1824) (Col., Chrysomelidae) na região de Pelotas, RS. *Ann. Soc. Entomol. Bras.* **1997**, *26*, 81–85. [[CrossRef](#)]
106. Cabrera Walsh, G. Distribution, host specificity, and overwintering of *Celatoria bosqi* Blanchard (Diptera: Tachinidae), a South American parasitoid of *Diabrotica* spp. (Coleoptera: Chrysomelidae: Galerucinae). *Biol. Control* **2004**, *29*, 427–434. [[CrossRef](#)]

107. Cabrera Walsh, G.; Athanas, M.M.; Salles, L.A.B.; Schroder, R.F.W. Distribution, host range, and climatic constraints on *Centistes gasseni* (Hymenoptera: Braconidae), a South American parasitoid of cucumber beetles, *Diabrotica* spp. (Coleoptera: Chrysomelidae). *Bull. Entomol. Res.* **2004**, *93*, 561–567. [[CrossRef](#)]
108. Cabrera Walsh, G.; Pinto, A.S.; Nava, D.E. Cap. 7: Controle biológico de *Diabrotica speciosa*: Parasitoides e predadores. In *Diabrotica Speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 107–117.
109. Pinto, A.d.S.; Parra, J.R.P. Liberação de inimigos naturais. In *Controle Biológico No Brasil: Parasitóides e Predadores*, 1st ed.; Parra, J.R.P., Botelho, P.S.M., Corrêa-Ferreira, B.S., Bento, J.M.S., Eds.; Manole: São Paulo, Brasil, 2002; pp. 325–342.
110. Cagan, L.; Stevo, J.; Gasparovic, K.; Matusikova, S. Mortality of the Western corn rootworm, *Diabrotica virgifera virgifera* larvae caused by entomopathogenic fungi. *J. Cent. Eur. Agric.* **2019**, *20*, 678–685. [[CrossRef](#)]
111. Santos, V.; Moino Junior, A.; Andalo, V.; Moreira, C.C.; Olinda, R.A. Virulence of entomopathogenic nematodes (Rhabditida: Steinernematidae and Heterorhabditidae) for the control of *Diabrotica speciosa* Germar (Coleoptera: Chrysomelidae). *Cienc. Agrotec.* **2011**, *35*, 1149–1156. [[CrossRef](#)]
112. Consolo, V.; Salerno, G.; Beron, C. Pathogenicity, formulation and storage of insect pathogenic hyphomycetous fungi tested against *Diabrotica speciosa*. *BioControl* **2003**, *48*, 705–712. [[CrossRef](#)]
113. Tigano-Milani, M.S.; Carneiro, R.G.; Faria, M.R.; Frazão, H.S.; McCoy, C.W. Isozyme characterization and pathogenicity of *Paecilomyces fumosoroseus* and *P. lilacinus* to *Diabrotica speciosa* (Coleoptera: Chrysomelidae) and *Meloidogyne javanica* (Nematoda: Tylenchidae). *Biol. Control* **1995**, *5*, 378–382. [[CrossRef](#)]
114. Vianna, M.F. Capacidad biocida de hongos entomopatogénos para el control de plagas del tabaco (*Nicotiana tabacum* L.) en la provincia de Jujuy, República Argentina. Ph.D. Thesis, Universidad de La Plata, La Plata, Argentina, 2019.
115. Silva-Werneck, J.O.; de Faria, M.R.; Abreu Neto, B.P.; Magalhães, B.P.; Schimidt, F.G.V. Técnica de criação de *Diabrotica speciosa* (Germ.) (Coleoptera: Chrysomelidae) para bioensaios com bacilos e fungos entomopatogênicos. *An. Soc. Entomol. Bras.* **1995**, *24*, 45–52.
116. Pinto, A.d.S.; Hernandez, A.J.; Miyazaki, M.J.; Miralha, V.R.; Rodrigues, L.R.; de Sousa, E.N. Tratamento de sementes de feijoeiro com *Beauveria bassiana* e *Metarhizium anisopliae* visando ao manejo de pragas de folhas. In Proceedings of the 16 Simpósio de Controle Biológico, Londrina, Brazil, 11–15 August 2019; EMBRAPA Soja: Londrina, Brazil, 2019; p. 53.
117. Jaffuel, G.; Imperiali, N.; Shelby, K.; Campos-Herrera, R.; Geisert, R.; Maurhofer, M.; Loper, J.; Keel, C.; Turlings, T.C.J.; Hibbard, B.E. Protecting maize from rootworm damage with the combined application of arbuscular mycorrhizal fungi, *Pseudomonas* bacteria and entomopathogenic nematodes. *Sci. Rep.* **2019**, *9*, 3127. [[CrossRef](#)] [[PubMed](#)]
118. Disi, J.O.; Kloepper, J.W.; Fadamiro, H.Y. Seed treatment of maize with *Bacillus pumilus* strain INR-7 affects host location and feeding by Western corn rootworm, *Diabrotica virgifera virgifera*. *J. Pest Sci.* **2018**, *91*, 515–522. [[CrossRef](#)]
119. Modic, S.; Zigon, P.; Kolmanic, A.; Trdan, S.; Razinger, J. Evaluation of the field efficacy of *Heterorhabditis bacteriophora* Poinar (Rhabditida: Heterorhabditidae) and synthetic insecticides for the control of Western Corn Rootworm Larvae. *Insects* **2020**, *11*, 202. [[CrossRef](#)]
120. Jaffuel, G.; Sbaiti, I.; Turlings, T.C. Encapsulated entomopathogenic nematodes can protect maize plants from *Diabrotica balteata* larvae. *Insects* **2020**, *11*, 27. [[CrossRef](#)]
121. Toth, S.; Szalai, M.; Kiss, J.; Toepfer, S. Missing temporal effects of soil insecticides and entomopathogenic nematodes in reducing the maize pest *Diabrotica virgifera virgifera*. *J. Pest Sci.* **2020**, *93*, 767–781. [[CrossRef](#)]
122. Santos, V.; Leite, L.G.; Moino Junior, A. Cap. 8. Controle de *Diabrotica speciosa* com entomopatogénos. In *Diabrotica Speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 121–136.
123. Chiriboga, X.; Guo, H.; Campos-Herrera, R.; Röder, G.; Imperiali, N.; Keel, C.; Maurhofer, M.; Turlings, T.C. Root-colonizing bacteria enhance the levels of (E)- $\beta$ -caryophyllene produced by maize roots in response to rootworm feeding. *Oecologia* **2018**, *187*, 459–468. [[CrossRef](#)]
124. Nickle, W.R.; Schroder, R.F.W.; Krysan, J.L. A new Peruvian *Hexamermis* sp. (Nematoda: Mermithidae) parasite of corn rootworms, *Diabrotica* spp. *Proc. Helminthol. Soc. Wash.* **1984**, *51*, 212–216.
125. Gassen, D.N. *Circular Técnica, 1. Parasitos, Patógenos e Predadores de Insetos Associados à Cultura do Trigo*, 2nd ed.; EMBRAPA-CNPT: Passo Fundo, Brazil, 1986; pp. 32–33.

126. Creighton, C.S.; Fassuliotis, G. Infectivity and suppression of the banded cucumber beetle (Coleoptera: Chrysomelidae) by the mermithid nematode *Filipjevimermis leipsandra* (Mermithida: Mermithidae). *J. Econ. Entomol.* **1983**, *76*, 615–618. [[CrossRef](#)]
127. Hammack, L. Calling behavior in female western corn rootworm beetles (Coleoptera: Chrysomelidae). *Ann. Entomol. Soc. Am.* **1995**, *88*, 562–569. [[CrossRef](#)]
128. Nardi, C.; Ventura, M.U.; Santos, F.; Bento, J.M.S. Cap. 10: Comportamento e ecologia química de *Diabrotica speciosa*. In *Diabrotica speciosa*, 1st ed.; Nava, D.E., Ávila, C.J., Pinto, A.S., Eds.; Occasio Editora: Piracicaba/São Paulo, Brasil, 2016; pp. 153–184.
129. Nardi, C. Estímulos Olfativos Envolvidos no Comportamento Sexual e na Seleção Hospedeira de *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae). Ph.D. Thesis, Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, Brazil, 2010.
130. Ventura, M.U.; Mello, E.P.; Oliveira, A.R.M.; Simonelli, F.; Marques, F.A.; Zarbin, P.H.G. Males are attracted by female traps: A new perspective for management of *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) using sexual pheromone. *Neotrop. Entomol.* **2001**, *30*, 361–364. [[CrossRef](#)]
131. Chuman, T.; Guss, P.L.; Doolittle, R.E.; McLaughlin, J.R.; Krysan, J.L.; Schalk, J.M.; Tumlinson, J.H. Identification of female-produced sex pheromone from banded cucumber beetle, *Diabrotica balteata* LeConte (Coleoptera: Chrysomelidae). *J. Chem. Ecol.* **1987**, *13*, 1601–1616. [[CrossRef](#)] [[PubMed](#)]
132. McLaughlin, J.R.; Tumlinson, J.H.; Mori, K. Responses of male *Diabrotica balteata* (Coleoptera: Chrysomelidae) to stereoisomers of the sex pheromone 6,12-dimethylpentadecan-2-one. *J. Econ. Entomol.* **1991**, *84*, 99–102. [[CrossRef](#)]
133. Mori, K.; Igarashi, Y. Synthesis of the four stereoisomers of 6,12-dimethyl-2-pentadecanone, the sex pheromone of *Diabrotica balteata* LeConte. *Liebigs Ann. Chem.* **1988**, *7*, 717–720. [[CrossRef](#)]
134. Enders, D.; Jandeleit, B.; Prokopenko, O.F. Convergent synthesis of (R,R)-6,12-dimethylpentadecan-2-one, the female sex pheromone of the banded cucumber beetle by iron mediated chirality transfer. *Tetrahedron* **1995**, *51*, 6273–6284. [[CrossRef](#)]
135. Shen, W.; Hao, X.; Shi, Y.; Tian, W.S. Synthesis of (6R,12R)-6,12-dimethylpentadecan-2-one, the female-produced sex pheromone from banded cucumber beetle *Diabrotica balteata*, based on a chiron approach. *Nat. Prod. Commun.* **2015**, *10*, 2155–2160. [[CrossRef](#)]
136. Schalk, J.M.; McLaughlin, J.R.; Tumlinson, J.H. Field response of feral male banded cucumber beetles to the sex pheromone 6,12-dimethylpentadecan-2-one. *Fla. Entomol.* **1990**, *73*, 292–297. [[CrossRef](#)]
137. Evergreen Growers Supply. Available online: [www.evergreengrowers.com/banded-cucumber-beetle-lure-group-diabal.html](http://www.evergreengrowers.com/banded-cucumber-beetle-lure-group-diabal.html) (accessed on 6 May 2020).
138. Ventura, M.U.; Martins, M.C.; Pasini, A. Responses of *Diabrotica speciosa* and *Cerotoma arcuata tingomariana* (Coleoptera: Chrysomelidae) to volatile attractants. *Fla. Entomol.* **2000**, *83*, 403–410. [[CrossRef](#)]
139. Marques, F.A.; Wendler, E.P.; Macedo, A.; Wosch, C.L.; Maia, B.H.S.; Mikami, A.Y.; Arruda-Gatt, I.C.; Pissina, A.; Mingotte, F.L.C.; Alves, A.; et al. Response of *Diabrotica speciosa* (Coleoptera: Chrysomelidae) to 1,4-Dimethoxybenzene and analogs in common bean crop. *Braz. Arch. Biol. Technol.* **2009**, *52*, 1333–1340. [[CrossRef](#)]
140. Pereira, T.; Ventura, M.U.; Marques, M.A. Comportamento de larvas de *Diabrotica speciosa* (Coleoptera: Chrysomelidae) em resposta ao CO<sub>2</sub> e a plântulas de espécies cultivadas. *Cienc. Rural* **2005**, *35*, 981–985. [[CrossRef](#)]
141. Johnson, S.N.; Gregory, P.J. Chemically-mediated host-plant location and selection by root-feeding insects. *Physiol. Entomol.* **2006**, *31*, 1–13. [[CrossRef](#)]
142. Nardi, C.; Luvizotto, R.A.; Parra, J.R.P.; Bento, J.M.S. Mating behavior of *Diabrotica speciosa* (Coleoptera: Chrysomelidae). *Environ. Entomol.* **2012**, *41*, 562–570. [[CrossRef](#)] [[PubMed](#)]
143. Lorenzato, D. Controle integrado de *Diabrotica speciosa* (Germar 1824) em frutíferas de clima temperado com cairomônio encontrado em raízes de plantas nativas da família Cucurbitaceae. In Proceedings of the 7 Congresso Brasileiro de Fruticultura, Florianópolis, Brazil, 25–26 July 1983; Empresa de Pesquisa Agropecuária e Extensão Rural: Florianópolis, Brazil, 1984; pp. 347–355.
144. Hamerschmidt, I. Uso do tajuá e purungo como atraentes de vaquinha em olericultura. *Hortic. Bras.* **1985**, *3*, 45.

145. Shaw, J.T.; Ruesink, W.G.; Briggs, S.P.; Luckmann, W.H. Monitoring populations of corn rootworm beetles (Coleoptera: Chrysomelidae) with a trap baited with cucurbitacins. *J. Econ. Entomol.* **1984**, *77*, 1495–1499. [[CrossRef](#)]
146. Ventura, M.U.; Ito, M.; Montalván, R. An attractive trap to capture *Diabrotica speciosa* (Ger.) and *Cerotoma arcuata tingomariana* Bechyné. *An. Soc. Entomol. Bras.* **1996**, *25*, 529–535.
147. Cabrera Walsh, G.; Weber, D.C.; Mattioli, F.M.; Heck, G. Qualitative and quantitative responses of Diabroticina (Coleoptera: Chrysomelidae) to cucurbit extracts linked to species, sex, weather, and deployment method. *J. Appl. Entomol.* **2008**, *132*, 205–215. [[CrossRef](#)]
148. Cabrera Walsh, G.; Mattioli, F.; Weber, D.C. A wind-oriented sticky trap for evaluating the behavioural response of the leaf-beetle *Diabrotica speciosa* to cucurbit extracts. *Int. J. Pest Manag.* **2014**, *60*, 46–51. [[CrossRef](#)]
149. Daoust, R.A.; Pereira, R.M. Stability of entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* on beetle-attracting tubers and cowpea foliage in Brazil. *Environ. Entomol.* **1986**, *15*, 1237–1243. [[CrossRef](#)]
150. Metcalf, R.L.; Ferguson, J.E.; Lampman, R.L.; Andersen, J.F. Dry cucurbitacin-containing baits for controlling diabroticite beetles (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* **1987**, *80*, 870–875. [[CrossRef](#)]
151. Lance, D.R.; Sutter, G.R. Field-cage and laboratory evaluations of semiochemical-based baits for managing western corn rootworm (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* **1990**, *83*, 1085–1090. [[CrossRef](#)]
152. Barbercheck, M.E.; Herbert, D.A., Jr.; Warrick, W.C., Jr. Evaluation of semiochemical baits for management of southern corn rootworm (Coleoptera: Chrysomelidae) in peanuts. *J. Econ. Entomol.* **1995**, *88*, 1754–1763. [[CrossRef](#)]
153. Schroder, R.F.W.; Martin, P.A.W.; Athanas, M.M. Effect of a phloxine B-cucurbitacin bait on Diabroticite beetles (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* **2001**, *94*, 892–897. [[CrossRef](#)] [[PubMed](#)]
154. Pedersen, A.B.; Godfrey, L.D. Evaluation of cucurbitacins-based gustatory stimulant to facilitate cucumber beetle (Coleoptera: Chrysomelidae) management with foliar insecticides in melons. *J. Econ. Entomol.* **2011**, *104*, 1294–1300. [[CrossRef](#)] [[PubMed](#)]
155. Cabrera Walsh, G.; Mattioli, F.; Weber, D.C. Differential response of male and female *Diabrotica speciosa* (Coleoptera: Chrysomelidae) to bitter cucurbit-based toxic baits in relation to the treated area size. *Int. J. Pest Manag.* **2014**, *60*, 128–135. [[CrossRef](#)]
156. Tallamy, D.T.; Halaweish, F.T. Effects of age, reproductive activity, sex and prior exposure on sensitivity to cucurbitacins in southern corn rootworm (Coleoptera: Chrysomelidae). *Environ. Entomol.* **1993**, *22*, 925–932. [[CrossRef](#)]
157. Ventura, M.U.; Resta, C.C.M.; Nunes, D.H.; Fujimoto, F. Trap attributes influencing capture of *Diabrotica speciosa* (Coleoptera: Chrysomelidae) on common bean fields. *Sci. Agric.* **2005**, *62*, 351–356. [[CrossRef](#)]
158. Chandler, L.D. Corn rootworm areawide management program: United States Department of Agriculture-Agricultural Research Service. *Pest Manag. Sci.* **2003**, *59*, 605–608. [[CrossRef](#)] [[PubMed](#)]

