

## RESEARCH ARTICLE

### Survival and fecundity of *Dichroplus maculipennis* and *Ronderosia bergi* (Orthoptera: Acrididae: Melanoplineae) following infection by *Beauveria bassiana* (Ascomycota: Hypocreales) under laboratory conditions

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This study examined the effects of strain *Beauveria bassiana* (LPSC 1067) on nymphal development time, fecundity and adult survival in *Dichroplus maculipennis* and *Ronderosia bergi* under laboratory conditions. It was observed that infection with  $1 \times 10^3$  conidia/ml altered nymphal development time, fecundity and adult survival in both species. Mortality of *D. maculipennis* during third through the last instar (sixth) was significantly higher among treated nymphs ( $66 \pm 3.8\%$ ) than in controls ( $15 \pm 1.7\%$ ). Similarly, mortality in *R. bergi* during third through the last instar (fifth) was higher in treated nymphs ( $71 \pm 2.8\%$ ) than in controls ( $19 \pm 1.5\%$ ). Nymphal development times of both infected *D. maculipennis* and *R. bergi* were longer than controls. On the other hand, among survivors of both the species, control adults lived longer than infected adults. Finally, control grasshoppers of both species were much more successful reproductively than infected grasshoppers.

**Keywords:** *Dichroplus maculipennis*; *Ronderosia bergi*; Orthoptera: Acrididae; grasshoppers; *Beauveria bassiana*; entomopathogenic fungi

#### Introduction

As in other temperate grasslands of the world, grasshoppers are among the most important native herbivores throughout the Argentine Pampas and parts of Patagonia (Mariottini, De Wysiecki, & Lange, 2011a). The economic importance as agricultural pests of these insects has been recognised in the country since the mid-to-late nineteenth century, and outbreaks of different species are a recurring phenomenon (Lange, Cigliano, & De Wysiecki, 2005). The melanopline grasshoppers selected for this study are two of the 18 grasshopper species considered as economically important in Argentina (Cigliano, Pocco, & Lange, in press). *Dichroplus maculipennis* (Blanchard) is a characteristic univoltine species of grasshopper communities in the areas of the Pampas and Patagonia regions (Lange & Azzaro, 2008; Mariottini et al., 2011a). *Ronderosia bergi* (Stål) is a common species with no obligatory embryonic diapause (i.e., multivoltine capacity) in natural grasslands and crops in areas of central and northern Argentina (Mariottini,

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De Wysiecki, & Lange, 2010). Both species have a wide geographic distribution, occurring in southernmost Brazil, much of Argentina and Chile and Uruguay (Mariottini, De Wysiecki, & Lange, 2006; Mariottini et al., 2011a). Although an introduced biocontrol agent, the microsporidium *Paranosema locustae* (Canning) is known to be established in parts of the Pampas and Patagonia (Bardi, Mariottini, Plischuk, & Lange, 2012; Lange & Azzaro, 2008); chemical insecticides are still the only available option for grasshopper control in the country, but their use is of significant environmental concern (Goldstein et al., 1999; Gonzalez, Miglioranza, Aizpún, Isla, & Peña, 2010; Jergentz, Mugni, Bonetto, & Schulz, 2005).

Fungal entomopathogens are important biological control agents worldwide and have been the subject of intense research for more than 100 years (Vega, Meyling, Luangsa-ard, & Blackwell, 2012). While the majority of studies assessing pathogens as biocontrol agents deal with their ability to produce mortality in the target pest (Blanford & Thomas, 2001), previous studies have indicated that infection with the fungal entomopathogen *Metarhizium acridium* (Driver & Milner) can reduce feeding and flight ability in the desert locust *Schistocerca gregaria* Forskal (Moore, Reed, Le Patourel, Abraham, & Prior, 1992; Seyoum, Moore, & Charnley, 1994). However, the sublethal effects produced by entomopathogenic fungi on grasshoppers that survive infection have been seldom addressed.

As in other insects, some features of the life cycle of grasshoppers such as longevity, reproduction and development time, among others, are key factors in the population dynamics of the different species (Joern & Gaines, 1990). Understanding the influence of the pathogen on the developmental period and reproduction of an insect pest is important in order to develop a successful biocontrol agent. Therefore, the aim of this study was to evaluate the influence of *Beauveria bassiana* (LPSC 1067) (Ascomycota: Hypocreales) on nymphal development time, fecundity and adult survival in the pest grasshoppers *D. maculipennis* and *R. bergi* under laboratory conditions.

## Materials and methods

### Collection of insects

Adult males and females of *D. maculipennis* and *R. bergi* were collected with insect 1 nets in natural and improved pastures at the locality of Laprida (36° 02'S, 59° 06'W), Buenos Aires province, in the southern Pampas region as defined by Morrone (2006). Once in the laboratory, grasshoppers were kept following general procedures as described by Henry (1985). Individuals of both sexes were placed in wire-screened, aluminium cages (20 × 20 × 30 cm) in a rearing room under controlled conditions (30°C, 14L:10D, 40% RH) routinely used worldwide (Hinks & Erlandson, 1994; Mariottini et al. 2010, 2011b). Grasshoppers were fed daily with thoroughly washed, fresh leaves of a variety of grasses, lettuce, cabbage and wheat bran flakes. Each cage was provided with substrates for egg-pod laying that consisted of plastic containers (10 cm deep) filled with sterilised sand. Thermoregulation and mating was stimulated with 75W bulbs suspended 15 cm above each cage. Grasshoppers were maintained until death when they were immediately examined by dissection (Lange, 1996) or incubated in humid chambers (Lacey & Brooks, 1997) to check for their sanitary

condition. Nymphs emerging from the resulting egg-pods were used in the laboratory assays. This procedure was carried out separately for both species of grasshoppers.

### **Fungal isolate**

The fungal strain used was *B. bassiana* (LPSC 1067) from the culture collection of the Spegazzini Institute (LPSC), La Plata, Argentina. The choice of this fungal strain was based on its laboratory efficacy against other pest grasshopper and locust species of Argentina (Pelizza et al. 2012a; Pelizza, Eliades, Scorsetti, Cabello, & Lange 2012b). Conidia of the fungal strain were obtained from the cultures on potato-dextrose-agar medium after incubation for 10 days at 25°C in darkness.

### **Preparation of conidial suspension**

Conidia were harvested with disposable cell scrapers (Fisherbrand®) from 10-day-old cultures and placed in test tubes containing 0.01% (v/v) Tween 80® (polyoxyethylene sorbitan monolaurate) (Merck). Suspensions were vortexed for 2 min, filtered through four layers of sterile muslin and adjusted to  $1 \times 10^3$  conidia/ml according to Blanford and Thomas (2001) after cell counting in a Neubauer haemocytometer. Viability of the fungal conidia was determined after 24 h as described by Lane, Humphreys, Thompson, and Trinci (1988). This germination test was repeated for each stock suspension to maintain the fidelity of the viability assessments.

### **Insect rearing and inoculation procedure**

At hatching, groups of five nymphs were placed in acetate tubes (50 cm long  $\times$  9 cm diameter) (Henry, 1985). After the first moult, grasshoppers were kept individually in similar cages, but smaller (20 cm long  $\times$  10 cm diameter). After the second moult, 161 and 200 individuals of *D. maculipennis* and *R. bergi*, respectively, were inoculated individually by spraying with 1 ml of a conidial suspension of  $1 \times 10^3$  conidia/ml (in 0.01% [v/v] Tween 80®). As control groups, 60 and 66 individuals of *D. maculipennis* and *R. bergi*, respectively, were used. The controls were sprayed in the same fashion, but with 1 ml of 0.01% [v/v] Tween 80® only. After inoculation, grasshoppers were kept under controlled conditions (30°C, 14L:10D, 40% RH) while nymphal development time, fecundity and adult survival were monitored and recorded on a daily basis. Immediately after moulting to adults, females and males of both species were separated into couples (1 ♂, 1 ♀). Each couple was placed in a wire-screened, aluminium cage (12  $\times$  12  $\times$  16 cm). Survival and egg production (number of eggs per pod) by pairs were monitored and recorded throughout their lives. Dead grasshoppers were removed and immediately deposited in high-humidity chambers (sterile Petri dishes with filter paper dampened with sterile distilled water). Mycosis was confirmed by microscopic examination of the dead grasshoppers.

### **Statistical analyses**

An Analysis of Variance (ANOVA model I) in accordance with bifactorial methodology was performed to determine if the differences were significant between controls and treatments at each nymphal stage evaluated for both *R. bergi* and

*D. maculipennis*. This model evaluates the species\*treatment interaction. The variable used was numbers of days lived by species evaluated to each nymphal stage. The parameters for ANOVA test were analysed. For later comparisons a Tukey test for unbalanced data was used.

A unifactorial ANOVA test was used for evaluation of the significant difference between treatment and control of the sixth stage of *D. maculipennis*. A Model I multifactorial ANOVA test (species, treatment and sex) was used for evaluation of the number of days lived for both species since adulthood to death. Data were transformed by square root and then analysed by ANOVA and Tukey tests (interaction sex\*treatment for each grasshoppers species). ANOVA with accordance bifactorial and multifactorial ANOVA test were performed with the software Version InfoStat 2007 (InfoStat, 2001).

## Results

The inoculation of grasshoppers with the fungus significantly altered nymphal development time, fecundity and adult survival of both grasshopper species. Mortality in *D. maculipennis* during third through sixth instars was substantially higher among treated nymphs ( $66 \pm 3.8\%$ ) than in controls ( $15 \pm 1.7\%$ ). Similarly, mortality in *R. bergi* during third through fifth instar was higher in treated nymphs ( $71 \pm 2.8\%$ ) than in controls ( $19 \pm 1.5\%$ ). More than 95% of the dead grasshoppers exhibited outward growth of the fungus after 24 h under humidity chamber incubation. Similarly, nymphal development times of infected *D. maculipennis* and *R. bergi* were longer than in controls (Table 1).

Statistical analysis showed that for third and fourth instars, differences were highly significant ( $p < 0.01$ ) for species and treatment factors, but the interaction between these was not significant ( $p > 0.001$ ) (Table 2). Not significant differences ( $p > 0.01$ ) were observed for the Species factor in the fifth stage. The treatment factor and the interaction between both factors (species\*treatment) were highly significant ( $p < 0.01$ ) (Table 2). The sixth instar of *D. maculipennis* showed highly significant differences ( $p < 0.01$ ) between treated and controls.

Among the survivors of both species, control adults lived considerably longer than treated adults (Figures 1 and 2). Statistical analysis showed that for the evaluation of the number of days lived for both species from adulthood to death,

Table 1. Number of days lived by *Dichroplus maculipennis* and *Ronderosia bergi* (mean  $\pm$  SD) in each nymphal instar, at 30°C and 14:10 L.D. Number of days lived followed by the same letter are not significantly different according to the Tukey test for unbalanced data ( $\alpha = 0.01$ ), CV = coefficient of variability.

Species	Treatment	Third instar	Fourth instar	Fifth instar	Sixth instar
		CV = 16.11 N = 324	CV = 15.59 N = 250	CV = 15.86 N = 231	CV = 16.84 N = 106
<i>R. bergi</i>	Treated	13 $\pm$ 1.3 a	14 $\pm$ 1 a	18 $\pm$ 1.9 a	–
<i>R. bergi</i>	Control	7 $\pm$ 0.8 c	8 $\pm$ 1.2 c	9 $\pm$ 1.1 d	–
<i>D. maculipennis</i>	Treated	12 $\pm$ 2.4 b	15 $\pm$ 2 b	17 $\pm$ 3.4 b	19 $\pm$ 2.8 a
<i>D. maculipennis</i>	Control	7 $\pm$ 1.8 c	8 $\pm$ 2.4 c	10 $\pm$ 1.4 c	13 $\pm$ 2.5 b

Table 2. Results of ANOVA for species factor, treatment factor and the interaction between both factors (species\*treatment).

	Third instar			Fourth instar			Fifth instar			Sixth instar		
	DF	F value	P	DF	F value	P	DF	F value	P	DF	F value	P
Species	1	13.01	<0.0004	1	17.61	<0.0001	1	0.03	0.8580	1	124.55	<0.0001
Treatment	1	881.35	<0.0001	1	744.32	<0.0001	1	802.87	<0.0001			
Species*Treatment	1	2.37	0.1248	1	0.70	0.4034	1	16.78	<0.0001			

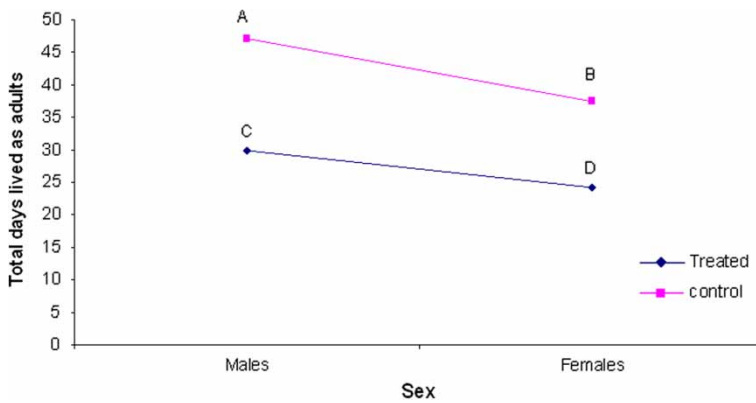


Figure 1. Total days lived as adults for males and females of *Dichroplus maculipennis* treated and control. Different letters indicate significant differences according to the Tukey test ( $\alpha=0.01$ ).

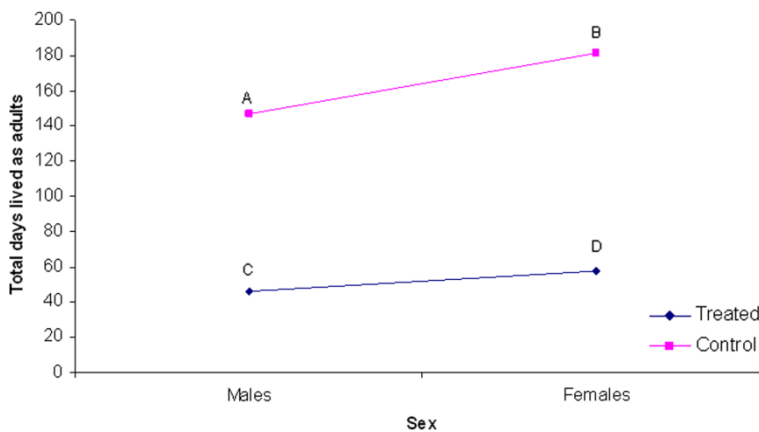


Figure 2. Total days lived as adults for males and females of *Ronderosia bergi* treated and control. Different letters indicate significant differences according to the Tukey test ( $\alpha=0.01$ ).

only the interaction treatments\*sex was not significant ( $p > 0.01$ ), being significant for all other interactions ( $p < 0.01$ ) (Table 3).

In the interaction sex\*treatment of *D. maculipennis*, a highly significant difference ( $p < 0.01$ ) for treatment and sex factor was observed but not for their interaction (treatment\*sex) ( $p > 0.01$ ) (Table 4, Figure 1).

In the interaction sex\*treatment of *R. bergi*, significant differences for the two factors and their interactions were observed ( $p < 0.01$ ) (Table 4, Figure 2).

Finally, control grasshoppers of both species were much more successful reproductively than infected grasshoppers. While infected females of both species did not copulate or lay eggs, control females of *D. maculipennis* and *R. bergi* copulated and laid on average  $22.35 \pm 3.82$  and  $13.08 \pm 2.08$  eggs per pod, respectively.

Table 3. Results of ANOVA for the evaluation of the numbers of days lived for *D. maculipennis* and *R. bergi* since adulthood to death.

	DF	F value	P value
Species	1	4563.78	<0.0001
Treatment	1	3151.11	<0.0001
Sex	1	10.71	0.0012
Species*treatment	1	1222.58	<0.0001
Species*sex	1	198.76	<0.0001
Treatment*sex	1	1.77	0.1852
Species*treatment*sex	1	10.22	0.0016

Table 4. Results of Analysis of Variance (ANOVA) for the interaction sex\*treatment of *D. maculipennis* and *R. bergi*.

	DF	<i>D. maculipennis</i>		<i>R. bergi</i>		
		F value	P value	DF	F value	P value
Treatment	1	110.38	<0.0001	1	35984.85	<0.0001
Sex	1	28.87	<0.0001	1	1308.30	<0.0001
Treatment*sex	1	0.86	0.3560	1	88.85	<0.0001

## Discussion

This is the first report on sublethal effects caused by the entomopathogenic fungus *B. bassiana* on *D. maculipennis* and *R. bergi* of Argentina. Our results showed that the insects of both species that were inoculated with *B. bassiana* (LPSC 1067) had a higher mortality in each of the different nymphal stages when compared with control grasshoppers. Similar results were observed by Blanford and Thomas (2001) on the Desert locust *S. gregaria* Forskal after inoculation with a sublethal dose of *M. anisopliae* var. *acridum*. Furthermore, we observed that nymphal development was prolonged in treated grasshoppers of both the species as compared with controls. Although the entomopathogenic fungus *B. bassiana* prolonged the number of days that grasshoppers lived as nymphs, it is important to note that insects fed very little and were lethargic as observed by Sanehdeep, Harminder, Kirandeep, and Amarjeet (2011) in larvae of *Spodoptera litura* (Fabricius) infected with *B. bassiana*. Hernández, Padilla, and Toriello (2007) also observed a reduction in the feeding of *Schistocerca piceifrons* (Walker) following infection by *Metarhizium anisopliae* var. *acridum*. Freimoser, Screen, Savita, Hu, and St Leger (2003) mentioned that the reduction of feeding, movement and flying abilities of grasshoppers is related to the development and colonisation of the fungus rather than toxin production.

In relation to fecundity, females of *D. maculipennis* and *R. bergi* infected with *B. bassiana* did not copulate or lay eggs while control females of both species did with no apparent drawbacks as reported by Mariottini et al. (2010) and Mariottini, Wysiecki, and Lange (2011b). Similar results were observed by Hornbostel, Ostfeld, Zhioua, and Benjamin (2004) after applying a sublethal dose of *M. anisopliae* on engorged larvae of *Ixodes scapularis* Say.

Finally, grasshoppers of both the species infected with *B. bassiana* in our study were shorter lived as adults compared with the controls. Gindin, Levski, Glazer, and Soroker (2006) reported decreased longevity of red palm weevil females due to fungal infection with *B. bassiana* and *M. anisopliae*. However, our results differ from those obtained by Blanford and Thomas (2001), who found no difference in survival and fecundity of adults of *S. gregaria* infected with the fungus *M. anisopliae* with respect to controls. This difference with our study might be related to the fact that they applied a sublethal dose of the fungus *M. anisopliae* on adults and newly fledged locusts. One possible hypothesis that would allow an understanding why the grasshoppers infected with *B. bassiana* have lower survival and fecundity than controls is suggested by Sanehdeep et al. (2011). They proposed that the fungal infected insects may have acquired and stored less nutrient resources than that of control insects which might have affected the longevity and fecundity of females. This is supported by Khachatourians (1986) who suggests that entomopathogenic fungi caused the death of their host due to exhaustion of nutrients and liberation of toxins in the hemolymph. So, nutritional deficiency and toxins acting separately or in unison can drastically affect the development of an insect, especially reproduction and moulting which have high energetic demands.

From a control point of view, sublethal effects caused by *B. bassiana* on *D. maculipennis* and *R. bergi* populations may be important if, for instance, strain *B. bassiana* (LPSC 1067) is combined with 'biorational' insecticides for some rapid knockdown while retaining the advantages of the residual effects of the fungus.

Even though further studies are needed, particularly under natural conditions, our results suggest that strain *B. bassiana* (LPSC 1067) has potential as a control agent for *R. bergi* and *D. maculipennis* by substantially increasing mortality during third through fifth and sixth instars, respectively, and preventing mating and oviposition by both species.

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