



El ácaro de terciopelo rojo *Balaustium leanderi*, enemigo natural de plagas agrícolas en Colombia

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Universidad Militar Nueva Granada
Facultad de Ciencias Básicas y Aplicadas
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Dedicatoria

A mi papito Luis porque siempre ha confiado en mí, porque nunca me dejó desfallecer, por su infinito apoyo y por su gran amor.

A mi mamita Rosalba por gran amor, más que incondicional.

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Resumen

En los cultivos de flores y hortalizas en la Sabana de Bogotá (Colombia), *Balaustium leanderi* (Haitlinger 2000) se ha observado consumiendo ácaros (*Tetranychus urticae* Koch), mosca blanca de invernaderos (*Trialeurodes vaporariorum* Westwood) y trips (*Frankliniella occidentalis* Pergande). *B. leanderi* puede ser una especie promisoria para el control de plagas en cultivos bajo cubierta, pero es necesario realizar estudios básicos de biología y comportamiento que permitan evaluar su potencial y eventualmente servir como base para la definición de criterios de manejo de este enemigo natural. La presente investigación esta estructurada en tres capítulos, en el primero: se describen los caracteres taxonómicos de adultos (hembras), deutoninfas y larvas de *Balaustium leanderi* (Haitlinger 2000) **comb. nov.** (Actinotrichida: Erythraeidae) y se reporta esta especie en Colombia. En el segundo capítulo se evalúa su ciclo de vida de huevo a huevo sobre diferentes dietas, que se desarrolla en un periodo de dos meses con un patrón de reproducción de semelparidad pronunciada porque oviposita todos los huevos en 1 a 2 días. La mayor tasa de crecimiento se obtuvo cuando se ofrece la combinación de presas constituida por huevos de mosca blanca y araña roja ($rm = 0.066$ hembras / hembra / día). En el tercer capítulo se determina la respuesta funcional, que es tipo III, según el modelo de Real (1979). Finalmente se presenta un análisis del potencial de *Balaustium leanderi* como controlador biológico.

Palabras clave: Parasitengona, respuesta functional, parámetros de tabla de vida, ciclo de vida, semelpariedad, dietas mixtas, depredador generalista.

Abstract

In Flower and vegetable crops in the Sabana of Bogotá (Colombia), *Balaustium leanderi* (Haitlinger 2000) has been observed consuming spidermites (*Tetranychus urticae* Koch), whiteflies (*Trialeurodes vaporariorum* Westwood) and thrips (*Frankliniella occidentalis* Pergande). *B. leanderi* could be a promising species for controlling pests in crops under greenhouse. Nevertheless it is necessary to conduct basic biological and behavioral studies to assess its potential and eventually serve as a basis for defining criteria for management of this natural enemy. This research is divided into three chapters, in the first: the taxonomic characters of adults (females), deutonymphs and larvae *Balaustium leanderi* (Haitlinger 2000) comb nov (Actinotrichida: Erythraeidae) are described, and the species is reported in Colombia. In the second chapter the life cycle *B. leanderi* from egg to egg offering different diets was evaluated. The developmental period was approximately two months showing a reproduction pattern of marked semelparity because all eggs are oviposited in 1 to 2 days. The highest growth rate was obtained with the combination of prey eggs made by whitefly and red spider ($rm = 0.066$ females / female / day). In the third chapter the functional response was determined, which was type III, according to the model of Real (1979). Finally, an analysis of the potential of *Balaustium leanderi* as a biological control agent is presented.

Keywords: Parasitengona, functional response, life table parameters, life cycle, semelpariedad, mixed diets, generalist predator.

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Introducción

Los cultivos de flores bajo invernadero tienen gran importancia económica en Colombia (Asocolflores, 2014), y las plagas más limitantes por su daño económico son *Trialeurodes vaporariorum*, *Frankliniella occidentalis* y *Tetranychus urticae* (Corredor y García, 1992; Corredor, 1997; Velez, 1997; Cardona *et al.*, 2001; Mendoza *et al.*, 2001; Cardona *et al.*, 2005; Acosta, 2010). Estas plagas son controladas con productos químicos, sin embargo su uso continuo ha seleccionado poblaciones resistentes a los diferentes componentes activos de los plaguicidas (Beers *et al.*, 1998; Jensen, 2000; Cardona *et al.*, 2001; Stumpf *et al.*, 2001; Yang *et al.*, 2001; Herron y Rophail, 2002; Uesugi *et al.*, 2002; James y Price, 2002; Tsagkarakou *et al.*, 2002; Anazawa *et al.*, 2003; Bielza *et al.*, 2007; Van Leeuwen *et al.*, 2010). Además del problema de resistencia, los plaguicidas químicos tienen un impacto negativo en los recursos agua, suelo y aire (Navarro *et al.*, 2013). Es necesario contemplar otras alternativas diferentes al manejo químico, como la implementación del control biológico en un contexto de manejo integrado de plagas (Cardona *et al.*, 2001; Bielza *et al.*, 2007; Flores *et al.*, 2007; Pallini *et al.*, 1997; Venzon *et al.*, 2001). Los artrópodos depredadores nativos son de gran importancia en programas de manejo integrado de plagas debido a su adaptación, esto les confiere una mayor posibilidad de establecerse en el cultivo y de controlar las plagas de una manera eficiente (Symondson *et al.*, 2002). Autores como Cadogan y Laing (1977), Welbourn y Jennings (1991), Yoder *et al.*, (2006) y Solomon *et al.*, (2000) han establecido que depredadores generalistas del género *Balaustium* (Acari: Erythraeidae) tienen gran potencial como controladores biológicos.

El género *Balaustium* es cosmopolita y pertenece a la familia Erythraeidae (Hayes, 1985) subfamilia Balaustiinae (Haitlinger, 2005). Varias especies pertenecientes a la familia Erythraeidae son depredadores durante los estados de adulto y ninfa, pero las larvas son parásitos de algunas especies de invertebrados como insectos o arañas (Halliday, 2001), en Norteamérica han sido estudiados como controladores biológicos de otros artrópodos como el ácaro fitófago *Tetranychus urticae* (Yoder *et al.*, 2006). Los ácaros del género *Balaustium* son relativamente grandes (alrededor de 1,0 a 2,5 mm de largo en la edad adulta), de color rojizo, a veces con líneas blanquecinas, y se pueden encontrar en suelo, en arbustos, e inclusive en casas o edificios. Todos los estadios activos de *Balaustium*, y algunos Balaustiinae, son de vida libre; la gran mayoría reportados como depredadores o polinívoros (Newell, 1963; Childers y Rock, 1981; Hayes, 1985; Halliday, 2001; Makol *et al.*, 2012; Muñoz-Cárdenas *et al.*, 2014).

Hay especies del género *Balaustium* reportados como perjudiciales, como es el caso de *B. medicagoense* de Australia, denominada sólo una vez, como plaga agrícola (Halliday,

2001, 2005; Arthur *et al.*, 2008, 2010.) También hay algunos señalados sólo a nivel de género asociados al daño en la piel en algunas personas (James 1995; James *et al.*, 1995). Es así, como *B. murorum* y *Balaustium* sp., indican que pueden afectar a seres humanos (Rack 1973, 1983, Ido *et al.*, 2004, Newell 1963, James 1995; James *et al.*, 1995). Pero es de destacar, que son más los reportes sobre diferentes especies de *Balaustium* sp., como controladores naturales, confirmado a través de su alimentación sobre diferentes insectos y ácaros (Ebeling, 1934; Cadogan y Laing 1977, 1981; Yoder y Heydinger 2011; Childers y Rock 1981; Welbourn y Jennings 1991; Welbourn, 1995; Hoddle *et al.*, 2002; Yoder *et al.*, 2006; Muñoz *et al.*, 2009). El ciclo de vida y la capacidad depredadora se ha estudiado con más detalle para tres especies: *B. putmani* (Cadogan y Laing, 1977, 1981); *B. hernandezi* (Makol *et al.*, 2012) y *B. leanderi* (Muñoz-Cárdenas *et al.*, 2014). *B. leanderi* ha sido estudiado y reportado en Colombia durante los últimos años (Fuentes *et al.*, 2014). *Balaustium* sp. se ha encontrado con frecuencia en la vegetación cerca o dentro de los invernaderos comerciales con bajas presiones de aplicaciones químicas (Getiva y Acosta, 2004; Muñoz *et al.*, 2009). Además, en evaluaciones de preferencia de consumo se ha observado alimentándose de especies plaga de gran importancia como: los huevos de *T. vaporariorum* y de *T. urticae* (Muñoz *et al.*, 2009). En el presente trabajo se describe e identifica los caracteres taxonómicos de adultos (hembras), deutoninfas y larvas, se evalúa diferentes parámetros biológicos para determinar el ciclo de vida, se construye la tabla de vida bajo diferentes dietas y se analiza la capacidad de depredación, a través de la respuesta funcional de *Balaustium leanderi*. Aunque no hay estudios sobre su potencial como agente de control biológico, con los mencionados reportes más los resultados de la presente investigación, se genera una base para analizar su potencialidad en la regulación de poblaciones plaga.

Objectives

- Describir los caracteres taxonómicos de las hembras adultas, deutoninfas y larvas de *Balaustium leanderi*, de especímenes capturados en Colombia.
- Evaluar los parámetros biológicos de *Balaustium* sp. sobre diferentes presas en dietas mixtas.
- Determinar la capacidad de depredación de *Balaustium leanderi* sobre *Tetranychus urticae*, *Trialeurodes vaporariorum* y *Frankliniella occidentalis*.
- Analizar el potencial de *Balaustium leanderi*, como agente controlador biológico.

Chapter I

A re-description of *Balaustium leanderi* (Haitlinger, 2000) comb. nov. (Actinotrichida, Erythraeidae) with first report on characteristics of all active instars and taxonomic notes on the genus¹

1.1 Abstract

Balaustium leanderi (Haitlinger 2000) comb. nov. (Actinotrichida: Erythraeidae), previously known only from the larval stage is re-described based on material originating from a laboratory culture of specimens collected in Colombia. This is also the first report of *Balaustium leanderi* (Haitlinger 2000) in this country. The taxonomic characters of adult (female), deutonymph and larva are provided. The species re-described in this paper, is one of 37 nominal species presently assigned to the genus. With *Balaustium leanderi* (Haitlinger, 2000) there are just 6 species known both from larvae and active postlarval forms. *Palenquistium* Haitlinger (2000) is considered a junior synonym of *Balaustium*, which is one of 12 genera recognized within the Balaustiinae. A modified diagnosis of *Balaustium* von Heyden, 1826 is provided.

¹ Fuentes, L. S., Muñoz-Cárdenas K., Combita, O., Jimeno, E. Getiva, J.C., Cantor, F., Rodríguez, D., Makol, J. (2014) A re-description of *Balaustium leanderi* comb. nov. (Actinotrichida, Erythraeidae) with first report on characteristics of all active instars and taxonomic notes on the genus. Florida Entomologist. 97 (3), 937-951. Septiembre, 2014.

1.2 Introduction

Mites in the genus *Balaustium* von Heyden, 1826 belong to the family Erythraeidae and are one of 19 families recognized within the terrestrial Parasitengona (Mąkol and Wohltmann 2012). They are relatively large (ca. 1–2.5 mm long as adults), reddish in color, sometimes whitish to greenish in color. These mites can be found on the soil surface, on trees and plants or climbing the walls of buildings. All active instars of *Balaustium* and most likely other Balaustiinae, are predatory or pollen feeders (Newell 1963; Childers and Rock 1981; Hayes 1985; Halliday 2001; Mąkol *et al.*, 2012; Muñoz-Cárdenas *et al.*, 2014), contrary to other members of Erythraeidae whose larvae parasitize arthropods.

Of the 13 genera assigned to Balaustiinae (Mąkol and Wohltmann 2012, 2013), only the larvae and postlarval forms of *Balaustium* have been described. The mosaic distribution of instars known for other genera makes the critical reappraisal of the generic identity difficult and blurs conclusions on within-family relationships. At present, the genus *Balaustium* includes 36 species with only 5 known from both larvae and active postlarval forms (Mąkol and Wohltmann 2012, 2013).

The identity of most species of *Balaustium*, especially from the Southern Hemisphere, as already stated by Halliday (2001), is unresolved due to the unknown level of synonymy and the likelihood of misidentifications. Our knowledge of circumtropical Balaustiinae of the Western Hemisphere is based mostly on taxa known from larvae (Haitlinger 2000, 2005; Mąkol and Wohltmann 2012). The present paper contains a re-description of *Balaustium leanderi* (Haitlinger 2000) comb. nov. based on material originating from Colombia and combined with first characteristics of all the stages. Some species of *Balaustium* are naturally associated with flower crops in Colombia (Torrado *et al.*, 2001; Getiva and Acosta 2004) and may have potential for use in biological pest control.

1.3 Materials and methods

Specimens taken from a laboratory colony (Jan 2012) were used for the studies presented in this article. The individuals used to start the colony were collected in Chía, Sabana of Bogotá, Colombia (N 04° 55' 00" –W 74° 03' 00") and transferred to the Center of Biosystems of the Jorge Tadeo Lozano University (CBIOS-UJTL). The colony of mites was kept in plastic containers in environmentally controlled rooms (temperature of 22.1 ± 2.0 °C, 75% RH and 12:12 h L:D photoperiod. A total of 15 adult specimens were introduced in a plastic container (18 cm diam, 20 cm height) with an opening (10 cm diam) covered by a mite-proof steel mesh for ventilation. Representatives of *Balaustium* were provided with plant material infested with all stages of spider mites (*Tetranychus urticae* Koch; Tetranychidae), western flower thrips (*Frankliniella occidentalis* (Pergande) Thysanoptera: Thripidae) and whiteflies (*Trialeurodes vaporariorum* Westwood; Hemiptera: Aleyrodidae), which served as food (Muñoz *et al.*, 2009; Muñoz-Cárdenas *et al.*, 2014).

For the purpose of light microscopy the material was cleared in 85% lactic acid or in Nesbitt fluid and mounted in Hoyer's solution to create permanent slides. Measurements were taken under Leica DNL and Nikon Eclipse E600 microscopes equipped with differential interference contrast (Table 1-1); drawings were made with Leica DNL equipped with camera lucida and processed with Adobe illustrator CS5. We calculated averages and standard errors of all measurements using Excel 2007. The terminology follows Mąkol (2010), with updates contained in Mąkol *et al.*, (2012). All measurements are given in micrometers (μm). In NDV formula setae on idiosoma dorsum (fD), arising behind the level of the scutum, setae placed between coxae II and III as well as ventral setae located behind the level of coxae III (fV) were considered. Also the holotype of *Palenquistium leanderi* Haitlinger, 2000 (deposited in the place: Museum of Natural History, University of Wrocław) was examined.

Table 1-1: Abbreviations and explanation of measurements taken

Meaning	Abbreviation
Length of palp trochanter	PaTr (L)
Length of palp femur	PaFe (L)
Width of palp femur	PaFe (W)
Length of palp genu	PaGe (L)
Width of palp genu	PaGe (W)
Length of palp tibia	PaTi (L)
Width of palp tibia	PaTi (W)
Length of palp tarsus	PaTa (L)
Width of palp tarsus	PaTa (W)
Length of odontus	Odo
Length of idiosoma (without gnathosoma)	IL
Width of idiosoma (the widest point)	IW
Length of gnathosoma	GL
Number of setae AL (normal setae on anterior sensillary area of crista metopica)	AL(n)
Length of sensillary setae on anterior sensillary area of crista metopica	ASE=Asens

Length of sensillary setae on posterior sensillary area of crista metopica	PSE=Psens
Distance between ASens bases	Sba
Distance between PSens bases	SBp
Length of scutum	L
Width of scutum	W
Distance between the level of ASens and PSens	ISD
Length of non-sensillary setae of first pair on scutum	AL
Length of non-sensillary setae of second pair on scutum	ML
Length of posterior non-sensillary setae (third pair) on scutum	PL
Distance between AL bases	AW
Distance between ML bases	MW
Distance between PL bases	PW

1.4 Results

1.4.1 *Balaustium* Von Heyden, 1826

Guatustium Haitlinger, 2000

Palenquistium Haitlinger, 2000, **syn. nov.**

Balaustium leanderi (Haitlinger, 2000) Fuentes, 2013

- Diagnosis (after Southcott 1961, but modified)
- Adult and Deutonymph. Crista metopica inserted in the scutum. One eye on each side of the prodorsum. A pair of urnulae located posteriorly to the eyes. Odontus with ventral protrusion.
- Larva. Crista metopica inserted in the scutum. One eye on each side of the prodorsum. Urnulae absent. Odontus with ventral protrusion. One seta on the palp trochanter, 1–2 setae on the palp femur. fnCx 1–1–1, fnTr 3–3–[2–3], fnbFe 4–4–[2–4]. Posterior claw on tarsi I–III bifurcate, composed of a simple and of pulvilliform branch.

1.4.2 *Balaustium leanderi* (Haitlinger, 2000) Fuentes, 2013

Balaustium leanderi (Haitlinger, 2000), comb. nov.

Palenquistium leanderi Haitlinger, 2000

- Diagnosis
- Larva. Palp femur with 2 setae. PaGe L/W 1.84–2.80. fD 102–120, NDV 188–219. ISD 66–83. fnbFe 4–4–4. fnTr 3–3–3. IP 1662–1893. Setae on palp tarsus smooth.
- Deutonymph and Adult (Female). Semipectinalae on palp genu absent. pDS 23–46. PaGe L/W 2.45–3.15 (deutonymph), 3.06–3.63 (adult).
- Male. Not known.

For comparison with other taxa see Remarks on taxonomy.

1.4.3 Description

Body oval in shape. Color in life red, with longitudinal rows of whitish setae on opisthosomal dorsum; the pattern weakly marked in larvae (Figure 1-1), more distinct in deutonymphs (Figure 1-2) and the most contrasting in adults (Figure 1-3).



Figure 1-1: *Balaustium leanderi* comb. nov. Larva: Habitus, dorsal view, in vivo



Figure 1-2: *Balaustium leanderi* comb. nov. Deutonymph: Habitus, dorsal view, in vivo



Figure 1-3: *Balaustium leanderi* comb. nov. Adult female: Habitus, dorsal view, in vivo

Larva (Figures from 1-1 to 1-11). Metric data are provided in Table 1-2. Meristic data are based on fifteen specimens.

Table 1-2: Morphometric data of *Balaustium leanderi* larvae. X = measurements (μm). SE = standard error.

Character	X (n = 12)	SE
PaTr (L)	29.299	0.751
PaFe (L)	73.848	2.257
PaFe (W)	31.190	1.192
PaGe (L)	62.232	2.096

PaGe (W)	24.652	0.446
PaGe L/W	2.077	0.291
PaTi (L)	16.047	0.428
PaTi (W)	17.045	0.273
PaTa (L)	25.379	1.019
PaTa (W)	5.052	0.112
Odo	24.434	0.788
GL	138.463	4.817
LB	575.129	17.794
WB	381.271	31.857
LB/WB	1.574	0.078
ASE=Asens	57.639	1.860
PSE=Psens	79.639	1.695
AL.	35.387	2.360
ML	36.611	1.290
PL	37.426	0.867
AW	41.649	0.961
MW	39.214	0.630
PW	47.735	0.824
Sba	13.193	0.344
SBp	15.648	0.280
L	111.646	2.477
W	51.426	1.302
ISD	76.123	1.581
MDS	39.918	1.032
PDS	34.844	1.098

MVS	33.795	1.036
OCM	61.834	8.801
OAS	84.726	4.238
OPS	50.279	4.300
O	17.760	0.495
O – O	136.398	6.686
Cx I	71.433	2.564
Tr I	52.487	1.434
bFe I	70.563	2.790
tFe I	62.734	1.582
Ge I	127.627	2.291
Ti I	129.855	3.926
Ta I	107.912	1.016
Ta I (H)	35.668	1.687
Leg I	627.094	12.139
Cx II	81.518	3.184
Tr II	46.620	1.228
Bf II	55.976	1.829
tFe II	51.133	1.087
Ge II	96.745	1.632
Ti II	113.115	1.946
Ta II	92.012	1.577
Ta II (H)	28.850	1.186
Leg II	541.403	8.020
Cx III	85.276	2.259
Tr III	51.255	1.274

Bf III	65.908	1.652
tFe III	65.721	0.995
Ge III	113.547	1.375
Ti III	145.193	2.106
Ta III	105.673	1.397
Ta III (H)	27.662	1.164
Leg III	632.572	7.913
IP	1703.693	78.652

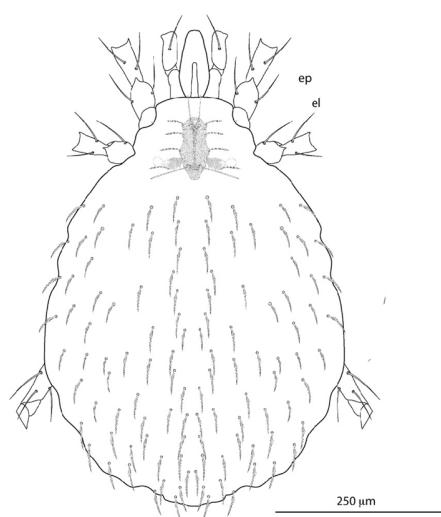


Figure 1-4: *Balaustium leanderi* comb. nov. Larva: Idiosoma, dorsal view. Structure of integument partly shown (between scutum and eyes)

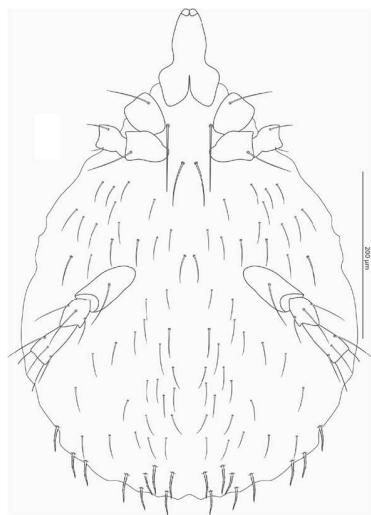


Figure 1-5: *Balaustium leanderi* comb. nov. Larva: Idiosoma, ventral view.

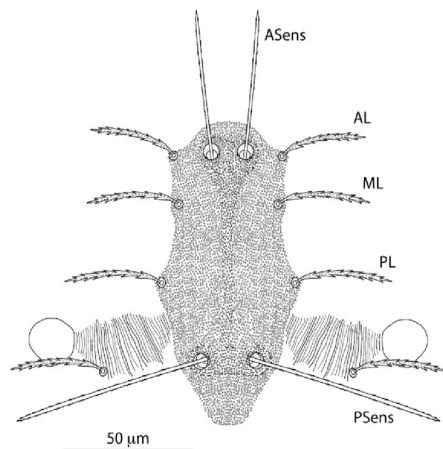


Figure 1-6: *Balaustium leanderi* comb. nov. Larva: Dorsal scutum and eyes. Structure of cuticle partly shown (between scutum and eyes)

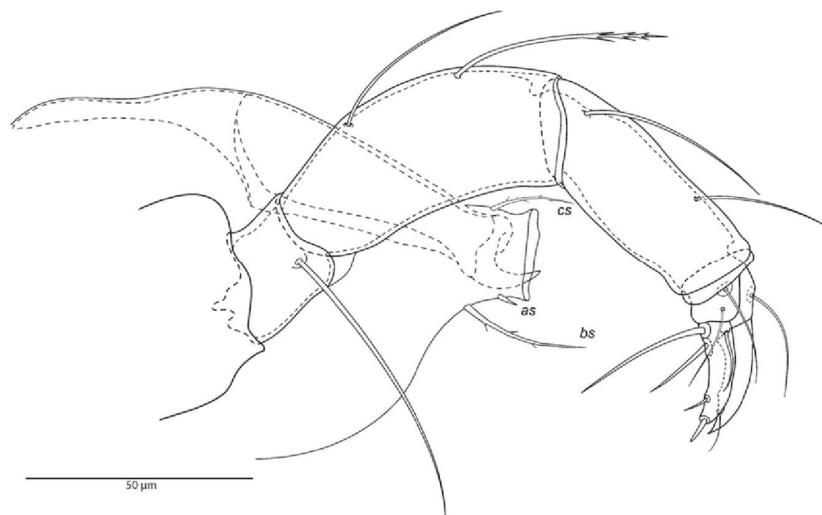


Figure 1-7: *Balaustium leanderi* comb. nov. Larva: Gnathosoma, lateral view

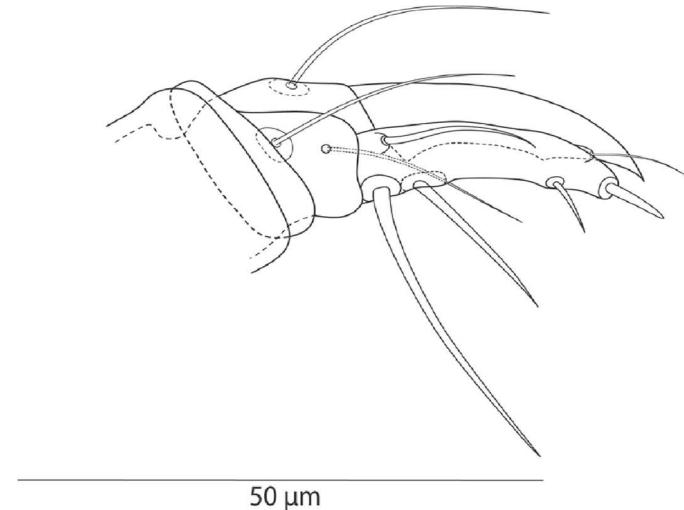


Figure 1-8: *Balaustium leanderi* comb. nov. Larva: Palp tibia and palp tarsus, lateral view

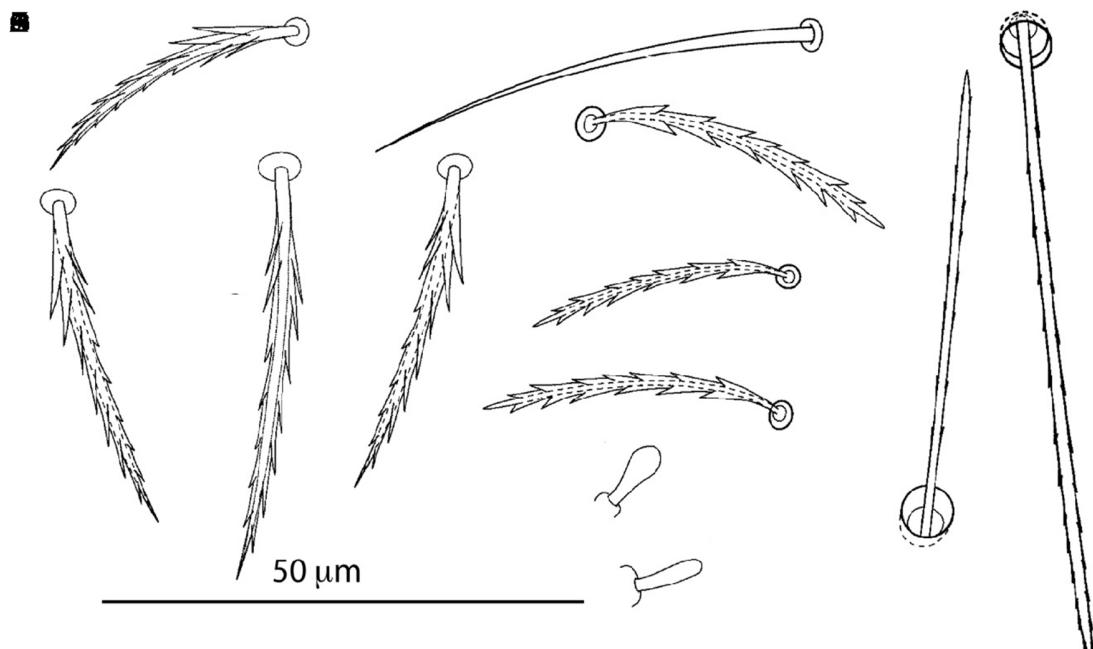


Figure 1-9: *Balaustium leanderi* comb. nov. Larva: A. Dorso-lateral seta; B. Postero-dorsal seta; C. Mid-dorsal seta; D. Mid-ventral seta; E. Postero-ventral seta; F. Seta AL; G. Seta ML; H. Seta PL; I. Anterior sensilla (ASens); J. Posterior sensilla (PSens); K. Seta el; L. Seta ep

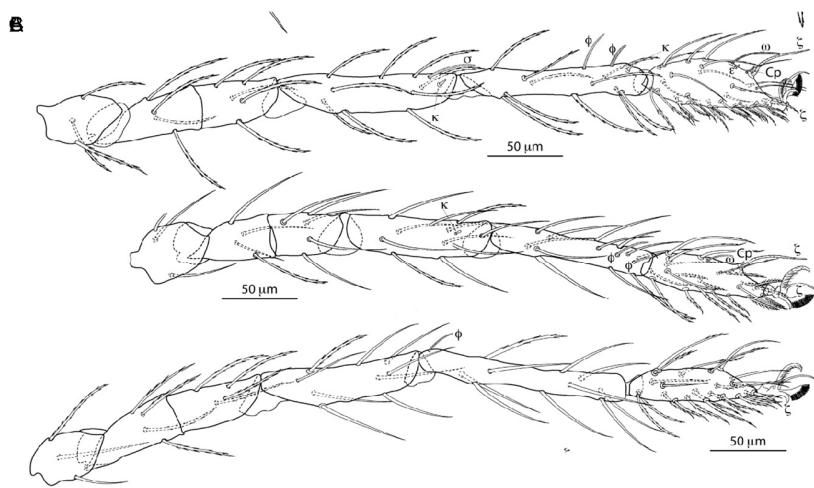


Figure 1-10: *Balaustium leanderi* comb. nov. Larva, legs (coxae omitted): A. Leg I; B. Leg II; C. Leg III

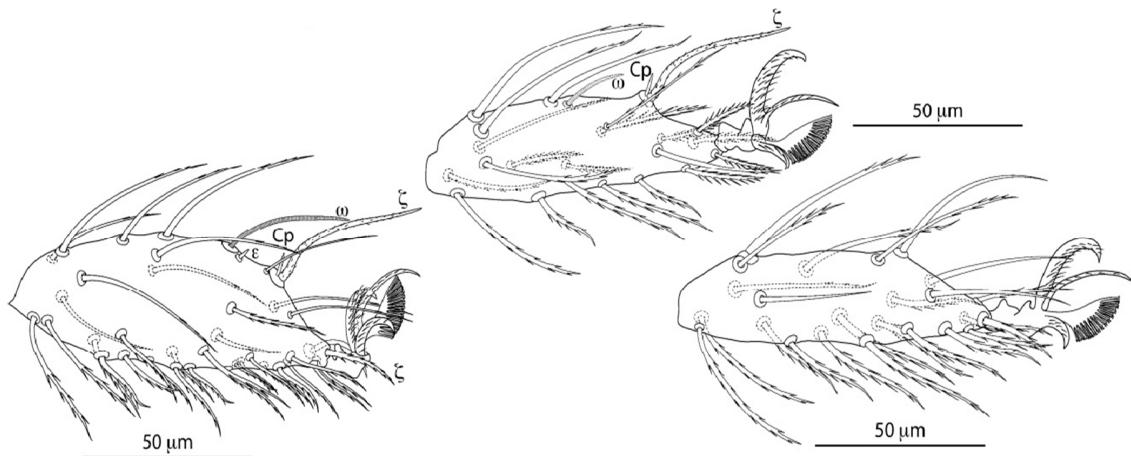


Figure 1-11: *Balaustium leanderi* comb. nov. Larva: A. Tarsus leg I; B. Tarsus leg II (subterminal eupathidium not shown); C. Tarsus leg III (subterminal eupathidium not shown)

Gnathosoma. Chelicerae composed of basal segment and movable claw (Figure 1-5). Adoral setae (cs) and subcapitular setae (bs) of similar length (c. 23), with few tiny barbs. Setae as (c. 2 µm) short, acicular. Palps slender, PaGe L/W 1.84–2.80. Pedipalp setal formula (fPp) N-NB-NN-NNN-NNNNζω (Figures 1-7 and 1-8). Odontus with tooth-like protrusion located ventrally at c. 3/5 of the claw length. Palpal supracoxalae (ep, c. 4 µm) thumb-like (Figure 1-9L).

Idiosoma, Dorsal Side (Figure 1-4). Behind the level of crista metopica 102–118 barbed, similar in shape, setae (Figure 1-9A,B,C). Scutum (Figure 1-6) indistinct, with weakly marked margins. Crista well sclerotized, extending between bases of ASens and PSens. Setae AL, PL and ML (Figure 1-9F,G, H) of similar length, all barbed; PL located within or off scutum. AL leveled with ASens or slightly posterior of ASens. ASens shorter than PSens, both barbed distally (Figure 1-9I, J).

Idiosoma, Ventral Side (Figure 1-5). Sternulae 1a and 2a present between coxae I and II, respectively, 30–35 setae between coxae II-III and 56–66 setae behind coxae III, all nude (Fig. 10). Setae located along the posterior margin of opisthosoma (Figure 1-9E) barbed, similar to those covering the idiosoma dorsum.

Legs (Figures 1-9K, 1-10A,B, C and 1-11A, B,C). Leg segmentation formula 7–7–7; leg chaetotaxy: leg I: Cx 1B, Tr 3B, bFe 4B, tFe 5B, Ge 9B + 1σ+ 1κ, Ti 11B + 2φ + 1κ, Ta 33–35B + 2ζ + 1Cp + 1ω + 1ε; leg II: Cx 1B, Tr 3B, bFe 4B, tFe 5B, Ge 8–10B + 1κ, Ti 10–12B + 2φ, Ta 23–25B + 2ζ + 1Cp + 1ω; leg III: Cx 1B, Tr 3B, bFe 4B, tFe 5B, Ge 9B, Ti 10–11B + 1φ, Ta 22–25B + 1ζ. supracoxala of leg I (el, c. 3 µm) thumb-like (Figure 1-9A). Normal setae on legs I–III slightly barbed along the entire stem or close to the tip. On legs II and III (Figures 1-10B and 1-11B) setae with adhering setules, making an impression of seta being

nude, are also present. On tarsi I–III several setulated setae resembling the eupathidia, nude and bent apically, with blunt termination most often oriented towards the basal part of tarsus, arise along the ventro-lateral margin of the segment. Dorsal eupathidia on tarsi I–II ciliated along the entire stem, with adjacent companalae. Tarsi I–III terminated with 2 claws and claw-like empodium. Anterior claw sickle-like, ciliated, posterior claw composed of 2 branches: one similar to anterior claw but shorter and another one terminated with discoid, pulvilliform structure.

Deutonymph (Figures 1-2, 1-12, 1-13A-D, 1-14 and 1-15). Metric data provided in Table 1-3. Meristic data based on 9 specimens.

Table 1-3: Morphometric data of the *Balaustium leanderi* deutonymph. X = measurements (μm). SE = standard error.

Character	X (n = 9)	SE
PaTr (L)	40.854	3.065
PaFe (L)	121.124	6.146
PaFe (W)	48.464	3.399
PaGe (L)	97.075	3.390
PaGe (W)	34.114	1.940
PaTi (L)	27.284	1.073
PaTi (W)	24.416	0.824
PaTa (L)	32.027	1.635
PaTa (W)	10.466	0.447
Odo	29.983	0.606
IL	946.833	59.194
IW	712.373	56.149
IL/IW	1.351	0.052
AL (n)	4.000	0.000
ASE=Asens	62.119	1.270
PSE=Psens	86.023	1.682

SBa	16.953	0.431
SBp	16.217	0.600
L	215.836	6.414
W	39.736	1.158
ISD	149.783	4.144
mDS	32.245	0.824
pDS	28.106	1.003
pVS	43.387	0.941
O	21.992	0.479
Ur	29.063	1.596
AOP	39.964	2.549
Cx I	200.860	9.738
Tr I	87.202	3.438
bFe I	116.573	4.443
tFe I	206.408	6.512
Ge I	240.784	10.788
Ti I	238.952	10.296
Ta I	160.169	4.330
Ta I (H)	63.681	3.070
Leg I	1250.948	38.214
Cx II	162.104	6.419
Tr II	77.442	1.357
bFe II	89.178	4.273
tFe II	129.924	5.150
Ge II	146.980	6.558
Ti II	178.028	5.966

Ta II	109.079	2.996
Ta II (H)	47.644	2.483
Leg II	892.736	29.479
Cx III	144.167	4.946
Tr III	77.932	2.605
bFe III	91.296	5.414
tFe III	148.671	7.099
Ge III	181.532	6.697
Ti III	216.811	9.572
Ta III	109.549	2.962
Ta III (H)	43.018	3.221
Leg III	969.958	30.675
Cx IV	186.919	4.868
Tr IV	80.313	4.241
bFe IV	116.305	7.536
tFe IV	210.946	9.339
Ge IV	231.647	11.234
Ti IV	270.468	10.239
Ta IV	110.436	3.619
Ta IV (H)	44.160	2.943
Leg IV	1207.033	45.119
IP	4320.675	138.280

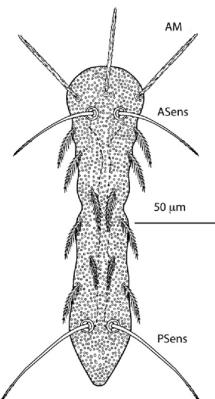


Figure 1-12: *Balaustium leanderi* comb. nov. Deutonymph: Dorsal scutum.

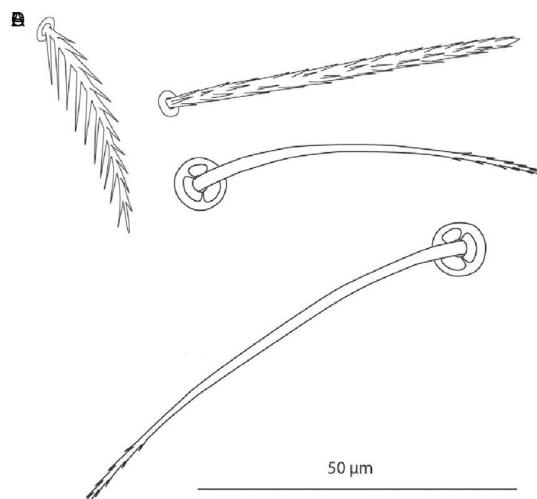


Figure 1-13: *Balaustium leanderi* comb. nov. Deutonymph: A. Seta arising on scutum between the level of ASens and PSens; B. Seta AM; C. Anterior sensilla (ASens); D. Posterior sensilla (PSens)

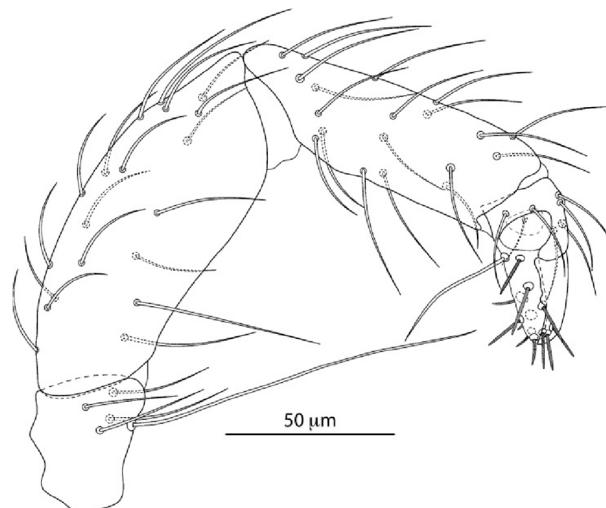


Figure 1-14: *Balaustium leanderi* comb. nov. Deutonymph: Palp, medial aspect.

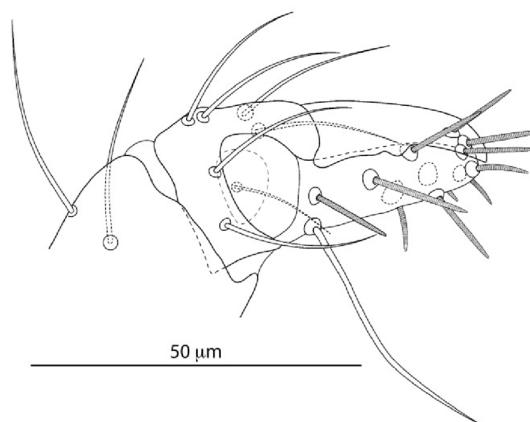


Figure 1-15: *Balaustium leanderi* comb. nov. Deutonymph: Palp tibia and palp tarsus, medial aspect.

Gnathosoma. Palps (Figure 1-14) slender. Palp trochanter with 5 setae, of which one (c. 140) is much longer than the remaining ones, palp femur with 19–23 setae, palp genu with 19–21 setae, palp tibia with 7 setae. Setae on PaTr – PaTi either nude or weakly barbed. Palp tarsus (Figures 1-14 and 1-15) with one long, nude seta located proximally and with c. 11 solenidia. Palpal supracoxalae ep (c. 4 µm) thumb-like.

Idiosoma, Dorsal Side. Crista metopica well sclerotized and inserted in scutum (Figure 1-12). ASens (Figure 1-13C) shorter than PSens (Figure 1-13D), both with tiny barbs in the distal part. A group to 3 to 5 AM setae (Figure 1-13B), covered with short, adhering setules and placed anterior of, or at the level of ASens. Eight to 12 setae (Figures 1-12 and 1-13A) located within scutum, between ASens and PSens. Single eyes at each side of symmetry axis, c. at the level of posterior sensillae. Urnulae placed postero-medially to eyes. Dorsal

opisthosomal setae uniform in shape. Setal stem with 3 cuticular ridges, running from the base to the top of seta; along one ridge the relatively long, narrowing apically setules are distributed; 2 other ridges covered with relatively short, robust and not sharpened terminally setules (see Figure 1-16A,B, for adults).

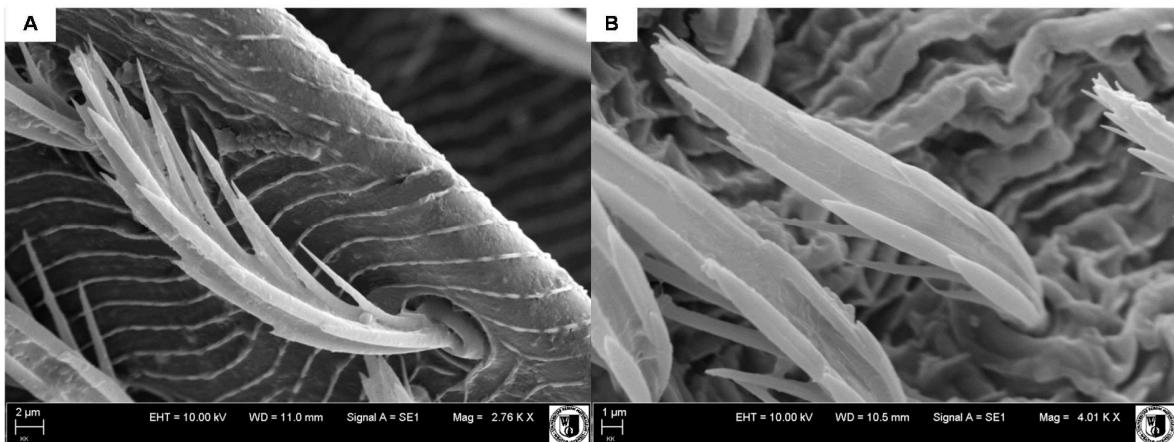


Figure 1-16: *Balaustium leanderi* comb. nov. Adult female, SEM micropgraphs: A. Dorsal seta, side view; B. dorsal seta, view from above.

Idiosoma, Ventral Side. Ventral setae aciculae, longer than the dorsal setae, either smooth or with very tiny barbs. One seta on coxae I, II and III distinctly longer than the remaining coxal setae. At the level of coxae I and II, medially, 2 pairs of setae much longer than the remaining ventral setae. Another 2–3 pairs of distinctly elongated setae present anterior of and at the level of coxae III-IV.

Legs. Supracoxal setae el (c. 6 μm) tiny and thumb-like. Two supracoxalae ell (c. 6 μm) present on each of coxae II, dorsally, in antero-lateral position. All legs covered with very weakly barbed or nude setae; setulose setae arise along ventral and ventro-lateral surface of tarsi. Specialized setae of leg I: Ge 3 σ + 1 κ , Ti 4 φ + 1 κ , Ta 1 ω (in dorsal position), 12–14 ω (placed laterally) + 2–3 ζ + 1 ε ; leg II: Ge 1–2 σ + 1 κ , Ti 3–4 φ , Ta 2–3 ω + 2 ζ ; leg III: Ge 1–2 σ , Ti 2 φ , Ta 1 ω + 2 ζ ; leg IV: Ge 2 σ , Ti 2 φ , Ta 2 ζ ; along the ventral surface of tarsi, several eupathidium-like setae, similar to other setulose setae but with blunt tip present; these setae are especially numerous on tarsus I. Tarsi terminated with paired, covered with fimbriae, claws.

1.4.4 Adult, Female (Figures From 1-16 to 1-25).

Metric data provided in Table 1-4. Meristic data based on 11 specimens. Body setation more dense than in deutonymphs.

Table 1-4: Morphometric data of the adult female *Balaustium leanderi*. X = measurements (μm). SE = standard error.

Character	X (n = 9)	SE
PaTr (L)	70.627	1.019

PaFe (L)	215.210	4.265
PaFe (W)	73.203	1.895
PaGe (L)	157.997	2.811
PaGe (W)	48.313	0.741
PaTi (L)	43.432	0.771
PaTi (W)	36.906	0.593
PaTa (L)	55.230	0.864
PaTa (W)	17.118	0.363
Odo	35.973	0.806
IL	1496.460	101.228
IW	1168.583	69.545
IL/IW	1.281	0.035
AL(n)	6.800	0.279
ASE=Asens	80.532	2.299
PSE=Psens	104.030	1.244
Sba	19.147	0.323
SBp	21.259	0.517
L	346.369	6.416
W	66.119	4.043
ISD	241.859	3.829
MDS	34.762	0.869
PDS	35.478	0.499
MVS	50.004	3.347
OCM	212.414	10.106
OAS	294.393	11.962
OPS	247.114	12.008

O-Ur	38.373	1.470
O	32.186	0.617
Ur	38.739	0.918
O - O	490.971	22.874
GOP	247.220	8.017
AOP	65.032	1.223
Cx I	323.492	9.693
Tr I	163.541	5.865
bFe I	198.466	6.669
tFe I	368.613	8.173
Ge I	432.324	8.363
Ti I	419.004	7.005
Ta I	273.453	4.701
Ta I (H)	94.730	2.595
Leg I	2188.191	39.276
Cx II	277.133	4.796
Tr II	136.110	6.033
bFe II	145.000	2.837
tFe II	233.097	4.359
Ge II	266.953	5.368
Ti II	295.582	5.833
Ta II	178.142	3.392
Ta II (H)	73.139	2.750
Leg II	1532.018	26.492
Cx III	258.866	5.967
Tr III	139.838	5.265

bFe III	154.393	3.367
tFe III	274.544	5.903
Ge III	316.480	6.290
Ti III	343.344	7.653
Ta III	180.254	3.635
Ta III (H)	70.482	1.871
Leg III	1667.720	31.759
Cx IV	331.493	9.423
Tr IV	157.453	6.297
bFe IV	203.116	4.570
tFe IV	378.071	6.616
Ge IV	417.560	9.277
Ti IV	457.026	8.016
Ta IV	187.513	4.423
Ta IV (H)	68.337	1.867
Leg IV	2138.836	44.742
IP	7545.138	140.377

Gnathosoma. Palps slender (Figures 1-22 and 1-23). Palp trochanter with 6 nude setae, of which one (c. 178) is much longer than the remaining setae. Palp femur with 44–48 setae, palp genu with 34–38 setae, palp tibia (Figures 1-24A, B) with 10–12 setae, all setae nude or weakly barbed. Palp tarsus (Figures 1-24A, B) with one long, nude seta and with c. 20 solenidia. Supracoxalae ep thumb-like (c. 5 µm).

Idiosoma, Dorsal Side. Dorsal view as in Figure 1-18A. Rod of crista metopica extended between bases of ASens and PSens and inserted in well sclerotized, narrowing posteriorly scutum (Figure 1-21). ASens and PSens sparsely setulose in distal part (Figure 1-21 and 1-25B, C), ASens always shorter than PSens. Five to 10 non-sensillary setae AM, with adhering setules (Figures 1-21 and 1-25A). Circa 32–40 setae, similar in shape to opisthosomal setae, arise on scutum, between the level of ASens and PSens (Figures 1-21 and 1-25D). Single eyes at each side of symmetry axis, placed before or at the level of

posterior sensillae. Urnulae located postero-medially to eyes (Figure 1-18A). Dorsal opisthosomal setae (Figures 1-25E to 1-25G and 1-16) as in deutonymphs.

Ventral Side of Idiosoma. Dorsal view as in Figure 1-18B. Ventral setae and setae on coxae similar to those occurring in deutonymphs. At opisthosoma termination ventral setae display transitional form between mid-ventral and dorsal ones. Genital opening elongate, with extrusible ovipositor (Figures 1-19 and 1-20), genital valves covered with setae similar in shape to ventral setae, but shorter (Figure 1-26H). Anus (Figure 1-19) oval, surrounded by distinct sclerite with c. 12 setae.

Legs. One supracoxala el ($8 \mu\text{m}$) and 2 supracoxalae ell ($8 \mu\text{m}$), all tiny, thumb-like, located in dorso-lateral part of coxal plates. Leg segments with weakly barbed or nude setae, setae covered with setules arise along ventral and ventro-lateral side of tarsi. Specialized setae of leg I: Ge $5\sigma + 1\kappa$, Ti $14\varphi + 1\kappa$, Ta c. $15\omega + 4\zeta + 1\varepsilon$; leg II: Ge $2-3\sigma + 1\kappa$, Ti 6φ , Ta c. $6\omega + 2-4\zeta$; leg III: Ge $2-3\sigma$, Ti $3-4\varphi$, Ta $3-4\omega + 2-4\zeta$; leg IV: Ge 4σ , Ti 4φ , Ta c. $2\omega + 2-4\zeta$. Setae of eupathidium-type, not sharpened terminally and covered with setules, slightly bent towards proximal part of the segment, especially numerous on tarsus I, present among other setulose setae arising at ventral side of tarsi. Tarsi terminated with paired claws, each claw covered with fimbriae.



Figure 1-17: *Balaustium leanderi* comb. nov. Adult female: Habitus, dorsal view, in vivo.

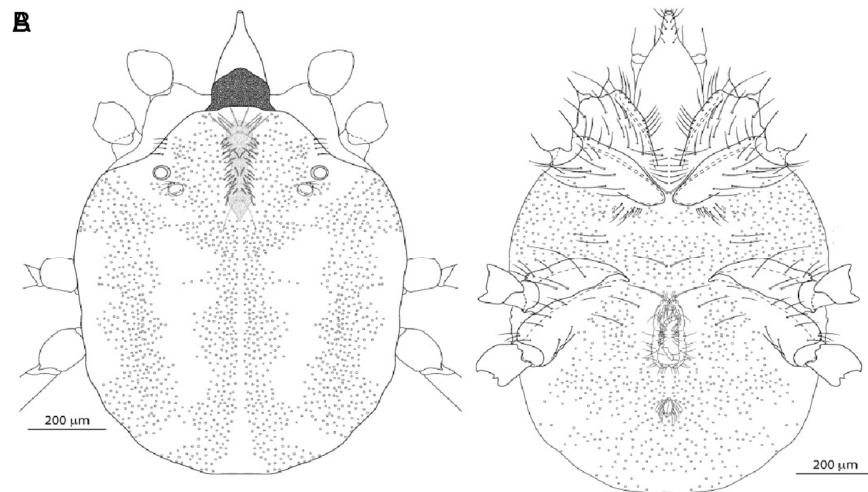


Figure 1-18: *Balaustium leanderi* comb. nov. Adult female: Idiosoma, A: dorsal view, B: ventral view.

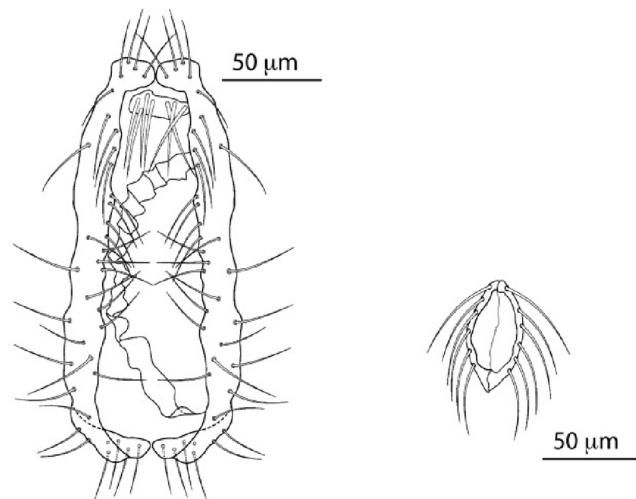


Figure 1-19: *Balaustium leanderi* comb. nov. Adult female: Genital and anal region

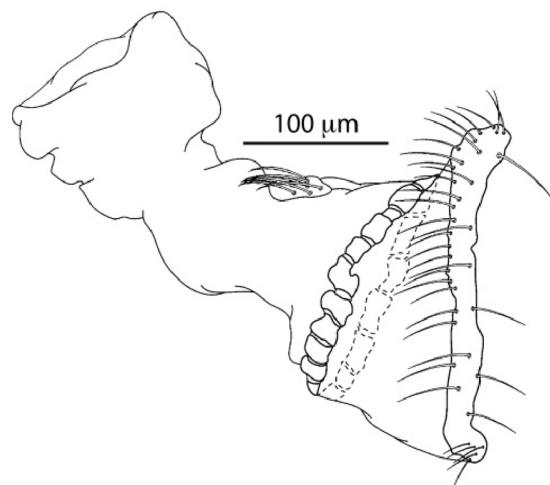


Figure 1-20: *Balaustium leanderi* comb. nov. Adult female: Extruded ovipositor

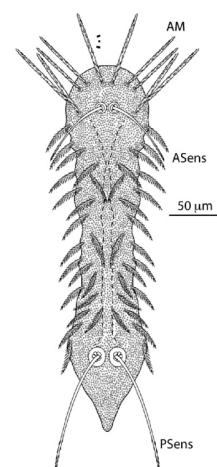


Figure 1-21: *Balaustium leanderi* comb. nov. Adult female: Dorsal scutum.

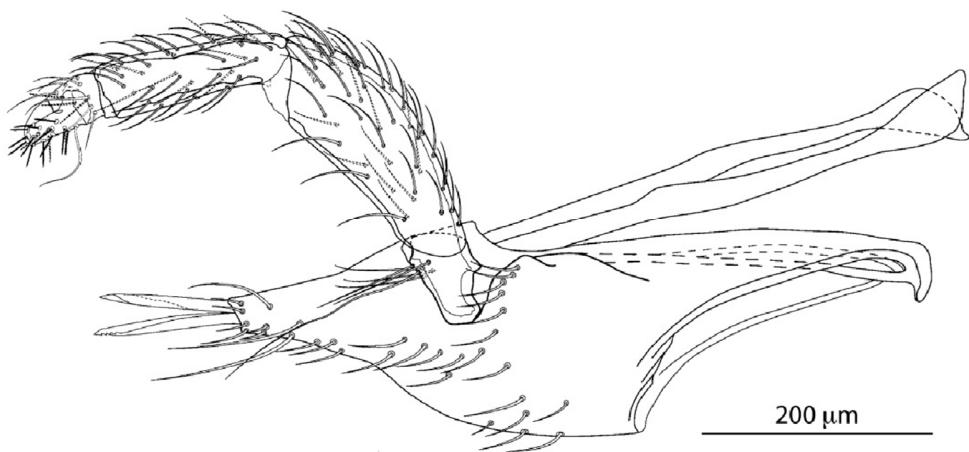


Figure 1-22: *Balaustium leanderi* comb. nov. Adult female: Gnathosoma, lateral aspect

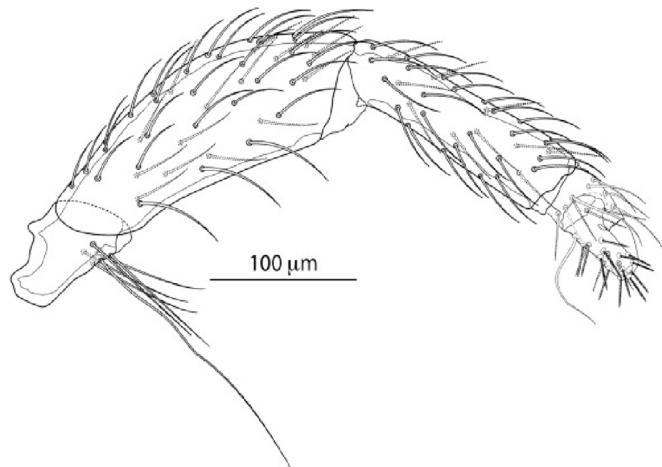


Figure 1-23: *Balaustium leanderi* comb. nov. Adult female: Palp, lateral aspect.

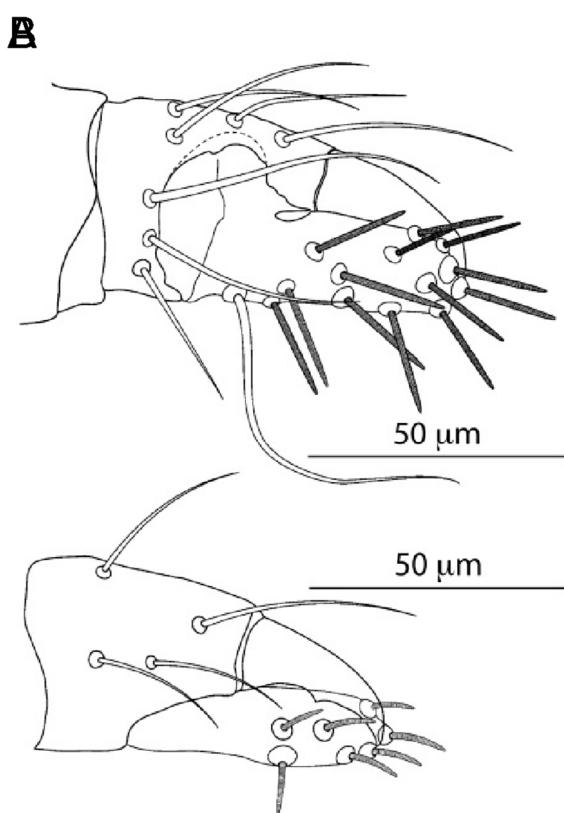


Figure 1-24: *Balaustium leanderi* comb. nov. Adult female: A. Palp tibia and palp tarsus, lateral aspect; B. Palp tibia and palp tarsus, medial aspect.

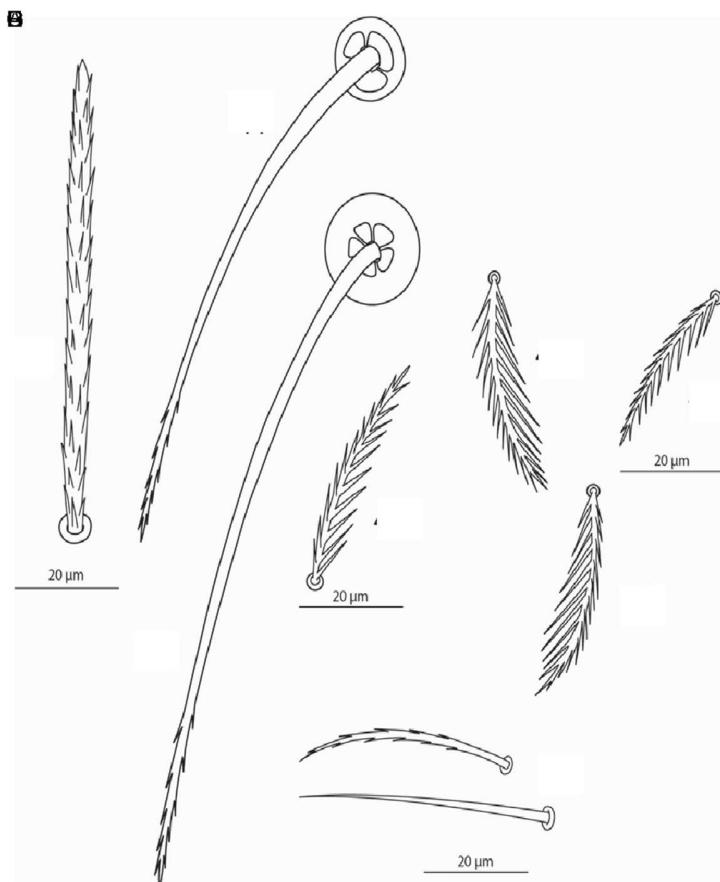


Figure 1-25: *Balaustium leanderi* comb. nov. Adult female: A. AM seta; B. Anterior sensilla (ASens); C. Posterior sensilla (PSens); D. Seta arising on scutum between the level of ASens and PSens; E. Mid-dorsal seta; F. Latero-dorsal seta; G. Postero-dorsal seta; H. Genital setae

1.4.5 Material Deposition

A series of specimens, comprising four adult females (ICN-Ac-155–ICN-Ac-158), four deutonymphs (ICN-Ac-159–ICN-Ac-162) and four larvae (ICN-Ac-163–ICN-Ac-166) is deposited in the “Instituto de Ciencias Naturales ICN, Universidad Nacional de Colombia”. Three adults, three deutonymphs and three larvae are deposited in the collection of the Laboratory of Entomology, University of Bogotá Jorge Tadeo Lozano. Four slide-mounted adults (OSAL006617–006620) are deposited in the acarological collection of the Ohio State University. Two adults, two deutonymphs and five larvae - in the collection of the Department of Invertebrate Systematics and Ecology, Wrocław University of Environmental and Life Sciences.

1.4.6 Distribution

Colombia, México.

Remarks on Taxonomy

The following set of diagnostic characters allow to differentiate between larvae of *Balaustium* spp. and of other balaustiine genera: the palp tibial claw with a prominent tooth on ventral surface, one seta on palp trochanter, 1–2 setae on palp femur and three setae on trochanter I (see also Diagnosis). Some of these characters, however, can be recognized also in other balaustiine genera known from larvae.

The presence of two setae on the palp femur, combined with the presence of one seta on the palp trochanter in larvae has been stated for monotypic *Palenquistium* Haitlinger, 2000 and also for *Pollux kovalamicus* Haitlinger, 2002. However, the members of *Pollux* Southcott, 1961 can be distinguished from *Balaustium* spp. by different termination of tarsus III. *Palenquistium*, with *Palenquistium leanderi* was described by Haitlinger (2000) based on two larvae collected from plants in Mexico. The simple odontus, without median tooth, two setae on the palp femur, bFe 4–4–4, Tr 3–3–3 and Ge 9–9–9, were listed as diagnostic characters for newly erected genus.

Examination of the holotype of *Palenquistium leanderi*, revealed that the distinct tooth is present at c. half length of the tibial claw, ventrally. Also, one barbed seta and one nude (instead of two nude setae) are present on palp femur, whereas the chaetotaxy of tibia II includes 10 normal setae and two solenidia. Thus the data contained in the original description should be corrected for fPp N-NB-NN-NNN-NNNNζω, f_nTi 11–10–11 and f_{sol}Ti 2–2–1. Additionally, the AL setae are leveled with ASens (AL anterior of ASens stated in the original description might have been due to the shift of the left side of the idiosoma towards anterior position in relation to the right side of the body). The above verification of diagnostic characters, results in the presence of character states which are observed also in some members of *Balaustium*. Hence the separate identity of *Palenquistium* Haitlinger, 2000 is not justified anymore and the latter genus should be considered a junior synonym of *Balaustium* von Heyden, 1826. Moreover, the discrepancy in data contained in the original description, applying to the ISD value (50 – in the diagnosis, 68 and 78 – for the holotype and paratype, respectively – in the table), should be corrected in favor of the value provided in the table. PaGe L/W ratio in *Balaustium leanderi* comb. nov. equals 70 in the holotype.

Balaustium leanderi comb. nov. shares generic traits with other members of the genus, as evidenced by data on larvae and active postlarval forms. Difference between the larvae of *Balaustium leanderi* and of other *Balaustium* spp., besides the presence of two setae on the palp femur, pertains also to the number of normal setae on the basifemur (f_nbFe 4–4–4). The formula f_nbFe 4–4–4 has been known also for the monotypic *Moldoustium* Haitlinger, 2008, but the separate generic identity of the latter genus is supported by the absence of setae on the palp trochanter (vs one seta present in *Balaustium*).

Active postlarval forms of *Balaustium leanderi* belong to the group of *Balaustium* spp. having long and slender palps (PaGe L/W > 2) and lacking semipectinalae on the palp genu. The latter group comprises also *B. hernandezi* Mąkol et al. 2012. The most striking

differences between these 2 species (except for characters which differentiate larvae) are expressed in the length of dorsal opisthosomal setae (23–46 in *B. leanderi* vs 45–75 in *B. hernandezii*) and in the PaGe L/W ratio (2.45–3.15 in DN and 3.06–3.63 in AD of *B. leanderi* vs 2.29 in DN and 2.7 in AD of *B. hernandezii*).

For several species known exclusively from active postlarval forms, the data on the PaGe L/W ratio and/or on the presence/absence of semipectinalae have not been described. The latter applies to the following species, from the circumtropical zone: *B. aonidiphagus* (Ebeling, 1934), *B. cristatum* Meyer and Ryke, 1959, *B. graminum* Meyer and Ryke, 1959, *B. medicagoense* Meyer and Ryke, 1959, *B. southcotti* Feider and Chioreanu, 1977. *Balaustium leanderi* differs from *B. aonidiphagus* in the body coloration, which in *B. aonidiphagus* is red but with greenish or bluish iridescence, from *B. cristatum* – in the number of AM setae in deutonymph (one seta in *B. cristatum*) and in PaGe L/W ratio (1.25 in *B. cristatum*, calculated from the drawing), from *B. graminum* – in the length of dorsal opisthosomal setae (22 in DN of *B. graminum*) and in PaGe L/W ratio (1.24 in *B. graminum*, calculated from the drawing), from *B. medicagoense* – in the lack of papillae-like structures on legs, from *B. southcotti* – in the length of the palp, excl. palp tarsus (203–261 in females of *B. southcotti*, 496–556 in females of *B. leanderi*).

The relatively wide range of morphometric data (Tabs 1-2, 1-3) observed in *B. leanderi*, not known for other *Balaustium* spp. poses a question on separate identity of species for which the minor differences in metric data served as the only source to distinguish the new taxon.

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Chapter II

Generalist red velvet mite predator (*Balaustium sp.*) performs better on a mixed diet²

2.1 Abstract

Generalist predators have the potential advantage to control more than one pest and to be more persistent than specialist predators because they can survive on different foods. Moreover, their population growth rate may be elevated when offered a mixture of prey species. We studied a generalist predatory mite *Balaustium sp.* that shows promise for biological control of thrips and whiteflies in protected rose cultures in Colombia. Although starting its life in the soil, this predator makes excursions onto plants where it feeds on various arthropods. We quantified life history parameters of the predator, offering high densities of three pest species: first-instar larvae of *Frankliniella occidentalis*, eggs of *Trialeurodes vaporariorum* and *Tetranychus urticae*, either alone or in combination. The predators completed their life cycle on each diet. The egg-to-egg period was c. 2 months. All eggs were laid in one batch in 1 to 2 days, indicating a pronounced semelparous reproduction pattern. In general, females reproduced earlier and laid more eggs on mixed diets, and these early reproducers consequently had higher population growth rates than late reproducers. The best diet in terms of egg-to-egg period and juvenile survival was the combination of eggs from whiteflies and spider mites. Spider mite eggs alone and western flower thrips larvae alone were the worst diets. It remains to be investigated whether mixed diets promote the population growth rate of *Balaustium* sufficiently for biocontrol of

² Muñoz-Cárdenas K, Fuentes LS, Cantor F, Rodríguez D, Janssen A, Sabelis MW. (2014). Generalist red velvet mite predator (*Balaustium sp.*) performs better on a mixed diet. Experimental and Applied Acarology. 2014 Jan; 62(1):19-32. ISSN 0168-8162. DOI: 10.1007/s10493-013-9727-1.

whiteflies and thrips in the presence of alternative prey, such as spider mites, to become effective.

2.2 Introduction

Whether to use generalist or specialist predators for biological control of crop pests is an important and hotly debated topic (Symondson *et al.*, 2002). Most attention has been paid to specialist biocontrol agents, because their dynamics are tightly linked to that of the prey and because of the lower risk of side effects on populations of non-target organisms (Murdoch *et al.*, 1984; Murdoch *et al.*, 1985; Hassell and May 1986; Murdoch 1994). However, generalist predators are increasingly used for biocontrol (Chiverton 1986; Rosenheim *et al.*, 1993; Settle *et al.*, 1996; Chang and Kareiva 1999; Symondson *et al.*, 2002; Messelink *et al.*, 2012). This also applies to generalist phytoseiid mites that live on plants and feed on various arthropod herbivores (Nomikou *et al.*, 2001; Messelink *et al.*, 2008; Messelink *et al.*, 2010; Messelink *et al.*, 2012), as well as on plant food such as pollen (Nomikou *et al.*, 2002; van Rijn *et al.*, 2002) and on plant fungi, such as spores of mildew (Pozzebon and Duso 2008). Compared to specialist natural enemies, the advantage of using generalist predators is that they can feed on other prey than the target pest, thereby enabling persistence of their populations at high densities, even in periods of low pest density. A disadvantage of using generalist predators is that they may also attack non-target prey or even other predators (intraguild predation or higher-order predation, Rosenheim *et al.*, 1995; Rosenheim 1998). Although this could potentially disrupt biological control, this is often not the case for intraguild predation (Janssen *et al.*, 2006), but can occur in the case of higher-order predation (Messelink *et al.*, 2011).

Generalist predators may be present on the plants, but they may also live in the soil, yet make foraging excursions onto the plants. In this case, their population size depends on the community of arthropod decomposers and predators in the soil or litter (Settle *et al.*, 1996; Scheu 2001), as well as on the community of arthropod herbivores on the plant canopy. Some species in the genus *Balaustium* (Acari: Erythraeidae) are good examples of species that occur in the litter and on plants (Putman 1969; Childers and Rock 1981; Welbourn 1983; Welbourn and Jennings 1991). Moreover, these species prey on a range of species on plants; they have been observed to feed on fruit-tree red spider mites (*Panonychus ulmi*, Acari: Tetranychidae) (Putman 1969; Cadogan and Laing 1977), eggs and larvae of Lepidoptera and Diptera, aphids and pollen (Hayes 1985). Muñoz *et al.*, (2009) observed that an undescribed species of *Balaustium* (Cal Welbourn, pers. comm. 2008) feeds preferentially on immatures of three plant pests: two-spotted spider mites *Tetranychus urticae* (Acari: Tetranychidae), western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae) and greenhouse whiteflies, *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae). The same species was used in this study. These predatory mites are found in the vegetation outside greenhouses of flower cultures on the Bogotá Plateau in Colombia (Torrado *et al.*, 2001) in cold as well as temperate zones (Getiva and Acosta 2004). Provided pesticides are not applied, they can be abundant and they are considered as candidate predators for control of several pest species (Muñoz *et al.*, 2009).

In this research it was assessed the potential of a *Balaustium* sp. to feed and reproduce on a diet of spider mites, thrips and whiteflies. It was measured prey mortality when exposed to mobile life stages of this predator and we determined the life table parameters on a diet of each of these pest species as well as all possible mixtures. The mixtures were offered because several generalist predatory mites have been shown to reproduce better on

mixtures of prey species than on each prey species alone (Oelbermann and Scheu 2002; Messelink *et al.*, 2008), which further increases their capacity for pest control (Messelink *et al.*, 2008; Messelink *et al.*, 2010). This research may pave the way for future research on the efficacy of *Balaustium* as a biocontrol agent and on the role of soil-inhabiting prey (e.g. fungivorous mites) to boost their populations and thereby improve pest control.

2.3 Materials and methods

2.3.1 Predator and prey cultures

Predators and prey were reared under local greenhouse conditions with a daily maximum and minimum temperature of $31.7 \pm 3.5^\circ\text{C}$ and $11.1 \pm 2^\circ\text{C}$ (mean \pm S.D.). The whitefly *T. vaporariorum* was reared on tomato plants (*Solanum lycopersicum*), whereas the thrips *F. occidentalis* was reared on *Pelargonium grandiflorum* flowers in plastic containers (30 x 16 x 12 cm) with moist paper towels on the bottom to promote humidity. The spider mite *T. urticae* was reared on bean plants. The tomato and bean plants were two weeks old at infestation; *P. grandiflorum* flowers were bought weekly from a commercial producer, which sprayed minimal levels of pesticides. The cultures of whiteflies and spider mites were kept in separate compartments in a greenhouse inside cages to avoid contamination.

Predator rearing units consisted of closed plastic containers (18 cm diameter, 20 cm height) with an opening (10 cm diameter) covered with a mite-proof steel mesh for ventilation. To provide a suitable substrate for juvenile development, the bottom of the container was covered with a layer of moist peat (c. 3 cm deep). A disc of paper towel (17 cm diameter) was placed on top of the layer to maintain moisture. A total of 15 adult predator individuals were placed in the container and they were provided with plant material infested with all stages of whiteflies, thrips and spider mites twice per week.

To obtain a cohort of *Balaustium* eggs, we offered individual young adult females a mixture of the three prey species (Muñoz *et al.*, 2009). To this end, *Balaustium* adults were placed individually in an arena consisting of a rose leaflet on top of an inverted Petri dish (3 cm diameter), which was used as a base for the leaflet; the petiole was inserted in a water-filled plastic tube (6 cm long, 2 cm diameter) to provide water to the leaflet. Mites were kept on the leaflet inside a ring consisting of an opaque PVC tube (1 cm high and 2 cm diameter), with a hole in its wall, closed by a piece of cork underneath which the mites preferred to lay eggs. The ring was closed with plastic wrap (Vinipel) (Figure 2-1). After 7 to 10 days, they had laid at least 50 eggs, these egg batches were transferred to a Petri dish with wet cotton wool (Cadogan and Laing 1977). As soon as the pre-larvae had hatched from the eggs, they were transferred each to a separate arena (the same as described above but now without a hole). In this way, batches of 50 individuals at the onset of the pre-larval stage were obtained.



Figure 2-1: Predator cultures, (Photos were taken by Jan van Arkel, IBED, University of Amsterdam).

2.3.2 Developmental stages, survival and reproduction

Preliminary observations (Muñoz, pers. obs., 2008) showed that *Balaustium* reproduces by thelytoky, as is the case in a related species (*B. murorum*, Halliday 2005; *B. nr. putmani*, Hedges et al., 2012). We therefore studied the life cycle of *Balaustium* with individuals kept singly in an arena (as described above) throughout their life span.

There were seven treatments, three of which involved a daily supply with one of the three prey species, offered in sufficient numbers to prevent prey depletion: 80 spider mite eggs, 80 whitefly eggs or 20 first instar thrips. Predator larvae were offered half these amounts because of their lower prey requirements. Each treatment was replicated with c. 50 *Balaustium* individuals, each in a separate experimental unit. We also carried out four treatments involving the following prey combinations based on a replacement design (i.e. half or a third of the amounts of prey offered in the monocultures): (1) 40 eggs of *T. urticae* and of *T. vaporariorum*, (2) 40 eggs of *T. vaporariorum* and 10 larvae of *F. occidentalis* (3) 40 eggs of *T. urticae*, 10 larvae of *F. occidentalis* and (4) 30 eggs of *T. urticae*, 30 eggs of *T. vaporariorum* and 6 larvae of *F. occidentalis*. Each of these treatments was replicated with 15 *Balaustium* individuals. Predator larvae again received half the amount of prey. Prey mortality was measured to verify that enough prey was offered to the predatory mites.

Spider mite eggs and thrips larvae were replaced daily with fresh prey from the cultures, using a fine paintbrush. Thus, spider-mite eggs were offered free of the silken web produced by *T. urticae*. Whitefly eggs were replaced once per week as follows. Three whitefly females were allowed to lay eggs on rose leaflets in a clip cage in the presence of males for a period of three days. The leaflets with eggs were subsequently used as arenas for predatory mites. Excesses of whitefly eggs and honeydew were removed with a small wet cotton swab. We registered the number of days of every stage, the day at which every *Balaustium* female laid eggs and the day they died.

Effects of diet on life span and pre-oviposition period were analysed using generalized linear models (GLM) with a Poisson error distribution. For fecundity, a quasi-Poisson error distribution was used to correct for overdispersion. The effect of diet on survivorship was analyzed using a Cox proportional hazards model (Hosmer and Lemeshow 1999; Crawley 2007). To test the effect of diet on the percentage of non-reproductive predatory mites, we performed a GLM with a quasi-binomial error distribution to correct for overdispersion. Treatments were compared using the multcomp package (Hothorn *et al.*, 2008).

2.3.3 Life table parameters

As shown below, the reproduction of *Balaustium* represents a special type of semelparity (Stearns 1976; Roff 1992; Stearns 1992), appropriately referred to as 'pronounced' semelparity (Hautekeete *et al.*, 2001): all eggs are deposited within a very short time span (also called "big-bang reproduction", Diamond 1982; Zeineddine and Jansen 2009). Under big-bang reproduction and thelytoky, the life history can be summarized by the following variables: (2.1) the egg-to-egg developmental time, which then equals the generation time T ; (2.2) the number of eggs produced per reproductive female at age T (m_T); (2.3) the survival from egg deposition until reproducing adult (I_T). The latter variable is the product of the survival until adulthood (I_A) and the proportion of adults that reproduces (S_T). Based on these life table parameters, we calculated the net reproduction rate ($R_0 = I_T m_T$) and the intrinsic rate of increase (r_m), which for the special case of big-bang reproduction equals (Carey 1993):

$$r_m = \ln(R_0)/(T + 1) \quad (2.1)$$

Under big bang reproduction, the variables T and m_T can be quantified for each individual separately. Such an individual-based assessment is obviously not possible for the survival probability until becoming a reproducing adult (I_T). We therefore provisionally used population estimates of I_T when estimating the r_m for each individual, which enabled us to estimate the mean and the variance of r_m .

To explore trade-offs between the net reproduction and the egg-to-egg period, we carried out a regression analysis of individual R_0 against individual T and individual r_m against individual T . To help exploring how the trade-off between individual R_0 and individual T influences the relation between individual r_m and individual T , we plotted r_m based on the overall mean of R_0 and T in relation to T (necessarily leading to a hyperbolic relation because R_0 is constant).

The effect of diet on intrinsic rate of population increase was analysed with a GLM with a Gaussian error distribution. To detect trade-offs and possibly other trends in the intrinsic rate of population increase and the net reproduction, these parameters were plotted against the egg-to-egg developmental time. All the statistical tests were done using the software R (2.15.1).

2.4 Results

2.4.1 Developmental stages

It was observed seven developmental stages (Figure 2-2), comparable to the related species *B. putmani* (Putman 1969; Cadogan and Laing 1977) and *B. hernandezi* (Macol et al., 2012): (1) the spherical egg (diameter = c. 0.16 mm), initially red but turning dark red later; (2) the red oval prelarva with an orange band (diameters: c. 0.2 mm wide, c. 0.3 mm long); (3) the orange-red, six-legged larva; (4) the scarlet, oval and quiescent (legless and sessile) protonymph; (5) the scarlet, oval and eight-legged deutonymph showing three distinctive parallel white dorsal lines; (6) the orange-red tritonymphs (morphologically similar but larger than the protonymph); (7) the bright-red to dark-red adults with four pairs of legs and three white lines on the dorsum (like the deutonymph) (1mm wide, 1.5 mm long). We found only females, as in *B. murorum* (Halliday 2005).

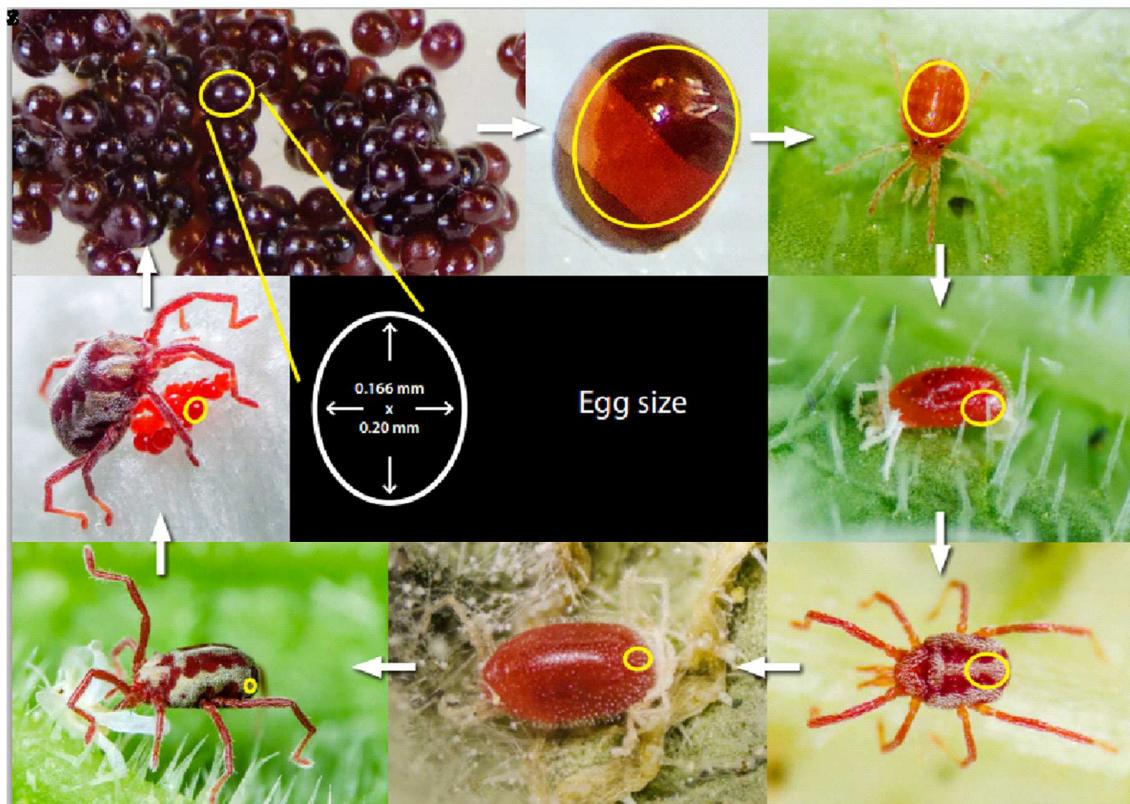


Figure 2-2: Life cycle of *Balaustium* (Photos were taken by Jan van Arkel, IBED, University of Amsterdam).

The overall life span varied significantly with diet (Figure 2-3A; GLM, deviance = 67.7, d.f. = 6,73, $P < 0.0001$). The shortest mean life span was found on a mixed diet of eggs of whiteflies and spider mites, the longest when offered thrips larvae. Most of the variation in overall life span was due to differences in the longevity of the adults (Figure 2-3A).

The time from emergence as an adult to the first egg laid (the pre-oviposition period) also varied significantly with the diet offered (Figure 2-3B; GLM, deviance = 123.7, d.f. = 6,47, $P < 0.0001$). It was shortest on a mixed diet of whiteflies and spider mites and on a diet of spider mites and thrips, and longest on a diet of thrips or spider mites alone, thrips alone and the combination of all three prey species.

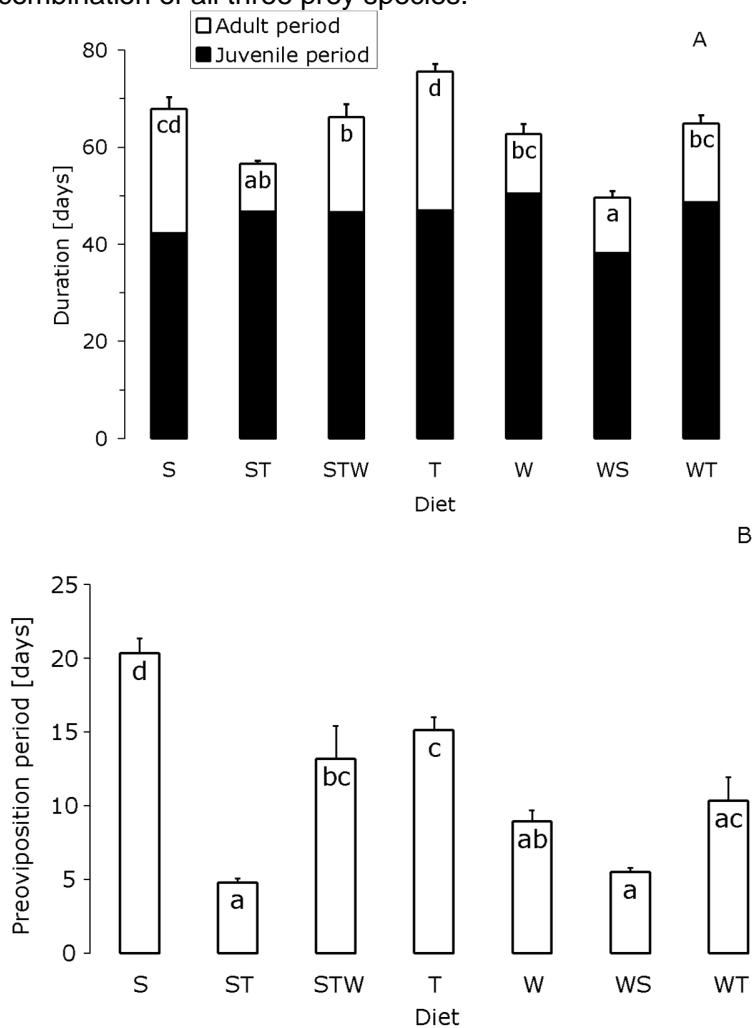


Figure 2-3: The effect of single prey species and mixtures of species on the life span of *Balaustium*. Diets consisted of whitefly eggs (W), thrips larvae (T), spider mite eggs (S), or combinations of these prey. a Mean (+S.E.) life span, including the mean duration of the immature phase indicated by the black bars and the adult longevity indicated by the white bars. b Mean (+S.E.) preoviposition period. Different letters indicate significant

differences among diets for the total life span (a, white plus black bars) and for the preoviposition period (b).

2.4.2 Survival

Survival varied significantly with diet (Figure 2-3, Log rank test = 13.36, d.f = 6, P = 0.038). The predatory mites fed with thrips alone or in combination with spider mites showed significantly more mortality compared to the predatory mites fed with the other diets. In general, most mortality occurred during the development from pre-larvae to larvae, which occurs from day 15 to day 30 (Figure 2-4).

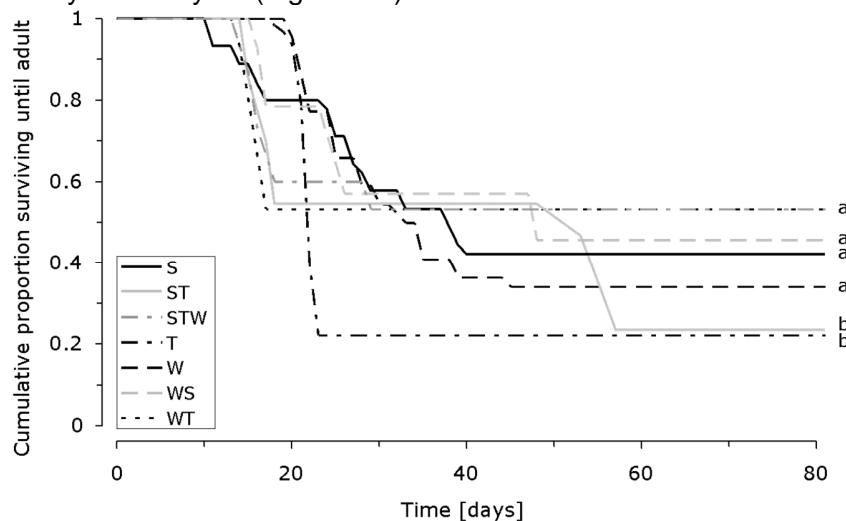


Figure 2-4: Cumulative survivorship of *Balaustium* predators on different diets. S refers to spider mite eggs, T to thrips larvae and W to whitefly eggs. Different letters next to the survivorship curves indicate significant differences.

2.4.3 Reproduction

Oviposition occurred within 1 or 2 days, implying big-bang reproduction. Thus, to characterize reproductive effort, it suffices to focus on fecundity per reproductive female (Figure 2-5A). Fecundity varied significantly with diet (GLM, $F_{6,46} = 3.34$, $P = 0.008$). In particular, fecundity on a diet of spider mite eggs was significantly lower than that on a diet of whitefly eggs or of thrips larvae.

The percentage of non-reproductive predatory mites (S_7) also varied with diet (Figure 2-3B; GLM, $F_{6,71} = 2.58$, $P = 0.026$). On a diet of whitefly eggs either with or without spider mites, fewer than 10% of the adult predators did not oviposit, whereas on the other diets this was 25 % or more. The proportion of non-reproductive predators fed on the mixed diet of eggs of whiteflies and spider mites and that fed on a diet of whiteflies alone was significantly lower than in the other treatments (Figure 2-5B).

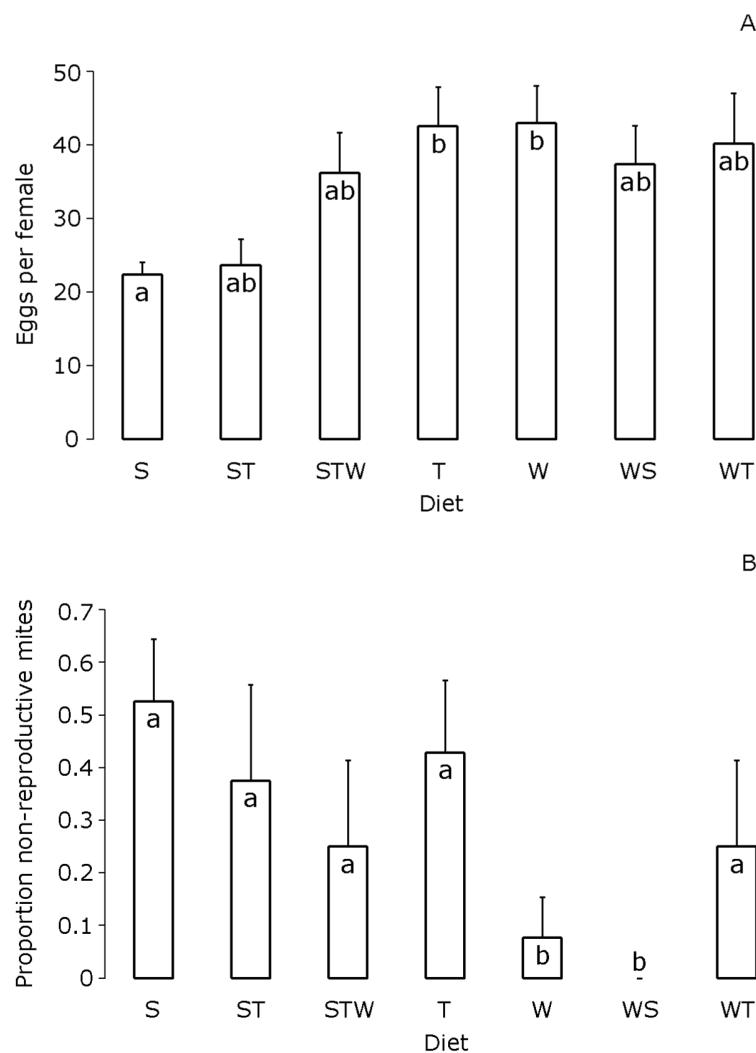


Figure 2-5: The effect of diet on a the average (+S.E.) total number of eggs laid by reproductive adult females of *Balaustium* and b the average (+S.E.) proportion of non-reproductive *Balaustium* females. Different letters indicate significant differences. S refers to spider mite eggs, T to thrips larvae and W to whitefly eggs

2.4.4 Life table parameters

Using the individual estimates of T and m_T and the population estimates of I_T , we calculated ‘individual’ r_m , their mean and standard error for each diet (Figure 2-6) and found significant dietary effects on r_m (GLM, $F_{8,47} = 12.88$, $P < 0.0001$). Clearly, a mixed diet of whitefly and spider mite eggs together gave the highest value of r_m and a diet of exclusively thrips larvae or spider mites resulted in the lowest values.

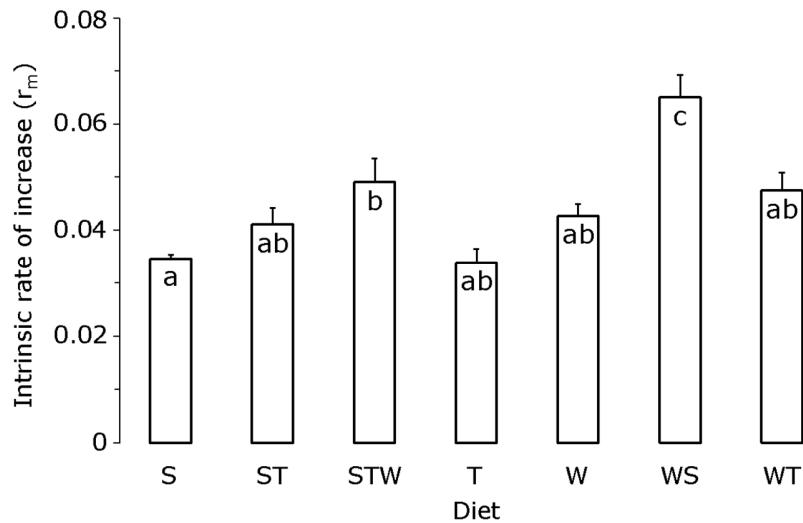


Figure 2-6: The effect of different diets on the intrinsic rate of population increase (r_m + S.E.) of *Balaustium*. Different letters indicate significant differences. S refers to spider mite eggs, T to thrips larvae and W to whitefly eggs

The effect of diet on R_0 was not tested separately because it essentially converges to analyzing the effect on fecundity (I_T being a population estimate). We found a non-significant negative correlation between the generation time T and the net reproductive rate $R_0 = I_T m_T$ (Figure 2-7A, linear regression, d.f. = 1,52, $R^2 = 0.045$, $P = 0.12$).

Regressing r_m against T is not very informative: because T was used to calculate r_m , it results in a spurious correlation. Instead, it was thought to be more instructive to see how r_m declines with T when r_m is calculated following expression (2-1), using each individual developmental time T (points in Figure 2-7B) and the overall mean R_0 (drawn line in Figure 2-6B). Clearly, the data points tend to be above the line for low values of T and below the line for higher values of T . This demonstrates the extent to which the R_0-T relation determines the individual r_m .

Figure 2-7 illustrates the main points of our life history assessment. First, a diet of thrips larvae or spider mites is the least profitable food in terms of R_0 and r_m (the data points cluster at the lower right end of the plot). Second, the mixture of eggs of whiteflies and spider mites tend to be the most profitable food source, especially when looking at r_m (all data point cluster at the higher left end of the plot, Figure 2-7B).

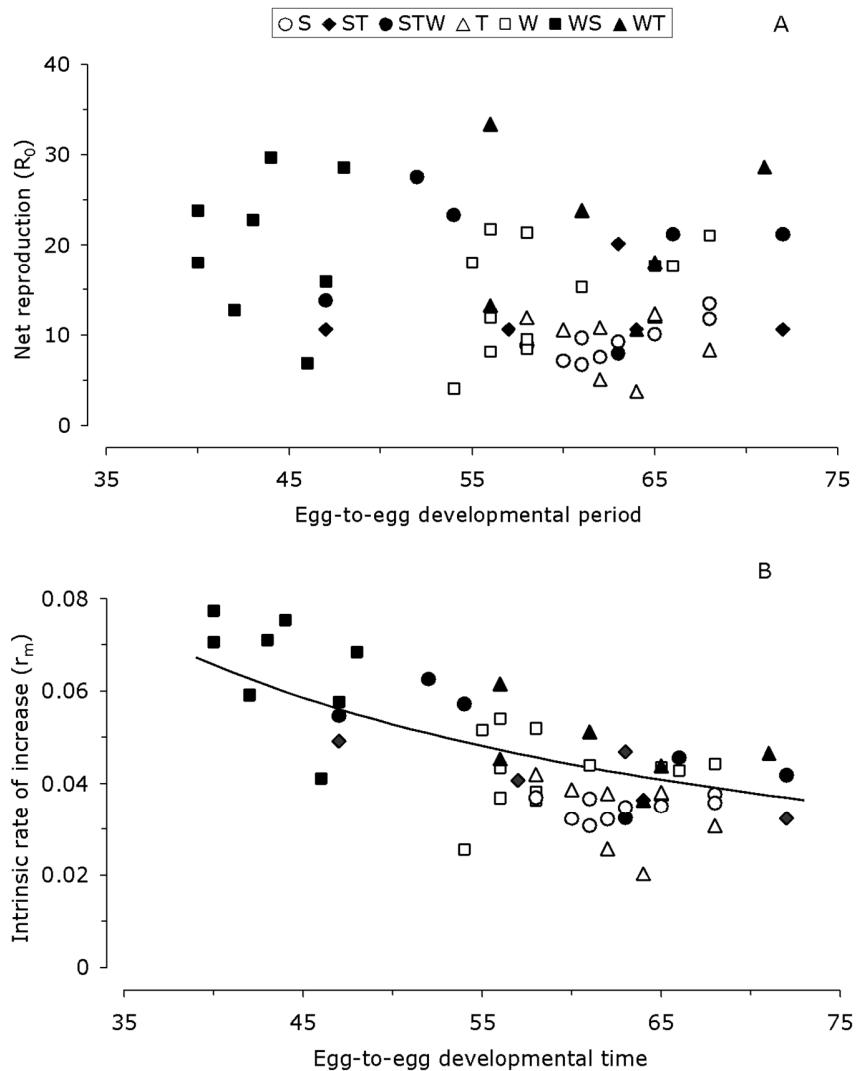


Figure 2-7: Relation of a net reproduction (R_0) and b the intrinsic rate of population increase (r_m) to egg-to-egg developmental period (T) of *Balaustium* on different diets (Figure 2-7A, linear regression, d.f. = 1, 52, $R^2 = 0.045$, $P = 0.12$).

Panel b only serves for visual inspection and was not used for a regression analysis because it would yield spurious correlations. The interpretation of this figure is facilitated by including a line expressing r_m as a function of T (see text). The deviation of the data from this line show the extent to which the relation between R_0 and T (Panel a) affects the value of r_m .

2.5 Discussion

2.5.1 Pronounced semelparity

We show that *Balaustium* exhibits big-bang reproduction or “pronounced semelparity” (Stearns 1976; Roff 1992; Stearns 1992; Hautekeete *et al.*, 2001): they lay all their eggs in

one or two days after a long period of development and die soon thereafter. Big-bang reproduction is widespread among the hard ticks (Acari: Ixodidae), whereas iteroparous reproduction prevails among the soft ticks (Acari: Argasidae) (Sonenshine 1991). On a continuous scale from “pronounced semelparity” to “pronounced iteroparity” (Hautekeete *et al.*, 2001), many fast-reproducing mites exhibit semelparous reproduction; examples are physogastric heterostigmatic mites (Bruce and Wrensch 1990; Kaliszewski *et al.*, 1995), prostigmatic mites such as eriophyoids (Sabelis and Bruin 1996) and tetranychoid mites (Sabelis 1991), and mesostigmatic mites such as phytoseiids (Sabelis and Janssen 1993). However, all these mites require a few weeks to produce all offspring and do not immediately die after reproducing (Blommers and van Arendonk 1979). Hence, they do not even come close to the phenomenon of big-bang reproduction as described here for *Balaustium* and elsewhere for *B. hernandezi* (Macol *et al.*, 2012). Theory on semelparous and iteroparous reproduction predicts that big-bang reproduction is favoured by natural selection when adult survival (up to the next reproductive bout) is predictably very low relative to juvenile survival (Cole 1954; Charnov and Schaffer 1973; Young 1981; Ranta *et al.*, 2002; Zeineddine and Jansen 2009). However, which ecological factors determine predictably low survival in adults of erythraeid predators remains to be elucidated. High soil surface temperatures may cause dramatic mortality, but at least some *Balaustium* spp. seem to resist temperatures up to 48 - 52°C and have a high dehydration tolerance (Hedges *et al.*, 2012). Critical factors determining survival of *Balaustium* clearly need to be investigated.

2.5.2 Effect of diet on life table parameters

In the case of big-bang reproduction, life-history theory predicts the existence of a switch point in the relative importance of net reproduction (R_0) and the generation time (T) (Caswell 1982). Here, we investigate the existence of such a switch point in *Balaustium*. The relative contribution of R_0 and T to r_m can be assessed from the ratio of r -values obtained after a fixed proportional increase (a) in R_0 (referred to as $r(R_0)$) and in $1/T$ (referred to as $r(T)$):

$$\frac{r(R_0)}{r(T)} = \frac{\ln(aR_0)/(T+1)}{a\ln(R_0)/(T+1)} = \frac{\ln(aR_0)}{a\ln(R_0)} \quad (2.2)$$

In order to study the relative importance of R_0 and T for the population growth rate of *Balaustium*, we assessed the change of r_m as a result of changing from feeding and developing on one diet to another diet. Because the change from diet j to diet i and the change from diet i to j would result in the same absolute value of the change in r_m , we took the subset of changes from an inferior diet to a superior diet. Hence, each combination of diets was represented once.

Expression (2) can be used to calculate the relative contribution of R_0 and T to r_m as a function of R_0 for equal proportional changes (a) in both parameters. However, the changes in R_0 and T were not equal in our data set. The R_0 on the best diet (whiteflies plus thrips) was 21.29 and on the worst diet (thrips) 9.35. Hence, the maximum proportional change in R_0 was $a = 2.277 (= 21.29/9.35)$. Likewise, T on the best diet (whiteflies plus spider mites) was 43.75, and on the worst diet (thrips) it was 63.0, resulting in a proportional change of $b = 1.44 (= 63.0/43.75)$. We used these values to calculate the relative contribution of R_0 and T to r_m as a function of R_0 using

$$\frac{r(R_0)}{r(T)} = \frac{\ln(aR_0)}{b\ln(R_0)} \quad (2.3)$$

The curve resulting from this (Figure 2-6) shows that R_0 contributes more to increases of r_m for values of $R_0 < 7$, whereas T is more important for higher values. Hence, there is indeed a switch point from R_0 being more important to T being more important for realistic values of these parameters.

We subsequently considered all possible diet changes of *Balaustium* that resulted in an increase of the intrinsic growth rate (hence, changing to a better diet) and calculated the contribution of R_0 and T to the increase in r_m using expression (2-3), using the relative changes in R_0 and T for this particular diet shift as estimates of a and b . The results are shown as points in Figure 2-6. Our data indeed show that the contribution of T to r_m is higher than that of R_0 for higher values of R_0 , whereas the opposite is true for low values of R_0 (Figure 2-8). However, the switch point seems to occur for somewhat higher values of the R_0 on the inferior diet than predicted (cf. points and curve in Figure 2-6). The existence of such a switch point has interesting consequences for the evolution of the life-history of *Balaustium*, which will experience stronger selection for higher net reproduction than for a shorter developmental period on some diets, and the reverse on other diets. This could be verified by setting up an experimental evolution approach with samples from the same population of this predator on different diets.

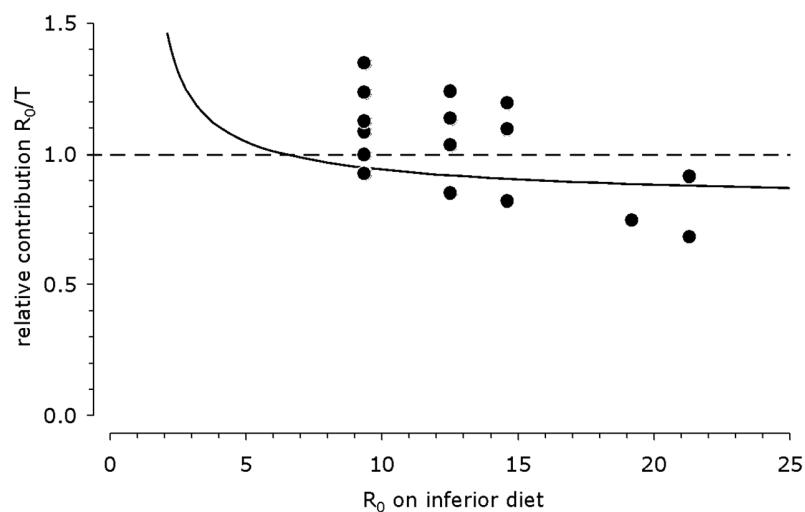


Figure 2-8: The relative contribution of R_0 and T to changes in intrinsic growth rate as a result of changing from an inferior diet to a superior diet. Above the interrupted line, the contribution of R_0 to an increase in r_m as a result from the switch from an inferior diet to a superior diet is more important, below this line, the contribution of T is larger. The curve is calculated using expression (2-3), (see text), points were calculated from the data of each possible shift from an inferior to a superior diet.

2.5.3 Thrips and spider mites as inferior prey

To explain the low performance on a diet of thrips larvae only, the above analysis indicates that we should focus on the factors that decrease net reproduction of the erythraeid predator (R_0). Thrips are known to counter-attack predatory mites, especially their eggs (Faraji *et al.*, 2002a, b; Janssen *et al.*, 2002; Magalhães *et al.*, 2005), and this may offer explanations for the low numbers of eggs found for predators on a diet of thrips. Firstly, the female predators may oviposit normally on a diet of thrips larvae, but counterattacks by the thrips may have resulted in egg mortality, thus falsely giving the impression that the oviposition rate of the predators was low. Second, it is known that predators may retain eggs when eggs run the risk of being preyed upon (Montserrat *et al.*, 2007), and this may have occurred here. Third, it is possible that thrips also injure adult predators, which are therefore unable to produce eggs (for such effects on phytoseiid predators, see Bakker and Sabelis 1989). Furthermore, the low juvenile survival on a diet of thrips larvae (Figure 2-4) may directly result from attacks on predator larvae by thrips larvae. In particular, the larvae of the erythraeid predator are vulnerable because they are similar in size to thrips larvae. The deutonymphs, however, are larger and therefore suffer less from counterattack by thrips larvae. All these possible effects warrant a more detailed study of counterattacking behaviour of the thrips and the impact on the predatory mites.

On the other hand, the decreased performance on a diet of spider mites which led to a r_m as low as the one obtained for the predators fed on thrips (Figure 2-6) was not due to low survival (Figure 2-4) but to the long generation and pre-oviposition time, the low oviposition, and the high number of individuals that did not reproduce. This could indicate that there is a deficiency in the nutrients found in the spider mite eggs: this possible lack of nutrients may have affected the development and reproduction of *Balaustium*.

2.5.4 The benefit of a mixed diet

The major outcome of this study is that the intrinsic rate of population increase was significantly higher when the predators fed on a mixture of whitefly eggs and spider-mite eggs compared to other diets. Such effects of mixed diets have been reported before (Toft and Wise 1999; Oelbermann and Scheu 2002; Messelink *et al.*, 2008; Harwood *et al.*, 2009). Because it was used a replacement design for the number of each prey species in the mixtures and because spider-mite eggs are smaller than whitefly eggs (thus containing less food), the higher reproductive capacity must be due to the nutritional composition of the mixed diet and not due to an increased availability of food. However, the quality of the diet is probably not only determined by nutritional content, but also by interference among the prey species, i.e. intraguild predation by thrips larvae, and by prey defences, such as the web of spider mites which protects the eggs, but can also be used as a refuge by thrips larvae. These latter factors were not taken into account in experiments (since the web was removed) and therefore it is need to be considered in future experiments.

Clearly, the role of mixed diets for predatory arthropods that are used as biological control agents needs more attention. Mixed diets may boost populations of predators, thereby increasing their impact on pest populations (see also Messelink *et al.*, 2008), even on

pests that are difficult to attack by the predators (Messelink *et al.*, 2010). Therefore it is advocate elaborate testing of dietary effects of all arthropods that are sufficiently abundant in the litter and on the plant and may serve as prey for biological control agents. Moreover, it would be worthwhile to investigate which alternative foods/prey can be manipulated to boost predator populations in the litter layer, thereby increasing their impact on pests in the crop.

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Chapter III

Capacidad de depredación de *Balaustium leanderi* sobre *Tetranychus urticae*, *Trialeurodes vaporariorum* y *Frankliniella occidentalis*

3.1. Resumen

Balaustium leanderi es un ácaro depredador que puede cambiar su tasa de depredación en función de la disponibilidad de presas. Los parámetros evaluados indican una respuesta funcional de tipo denso-dependiente directo, bajo el consumo de presas en estado inmaduro de *T. urticae*, *T. vaporariorum* y *F. occidentalis*. Las tasas máximas de consumo para todas las etapas de *B. leanderi* se obtuvieron para la mosca blanca (*T. vaporariorum*), seguido por los ácaros (*T. urticae*), mientras que el consumo de trips (*F. occidentalis*) fue considerablemente más bajo. Estos análisis se ajustaron a una respuesta funcional tipo III, con las tres especies de presa según el modelo de Real (1979). Este modelo fue desarrollado para describir a un depredador que "aprende" a mejorar su eficiencia de forrajeo según la densidad de presas, además proyecta el comportamiento de un depredador generalista.

3.2 Introducción

Los ácaros de la familia Erythraeidae presentan un ciclo de vida en diferentes estados de desarrollo que incluye una etapa inactiva (calyptostasic), cuando se encuentran en el estado de larva o ninfa. Los estados de desarrollo activo presentan diferentes hábitos de alimentación (Belozerov, 2008). La mayoría de las larvas son parásitos de diversos

artrópodos, mientras que los adultos y deutoninfas son depredadores. Sin embargo, hay excepciones en algunos Erythraeide, para éste comportamiento como es el caso de la mayoría del género *Balaustium*, reportado como depredador de diferentes artrópodos y en algunos casos se alimentan de polen cuando se encuentran en el estado de larva (Newell, 1963; Wellbourn, 1983; Halliday, 2001; Makol et al., 2012; Wohltmann et al., 2007; Muñoz-Cárdenes et al., 2014). *B. hernadezi* es un ácaro depredador que fue reportado recientemente en un cultivo de pimiento de invernadero (*Capsicum annuum*) en la provincia de Almeria, España y luego en cultivos de pepino (*Cucurbita pepo* L.) y berenjena (*Solanum melongena* L.) (Makol et al., 2012).

En Colombia se detectó la presencia natural de ácaros del género *Balaustium* en cultivos de flores en la Sabana de Bogotá (Torrado et al., 2001; Getiva y Acosta 2004), se describieron e identificaron los caracteres taxonómicos de los adultos (hembras), deutoninfas y larvas para *B. leanderi* (Fuentes et al., 2014). También se ha evaluado la preferencia de consumo hacia los huevos de *T. vaporariorum* y de *T. urticae* (Muñoz et al., 2009). Además, Muñoz-Cárdenes et al., 2014 determinaron el ciclo de vida, bajo diferentes combinaciones de presa (Larvas de *F. occidentalis*, huevos *T. vaporariorum* y *T. urticae*), y la combinación de huevos de *T. vaporariorum* y *T. urticae* presenta la tasa intrínseca de crecimiento más alta ($rm = 0,066$).

Es de gran importancia determinar todos los parámetros biológicos y ecológicos de un controlador natural que permitan, identificar su potencial efecto regulador de una población plaga (Hagen et al., 1976; Symondson et al., 2002). Según Luff (1983), hay características de relación depredador-presa básicas, como: voracidad, área de descubrimiento, respuesta funcional a la densidad de presas, interferencia mutua, respuesta numérica reproductiva y de comportamiento, heterogeneidad espacial y la respuesta de agregación del depredador. Estas deben ser consideradas y evaluadas para determinar su potencial como “controlador biológico”, y entre estas se resalta la evaluación de la respuesta funcional a la densidad de presas.

La respuesta funcional de un depredador es un factor clave en la dinámica poblacional de los sistemas depredador-presa (Holling, 1966), usualmente evaluada en función de la densidad de la presa por unidad de tiempo, e indica la máxima capacidad de consumo que puede tener un depredador o parasitoide respecto a la densidad de la presa u hospedero (Solomon, 1949). Estas variables se ajustan a un modelo que genera una curva, conocida como respuesta funcional (Gutierrez, 1996), que indica la estrategia de alimentación que puede presentar la especie evaluada (Morales et al., 2001). Existen diferentes modelos que pueden aplicarse, y la aplicabilidad de ellos depende de los datos recolectados, los modelos de mayor aplicabilidad son el modelo de Royama (1971) y Rogers (1972), el modelo de Fuente-Demanda de Gutierrez y Baumgartner (1996), y el modelo de la ecuación de disco de Holling (1959) (Gutierrez, 1996). La respuesta funcional indica la capacidad de un depredador para regular la densidad de su presa (Oaten y Murdoch, 1975), pero puede variar dependiendo de muchos factores, como es: el estado de desarrollo de su presa (Santos, 1975), las especies de plantas en las que se produce la interacción (Skirvin y Fenlon 2001), y la distribución espacial de la presa (Ryoo, 1986). Resultados en ácaros depredadores de la familia Phytoseiidae, presentan la respuesta funcional como uno de los parámetros base, para determinar su capacidad depredadora (Laing y Osborn, 1974; Reis et al., 2003; Sepúlveda y Carrillo, 2008; Xiao y Fadapiro, 2010).

No se han encontrado reportes sobre la respuesta funcional del género *Balaustium*. Sin embargo, hay algunos estudios de *B. putmani* consumiendo presas de *Panonychus ulmi* (Acari: Tetranychidae), en los cuales se determinó el número total de huevos de *P. ulmi* consumidos por el depredador en cada uno de los estados de desarrollo móviles, bajo condiciones controladas. El promedio diario de consumo de *B. putmani* en el estado de larva, deutoninfa y adultos fue de 2.8, 14.7 y 15.9 huevos de *P. ulmi* respectivamente (Cadogan y Laing, 1977).

Según los hábitos alimenticios, algunos rasgos biológicos y morfológicos, se presenta una clasificación de cuatro principales estilos de vida para depredadores de la familia Phytoseiidae: Tipo I. Depredadores especialistas en especies del género *Tetranychus* ó familia Tetranychidae ó super familia Tydeoidea; Tipo II. Depredadores selectivos de Tetraníquidos (frecuentemente asociados a especies que producen densas telas); Tipo III. Depredadores generalistas según hábitat o microhabitat y Tipo IV. Depredadores generalistas que también se alimentan de polen (McMurtry y Croft, 1997; McMurtry et al., 2013). Esta clasificación es útil para analizar el rol del depredador en un sistema de control biológico (Croft et al., 2004). Se destaca algunos resultados de respuesta funcional, para ácaros depredadores especialmente de la familia Phytoseiidae: *Typhlodromus negevi* presenta una respuesta funcional tipo II, cuando consume ninfas de *T. urticae* (Rasmy et al., 2014), tres especies de ácaros depredadores: *Phytoseiulus persimilis*, *Galendromus occidentalis*, y *Neoseiulus californicus* presentan una respuesta funcional tipo II, cuando consumen ninfas de *Panonychus citri* (Acari: Tetranychidae) (Xiao y Fadamiro, 2010), *Amblyseius chungas* presenta una respuesta funcional tipo II bajo diferentes densidades de adultos de *P. citri* mostrando una curva que llega a un nivel constante (Guanilo y Martínez, 2009). Sin embargo, McMurtry y Croft (1997) reportan que *A. chungas* es un depredador generalista con respuesta funcional tipo III. *Neoseiulus californicus* ha sido clasificado en una categoría intermedia entre especialista (tipo II) y generalista (tipo III) (Croft et al., 1998). Según Castagnoli y Simoni (2003), *N. californicus* es un depredador selectivo tipo II, porque se alimenta preferentemente de *T. urticae*, pero también es tipo III, porque puede alimentarse de polen ofertada por algunas plantas y ninfas de trips (Makoto et al., 2005).

Esta investigación contiene los resultados de la respuesta funcional y tasa máxima de consumo para *B. leanderi* (Acari: Actinotrichida: Erythraeidae) sobre *T. urticae*, *T. vaporariorum* y *F. occidentalis*, ajustado según el modelo de Real (1979).

3.3 Materiales y métodos

3.3.1 Condiciones de cría de *Balaustium leanderi*

Este estudio se realizó en los cuartos de cría el Laboratorio de Entomología del Centro de Bio-Sistemas de la Universidad Jorge Tadeo Lozano (CBIOS-UJTL) ubicado en el municipio de Chía, Cundinamarca, Colombia, a una temperatura promedio de $22.1^{\circ}\text{C} \pm 2$, humedad relativa del 75% y un fotoperíodo de 12 horas luz: 12 horas oscuridad. La cría del depredador se realizó en recipientes plásticos cilíndricos con una circunferencia de malla de acero de 10 cm de diámetro en la tapa para ventilación, se colocó turba en el fondo y se introdujeron 15 adultos de *B. leanderi* adultos a los cuales se les suministró como alimento *T. urticae*, *T. vaporariorum* y *F. occidentalis* dos veces a la semana. El pie

de cría del depredador en el CBIOS-UJTL se encuentra bajo invernadero a una temperatura máxima promedio de $31.7 \pm 3.5^{\circ}\text{C}$ y mínima promedio de $11.1 \pm 2^{\circ}\text{C}$.

3.3.2 Respuesta funcional y capacidad de depredación de *Balaustium leanderi*

Se evaluó el consumo de cada uno de los estados de *B. leanderi* al ofrecer cada una de las presas en diferentes densidades durante 24 horas (Tabla 3-1). Se realizaron 10 repeticiones por cada densidad de presa. Los estados de desarrollo de las presas evaluadas (huevos para *T. vaporariorum* y *T. urticae* y larvas para *F. occidentalis*) se eligieron según los resultados de preferencia obtenidos por Muñoz *et al.*, (2009). La unidad experimental consistió en un foliolo de rosa sobre el cual se colocó una sección transversal de tubo de PVC de 2 cm de diámetro y como base una caja de Petri pequeña, en el interior del cual se colocaron las presas junto con un depredador. Para la hidratación del foliolo se introdujo el peciolo en tubos plásticos con agua (Figura 3-1).



Figura 3-1: Bandeja con unidades experimentales

Tabla 3-1: Densidades de presa evaluadas para determinar la capacidad depredadora para cada estado activo de *Balaustium leanderi*

<i>Balaustium leanderi</i>	Presa	Densidad
	<i>T. urticae</i>	10 20 30 40 50 60 70 90 100 150 200 300 350
Adulto	<i>T. vaporariorum</i>	10 15 20 25 30 35 40 100 200 300 350
	<i>F. occidentalis</i>	3 6 9 11 15 20 40 60 80 100
Ninfa	<i>T. urticae</i>	10 15 20 25 30 40 45 60 90 120

	<i>T. vaporariorum</i>	10	15	20	25	30	35	70	100	130	150
	<i>F. occidentalis</i>	3	6	9	12	15	18	36	48		
	<i>T.urticae</i>	5	10	15	20	25	30	35	70	90	
Larva	<i>T. vaporariorum</i>	5	10	15	20	25	30	60	90		
	<i>F. occidentalis</i>	1	3	5	7	9	11	15	18		

Con el fin de identificar el modelo de respuesta funcional apropiado, se evaluaron ajustes mediante regresión no lineal a las ecuaciones de Holling (1966), Gutierrez-Baumgartner (1996) y Real (1979). Para analizar el potencial de depredación de *B. leanderi* sobre las diferentes presas, se utilizó un modelo de respuesta funcional general que representa respuestas de tipo II y tipo III (Real 1977; 1979).

$$Na = \frac{KA^\phi}{\chi + A^\phi} \quad (3-1)$$

El número de presas atacadas (*Na*) en función de las presas ofrecidas (*A*), la máxima tasa de consumo (*K*), y Φ es un parámetro que cuantifica la tasa de aumento en la detección de presas con el aumento de la densidad, que también es conocido como un "parámetro de aprendizaje" (Gutiérrez 1996). Si $\Phi=1$ la tasa de búsqueda de presa es constante y la respuesta funcional es de tipo II. Valores $\Phi>1$ indican aumento en la detección de presas y como la densidad de presas aumenta, la ecuación (3-1) genera una respuesta funcional de tipo III. El tipo de respuesta funcional fue confirmada por regresión logística polinómica sobre *Na/N* e interpretando el signo de los coeficientes, según lo propuesto por Juliano (2001).

Se consideraron los criterios de selección para el ajuste del modelo a los datos observados y la concordancia entre la interpretación de los parámetros matemáticos del modelo, la biología y el comportamiento del depredador. Los análisis se realizaron en el software R versión 3.01 de libre distribución.

3.4 Resultados

3.4.1 Capacidad de depredación

Todos los estados de desarrollo de *B.leanderi* presentan un mayor consumo *T. vaporariorum* seguido por *T. urticae* y finalmente *F. occidentalis* (Figura 3-2).

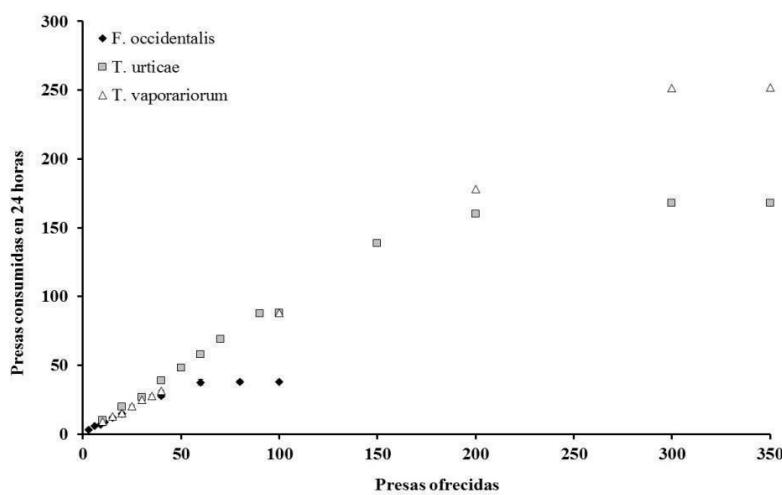
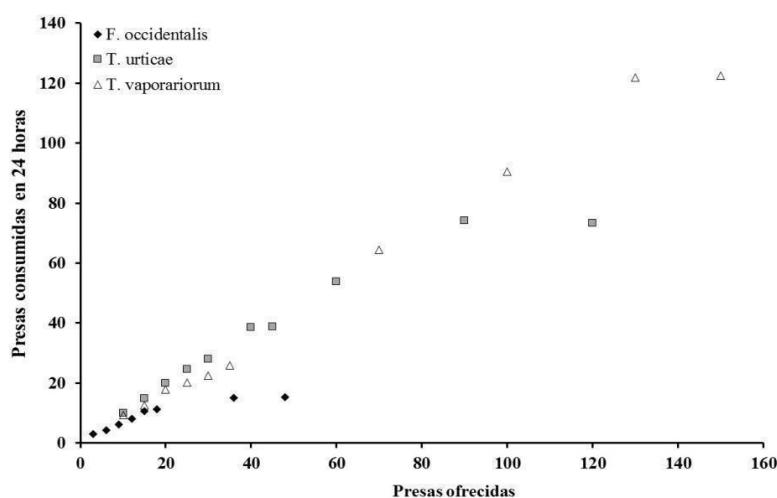
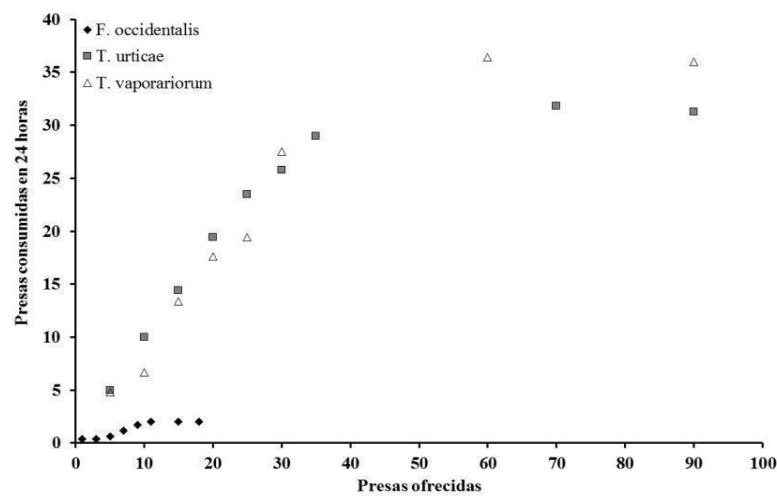
**a****b****c**

Figura 3-2: Consumo de presas de *Balaustium leanderi* (a) en el estado de adulto, (b) en el estado de deutoninfas, (c) en el estado de larva.

La tendencia de *B. leanderi* es consumir presas a medida que aumenta la densidad de la misma, hasta que se alcanza el máximo de capacidad de depredación por día. Las tasas máximas de consumo para todas las etapas de *B. leanderi* se obtuvieron para la mosca blanca (*T. vaporariorum*), seguido por los ácaros (*T. urticae*), mientras que el consumo de trips (*F. occidentalis*) fue considerablemente más bajo (Tabla 3-2).

3.4.2 Respuesta funcional

El parámetro de aprendizaje asume los valores por encima de 1 para las diferentes combinaciones de presa y depredador, lo que indica que *B. leanderi* exhibe una respuesta funcional de tipo III, según al modelo de Real (1979) (Tabla 3-2 y Figura 3-3), y fue confirmada por el análisis de regresión logística polinómica en todos los casos según lo propuesto por Juliano (2001).

Tabla 3-2: Los parámetros biológicos estimados para *Balaustium leanderi* asumiendo el modelo de respuesta funcional tipo III por Real (1979)

Estado de desarrollo <i>Balaustium leanderi</i>	Presa	Máximo consumo	Parámetro de aprendizaje	Pendiente máxima de alimentación
		K	ϕ	X
Larvas	<i>T. urticae</i>	33,7	1,85	172,5
	<i>T. vaporariorum</i>	40,5	1,82	298,6
	<i>F. occidentalis</i>	2,1	3,06	276,1
Ninfas	<i>T. urticae</i>	108,3	1,36	274,2
	<i>T. vaporariorum</i>	280,8	1,33	980,1
	<i>F. occidentalis</i>	18,4	1,36	34,4
Adultos	<i>T. urticae</i>	198,4	1,61	1724,0
	<i>T. vaporariorum</i>	454,7	1,31	1677,0
	<i>F. occidentalis</i>	46,6	1,47	150,2

El modelo de Real (1977) fue desarrollado para describir a un depredador que "aprende" a mejorar su eficiencia de forrajeo según la densidad de presas. Holling (1966) demostró que una respuesta tipo III son características de los vertebrados depredadores, los que tienen una capacidad relativamente alta de aprendizaje y cambio de comportamiento. Sin embargo, la respuesta funcional tipo III se ha evidenciado en muchos insectos depredadores y parasitoides (Hassell y Comins, 1977). La respuesta funcional III debe mostrar la dependencia de la densidad. Es decir, el depredador debe responder a la densidad de presas más altas por el consumo de una proporción creciente de la presa disponible en un rango de densidades de presas. Se caracterizan por su forma sigmoidal al trazar el número de presas consumidas por el depredador contra el número de presas disponibles (Holling, 1966) (Figura 3-3).

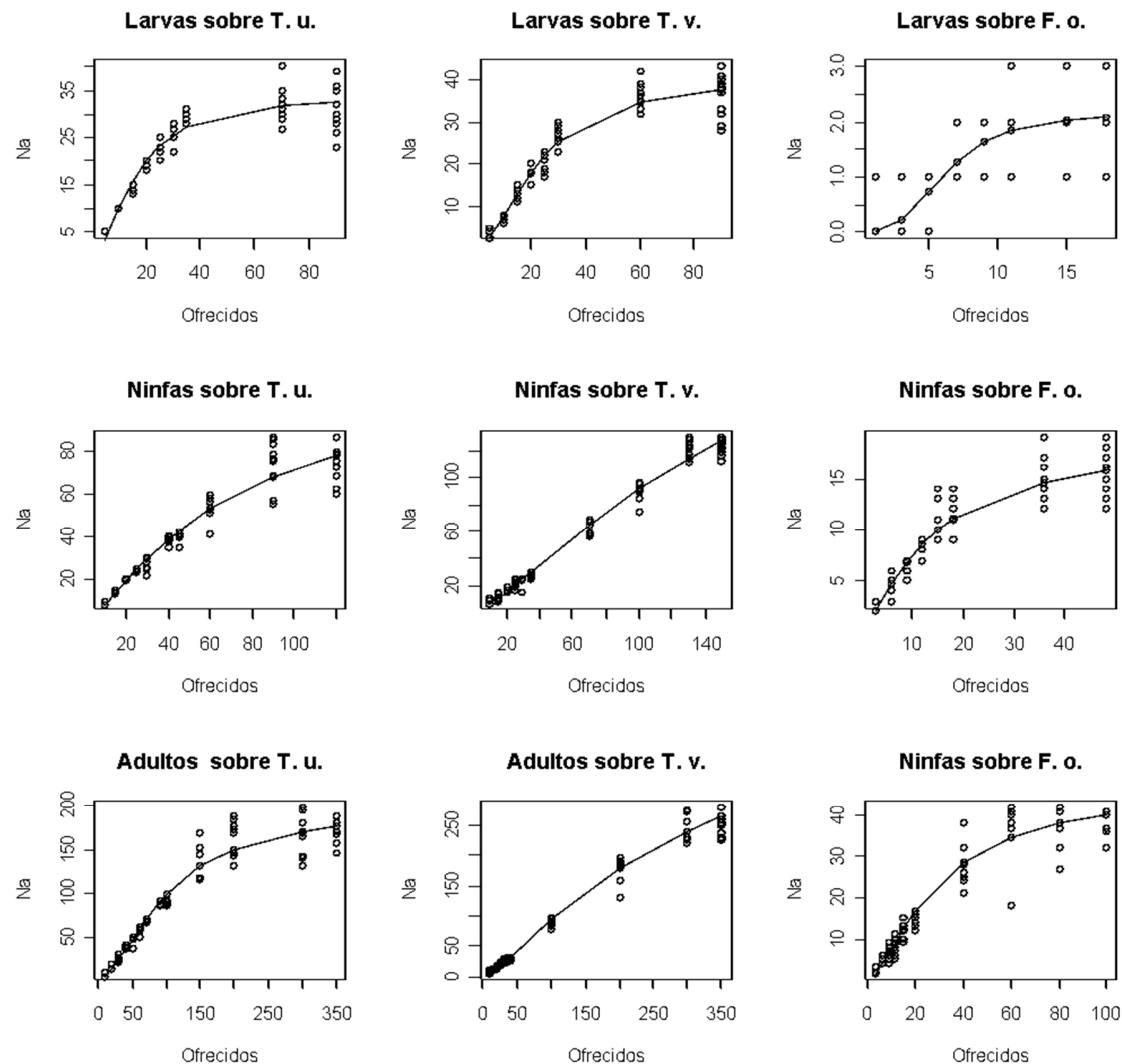


Figura 3-3: Respuesta funcional tipo III para cada uno de los estados del depredador y cada una de las presas. T.u.= *T. urticae*, T.v. = *T. vaporariorum*, F.o.= *F. occidentalis*.

3.5 Discusión

3.5.1 Capacidad de depredación

El consumo de *B. leanderi* en todos sus estados de desarrollo, es aproximadamente cinco veces mayor, comparado con *B. putmani*. Los resultados obtenidos para *B. leanderi* en su estado adulto, es de 168.1 ± 12.31 huevos/hembra/día de *T. urticae*, mientras que *B. putmani* en su estado adulto, presenta un consumo de 29.5 huevos/hembra/día de *P. ulmi*, según lo reportado por Cadogan y Laing (1977). Los mismos autores también indican el consumo en el estado de larva del depredador con 5.3 huevos/hembra/día de *P. ulmi* y 20.8 huevos/hembra/día de *P. ulmi* en el estado de ninfa del depredador *B. putmani*.

Es interesante comparar a *B. leanderi* con otros depredadores como *N. californicus*, aunque son especies muy diferentes, pertenecen a la subclase: Acari y tienen el mismo blanco biológico o presa. *B. leanderi* en presencia de *T. urticae* consume más del 90% que lo reportado por Cedola et al. (2002) con *Neoseiulus californicus*, bajo una dieta compuesta y una densidad máxima de 64 presas (adultos y huevos) de *T. urticae*, indican que el mayor consumo promedio es de 4.11, 4.00 y 4.33 para los estados de protoninfa, deutoninfa y adulto del depredador respectivamente, en 24 horas. En el mismo estudio, también reportan que el número de presas consumidas por *N. californicus* se incrementa con la densidad de la presa, y que los adultos y las deutoninfas mostraron un mayor consumo que las protoninfas.

Al comparar *B. leanderi* con otros depredadores de mosca blanca (*T. vaporariorum*) como *Macrolophus caliginosus*, se presenta tendencias similares como el incremento de consumo al aumentar la densidad de la presa, en un rango de 0 a 300 huevos de *T. vaporariorum* / hembra/ día. Según Hamdan (2006), *M. caliginosus* consume en promedio 40.7 huevos de *T. vaporariorum*, a una densidad de 50, es decir consume el 81.3% de las presas ofrecidas, mientras que a una densidad de 100 huevos aumenta la cantidad de consumo a 67.3 huevos/hembra/día, pero decrece su porcentaje a 67.3 %. Además que *M. caliginosus* a una densidad de 300 huevos, consume 93.5 huevos/hembra/día, es decir el 31% de la presa ofrecida. Al equiparar estos resultados con los presentados en *B. leanderi* en su estado adulto, el porcentaje de consumo de *B. leanderi* es más estable bajo diferentes densidades de la presa, con 78,5%, 87,9% y 72% de consumo de huevos/hembra/día de *T. vaporariorum* bajo las densidades de 40, 100 y 350 respectivamente.

B. leanderi también se puede comparar con otros ácaros depredadores generalistas como *Amblyseius swirskii* de la familia Phytoseiidae, que consumen de preferencia huevos y ninfas de *B. tabaci*, *T. vaporariorum* y estados inmaduros de *F. occidentalis* (Allen, 2010). Además consume *T. urticae*, *T. cinnabarinus*, *P. latus* y polen (Mansur, 1990; Arthurs et al., 2009; van Maanen et al., 2010). Adultos de *A. swirskii* consumen 32 presas/hembra/día de adultos de *P. latus*, (Onzo et al., 2012), presentando un patrón en la tasa de consumo que se estabiliza y se mantiene constante en el tiempo, independientemente del aumento en la densidad de presas (Tal et al., 2007). *B. leanderi* al igual que *A. swirskii* presenta alta capacidad de depredación.

3.5.2 Respuesta funcional

Se destaca la importancia de conocer la respuesta funcional de *B. leanderi*, porque según Turchin (2003), es un parámetro de evaluación biológica concluyente e importante en la dinámica de la población de depredadores. Para un gran número de artrópodos entomófagos, ha sido significativo conocer la tasa de depredación en función de la densidad de la presa, a través de la respuesta funcional (Hassell, 1978; Pitt y Ritchie, 2002; Vonesh y Bolker, 2005; Kratina *et al.*, 2009). En sistemas agrícolas productivos, la regulación de las poblaciones plaga, depende en gran medida de la respuesta funcional de los depredadores y parasitoides (Huang *et al.*, 2006; Timms *et al.*, 2008).

En todos los estados de desarrollo móviles de *B. leanderi*, presenta una respuesta funcional tipo III, con cada especie de presa ofrecida (*T. urticae*, *T. vaporariorum*, *F. occidentalis*), al igual que varios depredadores de la familia Phytoseiidae presentan una respuesta funcional tipo III (Croft *et al.*, 1998; Pratt *et al.*, 1999). La respuesta funcional de *N. californicus* y *T. bagdasarjani* sobre huevos y ninfas de *T. urticae* es tipo II (Farazmand *et al.*, 2012) y en ausencia de *T. urticae*, alimentándose de larvas de *Scolothrips longicornis* y de estados inmaduros de fitoseídos heteroespecíficos, *N. californicus* y *T. bagdasarjani* presentan una respuesta funcional Tipo III (Farazmand *et al.*, 2013). *Amblyseius swirskii* presenta una respuesta funcional Tipo III (Ragusa y Swirski, 1975), y una respuesta funcional Tipo II en diferentes densidades de *P. latus* (Tal *et al.*, 2007).

La respuesta funcional de *B. leanderi* es tipo III y según Hassell (1976) y Hassell (1978) los depredadores con este tipo de respuesta, tienen la capacidad de contribuir a la regulación de la población presa. Además, Berryman y Gutierrez (1999), indican que es una respuesta típica de enemigos naturales generalistas, que fácilmente cambian de una especie de presa a otra, y a medida que aumenta la densidad de presas, la depredación es más intensa, concentrando su ataque en zonas donde el recurso es más abundante (Turchin, 2003). Es una descripción de comportamiento de mayor complejidad, por contemplar la posibilidad de desplazamiento de los depredadores en una misma planta o entre plantas, según la densidad variable de las colonias presa (Badii y McMurtry, 1988). Los experimentos en dispersión con diferentes densidades de presa en la familia Phytoseiidae, han demostrado que las hembras se dirigen a los focos de alta densidad de la presa, y tienden a dejar a un lado las colonias con baja densidad de la presa, dedicando más tiempo en buscar una mayor oferta de alimentos. La depredación de la progenie en las colonias de baja densidad (por baja dispersión del depredador en los estados juveniles), conduce a un comportamiento adaptativo, de respuesta funcional de tipo III (Sabelis, 1985). En Colombia se realizó la evaluación de dispersión de *B. leanderi* en plantas de frijol infestadas con *T. urticae* Koch, separadas por 30, 40 o 50 cm, y con diferentes relaciones de depredador: presa (1: 135, 1: 285 y 1: 435). La liberación se realizó en una planta donadora de depredadores ubicada en el centro de las plantas infestadas con la presa. Después de seis horas, el depredador se trasladó a todas las plantas, independientemente de la distancia entre plantas y la relación de depredador: presa. Los depredadores se trasladaron principalmente a las plantas ubicadas, más cerca del punto de liberación (Zuluaga, 2012). Actualmente poco se conoce del comportamiento de éste depredador en condiciones naturales de campo.

La tasa de respuesta funcional está influenciada por varios parámetros de evaluación y entre ellos, se encuentra el tamaño de la arena experimental (Sabaghi *et al.*, 2011). En

estudios realizados con *Chileseius camposi* sobre *P. ulmi*, se reporta la influencia del efecto por la arena experimental, que en 2 cm de diámetro de área foliar se presenta una respuesta funcional Tipo II, pero cuando se aumenta el tamaño de la arena experimental se evidencia una respuesta de Tipo III (Sepúlveda y Carrillo, 2008). Otros autores también reportan la diferencia en los resultados según el tamaño de la arena experimental, para *Phytoseiulus longipes* en diferentes estados de desarrollo de su presa (*Tetranychus pacificus*) en hojas cortadas, la respuesta funcional es de tipo II, y cambia a tipo III cuando se evalúa en plantas (Badii y McMurtry, 1988). En el caso de la arena experimental evaluada con *B. leanderi* se observa que la tasa de detección se reduce en bajas densidades y aumenta a medida que la densidad de presas aumenta. Lo que indica que en una arena experimental de mayor tamaño los depredadores podrían dispersarse desde las áreas de menor densidad de presas, a parches de mayor oferta de la presa (Hassell y Comins 1977; Nwilene y Nachman, 1996). Por lo anterior, es importante realizar otras investigaciones con *B. leanderi* en arenas experimentales de mayor tamaño.

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Chapter IV

El potencial de *Balaustium leanderi* como agente controlador biológico

Es importante conocer las características biológicas y ecológicas de un depredador que permitan identificar su efecto potencial como regulador de plagas (Huffaker and Messenger, 1976). Las características de relación depredador-presa se determinan con la medición de parámetros biológicos (Luff, 1983). Los depredadores generalistas deben cumplir con características de buena adaptabilidad a los cambios en las poblaciones de la plaga, sobrevivir en bajas densidades de la presa objetivo, tener hábitos flexibles de alimentación, altas habilidades reproductivas, buena capacidad de dispersión, mínima competencia intragremio y de baja interferencia mutua (Ehler y Miller, 1978; Ehler, 1990). Estos parámetros biológicos y de comportamiento permiten crear un marco de referencia cuantitativa para deducir las consecuencias potenciales de las interacciones biológicas que tienen lugar en los agroecosistemas (Luck *et al.*, 1988). Aún falta determinar otros parámetros biológicos y ecológicos del ácaro depredador *Balaustium leanderi*; como la interferencia mutua, la respuesta numérica del comportamiento reproductivo y el comportamiento de depredación intragremio que permitan identificar su potencial efecto regulador de poblaciones plaga (Hagen *et al.*, 1976).

Hay varios ácaros pertenecientes a la familia Erythraeidae con potencial para su uso en el control biológico (Welbourn, 1983). Investigadores como Cadogan y Laing (1977), Welbourn y Jennings (1991), Yoder *et al.*, (2006) y Solomon *et al.*, (2000) han establecido que depredadores generalistas del género *Balaustium* (Acari: Erythraeidae) tienen gran potencial como controladores biológicos ya que pueden sobrevivir sobre diferentes tipos de presas (Tabla 4-1). Los depredadores generalistas en ocasiones pueden lograr una disminución importante en la población de plagas de diferentes cultivos agrícolas. Los artrópodos depredadores nativos son de gran importancia en programas de manejo integrado de plagas debido a su adaptación a las condiciones ambientales del lugar, lo que les confiere una mayor posibilidad de establecerse en el cultivo y de controlar las plagas de una manera eficiente (Symondson *et al.*, 2002).

Table 4-1 Reporte de especies del género *Balaustium* como enemigo natural de plagas agrícolas

Habitat/ sustrato	Hervíboro o presa	Lugar	Especie	Referencia
Árboles y suelo de plantas de cítricos	[<i>Aonidiella aurantii</i> (Maskell)] (Hemiptera: Diaspididae) Y otros insectos y ácaros pequeños	California, USA	<i>B. aonidophagus</i>	Ebeling (1934)
Plantas de manzanas	Ácaros <i>Panonychus ulmi</i> (Koch) (Acari: Tetranychidae)	Ontario, Canada; Ohio, USA	<i>B. putmani</i>	Cadogan and Laing (1977, 1981); Yoder and Heydinger (2011)
Plantas de manzanas	<i>Bryobia praetiosa</i> , <i>P. ulmi</i> and <i>T. urticae</i>	Missouri, USA	<i>B dowelli</i>	Childers and Enns 1975
Plantas de algodón	Huevos de <i>Heliothis zea</i>	Arkansas, USA	<i>B dowelli</i>	Smiley (1964)
Plantas de manzanas	Ninfas de <i>Aphis pomi</i> DeGeer; <i>Dysaphis plantaginea</i> (Passerini); <i>Eriosoma lanigerum</i> (Hausmann); huevos de <i>Spodoptera frugiperda</i> (J.E. Smith); Estados inmaduros de <i>T. urticae</i> y <i>P. ulmi</i> Larvas de Cecidomyiid	North Carolina, USA	<i>B. putmani</i>	Childers and Rock (1981)
Plantas de durazno	<i>Panonychus ulmi</i> (Acari: Tetranychidae) <i>Quadraspidiotus perniciosus</i> Comstock (Hemiptera:Diaspididae) <i>Aphis pomi</i> De Geer Ninfas de <i>Paraphlepsius irroratus</i> Say (Hemiptera Cicadellidae)	Ontario, Canada,	<i>B. putmani</i>	Putman et al. 1970
	Larva de yema de abeto[<i>Choristoneura fumiferana</i> (Clemens)] (Lepidoptera: Tortricidae)	Maine, USA	<i>B. kendalli</i>	Welbourn and Jennings (1991) ; Welbourn (1995)
Aguacate (<i>Persea americana</i> Miller)	<i>Scirtothrips perseae</i> Nakahara (Thysanoptera: Thripidae)	Guatemala state, Guatemala	<i>Balaustium</i> sp.	Hoddle et al. (2002)
Palmitos, <i>Serenoa repens</i> (Bartr.) Pequeño Japanese tártago, <i>Pachysandra terminalis</i> Sieb. and Zucc.	Cochinillas (Hemiptera)	Ohio, USA	<i>Balaustium</i> sp.	Yoder et al. (2006)
Pimienta dulce, pepino y berenjena	Trips (Thysanoptera: Thripidae), Mosca blanca (Hemiptera: Aleyrodidae), Ácaros (Acari: Tetranychidae)	Almeria province, Spain	<i>B. hernandezii</i>	Makol et al. (2012)
Plantas de Rosa, tomate, frijol y <i>Trifolium repens</i>	<i>Frankliniella occidentalis</i> , <i>Trialeurodes vaporariorum</i> and <i>Tetranychus urticae</i>	Cundinamarca, Colombia	<i>B. leanderi</i>	Muñoz et al. (2009); Muñoz-Cárdenas et al. (2014)

Especies de *Balaustium* han sido considerados como depredadores benéficas en cultivos agrícolas, tales como *B. putmani*, *B. hernandezii*, *B. leanderi* (Tabla 4-1). Sin embargo, se sabe muy poco sobre su potencial como regulador de poblaciones plaga. *Balaustium leanderi* con una respuesta funcional tipo III, podría equilibrar la población de *T. vaporariorum* y *T. urticae* en condiciones de campo, porque al compararlo con varios ácaros depredadores que pertenecen a la familia Phytoseiidae, son ampliamente utilizados en todo el mundo para el control biológico de plagas (McMurtry, 1983; Opit et al., 2004; Cakmak et al., 2009; Arthurs et al., 2009) y han sido eficientes en el control de plagas como depredadores generalistas Tipo III (Sepúlveda, 2003), como *Amblyseius idaeus* Moraes y McMurtry (Cedola y Botto, 1996) y *Typhlodromus bambusae* Ehara (Zhang et al., 1999). Además los depredadores con respuesta funcional Tipo III, contribuyen en la regulación de la población de insectos o ácaros hervíboros (Hassell, 1976; Hassell, 1978).

En estudios de comportamiento básico con adultos de *B. leanderi*, el depredador presenta un similaridad en la proporción de tiempo sobre la presa, cuando se alimenta de *T. vaporariorum* (59%), y cuando se alimenta de *T. urticae* (57%) (Morales, 2012). La preferencia de consumo *B. leanderi* por los huevos de las presas ofrecidas se puede explicar por la facilidad de captura en éste estado de desarrollo (Lang y Gsödl, 2001; Reitz et al., 2006). Además, el depredador puede obtener los recursos necesarios con un nivel bajo de actividad. Presas móviles podrían tener estrategias de defensa física o química, que conllevan a un mayor esfuerzo y consumo, así como la reducción de la proporción de tiempo de reposo (Collier et al., 2007). El tiempo empleado en la búsqueda de presas fue significativamente mayor en los huevos de *T. vaporariorum* (18%) que en los huevos de *T. urticae* (8%) (Morales 2012). La explicación podría estar relacionada con la producción de compuestos volátiles de los huevos de *T. vaporariorum*, lo que podría perturbar la ubicación por el depredador, de una manera similar como un compuesto derivado de triptófano presente en las secreciones de áfidos, que afecta a la ubicación de los depredadores (van Emden and Hagen, 1976; Choi et al., 2003).

Al comparar bajo confinamiento la capacidad de depredación de *B. leanderi* en su estado adulto es de 252 ± 20.78 huevos/hembra/día de *T. vaporariorum*, que corresponde al 72% de consumo de la presa ofrecida. Estos resultados generan una expectativa importante para continuar estudiándolo, al compararlo con otros depredadores de mosca blanca como *M. caliginosus* que a una densidad de 300 huevos, consume 93.5 huevos/hembra/día, es decir el 31% de la presa ofrecida (Hamdan, 2006).

La tasa de depredación de *B. leanderi* es mayor sobre los huevos de *T. vaporariorum* que sobre huevos de *T. urticae*. Sin embargo, su tasa intrínseca de crecimiento de la población es mayor, bajo una dieta mixta de las dos presas mencionadas (Muñoz-Cárdenes et al., 2014), lo que indica que podría sobrevivir en cultivos con presencia de mosca blanca y ácaros.

Claramente el papel de las dietas mixtas para artrópodos depredadores que se utilizan como agentes de control biológico necesita más atención. Las dietas mixtas pueden aumentar las poblaciones de depredadores, lo que aumenta su impacto en las poblaciones de plagas (Messelink et al., 2008), incluso en las plagas que son difíciles de atacar por los

depredadores (Messelink *et al.*, 2010). La calidad de la dieta no sólo está determinada por el contenido nutricional, sino también por la interferencia entre las especies de presa, ejemplo la inter depredación de las larvas de trips (van Maanen *et al.*, 2012). Una barrera importante para acceder al alimento, es el mecanismo de defensa que pueden presentar las presas como es la red o telaraña que protege a los huevos de ácaros (*T. urticae*) y que a su vez pueden utilizar las larvas de trips como un refugio. Se resalta la importancia de realizar evaluaciones del efecto de la dieta que incluya ácaros detritívoros o saprófagos que pueden servir como presa alternativa para el establecimiento de los agentes de control biológico (Symondson, 2002).

Los hábitos polífagos de algunas especies de *Balaustium*, indican que podrían implementarse en algunos sistemas de manejo biológico de plagas. Sin embargo, la depredación intragremio podría ser un factor limitante y todavía no hay estudios que lo corroboren. En general *B. leanderi* podría implementarse en sistemas de control biológico por conservación, pero se necesita mayor investigación para dilucidar su potencial como agentes de control biológico. Por lo anterior, es importante indagar sobre presas o alimento alternativo que puede ser manipulado, para aumentar las poblaciones de depredadores en la capa de hojarasca, lo que aumenta su establecimiento y por ende, una disminución de la población de plagas en el cultivo. La existencia de éstas interrelaciones traen consecuencias interesantes para la evolución experimental del depredador en diferentes dietas, que generen información para la historia de vida de *B. leanderi*. Además, se deben evaluar las interacciones entre *B. leanderi* y otros enemigos naturales bajo condiciones de campo para identificar las sinergias positivas que se podrían utilizar para mejorar el control biológico (Symondson *et al.*, 2002).

Para complementar su potencial como controlador biológico se proyecta realizar varias investigaciones encaminadas a evaluar la interacción de *B. leanderi* con la estrategia de manejo de hábitat "push-pull", como una nueva herramienta eficaz en el manejo integrado de plagas (MIP), donde se utiliza la combinación de estímulos de comportamiento para manipular la distribución y abundancia de las plagas y / o de sus enemigos naturales (Cook *et al.*, 2006 y Bennison *et al.*, 2002). En la estrategia de "push-pull", las plagas son repelidas o disuadidas lejos del recurso protegido (push) por estímulos que perturban la ubicación de las plantas de producción. Mediante el uso de estímulos altamente atractivos, las plagas son atraídas simultáneamente (pull) a la fuente específica en la que se concentran, facilitando su eliminación y dejando el recurso protegido (Khan y Pickett 2004; Zhang *et al.*, 2013). Así mismo, dicha estrategia debe contemplar la atracción del depredador en la fuente (pull), como refugio a *B. leanderi* en proyección de optimizar el control biológico en cultivos de flores.

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Conclusiones

Se genera el primer reporte para Colombia de *Balaustium leanderi* como depredador de *Trialeurodes vaporariorum*, *Tetranychus urticae* y *Frankliniella occidentalis* asociados a plantas de rosas, fríjol y tomate.

Se presenta una re-descripción completa de *Palenquistium* Haitlinger (2000), bajo el género *Balaustium*, mediante la identificación de cada uno de los caracteres taxonómicos esenciales en el estado adulto (hembras), deutoninfa y larva para *Balaustium leanderi*.

Se reporta la importancia de las dietas mixtas, para obtener la mayor tasa intrínseca de crecimiento de la población de *B. leanderi* y se establece como una especie con reproducción de semelparidad pronunciada.

Se determina una respuesta funcional Tipo III y una alta capacidad de depredación con las diferentes densidades y presas ofrecidas, con la clara característica de un depredador generalista, lo que infiere en la capacidad *B. leanderi* para sobrevivir en plantas asociadas a mosca blanca y ácaros en condiciones de campo.

Se realizó un primer balance de proyección con las características positivas y negativas, que indican que *B. leanderi* tiene una perspectiva positiva de contribuir en un futuro a la regulación de la poblaciones plaga en cultivos de flores.