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Biological performance of the predatory mites *Amblyseius largoensis* and *Euseius concordis* fed on eggs of *Aleurodicus cocois*

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Aleurodicus cocois (Curtis) (Hemiptera: Aleyrodidae) represents one of the main threats to cashew tree crops, *Anacardium occidentale* L. (*Anacardiaceae*), in several countries of South America (Martin 1987; Byrne *et al.* 1990; Evans 2007). This threat is not only represented by direct damage caused by feeding on the plant phloem and secretion of honeydew (Byrne *et al.* 1990; Byrne & Bellows 1991) but also by the lack of effective control methods against this pest (Bleicher & Melo 1996; Melo & Bleicher 2002; Mesquita & Braga Sobrinho 2013).

In Brazil, which is one of the largest cashew producers in the world (Pessoa *et al.* 2015), there are no registered products for the control of *A. cocois* (Agrofit 2018). A potential alternative for the control of *A. cocois* is the use of predatory mites of the family Phytoseiidae as biological control agents. The diversity of predatory mites in cashew trees has been little explored. Some phytoseiid species have been reported on cashew trees (Lima & Gondim Jr 2008; Monteiro *et al.* 2017). A recent study reported that the phytoseiid mites *Amblyseius largoensis* (Muma) and *Euseius concordis* (Chant) are potential natural enemies for controlling *A. cocois* (de Alfaia *et al.* 2018). The functional response type II was observed for both phytoseiids when fed on eggs of *A. cocois*, suggesting effectivity for the control at low pest population density (de Alfaia *et al.* 2018).

Some phytoseiid mites (*Amblydromalus limonicus* (Garmam & McGregor), *Amblyseius swirskii* Athias-Henriot, and *Euseius gallicus* Kreiter & Tixier) have been used against another species of the whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) in several European countries and in North America (Nomikou *et al.* 2003; Hoogerbrugge *et al.* 2005; Knapp *et al.* 2013; Lee & Zhang 2018). Thus, it is possible that some of the species that commonly occur on these trees, as *A. largoensis* and *E. concordis*, have the potential to be used in the control of *A. cocois*, as suggested by de Alfaia *et al.* (2018). The present study was designed to evaluate whether *A. cocois* eggs may support the development and reproduction of the phytoseiid mites *E. concordis* and *A. largoensis*.

Specimens of *A. largoensis* and *E. concordis* were collected directly from cashew leaves in the experimental area of the Universidade Federal do Ceará, Fortaleza-CE, Brazil (-3°44'S, -38°44'W). The predators were kept in rearing units similar to those described by de Alfaia *et al.* (2018), at 25 ± 1 °C, RH of 70 ± 10%, and a photoperiod of 12 h. Both species of predators were fed with a mixture of *Tetranychus urticae* Koch (Acari: Tetranychidae) (supplied in fragments of *Canavalia ensiformes* L., each fragment contained approximately 100 individuals in different stages of development), honey, and castor pollen (*Ricinus communis* L). The food was replenished whenever necessary (avoiding contamination in the unit, for example, by the development of fungi) or every 2 days, whichever happened first.

The development and viability of predators were evaluated using *A. cocois* eggs as the exclusive source of food. The experiment was conducted under the same conditions of temperature, relative humidity, and photoperiod used for rearing the predatory mites. Initially, 100 adult females of each predator species were confined for 24 hours in new rearing units to obtain the eggs to be used to start the experiment. After the confinement period, these females were removed and returned to rearing units; only eggs with a maximum age of 24 hours remained in the rearing units. These units were observed every 12 hours for larvae detection. Detected larvae were immediately and carefully transferred and isolated in experimental units. The experimental units were built similarly to those used to rear the predators, but in smaller dimensions (3 x 3 cm PVC plates). *Aleurodicus cocois* eggs were provided as food on leaves fragments, two fragments were provided per experimental unit. The food was replenished every 2 days until the emergence of the adults.

Immature individuals that reached adulthood when fed exclusively on *A. cocois* eggs were sexed. Females were paired with males from rearing units and fed daily with newly collected *A. cocois* eggs. Again two leaves fragments containing around 25 eggs each, were provided per experimental unit. The experimental units were inspected daily for oviposition and mortality of adults. In case of a male death, it was replaced by another male from the rearing units. Thus, the periods of pre-oviposition, oviposition and post-oviposition, the number of eggs per female and longevity were determined. Due to the reduced number of *E. concordis* females that performed oviposition, the population parameters were only estimated for *A. largoensis*. Population parameters were estimated using a fertility life table. The fertility life table was elaborated, according to Silveira Neto *et al.* (1976), using data on age (x), mean oviposition (mx) and survival (lx). The following parameters were estimated: net reproduction rate:R_0=Σlxmx, mean generation time: T=Σxlxmx/Σlxmx, intrinsic population growth rate: r_m=Ln(R_0)/r_m, finite population growth rate; $\lambda = e^{r_m}$, and time for the population to double in number: TD= Ln(R_0)/r_m.

Aleurodicus cocois eggs allowed the survival and development of immature forms to reach adulthood in *E. concordis* and *A. largoensis* (Table 1). The high survival rate observed in immatures of both species suggests that the number of eggs offered per immature was adequate. Eveleigh & Chant (1982) demonstrated that dietary restrictions (reduced food supply) during the development of immature phytoseiids result in high mortality. Individuals of *A. largoensis* reached the adult phase in a shorter time than *E. concordis* (Table 1), suggesting differences in food requirement or differences in the ability to convert food into energy. The results obtained in the development time of both predators are similar to those reported in other studies evaluating phytophagous mites as the exclusive source of food (Rodriguez & Ramos 2004; Galvão *et al.* 2007; Carrillo *et al.* 2010; Marques *et al.* 2015).

Both *E. concordis* and *A. largoensis* presented reduced reproductive potential when fed on *A. cocois* eggs (Table 2). These results supports the hypothesis raised by de Alfaia *et al.* (2018) that *A. cocois* eggs may not represent a better dietary resource for *E. concordis*. In that study, the absence of a pattern of variation of predator oviposition according to prey densities was observed for both *E. concordis* and *A. largoensis* when fed on *A. cocois* eggs.

For *Euseius concordis* only 2 out of 29 females performed oviposition. Reduced reproductive potential have been reported in *E. concordis* fed on *Tetranychus evansi* (Acari: Tetranychidae) (Moraes & Lima 1983), on a mixture of *T. evansi* + *Aculops lycopersici* (Acari: Eriophyidae) (Massee) (Moraes & Lima 1983) and on different species of Astigmata (Barbosa & Moraes 2015). According to Sabelis (1985a, b), the production of eggs by phytoseiids requires a lot from their feeding, not only because of the number of eggs produced but also because of the amount of food invested per egg. Additionally, Gotoh & Tsuschiya (2008) report that in the presence of stress conditions and low food quantity and/or quality, mites can direct resources that would be destined to oviposition to extend their longevity. This fact may explain not only the lack of oviposition in most *E. concordis* females but also the numerically superior longevity of these females compared to *A. largoensis* females (Table 2).

Contrary to what was observed in *E. concordis*, most *A. largoensis* females performed oviposition (Table 2), which suggests distinct nutritional requirements between these two predators. Despite the oviposition, the reproductive parameters observed in *A. largoensis* indicate that the tested diet (*A. cocois* eggs) does not represent one of the best foods for this predator—in the line as those suggested by de Alfaia *et al.* (2018). The comparison of the results obtained in this study with those reported in studies conducted under similar conditions, and where *A. largoensis* was fed exclusively on mites, shows superior reproductive parameters (female longevity, oviposition, and net reproduction rate) in those studies in *A. largoensis* fed on *Polyphagotarsonemus latus* (Banks) (Acari: Tarsonemidae) (Rodriguez & Ramos 2004), *Aceria guerreronis* Keifer (Acari: Eriophyidae) (Galvão *et al.* 2007), *Tetranychus gloveri* Banks (Acari: Tetranychidae), and *Raoiella indica* Hisrt (Acari: Tenuipalpidae) (Carrillo *et al.* 2010).

TABLE 1. Duration of immature stages (mean ± SE) and survivorship (mean ± SE) of *A. largoensis* and *E. concordis* fed exclusively on *A. cocois* eggs.

	A. largoensis (37)		*E. concordis* (39)	
	Duration (days)	Survival (%)	Duration (days)	Survival (%)
Egg	2.0 ± 0.08	100	2.1 ± 0.05	100
Larva	0.93 ± 0.06	97.3 ± 2.63	1.5 ± 0.09	100
Protonymph	1.43 ± 0.07	100	1.85 ± 0.08	89.7 ± 4.92
Deutonymph	1.54 ± 0.09	94.4 ± 3.71	1.70 ± 0.06	97.1 ± 2.85
Egg–Adult	5.9 ± 0.13	91.9 ± 4.43	7.2 ± 0.11	87.2 ± 5.42

TABLE 2. Biological parameters (mean ± SE or mean followed by 95 % confidence intervals for life table parameters) of *A. largoensis* and *E. concordis* fed exclusively on *A. cocois* eggs.

	A. largoensis	*E. concordis*
Evaluated females	23	29
Females that oviposited	20	2
Pre-oviposition time (days)	2.6 ± 0.14	3.5 ± 0.50
Oviposition time (days)	2.9 ± 0.52	3.5 ± 2.50
Longevity (days)	8.8 ± 0.77	10.4 ± 0.65
Maximum survival time (days)	18	21
Oviposition (eggs per female)	3.1 ± 0.60	0.2 ± 01
Net reproduction rate (females/female)	1.5 (0.96–2.02)	-
Intrinsic growth rate (females/female/day)	0.04 (0.007–0.08)	-
Finite population growth rate	1.04 (1.00–1.08)	-
Generation time (days)	9.4 (8.74–10.11)	-
Time for population to double in number	12.6 (2.97–28.15)	-

The apparent difference in the nutritional requirements of *A. largoensis* and *E. concordis* can have important consequences at the population level. It is possible, for example in the field, that *E. concordis* adults would not use *A. cocois* eggs as food, and thus, avoid direct competition with *A.*

largoensis. It is important to highlight that both evaluated predator species are commonly found in cashew trees, regardless of the presence of *A. cocois*. Therefore, as long as it is possible for predators to use *A. cocois* eggs for their development or as food supplementation in the adult phase, these predators may contribute to the control of this pest. Conservative strategies aiming not only at the permanence of predators but also their increments should be explored. These strategies, in particular if implemented before the colonization of plants by *A. cocois*, could potentially prevent their establishment.

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