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Suitability of two exotic mealybug species as prey to indigenous lacewing species

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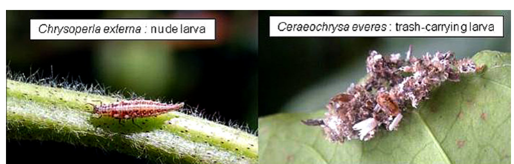
HIGHLIGHTS

- Two indigenous lacewings were tested against two exotic mealybugs species.
- Lacewing larvae at 2nd- and 3rd-instar preyed successfully both mealybugs.
- Mealybugs at 2nd-instar furnished development of all stages of both lacewings.
- Predation rate when significant was always superior for *Chrysoperla externa*.

GRAPHICAL ABSTRACT



Mealybugs	Lacewings (instars)		
	1st	2nd	3rd
2nd	Succeed	Succeed	Succeed
3rd	Failure	Succeed	Succeed
Adult female	Failure	Succeed	Succeed

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ABSTRACT

Mealybugs (Hemiptera: Pseudococcidae) have spread throughout subtropical and tropical regions, causing severe losses to crop production that have prompted much interest in discovering effective biological agents against these pests. The Brazilian indigenous lacewing (Neuroptera: Chrysopidae) species *Chrysoperla externa* (Hagen) and *Ceraeochrysa everes* (Banks) were studied against two exotic mealybug species, *Ferrisia dasylirii* (Cockerell) and *Pseudococcus jackbeardsleyi* Gimpel & Miller. To assess the relative potential of these lacewing species as control agents against these two pests, we confined 1st-, 2nd-, and 3rd-instar lacewing larvae with 2nd- and 3rd-instar nymphs and adult female mealybugs to evaluate development, survival, reproduction and predation rate. Lacewing larvae at 2nd- and 3rd-instar preyed successfully on mealybugs of all ages, and second instar mealybug nymphs supported successful development of lacewing larvae irrespective of the predators' age. However, 1st-instar lacewing larvae either failed to complete development or showed lower performance when fed only 3rd-instar or adult female of mealybugs of either species. Comparing the lacewing species, *Ce. everes* tended to produce more eggs, but showed delayed development and lower egg viability as compared to *Ch. externa*. Furthermore, in every case in which a significant difference in predation rate was detected, it was always superior for *Ch. externa*. Further studies to assess the establishment of these species and other lacewing species associated with these introduced mealybugs are reasonable to provide sustainable biological control.

1. Introduction

Mealybugs (Hemiptera: Pseudococcidae) are exclusively phytophagous, highly polyphagous, cosmopolitan insects infesting cultivated plants in many subtropical and tropical regions of the globe (Miller et al., 2002, 2012; Culik et al., 2006a,b; Silva-Torres et al.,

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2013). The introduction of mealybug species has been recorded in areas of Oceania, Africa, Asia, and in the Americas (Miller et al., 2002; Culik et al., 2006a,b; Silva-Torres et al., 2013; Mani et al., 2013). These exotic species have become problems for several reasons, such as lack of knowledge concerning efficient control practices such as registered insecticides, and the ample availability of cultivated host plants. The chemical control of mealybugs is restricted to broad-spectrum insecticides, especially organophosphates and neonicotinoids (Nagrare et al., 2011). However, several organophosphate insecticides registered to control mealybugs in Brazil and worldwide are facing removal from the market (EPA, 2012). Hence, a common reaction to the introduction of a new potential pest is to introduce natural enemies to counteract the problem (DeBach and Warner, 1969). However, when given enough time, indigenous natural enemies may establish associations with the exotic species in the new areas, helping with their control without the costs and risks created by a program of classical biological control (Hokkannen and Lynch, 2003; Colares et al., 2015).

In general, mealybugs have become a very attractive target for biological control practitioners due to their high concentration and stability over time. Whereas other sucking pests such as aphids and psyllids produce erratic population peaks insufficient to stabilize a relationship with natural enemies, mealybugs usually have a sessile habit, staying and feeding for long periods on the same plant spot after establishment until death. This generates a clumped population distribution within plant (Silva-Torres et al., 2013; Oliveira et al., 2014a) and in the crop ecosystem (Beltrá et al., 2013). High reproductive potential results in availability of eggs and nymphs at different developmental stages (Oliveira et al., 2014a). Further, abundant honeydew attracts natural enemies such as adults of parasitoids, ladybird beetles, and lacewings that consume the honeydew as a food supplement. These conditions are favorable to the establishment and the persistence of a natural enemy population in the new habitat. Fact that many biological control programs have successfully used predators and parasites of mealybugs (Bokonon-Ganta and Neuenschwander, 1995; Kairo et al., 2000; Neuenschwander, 2001; Meyerdirk et al., 2004; Roltsch et al., 2006; Muniappan et al., 2006; Attia et al., 2007; Afifi et al., 2010; Solangi et al., 2012; Barbosa et al., 2014a,b).

Lacewings (Neuroptera: Chrysopidae) are widely recognized as key predators of soft-bodied arthropods, especially aphids, psyllids, and mealybugs (Tauber et al., 2000; Senior and McEwen, 2001). Among predacious species used in biological control programs, lacewings provide good examples of successful mass production, commercial availability, and inundative releases to control pest species in protected (e.g. greenhouses) and field cropping systems (Principi and Canard, 1984; Tauber et al., 2000; Senior and McEwen, 2001). Furthermore, the use of *Chrysoperla carnea* (Stephens) has accounted for one third of all successful biological control programs in the world (Williamson and Smith, 1994; O'Neil et al., 1998), as well as *Chrysoperla rufilabris* (Burmeister) in North America (Tauber et al., 2000). Indigenous in Brazil, the lacewing species *Ceraeochrysa everes* (Banks) and *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) occur naturally in various crop ecosystems (Freitas, 2002; Santos et al., 2013), and like other lacewing species, they can be mass-produced using factitious prey in insectaries (Barbosa et al., 2002; Bortoli et al., 2006; Tavares et al., 2011).

Up on that, recent studies have shown that indigenous natural enemies exhibit significant preadaptation against exotic species (Qureshi and Stansly, 2011; Colares et al., 2015). Thus, we hypothesized that indigenous lacewings would express good adaptation on exotic mealybugs and may contribute to their natural or applied biological control. Therefore, this work determined the development, reproduction and predation rate of two indigenous lacewing species *Ce. everes* and *Ch. externa* upon two exotic mealybugs species recently introduced in Brazil, *Ferrisia dasylirii* (Cockerell) and *Pseudococcus jackbeardsleyi* Gimpel & Miller.

2. Material and methods

2.1. Mealybug species

The mealybug species studied, *F. dasylirii* (=*virgata*) and *P. jackbeardsleyi*, originated from stock colonies maintained in the Biological Control Laboratory of the Universidade Federal Rural de Pernambuco (UFRPE). Dead specimens were sent to Dr. Penny Gullan (The Australian National University) for species confirmation and voucher species deposit. Nymphs and adults of both mealybug species were reared on pumpkin *Cucurbita moschata* var. "Jacarezinho" following the method described in Oliveira et al. (2014a,b). Adult females of both species exhibit roughly similar body size [*F. dasylirii* body length varies from 3.14 to 5.30 mm and 1.36 to 2.86 width (Gullan and Kaydan, 2012); while *P. jackbeardsleyi* average 3.2 mm body length by 1.8 mm width (Gimpel and Miller, 1996)].

2.2. Lacewing rearing

Eggs of *Ce. everes* were obtained from CRISOBIOL/LABEN (Biofábrica de Chrysopidae/Laboratório de Entomologia) of the "Instituto Agronômico de Pernambuco (IPA)", Recife, PE; pupae of *Ch. externa* were obtained from the Biological Control Laboratory of the Universidade Federal de Lavras (UFLA), Lavras, MG. Adults, eggs, and larvae of both lacewing species were reared following the method described in Nordlund et al. (2001), with few adaptations. Stock colonies and all experiments conducted in this study were carried out at the Biological Control Laboratory of the UFRPE with regulated temperature, which averaged (mean ± SE) 24.9 ± 0.63 °C, 72.3 ± 8.1% RH and 13 h photophase.

2.3. Biology and predation of mealybugs by *Ceraeochrysa everes* and *Chrysoperla externa*

Larvae of both lacewing species were reared using three prey types: 1) second instar *F. dasylirii* nymphs; 2) second instar *P. jackbeardsleyi* nymphs; and 3) a factitious prey, *Anagasta kuehniella* eggs, used as a standard control for comparisons. In every case, each newly hatched lacewing larva was confined in a plastic petri dish (5.5 cm diam) lined with filter paper and offered the different prey treatments separately. Based on preliminary consumption trials, lacewing larvae in the first, second, and third instars were fed with second instar mealybug nymphs at rates of 4, 7, and 50 nymphs per day, respectively. Each treatment was run with 50 replications each for the mealybug species and 40 replications for the *A. kuehniella* eggs, consisting of one lacewing larva per replication. Thus, the experiment was conducted considering predator as a main factor (two species) and prey as secondary factor (three types).

In addition to the prey inside the petri dishes, a 1-cm long green stem taken from either a cotton plant or a hibiscus plant terminal was offered for *F. dasylirii* or *P. jackbeardsleyi*, respectively. The predator larvae were monitored daily to record molting dates, pupation date, mortality, adult emergence, and consumption of mealybug nymphs. Consumed mealybug nymphs were replaced daily; thus, the daily availability of prey was maintained constant throughout the experiment.

Emerged lacewing adults were separated by gender at emergence day, and pairs of one male and one female were formed. These adults were kept in PVC cages (15 cm height, 10 cm