

Distribution, host specificity, and overwintering of *Celatoria bosqi* Blanchard (Diptera: Tachinidae), a South American parasitoid of *Diabrotica* spp. (Coleoptera: Chrysomelidae: Galerucinae)

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Abstract

The genus *Diabrotica* (Coleoptera: Chrysomelidae) includes a great number of pest species, including some of the most important crop pests of the Americas. However, only five parasitoid species have been recorded for it. The parasitoid *Celatoria bosqi* Blanchard was the first parasitoid described from *Diabrotica* spp. in South America, where substantial parasitism has been observed. *C. bosqi* has been collected almost throughout the South American distribution of its main host, *Diabrotica speciosa* (Germar), in an area that includes temperate and tropical lowlands, and semiarid to humid highlands. Three *Diabrotica* species were found to host the parasitoid, *D. speciosa* (Germar), *Hystiopsis* sp., and *Diabrotica viridula* (F.), with a total parasitism of 2.60, 5.55, and <0.02%, respectively. Laboratory experiments with field beetles and puparia, reared in the laboratory, indicate that *C. bosqi* overwinters obligatorily in overwintering adult host beetles, remaining quiescent in its live host below developmental temperatures. Based on the known climatic range of *C. bosqi*, and its requirement of adult overwintering hosts, a potential distribution in North America is projected.

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1. Introduction

The tribe Luperini, subtribe Diabroticina (Coleoptera: Chrysomelidae: Galerucinae), has several polyphagous and oligophagous species that are pests on many cultivated plants. Consequently, they have been subject to many faunistic surveys for natural enemies (Blanchard, 1937; Bussart, 1937; Danielson et al., 2000; Eben and Barbercheck, 1996; Elsey, 1988; Fischer, 1981, 1983; Fronk, 1950; Gahan, 1922; Heineck-Leonel and Salles, 1997; Herzog, 1977; Nickle et al., 1984). Within the Diabroticina, the genus *Diabrotica* has the greatest number of pest species, including some of the most important crop pests of the Americas. Mainly *Diabrotica speciosa* (Germar), a pest of many crops in South America (Christensen, 1943; Link and Costa, 1978; Sarasola et al., 1980); *Diabrotica viridula* (F.), pestifer-

ous on maize in South and Central America (Krysan, 1986; Olalquiaga, 1980; Reyes and Castillo, 1988; Rouschop et al., 1999); the North and Central American banded, spotted (or southern corn rootworm), and western spotted cucumber beetles (*Diabrotica balteata* LeConte, *Diabrotica undecimpunctata howardi* Barber, and *Diabrotica undecimpunctata* Mannerheim, respectively), pests of cucurbits, beans and other crops; and notably the northern (*Diabrotica barberi* Smith and Lawrence), western (*Diabrotica virgifera virgifera* LeConte), and Mexican (*Diabrotica virgifera zea* Krysan and Smith) corn rootworms, severe pests of maize in North America (Krysan, 1986; Metcalf, 1986).

In spite of being a large genus with over 338 species (Smith and Lawrence, 1967), eight of which are pests, well represented throughout the Americas, and often very abundant, a surprisingly low number of parasitoids have been recorded for it. A total of five insect parasitoids, all of adult hosts, have been recorded for the genus, two in South America (*Celatoria bosqi* Blanchard and *Centistes*

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gasseni Shaw), one in Mexico (*Celatoria compressa* Wulp), and two in the US (*Celatoria diabroticae* (Shimer) and *Celatoria setosa* (Coquillett)) (Table 1).

Biocontrol attempts have so far involved mainly pathogenic nematodes in the Steinernematidae and Heterorhabditidae (Nematoda: Rhabditida), isolated from field *Diabroticina* (Tallamy et al., 1998), or from other groups (Ellers-Kirk et al., 2000; Jackson and Brooks, 1995; Wright et al., 1993). These nematodes invade the host through natural body openings, and once inside they release an associated bacterium that causes a septicemia. The nematodes then feed on the breakdown products. They are particularly suited for the control of insects that reside in soil or cryptic habitats protected from desiccation. They are not, however, specific to Chrysomelidae. Moreover, field applications have provided variable control levels, and the factors

behind these inconsistencies are unclear (Jackson, 1996). Parasitoids, on the other hand, have been studied mainly from an ecological perspective, but not actually applied in the field. Furthermore, they have rarely been reared in the laboratory (Fischer, 1981, 1983; Schroder and Athanas, 2002). The reasons for this are likely that the pest *Diabrotica* are native to their distribution areas, and that natural infestations of their parasitoids in North America have been reported to be usually low and irregular. Consequently, the practicality and chances of success of an augmentative or introduction release plan has never been seriously considered. However, limitations in the effectiveness of chemicals routinely used to control *Diabrotica* spp. in North America (Metcalf, 1986) diminished success of crop rotation as a management alternative (Levine and Oloumi-Sadeghi, 1996), and the accidental release of *D. v. virgifera* in

Table 1
Species of parasitoids recorded for *Diabrotica* spp

Parasite species	Host species	Country	References cited
Tachinidae			
<i>C. bosqi</i> Blanchard	<i>C. arcuata</i> Olivier	Brazil	Magalhães and Quintela (1987)
	<i>D. speciosa</i> (Germar)	Brazil, Argentina, Uruguay	Blanchard (1937), Christensen (1943), Gassen (1984, 1989), Guimarães (1971), Heineck-Leonel and Salles (1997), Magalhães and Quintela (1987) and D'Araujo e Silva et al. (1968)
<i>C. compressa</i> Wulp	<i>Acalymma blomorum</i> Munroe & Smith	Mexico	Eben and Barbercheck (1996)
	<i>A. fairmairei</i> (F.)	Mexico	Eben and Barbercheck (1996)
	<i>A. innubum</i> (F.)	Mexico	Eben and Barbercheck (1996)
	<i>A. trivittata</i> (Mannerheim)	Mexico	Eben and Barbercheck (1996)
	<i>D. balteata</i> LeConte	Mexico	Eben and Barbercheck (1996)
	<i>D. tibialis</i> Baly	Mexico	Eben and Barbercheck (1996)
	<i>D. porracea</i> Harold	Mexico	Eben and Barbercheck (1996)
	<i>D. scutellata</i> Baly	Mexico	Eben and Barbercheck (1996)
	<i>D. undecimpunctata</i>	Mexico	Eben and Barbercheck (1996)
	<i>duodecimnotata</i> Harold		
	<i>D. amecameca</i> Krysan & Smith	Mexico	Eben (2002)
	<i>D. viridula</i> (F.)	Mexico	Eben and Barbercheck (1996)
<i>C. diabroticae</i> (Shimer)	<i>A. trivittata</i>	USA	Arnaud (1978)
	<i>A. vittatum</i> (F.)	USA	Arnaud, 1978 and Bussart (1937)
	<i>C. trifurcata</i> (Forster)	USA	Fronk (1950) and Herzog (1977)
	<i>D. u. howardi</i> Barber	USA	Arnaud (1978), Elsey (1988), Fischer (1981), Fronk (1950), Meinke and Gould (1987), Sell (1915) and Summers and Stafford (1953)
	<i>D. u. undecimpunctata</i> Mannerheim	USA	Arant (1929), Arnaud (1978) and Fischer (1981)
	<i>D. longicornis</i> (Say)	USA	Fischer (1983)
	<i>D. v. virgifera</i> Le Conte	USA	Fischer (1981)
<i>C. setosa</i> (Coquillett)	<i>A. vittatum</i>	USA	Arnaud (1978), Bussart (1937), Elsey (1988) and Fischer (1981)
	<i>D. u. howardi</i>	USA	Fischer (1981)
	<i>D. u. undecimpunctata</i>	USA	Fischer (1981)
Hymenoptera			
<i>C. gasseni</i> Shaw	<i>D. speciosa</i>	Brazil	Heineck-Leonel and Salles (1997) and Schroder and Athanas (2002)

Europe (Baca, 1994), have spurred interest in parasitoids as alternative biocontrol agents (Kuhlman and van der Burgt, 1998).

Both known South American parasitoids of *Diabrotica*, *C. bosqi* Blanchard (Diptera: Tachinidae) and *C. gasseni* Shaw (Hymenoptera: Braconidae), and the Mexican species, *C. compressa* Wulp, have often shown high and regular natural infestations in the order of 11–32% (Blanchard, 1937; Eben, 2002; Eben and Barbercheck, 1996; Heineck-Leonel and Salles, 1997; Schroder and Athanas, 2002), suggesting they exert a certain level of control on their host populations.

However, the pest *Diabrotica* belong to either of two groups, *fucata* and *virgifera*, that have different reproductive bionomics in North America. The first are multivoltine and overwinter as adults, whereas the latter, which includes the main pest *Diabrotica* of North America, are uni- or semivoltine, and overwinter through the egg stage (Krysan, 1986). This trait further hinders any classical biocontrol programs, because as all the known insect parasitoids of Luperini attack the adult stage, the agents involved would have to be adapted to the disappearance of their hosts during most part of the year.

Previous work on the South American pest species *D. speciosa* (*fucata* group) and *D. viridula* (*virgifera* group) provided evidence that neither of these species have adaptations for overwintering involving dormant or diapausing stages: feeding and development occur whenever temperatures allow flying ($>15^{\circ}\text{C}$), and significant oviposition is observed after around 1 week of warm daytime temperatures ($>18^{\circ}\text{C}$) (Cabrera Walsh, 2001). Neither temperature-mediated egg diapause nor photoperiod-mediated reproductive diapause have been observed in either species (Cabrera Walsh, 2001, 2003). This contrast between the biology of the South American pest *Diabrotica* species and the main North American pest species called for a detailed study of the biology of the potential biocontrol candidates, in order to evaluate their adequacy for the North American fauna.

The objectives of this work are to report field observations and results of experiments performed at the ARS-USDA South American Biological Control Laboratory (SABCL), Hurlingham, Argentina on the host range, distribution, and biology of *C. bosqi*, including its potential distribution and hosts in North America.

2. Materials and methods

2.1. Host and parasitoid collections

The host beetles were collected between April 1994 and June 2002 in southern Brazil, central and northern Argentina, Paraguay, southern Bolivia, and Uruguay.

This area comprises most of the temperate to subtropical regions of South America, excluding the extremely arid areas with poor natural vegetation and little or no agricultural activities. Most collections were on crops, and/or spontaneous vegetation adjacent to these. Natural cucumber patches were also sampled when available. At each collection site all the available Luperini were collected with aspirators, sweep nets, bait cloths, or funnels attached to 1-liter plastic containers, into which flowers/fruit were shaken, depending on the crop (Cabrera Walsh, 2001). The beetles were transported to the laboratory in 2-liter plastic cages with sleeves (up to 500 beetles/cage) and provided slices of butternut or gooseneck squash for food and water. At the laboratory the beetles were identified and separated in species and incubated at $25 \pm 1^{\circ}\text{C}$, 14:10 (L:D) h photoperiod, in 1.5- or 19-liter cages, according to the sample size. The cages had a plastic mesh (1.7 mm) attached to the bottom through which emerging parasitoids could fall onto a moist sand bed. Adults were fed a diet based on Campbell and Jackson (1987) and slices of butternut or gooseneck squash, and provided water from 45-ml plastic cups with cotton wool wicks through the lids (Cabrera Walsh, 2001). Specimens of the beetles and their parasitoids are deposited in the collection of the Museo de La Plata (MLP), La Plata, Buenos Aires province, Argentina, and in the collection of the SABCL.

2.2. *Celatoria bosqi* laboratory rearing

Parasitoids were incubated, for identification or breeding, in plastic containers with a moistened plaster bottom, covered with a layer of moist peat moss. When adult flies emerged, they were chilled and transferred to 50-liter wire screen cages (20/cage) with a 3-cm layer of moist peat moss and provided dry unrefined sugar, butternut or gooseneck squash slices, and water in vials with cotton wicks. Unrefined sugar diluted in water (0.3:1) was sprayed on the cage walls. The cages were kept in rearing chambers at 14:10 (L:D) h photoperiod; $70 \pm 10\%$ RH, and $25 \pm 1^{\circ}\text{C}$ during the light period and $15 \pm 3^{\circ}\text{C}$ during the dark period. The temperature variations enhanced survival of the adult flies (unpublished data). When mating was observed, 30 laboratory reared *D. speciosa* adults were offered in the same cages. The beetles that were observed to be attacked were collected with aspirators, replaced, and incubated separately in the 1.5-liter cages described above. Last stage larvae emergence, pupation, and adult emergence data (in days) were recorded.

2.3. *Celatoria bosqi* quiescence and overwintering tests

Five groups of five *C. bosqi* puparia were kept in ventilated plastic containers with moist peat moss, in rearing chambers at $5 \pm 2^{\circ}\text{C}$, $70 \pm 10\%$ RH, 14:10 (L:D) h photoperiod, in order to evaluate their ability to

remain dormant below the developmental threshold. Every seventh day, one group was transferred to a 25 °C chamber, and the number of adults emerging was recorded. This experiment was repeated on three occasions, and the data were pooled.

Beetles were collected in the field during fall and winter in order to observe the overwintering process of host and parasitoid. Each sample was divided in two. One group was reared in garden conditions at the SABCL (34°35'S; 58°38'W; average annual temperature 16.5 °C; average minimum temperature 11.1 °C; altitude 22 m). The beetles were conditioned in the 19-liter cages described above, under an open, thatched shed, that protected the cages from the rain, but was otherwise subject to external temperature and humidity conditions. The other group was kept in a rearing chamber (25 ± 1 °C; 14:10 (L:D) h photoperiod; 70 ± 10% RH). The number, timing and emergence of puparia and adults were recorded, to obtain projections of the dynamics of overwintering and host re-colonization of *C. bosqi*. Also, small lots of the garden beetles were transferred every month to the rearing chamber, as were overwintering puparia, in order to detect signs of facultative diapause, such as delays in the appearance of new puparia, or in their emergence.

2.4. Distribution of *C. bosqi* and its host beetles

The distribution of *C. bosqi* was graphed, and physical-climatic boundaries were defined from comparison with climatic diagrams (Atlas Climático de la República Argentina, 1960; Cartas de Precipitação e Temperatura Mensais, 1990; Estadísticas Climatológicas, 1985) and altitudinal data (Trimble Scout GPS, Trimble Navigation Limited, CA). The variables taken into account and compared were altitude, minimum average temperature, maximum average temperature, average annual temperature, average rainfalls, and rainfall seasonality. These data, together with the biology of the known hosts of the parasitoid, were extrapolated to infer the potential distribution of *C. bosqi* in areas of North America where the parasitoid may be released. For this, climatic data on minimum average temperatures and monthly rainfalls (Climatic Atlas of the United States, 1977; Servicio Meteorológico Nacional, 2001) were overlaid onto distribution data of its potential North American hosts (Krysan, 1986; Meinke and Gould, 1987).

3. Results

3.1. Collection results

A total of 107,919 Diabroticina, principally *D. speciosa*, were collected between April 1994 and December 2002, in 212 different sites of Argentina, Bolivia, Brazil,

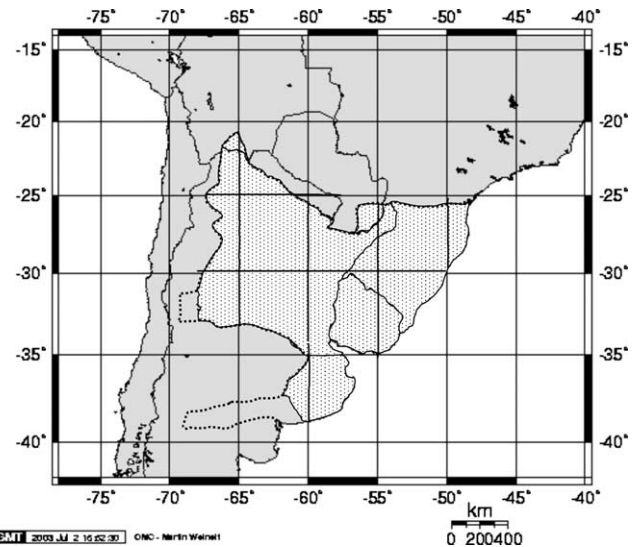


Fig. 1. Map of southern South America depicting the collection areas of *Diabrotica* spp. (area enclosed in the dotted line) and *C. bosqi* (stippled area).

Paraguay, and Uruguay (Fig. 1, area within dotted line; Table 2). So far, three species of Diabroticina were found to be natural hosts of *C. bosqi*: *D. speciosa*, *D. viridula*, and an uncommon species, *Hystiopsis* sp. Average parasitism was 2.60% for *D. speciosa*, two cases in 2483 *D. viridula* specimens (<0.02%), and a single case among 18 specimens of *Hystiopsis* sp. collected. Parasitism was observed all year round on its main host, *D. speciosa*, although rates were highly variable between sites, as well as within sites on different dates. Generally speaking, however, the parasitoid was more abundant in subtropical areas (average parasitism ± SE, 3.40% ± 0.35) than in temperate areas (average parasitism ± SE, 1.83% ± 0.39). It was also more abundant in humid and semiarid agricultural areas, than in arid areas (annual rainfall <400 mm) (Table 3). This paralleled the general abundance pattern of its main host beetle too. *D. speciosa* was more abundant throughout the year in subtropical/tropical environments, than in the cooler temperate regions, as reflected by the total number of beetles collected (Table 3).

A total of 6700 specimens of other Chrysomelidae in the Diabroticina, Alticinae, Chrysomelinae, Megascelinae, and Eumolpinae were also collected (Table 2). All the species collected were found on one or several of the host plants where the *C. bosqi* parasitized Diabroticina were collected, but they were not found to host the parasitoid.

3.2. Laboratory rearing and overwintering tests

Laboratory-reared *C. bosqi* completed development in 22 ± 2 days at 25 °C (egg + larval stage mean = 12.0 days, SE = 0.24; pupal stage mean = 10.0 days,

Table 2
List of chrysomelid species collected in southern South America, their relative abundance, and parasitism

Beetle species	No. collected	No. parasitoids
Galerucinae: Diabroticina		
<i>Diabrotica speciosa</i>	99,200	2579
<i>D. viridula</i>	2483	2
<i>D. limitata</i>	117	0
<i>D. amoena</i> Dalman	22	0
<i>D. tripunctata</i> (F.)	81	0
<i>D. marginata</i> Harold	12	0
<i>D. emorsitans</i> Baly	186	0
<i>D. panchroma</i> Bechyné	23	0
<i>Hystiopsis</i> sp.	18	1
<i>Acalymma bivittula</i> (Kirsch)	3690	0
<i>A. bruchii</i> (Bowditch)	192	0
<i>A. albidovittata</i> (Baly)	690	0
<i>A. vittigera</i> (Boheman)	25	0
<i>Paranapiacaba significata</i> (Gahan)	455	0
<i>P. duodecimmaculata</i> (Klug)	240	0
<i>Paranapiacaba</i> sp.	8	0
<i>Cochabamba rufolimbata</i> (Baly)	50	0
<i>Cerotoma arcuata</i> Olivier	232	0
<i>Cerotoma</i> sp.	32	0
<i>Platybrotica misionensis</i> Cabrera & Cabrera Walsh	118	0
<i>Amphelasma</i> spp.	45	0
Halticinae		
<i>Disonycha</i> sp.	41	0
<i>Caeporis</i> sp.	36	0
<i>Epitrix</i> sp.	26	0
Chrysomelinae		
<i>Phaedon</i> sp.	220	0
Eumolpinae		
<i>Colaspis</i> sp.	33	0
<i>Maecolaspis</i> spp.	72	0
Megascelinae		
<i>Megascelis</i> sp.	36	0
Total	108,383	2582

SE = 0.38). Mean adult longevity at fluctuating temperatures was 20.4 days (SE = 1.9). However, ideal conditions for *C. bosqi* to mate and oviposit were not mastered, so permanent colonies of the parasitoid could not be obtained. The number of successful attacks (host adults per female) was very low (mean = 3.50; max = 7).

In the autumn garden conditions at the SABCL, the emergence of prepupae of *C. bosqi* from field collected *D. speciosa* took up to 24 days ($n = 225$; mean = 10.48 days; SE = 1.95) and adult emergence took up to 22 days ($n = 54$; mean = 14.6 days), adding to a maximum span of the juvenile stages ≥ 46 days. During winter (average temperature, 11.3°C), the emergence of prepupae of *C. bosqi* from field collected *D. speciosa* took up to 41 days ($n = 11$; mean = 17.91 days; SE = 7.76), and adult emergence took up to another 25 day ($n = 6$; mean = 20.0 days), adding to a maximum span of the juvenile stages ≥ 66 days.

Development of *C. bosqi* was resumed at any time in overwintering beetles when they were transferred to rearing chambers at 25°C, producing the emergence of prepupae in 3–4 days. Likewise, adults from puparia emerged in winter conditions took the normal number of days to emerge (~10 days). Chilling was not required for either prepupae or adults to emerge. Furthermore, puparia chilled at 5°C did not survive more than 25 days, and only 20% survived up to 20 days chilled, indicating the pupa is not capable of remaining dormant for very long in constant cold conditions. Again, adults emerged from the chilled puparia in 3–4 days when placed at 25°C.

3.3. Distribution of *C. bosqi*

This tachinid has been collected almost throughout the area where its hosts were found and during every season (Fig. 1, stippled area). The climates of the collecting areas where *C. bosqi* was found were highly variable, ranging from semiarid temperate and subtropical highlands, to temperate, subtropical, and tropical lowlands, with and without dry winter season (Fig. 1). It was collected at altitudes ranging from 4 to 2500 m, with winter minimum, summer maximum, and annual average temperatures ranging from -3.4 to 11°C, 24 to 33.4°C, and 12 to 21.2°C, respectively. Most collection sites have at least sporadic sub-zero temperatures during winter, and the cooler areas can have occasional snowfalls. Annual rainfalls within the collection area ranged from 134 to 2200 mm.

Based on the known climatic range of *C. bosqi*, we have composed a map of its potential distribution in

Table 3
Average percent incidence \pm SE of *Celatoria bosqi* on *Diabrotica speciosa* in its temperate and subtropical/tropical ranges according to climatic zones.

Climate	Temperate		Subtropical	
	No. of beetles	% <i>C. bosqi</i>	No. of beetles	% <i>C. bosqi</i>
Humid	20,099	2.16 \pm 0.45	65,274	3.01 \pm 0.33
Semiarid	3130	0.11 \pm 0.11	8607	5.28 \pm 1.43
Arid	440	0	1650	2.37 \pm 1.76
Total	23,669	1.83 \pm 0.39	75,531	3.40 \pm 0.35

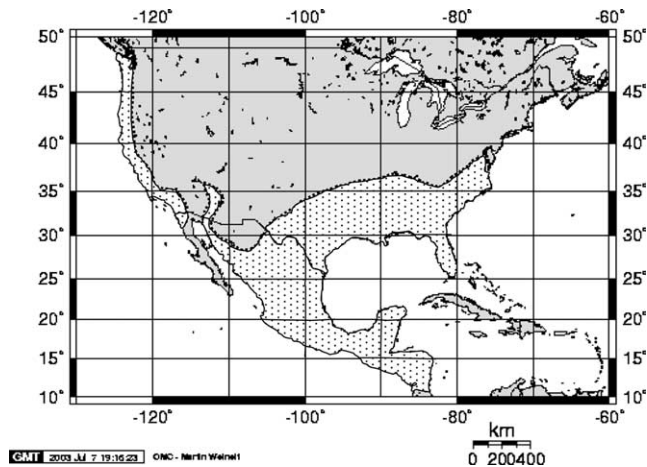


Fig. 2. Partial map of North America depicting hypothetical distribution areas of *C. bosqi* (stippled area), according to climatic conditions similar to its homeland (annual rainfall over 200 mm and minimum winter average temperature above -2°C), intersected with the distribution range of potential hosts with overwintering adults.

North America, intersecting annual rainfall over 200 mm, minimum winter average temperatures above -2°C , and the distribution ranges of *D. balteata*, *D. u. howardi*, and *D. u. undecimpunctata* according to Krysan (1986). The areas with such traits include all the west coast of the US, and most of the south and southeast. It also includes most of Mexico except for the arid peninsula of Baja California and a central northern portion with cold winters (Fig. 2, areas limited by the solid line).

4. Discussion

Despite the large sampling area covered and number of species in the family collected, no new parasitoids were found, confirming the pattern observed in North America: a large, abundant, widespread group showing a very low number of specific parasitoids, and even recurrent generalist parasitoids. The reasons for this scarcity of natural enemies may be related to the extensive adaptation within the Diabroticina of storing cucurbitacins from their host plants in fat bodies. There is evidence that these compounds have a preventive effect on predators, parasitoids, and pathogens alike (Brust and Barbercheck, 1992; Metcalf and Lampman, 1989; Nishida and Fukami, 1989; Tallamy et al., 1997, 1998). Surmounting these ancestral defenses may have challenged the adaptability of potential parasitoids in such a way that few taxa achieved it.

The known distribution of *C. bosqi* has been widened considerably as a result of these and other recent collections (Gassen, 1986; Heineck-Leonel and Salles, 1997; Magalhães and Quintela, 1987). It has been found so far in central and south Brazil, southern Bolivia, and practically throughout the distribution of *D. speciosa* in

Paraguay, Argentina, and Uruguay. Furthermore, its known distribution suggests that it may be present throughout the distribution of this host, which comprises all of South America, except Chile and southern Argentina.

Of the three species of Diabroticina hosting *C. bosqi*, *D. speciosa* was the only one found throughout the distribution area of the parasitoid (Araujo Marques, 1941; Bechyné and Bechyné, 1962; Cabrera Walsh, 2003; Krysan and Smith, 1987). It was also its main host, without counting the single case in *Hystiopsis* sp., which would need more extensive collections to confirm its significance. In any case, the literature and the numerical evidence suggest that the parasitoid is mostly specific to *D. speciosa*, and possibly *Cerotoma arcuata* Olivier (Magalhães and Quintela, 1987). However, there are still large areas in South America that need to be explored for natural enemies of Diabroticina.

It is interesting to note that the area climatically suited for *C. bosqi* depicted in Fig. 2, overlaps quite accurately the distribution areas of the main pestiferous species of adult overwintering North American *Diabrotica*: *D. u. undecimpunctata*, *D. u. howardi*, and *D. balteata*. This excludes the extended distribution area of *D. u. howardi*, where the beetle spreads during its spring northbound migrations.

The laboratory experiments on overwintering populations of *D. speciosa*, and its parasitoid *C. bosqi*, provided evidence that neither of these species have adaptations for overwintering in dormant or diapausing stages. All the known hosts of *C. bosqi*, and in fact all South American Diabroticina, studied to present (Cabrera Walsh, 2001, 2003; Krysan, 1986) overwinter as adults. The experiments described above show that *C. bosqi* overwinters as a larva inside its host and thus depends on the survival of adult beetles to overwinter. They also plainly suggest that the parasitoid has no mechanism to overwinter outside of adult hosts. Furthermore, chilling was not required for either prepupae or adults to emerge, indicating that a diapause mechanism is not involved in the overwintering strategy of *C. bosqi*. Rather, *C. bosqi* larvae and adults required a certain number of degree days in order to pupariate and emerge. This implies that any plan to release *C. bosqi* in North America or Europe as a biocontrol agent against pest *Diabrotica* must contemplate the existence of species that will host the parasitoid through the winter, regardless of whether they are target pests. In North America, the reserve hosts of choice in suitable climatic areas would be species that overwinter as adults, namely *D. balteata*, *D. u. undecimpunctata*, and *D. u. howardi*, which are important agricultural pests and valid targets for the parasitoid. This way, there would be an active population of parasitoids by the time the pest *Diabrotica* that overwinter as eggs (*D. barberi*, *D. v. virgifer*, and *D. v. zea*), appear in the field during the warm season.

Furthermore, *D. u. howardi* reaches as far north as Canada during its spring migrations (Elsey, 1988; Krysan, 1986), and might be expected to vector the parasitoid well into the distribution areas of the western and northern corn rootworms.

Herzog (1977), in his work on *Cerotoma trifurcata* (Forster), suggested *C. diabroticae* overwinters as pupa in the soil, despite collecting an overwintering beetle with a *C. diabroticae* larva. He based this conclusion on observations that few parasitized beetles entered the winter season and even less came out of it. However, these observations would not rule out the possibility that *C. diabroticae* overwinters in its host. Furthermore, *C. diabroticae* was reported to significantly reduce overwintering populations of *Diabrotica undecimpunctata howardi* in Alabama (Arant, 1929). Also, Fischer (1981) reported *C. setosa* overwintered in its hosts, mainly *Acalymma vittata* (F.), resuming development in spring. Overwintering in an adult host may in fact be a characteristic trait of the genus *Celatoria*.

In this work there is no conclusive evidence to suggest that *C. bosqi* would become an important biocontrol agent for North American pest *Diabrotica*. The prevalence of the parasitoid in the field was seldom close to its highest monthly averages of around 35% (Heineck-Lelonel and Salles, 1997; Magalhães and Quintela, 1987), and there is no laboratory or field evidence of its fertility being very high, or that it will even parasitize North American *Diabrotica*. However, climatically, it does seem to be a highly adaptable species and it is not strictly species specific. Consequently, it warrants consideration as a biocontrol candidate, particularly for *fucata* group *Diabrotica*. The impact of this parasitoid in a new environment cannot be predicted accurately and could yield higher parasitism than seen in South America. Provided host range tests prove it acceptable, the release of *C. bosqi* in the US may yet be recommendable.

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