Biological Control 91 (2015) 22–26

Contents lists available at ScienceDirect

Biological Control

journal homepage: www.elsevier.com/locate/ybcon

# Evaluation of astigmatid mites as factitious food for rearing four predaceous phytoseiid mites (Acari: Astigmatina; Phytoseiidae)

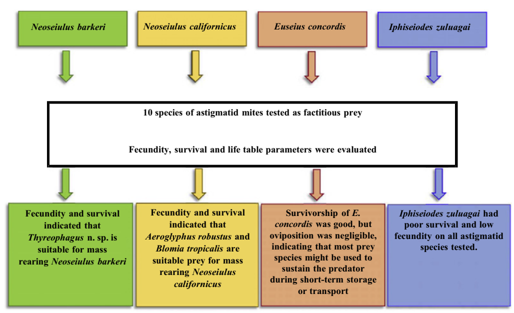
Marina F.C. Barbosa *, Gilberto J. de Moraes

*Depto. Entomologia e Acarologia, ESALQ-USP, 13418-900 Piracicaba, São Paulo, Brazil*

## HIGHLIGHTS

- Suitable prey were identified for *Neoseiulus barkeri* and *Neoseiulus californicus*.
- *Euseius concordis* survived on astigmatids, but did not oviposit.
- No Astigmatina species tested was suitable prey for *Iphiseiodes zuluagai*.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 8 September 2014
Revised 25 June 2015
Accepted 29 June 2015
Available online 30 June 2015

*Keywords:*
Augmentative biological control
Rearing method
Predatory mites

## ABSTRACT

Phytoseiids are possibly the most important mites used in biological control and are usually produced using a tritrophic system that, although efficient, is expensive and laborious. Mites of the cohort Astigmatina (Sarcoptiformes) have been used as factitious prey in the mass rearing of phytoseiids and may allow a much simpler production system. This research evaluated the potential of ten Astigmatina species to serve as factitious food sources for *Euseius concordis* (Chant), *Iphiseiodes zuluagai* Denmark and Muma, *Neoseiulus barkeri* Hughes and *Neoseiulus californicus* McGregor, all phytoseiid species commonly found in different countries. The high fecundity and survival rates obtained suggest that *Thyreophagus* n. sp. is a suitable prey for rearing *N. barkeri* and that *Austroglycyphagus lukoschusi* (Fain) and *Blomia tropicalis* is suitable for rearing *N. californicus*. Oviposition by *E. concordis* was negligible, but survivorship was high on most prey species, suggesting that these species may be useful for maintenance of the predator. *I. zuluagai* had low fecundity and survival on all the astigmatid species evaluated and none were suitable for its rearing.



## 1. Introduction

Phytoseiid mites are extensively used for the biological control of pest mites and insects (McMurtry et al., 2013) and the price of commercially available species is highly influenced by their production cost. Traditional phytoseiid production systems are tritrophic: the prey, usually a *Tetranychus* species (Tetranychidae), is typically reared on a leguminous host plant. Although functional, this system is laborious and requires costly infrastructure (Gerson et al., 2003; Hoy, 2009). Therefore, the development of more economic production systems is highly desirable.

Mites of the cohort Astigmatina (Oribatida: Sarcoptiformes) have been found to be suitable factitious food for several phytoseiid species (Gerson et al., 2003; Ramakers and van Lieburg,

* Corresponding author.
*E-mail address:* marina.ferraz@usp.br (M.F.C. Barbosa).

http://dx.doi.org/10.1016/j.biocontrol.2015.06.010
1049-9644/

1982; Schliesske, 1981). Some astigmatids can be easily produced in large numbers on flour, bran or similar substrates while maintained in relatively small containers (Griffiths, 1964; Sinha, 1964; Hughes, 1976; Ramakers and van Lieburg, 1982). This usually renders the rearing process less expensive than those using phytophagous mites as food, due to reduced requirements for space, labor and maintenance costs (Gerson et al., 2003).

The objective of this study was to evaluate Brazilian astigmatids as factitious food sources for four phytoseiid species common on crops in this country. Two of these, *Neoseiulus barkeri* Hughes and *Neoseiulus californicus* (McGregor), have been extensively used in biological control applications (Gerson et al., 2003; McMurtry et al., 2013). The other species have not been used commercially, but one of them, *Euseius concordis* (Chant), has been considered a promising predator of *Aculops lycopersici* (Masse) (Eriophyidae) on tomato (Moraes and Lima, 1983), whereas the other, *Iphiseiodes zuluagai* Denmark and Muma has been considered as potentially useful for the control of *Brevipalpus phoenicis* (Geijskes) (Tenuipalpidae) on citrus (Sato et al., 1994; Raga et al., 1996; Reis et al., 1998, 2000).

## 2. Material and methods

Studies were conducted between May and September 2011. Experimental units were maintained in incubators at 25 ± 1 °C, 90 ± 10% R.H., in the dark. Each experimental unit consisted of a plastic dish (2.7 cm in diameter x 1.2 cm high) about half full with a solidified paste (a mixture of nine parts gypsum to one part activated charcoal; Abbatiello, 1965), with humidity maintained by daily additions of distilled water. Each unit was sealed with a piece of transparent plastic film (Magipack®) to prevent mites from escaping.

The reproductive success is directly related to food quality and significant differences in reproductive parameters can be attributed to the provision of nutritional requirements (Ranabhat et al., 2014), although the preferred host for feeding or reproduction is not necessarily the best for development and survivorship (Shah and Liu, 2013). In the first part of this study, prey were screened to determine the two allowing the highest oviposition rates. In the second, these were compared in terms of the corresponding life table parameters of each predator.

### 2.1. Stock colonies

Phytoseiid mites were established two months before the beginning of the tests and kept in colonies using an adaptation of the rearing unit described by McMurtry and Scriven (1965). *N. barkeri* and *N. californicus* were obtained commercially (Promip, Engenheiro Coelho, São Paulo state, Brazil); *I zuluagai* and *E. concordis* were collected respectively from citrus and cassava crops in Piracicaba, São Paulo state. Colonies of *N. barkeri* were fed with a mixture of different stages of *Tyrophagus putrescentiae* (Schrank) (Astigmatina: Acaridae) on pieces of commercial dog food (Delidog®); *N. californicus* were fed with a mixture of different stages of *Tetranychus urticae* Koch (Acari: Tetranychidae) reared on *Canavalia ensiformis* (L.) (Fabaceae) as well as on *Typha angustifolia* L. (Typhaceae) pollen; *I. zuluagai* and *E. concordis* were fed *T. angustifolia* pollen and a 10% honey solution.

Species evaluated as prey were: Acaridae: *Aleuroglyphus ovatus* (Tropeau), *Cosmoglyphus oudemansi* (Zachvatkin), *Sancassania berlesei* (Michael), *Thyreophagus* n. sp. and *T. putrescentiae*; Echimyopodidae: *Blomia tropicalis* Bronswijk, de Cock and Oshima; Chortoglyphidae: *Chortoglyphus arcuatus* (Tropeau); Pyroglyphidae: *Dermatophagoides pteronyssinus* (Trouessart); Aeroglyphidae: *Austroglycyphagus lukoschusi* (Fain); Glycyphagidae: *Glycyphagus domesticus* (De Geer); Suidasiidae: *Suidasia nesbitti* Hughes and *Suidasia pontifica* Oudemans. All species were maintained in plastic containers adapted from Freire and Moraes (2007) and fed a mixture of 50% of yeast and 50% of wheat germ.

### 2.2. Oviposition tests

Using a stereomicroscope (Leica MZ12.5), 100 nymphs of each predator species were transferred from their respective stock colony to a similar rearing unit in which they were held until reaching the adult stage. Recently-molted males and females were held as pairs ($n = 30$) in experimental units and fed *ad libitum* with a mixture of all stages of the evaluated prey. Eventual dead males were replaced with new males from the respectively stock colony.

Each experimental unit was examined daily for 11 consecutive days to count the number of eggs laid and refresh the food. Eggs laid on the first day were excluded from analysis because they were presumed to reflect effects of pre-trial feeding. For diet evaluation of *N. californicus*, *C. oudemansi* and *G. domesticus* were replaced by *A. lukoschusi* and *B. tropicalis*, given that the former species were evaluated for this predator by Castagnoli et al. (2006).

Oviposition rates were classified as very low (<0.1 eggs/day), low (0.1–0.7), regular (0.9–1.8) and high (2.0–3.4) based on what was reported in numerous papers about phytoseiid oviposition rates (e.g. Sabelis, 1985).

### 2.3. Life tables

The study was initiated with eggs of similar ages, obtained by transferring 50 gravid females from the respective stock colony to each experimental unit; twelve hours later, the unit was examined removing the female and the excess eggs, leaving a single egg in each experimental unit. Post-embryonic stages of the predators were fed *ad libitum* with a mixture of all prey stages and units were observed three times a day to determine the duration of each immature stage. After predators reached adulthood, units were examined once a day to assess oviposition and the duration of the adult phase. Eggs laid by females of a species were grouped in a new experimental unit, where the mites were reared to adulthood to determine sex ratio. Other 30 recently-molted females of each species were isolated in experimental units without food as controls. All units were observed daily up to a maximum of 11 days to determine predator longevity and possible oviposition.

### 2.4. Data analysis

Statistical analysis of oviposition. Life stage duration, fecundity and survival (R Core Team, 2013). Because the data did not satisfy the assumptions of normality (Shapiro Wilk's test) and homoscedasticity (Levene test), nonparametric tests were used to compare treatments. Oviposition test and some life table results (developmental periods, duration of adult phases and oviposition) were compared using Kruskal–Wallis ANOVA and, for oviposition test, if significant ($p < 0.05$), treatments were separated using Mann–Whitney *U* test. Proportional data (survivorship and sex ratio) were analyzed using the Chi-square tests. Life table were elaborating according to Birch (1948) and parameters [net reproductive rate ($R_0$), intrinsic rates of population increase ($r_m$) and finite rate of increase ($\lambda$)] were compared according to Maia et al. (2000), SAS 9.2 version, (2008); means were compared using Student's *t* test.

## 3. Results

### 3.1. Oviposition tests

For each phytoseiid species, oviposition varied according to prey (Table 1; $H \leqslant 223.62$; $p < 0.05$ and $df = 9$ for all predators). *N. barkeri* and *I. zuluagai* oviposited on all prey species. Oviposition by the former was high on *S. nesbitti* and *Thyreophagus* n. sp. and moderate on the others, whereas oviposition of the latter was moderate on *D. pteronyssinus* and *S. nesbitti*, and low to very low on the others. *N. californicus* did not oviposit on *A. ovatus*, and oviposition was moderate on *A. lukoschusi* and *B. tropicalis* and low to very low on the others. *E. concordis* did not oviposit on *S. berlesei* or *C. arcuatus*, and oviposition was low to very low on the others (Table 1).

Survivorship of *N. barkeri* after 11 days was >87% on all prey and no significant differences were observed among treatments ($\chi^2 = 2.11$, $df = 9$, $p > 0.05$). *I. zuluagai* was the only phytoseiid with survivorship ⩽40% on all prey, except on *D. pteronyssinus*, where 53% of females survived, although no significant differences were observed ($\chi^2 = 12.06$, $df = 9$, $p > 0.05$). Survivorship of *N. californicus* was >76% on all prey except for *A. ovatus*, for which only 53% of females were alive at the end of the test ($\chi^2 = 26.40$; $p < 0.005$; $df = 9$). Survivorship of *E. concordis* was >83% on all prey, except on *D. pteronyssinus*, on which 58% of females survived, with no significant differences among treatments ($\chi^2 = 17.18$, $df = 9$, $p > 0.05$).

The prey species yielding the highest fecundity for *N. barkeri* were *S. nesbitti* and *Thyreophagus* n. sp.; for *N. californicus*, *B. tropicalis* and *A. lukoschusi*; for *E. concordis*, S. pontifica and *Thyreophagus* n. sp.; and for *I. zuluagai*, *S. nesbitti* and *D. pteronyssinus*. Therefore, these prey species were selected for construction of life tables.

### 3.2. Life tables

For each predator species, except *E. concordis*, no differences were significant among prey species for development period ($U \leqslant 3289.00$, $df = 1$, $p > 0.05$ in all cases; Table 2).

Survivorship of immature stages did not vary with diet for any predator ($\chi^2 \leqslant 0.131$, $df = 1$, $p > 0.05$ for all predators) and was at least 72% on all evaluated prey, excepting *I. zuluagai* which had survivorship slightly higher than 50% on both prey.*N. barkeri* had a significantly higher intrinsic rate of increase ($r_m$) on *Thyreophagus* n. sp. compared to *S. nesbitti*, a consequence of the considerably higher fecundity obtained on the former prey ($U = 408.00$; $df = 1$; $p < 0.001$; Table 3). *N. californicus* had about the same performance on *A. lukoschusi* and *B. tropicalis*, with minor to no difference between prey species for life table parameters and fecundity.

The very low fecundity and high mortality of *E. concordis* and *I. zuluagai* led to very low intrinsic rates of increase and net reproductive rates on both prey. Therefore, these parameters were not compared statistically. Without food, all females died prior to the eleventh day of the evaluation period, with mean ± SE survivorship of 5.2 ± 0.04, 5.9 ± 0.05, 4.1 ± 0.05 and 4.0 ± 0.05 days for *N. bakeri*, *N. californicus*, *E. concordis* and *I. zuluagai*, respectively. These predators did not lay eggs, except for *N. barkeri* that laid 0.2 ± 0.001 eggs/female/day.

## 4. Discussion

Among the astigmatid species evaluated, *Thyreophagus* n. sp. showed the most promise for rearing *N. barkeri*. The estimated values of fecundity and $r_m$ were much higher than previously reported for this predator on other astigmatid mites under similar environmental conditions, namely on *Rhizoglyphus echinopus* (Fumouze and Robin) (Zhang and Fan, 2005), *A. ovatus* (Xia et al., 2011) and *T. putrescentiae* (Huang et al., 2013).

The fecundity of *N. californicus* on *B. tropicalis* and *A. lukoschusi* were similar to, or slightly lower than, those reported by Castagnoli et al. (1999) on *Dermatophagoides farinae* (Hughes) (Pyroglyphidae), *G. domesticus* and *L. destructor* and similar to those reported on *T. urticae*, a natural prey (Castagnoli and Simoni, 2003). Thus, both *B. tropicalis* and *A. lukoschusi* could be suitable prey for mass-rearing of *N. californicus*, although *B. tropicalis* can cause human allergic reactions (Colloff, 2009).

Negligible oviposition was obtained for *E. concordis* in this study, suggesting that the Astigmatina may not be suitable for rearing this species, although its survivorship was high on almost all evaluated prey. Gotoh and Tsuchiya (2008) suggested that mites might relocate resources away from reproduction and toward maintenance to extend longevity in the presence of nutrient-poor or stressful conditions. *Euseius* species can pierce the cells of plant leaves and use the contents to complement their nutrition (Adar et al., 2012; McMurtry et al., 2013). Although the significance of this behavior is not completely understood, it seems to aid hydration of the predator (McMurtry et al., 2013). The chelicera of *Euseius* spp. are different from those of most phytoseiids, and may be unsuited for using astigmatids as prey, although some level

**Table 1**
Mean (±SE) daily oviposition and survival (after 11 days) of phytoseiids fed ten different prey species in the dark at 25 ± 1 °C and 70 ± 10% RH. No. eggs/days bearing the same letter were not significantly different within columns (Kruskal–Wallis, $\alpha = 0.05$); survival values bearing same letter were not significantly different within columns (Chi-square, $\alpha = 0.05$).

| | *Neoseiulus barkeri* | | | *Iphiseiodes zuluagai* | | | *Neoseiulus californicus* | | | *Euseius concordis* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Eggs/day[a] | Survival (%)[b] | *n* | Eggs/day[a] | Survival (%)[b] | *n* | Eggs/day[a] | Survival (%)[b] | *n* | Eggs/day[a] | Survival (%)[b] |
| *Aleuroglyphus ovatus* | 29 | 1.4 ± 0.1e | 90a | 24 | 0.7 ± 0.04bc | 33a | 28 | 0d | 53d | 28 | 0.06 ± 0.01bc | 86a |
| *Austroglycyphagus lukoschusi* | | | | | | | 27 | 1.3 ± 0.11a | 93a | | | |
| *Blomia tropicalis* | | | | | | | 29 | 1.2 ± 0.13a | 96a | | | |
| *Chortoglyphus arcuatus* | 29 | 1.7 ± 0.14d | 93a | 21 | 0.6 ± 0.06c | 33a | 27 | 0.5 ± 0.07b | 90a | 29 | 0d | 80a |
| *Cosmoglyphus oudemansi* | 29 | 1.6 ± 0.14d | 90a | 22 | 0.2 ± 0.02d | 23a | | | | 30 | 0.06 ± 0.01bc | 90a |
| *Dermatophagoides pteronyssinus* | 30 | 1.3 ± 0.10f | 90a | 26 | 0.9 ± 0.11b | 53a | 27 | 0.4 ± 0.4b | 90a | 26 | 0.1 ± 0.01b | 58a |
| *Glycyphagus domesticus* | 27 | 0.9 ± 0.09 g | 87a | 24 | <0.03 ± 0.1e | 23a | | | | 28 | 0.03 ± 0.01c | 83a |
| *Sancassania berlesei* | 29 | 1.5 ± 0.11e | 93a | 22 | 0.6 ± 0.08c | 23a | 26 | 0.1 ± 0.02b | 83b | 28 | 0d | 86a |
| *Suidasia nesbitti* | 30 | 2.0 ± 0.17b | 93a | 22 | 1.1 ± 0.10a | 40a | 29 | 0.3 ± 0.05b | 93a | 27 | 0.03 ± 0.01c | 86a |
| *Suidasia pontifica* | 29 | 1.5 ± 0.16d | 90a | 22 | 0.6 ± 0.08c | 40a | 29 | 0.1 ± 0.1b | 90a | 29 | 0.2 ± 0.03a | 90a |
| *Thyreophagus* n. sp. | 27 | 3.4 ± 0.26a | 90a | 24 | 0.6 ± 0.09c | 33a | 30 | 0.4 ± 0.08b | 90a | 27 | 0.3 ± 0.02a | 90a |
| *Tyrophagus putrescentiae* | 29 | 1.8 ± 0.09c | 93a | 26 | 0.7 ± 0.09bc | 23a | 26 | <0.1c | 76c | 28 | 0.06 ± 0.01bc | 90a |

Means within a column with the same letter are not significantly different ([a]Kruskal–Wallis ANOVA; [b]Chi-square test; $p < 0.05$).

**Table 2**
Mean (±SE) duration of immature stages and total developmental period (days) of four phytoseiid species fed ten different prey species in the dark at 25 ± 1 °C and 70 ± 10% RH. Values within rows bearing the same letter were not significantly different between prey types for a given predator species (Mann Whitney *U*-test, α = 0.05). No differences in survival were significant between prey types for any predator species (Chi-square, α = 0.05).

| Parameters | *Neoseiulus barkeri* | | *Neosiulus californicus* | | *Euseius concordis* | | *Iphiseiodes zuluagai* | |
|---|---|---|---|---|---|---|---|---|
| | *S. nesbitti* | *Thyreophagus* n. sp. | *A. lukoschusi* | *B. tropicalis* | *S. pontifica* | *Thyreophagus* n. sp. | *D. pteronyssinus* | *S. nesbitti* |
| Egg[a] | 1.5 ± 0.04a | 1.6 ± 0.03a | 1.6 ± 0.01a | 1.6 ± 0.03a | 1.6 ± 0.02a | 1.3 ± 0.03b | 1.2 ± 0.03a | 1.2 ± 0.03a |
| Larva[a] | 0.6 ± 0.02a | 0.7 ± 0.01a | 0.8 ± 0.02a | 0.8 ± 0.02a | 1.9 ± 0.04a | 0.9 ± 0.04b | 1.4 ± 0.02a | 0.8 ± 0.02b |
| Protonymph[a] | 0.6 ± 0.02a | 1.0 ± 0.01a | 2.0 ± 0.04a | 1.8 ± 0.02a | 1.9 ± 0.04a | 1.7 ± 0.04a | 1.6 ± 0.01a | 1.7 ± 0.04a |
| Deutonymph[a] | 1.8 ± 0.03a | 1.8 ± 0.03a | 2.3 ± 0.0a | 2.1 ± 0.03a | 1.9 ± 0.03a | 1.9 ± 0.02a | 1.8 ± 0.03a | 1.9 ± 0.02a |
| Egg-adult[a] | 5.7 ± 0.02a | 6.2 ± 0.17a | 6.4 ± 0.18a | 6.6 ± 0.11a | 6.7 ± 0.14a | 5.7 ± 0.10b | 6.1 ± 0.11a | 5.7 ± 0.13a |
| Survivorship (%)[b] | 72a | 74a | 86a | 86a | 86a | 88a | 51a | 52a |

Means within a line with the same letter are not significantly different ([a]Mann–Whitney *U*-test; [b]Chi-square test; $p < 0.05$).

**Table 3**
Mean (±SE) reproductive parameters, longevities, and life table parameters for females of four phytoseiid species fed ten different prey species in the dark at 25 ± 1 °C and 70 ± 10% RH. Values within rows bearing the same letter were not significantly different between prey types for a given predator species ([1]Mann Whitney *U*-test, α = 0.05; [2]Chi-square test, α = 0.05; [3]Student *t*-test, α = 0.05).

| Parameters | *Neoseiulus barkeri* | | *Neosiulus californicus* | | *Euseius concordis* | | *Iphiseiodes zuluagai* | |
|---|---|---|---|---|---|---|---|---|
| | *S. nesbitti* (*n* = 26) | *Thyreophagus* n. sp. (*n* = 28) | *A. lukoschusi* (*n* = 37) | *B. tropicalis* (*n* = 33) | *S. pontifica* (*n* = 35) | *Thyreophagus* n. sp. (*n* = 38) | *D. pteronyssinus* (*n* = 20) | *S. nesbitti* (*n* = 17) |
| Preoviposition period (d)[a] | 2.6 ± 0.19a | 2.1 ± 0.15a | 2.0 ± 0.18b | 2.4 ± 0.19a | 1.74 ± 0.09a | 1.81 ± 0.10a | 3.20 ± 0.14a | 3.29 ± 0.14a |
| Oviposition period (d)[a] | 15.2 ± 0.92a | 18.2 ± 1.02a | 17.6 ± 1.06a | 18.4 ± 0.95a | 13.4 ± 0.78a | 15.3 ± 0.94a | 17.0 ± 1.09a | 17.2 ± 0.89a |
| Post-oviposition period (d)[a] | 2.1 ± 0.10a | 2.2 ± 0.8a | 2.2 ± 0.1b | 3.5 ± 0.1a | 2.8 ± 0.2a | 1.7 ± 0.1b | 2.1 ± 0.1a | 2.3 ± 0.09a |
| Total female longevity[a] | 21.3 ± 0.95a | 24.1 ± 1.09a | 22.3 ± 0.96a | 23.7 ± 1.10a | 22.6 ± 0.83a | 23.3 ± 1.02a | 22.3 ± 1.10a | 23.0 ± 0.86a |
| Eggs/female/day[a] | 1.7 ± 0.91b | 2.9 ± 0.1a | 1.27 ± 0.9a | 1.0 ± 0.5a | 0.09 ± 0.1a | 0.18 ± 0.1a | 0.18 ± 0.2b | 0.34 ± 0.3a |
| Fecundity[a] | 24.3 ± 1.52b | 44.9 ± 2.1a | 21.7 ± 3.6a | 17.8 ± 1.9b | 1.5 ± 0.1a | 1.9 ± 0.2a | 1.9 ± 0.1a | 2.4 ± 0.1a |
| Sex ratio (% females)[b] | 68a | 71a | 78a | 72a | 76a | 86b | 69a | 65a |
| Intrinsic rate of increase ($r_m$)[c] | 0.172b | 0.223a | 0.177a | 0.156a | -0.001b | 0.040a | 0.057a | 0.080a |
| Net reproductive rate ($R_0$)[c] | 12.17b | 27.54a | 14.51a | 10.58a | 0.97a | 1.82a | 2.42a | 4.41a |
| Generation time (GT)[c] | 14.51a | 14.85a | 15.11a | 15.06a | 16.09a | 15.35a | 14.68a | 16.72a |

Means within a line followed by the same letter are not significantly different ([a]Mann–Whitney *U*-test; [b]Chi-square test; [c]Student *t*-test; $p < 0.05$).

of predation might have occurred. The improved survivorship of adults when astigmatids were available and the high survivorship of immature stages support this conclusion. Thus Astigmatina mites could be useful for short-term maintenance of this predator, such as during transport to release sites or to retain them on plants after release. The use of sachets containing factitious food for field release of phytoseiids is a common practice.

The astigmatids evaluated were not adequate for the mass production of *I. zuluagai*, nor did they support even temporary survivorship, as indicted by low values for intrinsic rate of increase, oviposition and survivorship. Albuquerque and Moraes (2008) reported even lower oviposition by this predator on post-embryonic stages of *T. putrescentiae*. Still, the predator did feed on *D. pteronyssinus* and *S. nesbitti*, and about half the immatures reached adulthood. The ability of larvae, protonymphs and deutonymphs to feed on both prey were comparable and survivorship ranged from 70% to 97%.

The preference of phytoseiid mites for eggs and larvae compared to other prey stages is well known (Badii et al., 2004; Blackwood et al., 2001; Collier et al., 2007; Ibrahim and Rahman, 1997). Albuquerque and Moraes (2008) observed better performance of *I. zuluagai* when *T. putrescentiae* eggs were provided compared to all life stages combined and obtained an $r_m$ value of 0.11 females per female per day. Prey foods may also influence predator performance: Sarwar et al. (2010) obtained faster development, higher fecundity and greater longevity of *Neoseiulus pseudolongispinosus* (Xin, Liang and Ke) when prey (*T. putrescentiae*) were reared on wheat flour compared to corn or soybean flour. Similarly, Huang et al. (2013) observed better fecundity of *N. barkeri* with the addition of protein or saccharid sources to wheat bran offered as food to its prey, *T. putrescentiae*. Thus, it is possible that the use of other food substrates for these Astigmatina may produce different results when they are fed to predators, possibly improving their suitability for *E. concordis* or *I. zuluagai*.

## 5. Conclusions

In conclusion, the results of the present study indicate the possibility of using some Astigmatina species as factitious foods for the mass-rearing of *N. barkeri* and *N. californicus*, potentially reducing production costs and fostering wider use of these biological control agents. Satisfactory results were not obtained for rearing *E. concordis* or *I. zuluagai*; however, complementary studies would seem warranted, even for the latter two species, as other factors could influence the suitability of these prey as food sources.

## Acknowledgments

This work was supported by the Brazilian "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior" (CAPES) and "Conselho Nacional de Desenvolvimento Científico e Tecnológico" (CNPq).

## References

Abbatiello, M.J., 1965. A culture chamber for rearing soil mites. Turtox News 43, 162–164.
Adar, E., Inbar, M., Gal, S., Doron, N., Zhang, Z.-Q., Palevsky, E., 2012. Plant-feeding and non plant-feed-ing phytoseiids: differences in behaviour and cheliceral morphology. Exp. Appl. Acarol. 58, 347–358.
Albuquerque, F.A., Moraes, G.J., 2008. Perspectives for mass rearing of *Iphiseiodes zuluagai* Denmark & Muma (Acari: Phytoseiidae). Neotrop. Entomol. 37, 328–333.

Badii, M.H., Hernández-Ortiz, E., Flores, A.E., Landeros, J., 2004. Prey stage preference and functional response os *Euseius hibisci* to *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae). Exp. Appl. Acarol. 34, 263–273.
Birch, L.C., 1948. The intrinsic rate of natural increase of an insect population. J. Anim. Ecol. 17, 15–26.
Blackwood, J.S., Schausberger, P., Croft, B.A., 2001. Prey-stage preference in generalist and specialist phytoseiid mites (Acari: Phytoseiidae) when offered *Tetranychus urticae* (Acari: Tetranychidae) eggs and larvae. Environ. Entomol. 30, 1103–1111.
Castagnoli, M., Simoni, S., 2003. *Neoseiulus californicus* (McGregor) (Acari Phytoseiidae): survey of biological and behavioural traits of a versatile predator. Redia 86, 153–164.
Castagnoli, M., Simoni, S., Biliotti, N., 1999. Mass-rearing of *Amblyseius californicus* (Acari: Phytoseiidae) on two alternative food sources. In: Bruin, J., Geest, L.P.S., Sabelis, M.W. (Eds.), Ecology and Evolution of the Acari. Kluwer Academic Publishers, Boston, pp. 425–431.
Castagnoli, M., Nannelli, R., Tarchi, F., Simoni, S., 2006. Screening of astigmatid mites for mass-rearing *Neoseiulus californicus* (McGregor) (Acari Phytoseiidae). Redia 89, 55–58.
Collier, K.F.S., Albuquerque, G.S., de Lima, J.O.G., Pallini, A., Molina-Rugama, A.J., 2007. *Neoseiulus idaeus* (Acari: Phytoseiidae) as a potential biocontrol agent of the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae) in papaya: performance on different prey stage – host plant combinations. Exp. Appl. Acarol. 41, 27–36.
Colloff, M.J., 2009. Dust Mites. CSIRO Publ, Melbourne.
Freire, R.A.F., Moraes, G.J., 2007. Mass production of the predatory mite *Stratiolaelaps scimitus* (Womersley) (Acari: Laelapidae). Syst. Appl. Acarol. 12, 117–119.
Gerson, U., Smiley, R.L., Ochoa, R., 2003. Mites (Acari) for Pest Control. Blackwell, Science, Oxford.
Gotoh, T., Tsuchiya, A., 2008. Food scarcity reduces female longevity of *Neoseiulus californicus* (Acari: Phytoseiidae). Exp. Appl. Acarol. 47, 249–256.
Griffiths, D.A., 1964. Experimental studies on the systematics of the genus *Acarus* Linnaeus, 1758 (Sarcoptiformes, Acarina). Acarologia 6, 101–116.
Hoy, M.A., 2009. Agricultural Acarology: Introduction to Integrate Mite Management. CRC Press, Boca Raton.
Huang, H., Xu, X., Lv, J., Li, G., Wang, E., Gao, Y., 2013. Impact of proteins and saccharides on mass production of *Tyrophagus putrescentiae* (Acari: Acaridae) and its predator *Neoseiulus barkeri* (Acari: Phytoseiidae). Biocontrol Sci. Technol. 23, 1231–1244.
Hughes, A.M., 1976. The mites of stored food and houses. Ministry of Agriculture and Fisheries, London (Technical Bulletin, 9).
Ibrahim, Y.B., Rahman, R.B.A., 1997. Influence of prey density and developmental stages on the predatory behavior of *Amblyseius longispinosus* (Acari: Phytoseiidae). Entomophaga 42, 319–327.
Maia, A.H.N., Luiz, A.J.B., Campanhola, C., 2000. Statistical inference on associated fertility life table parameters using jackknife technique: computational aspects. J. Econ. Entomol. 93, 511–518.
McMurtry, J.A., Scriven, G.T., 1965. Insectary production of phytoseiid mites. J. Econ. Entomol. 58, 282–284.
McMurtry, J.A., Moraes, G.J., Sourassou, N.F., 2013. Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Exp. Appl. Acarol. 18, 297–320.
Moraes, G.J., Lima, H.C., 1983. Biology of *Euseius concordis* (Chant) (Acarina: Phytoseiidae): a predator of the tomato russet mite. Acarologia 24, 251–255.
R Core Team, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, URL <http://www.R-project.org/>.
Raga, A., Sato, M.E., Cerávolo, L.C., Rossi, A.C., 1996. Distribuição de ácaros predadores (Phytoseiidae) em laranjeira (*Citrus sinensis* L. Osbeck). Rev. Ecossist. 21, 23–25.
Ramakers, P.M.J., Van Lieburg, M.J., 1982. Start of commercial production and introduction of Amblyseius mekenziei Sch. & Pr. (Acarina: Phytoseiidae) for the control of Thrips tabaci Lind. (Thysanoptera: Thripidae) in glasshouses. Med. Fac. Landbow Rijksuniv. Gent 47, 541 - 545.
Ranabhat, N.P., Goleva, I., Zebitz, C.P.W., 2014. Life tables of *Neoseiulus cucumeris* exclusively fed with seven different pollens. Biocontrol 59, 195–203.
Reis, P.R., Chiavegato, L.G., Alves, E.B., 1998. Biologia de *Iphiseiodes zuluagai* Denmark & Muma (Acari: Phytoseiidae). An. Soc. Entomol. Bras. 27, 185–191.
Reis, P.R., Chiavegato, L.G., Alves, E.B., Sousa, E.O., 2000. Ácaros da família Phytoseiidae associados aos citros no município de Lavras, Sul de Minas Gerais. An. Soc. Entomol. Bras. 29, 95–104.
Sabelis, M.W., 1985. Development. In: W. Helle, M.W. Sabelis (Eds.), Spider Mites, their biology, natural enemies and control, vol. 1(B), pp. 43–53.
Sarwar, M., Xuenong, X., Kongming, W., 2010. Effects of different flours on the biology of the prey *Tyrophagus putrescentiae* (Schrank) (Acarina: Acaridae) and the predator *Neoseiulus pseudolongispinosus* (Xin, Liang and Ke) (Acari: Phytoseiidae). Int. J. Acarol. 36, 363–369.
SAS Institute Inc., 2008. SAS/STAT® 9.2 User's Guide. Cary, NC: SAS Institute Inc.
Sato, M.E., Raga, A., Cerávolo, L.C., Rossi, A.C., Potenza, M.R., 1994. Ácaros predadores em pomar cítrico de Presidente Prudente, estado de São Paulo. An. Soc. Entomol. Bras. 23, 435–441.
Schliesske, J., 1981. Ueber die technik der massenanzucht von raubmilben (acari: phytoseiidae) unter kontrollierten bedingungen [On the technique for mass rearing of predatory mites (Acari: Phytoseiidae) under controlled conditions]. Med. Fac. Landbow. Rijksuniv. Gent. 46, 511–517.
Shah, M.M.R., Liu, T.-X., 2013. Feeding experience of *Bemisia tabaci* (Hemiptera: Aleyrodidae) affects their performance on different host plants. PLoS ONE 8 (10), 1–11.
Sinha, R.N., 1964. Ecological relationships of stored-products mites and seed-born fungi. Acarologia 6, 372–389.
Xia, B., Zou, Z., Li, P., Lin, P., 2011. Effect of temperature on development and reproduction of *Neoseiulus barkeri* (Acari: Phytoseiidae) fed on *Aleuroglyphus ovatus*. Exp. Appl. Acarol. 54, 1–9.
Zhang, Q.Q., Fan, Q.H., 2005. Developmental and reproductive response of *Amblyseius barkeri* on *Rhizoglyphus echinopus* and *Tyrophagus putrescentiae*. Entomol. J. East China 14, 165–168.