

## Life history of the predatory mites *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi*, candidates for biological control of *Aceria guerreronis*

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**Abstract** The eriophyoid mite *Aceria guerreronis* Keifer (Eriophyidae), commonly called the coconut mite, is a key pest of coconut fruits. Surveys conducted on coconut palms in Brazil revealed the predatory mites *Neoseiulus paspalivorus* DeLeon (Phytoseiidae) and *Proctolaelaps bickleyi* Bram (Ascidae) as the most commonly associated natural enemies of *A. guerreronis* on coconut fruits. However, virtually nothing is known about the life history of these two predators. We conducted laboratory experiments at  $25 \pm 0.1^\circ\text{C}$ , 70–90% RH and 12:12 h L:D photoperiod to determine the life history characteristics of the two predatory mites when feeding on *A. guerreronis* and other potential food sources present on coconut fruits such as *Steneotarsonemus furcatus* DeLeon (Tarsonemidae), coconut pollen and the fungus *Rhizopus cf. stolonifer* Lind (Mucoraceae). In addition, the two-spotted spider mite *Tetranychus urticae* Koch (Tetranychidae) was tested for its suitability as prey. Both predators, *N. paspalivorus* and *P. bickleyi*, thrived on *A. guerreronis* as primary food source resulting in shorter developmental time (5.6 and 4.4 days, respectively), higher oviposition rate (1.7 and 7.0 eggs/female/day, respectively) and higher intrinsic rate of increase (0.232 and 0.489 per female/day, respectively) than on any other diet but were unable to develop or lay eggs when fed

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*T. urticae*. Coconut pollen and *S. furcatus* were adequate alternative food sources for *N. paspalivorus* and *Rhizopus* for *P. bickleyi*. We discuss the relevance of our findings for natural and biological control of the coconut mite *A. guerreronis*.

**Keywords** Coconut · *Aceria guerreronis* · *Neoseiulus paspalivorus* · *Proctolaelaps bickleyi* · Natural control · Biological control

## Introduction

*Aceria guerreronis* Keifer (Acari: Eriophyidae) is worldwide the most important pest mite of coconut fruits (Mariau 1977; Fernando et al. 2002). The tiny mite resides beneath the perianth of fruits and feeds on the meristematic tissue, which leads to surface scars, growth distortions and premature fruit fall (Mariau 1977; Moore and Howard 1996). Yield losses due to *A. guerreronis* damage to coconut fruits have been recorded as ranging between 30 and 60% of the production (Moore et al. 1989; Nair 2002). Currently, considerable efforts are being devoted to biological control of the pest considering the secluded environment in which the mites live and the associated difficulties in the use of pesticides (Moore 2000; Ramaraju et al. 2002). Among the predatory mites found in association with *A. guerreronis*, species belonging to the families Phytoseiidae and Ascidae seem the most promising natural enemies (de Moraes and Zacarias 2002; de Moraes et al. 2004; Lawson-Balagbo et al. 2007a). The family Phytoseiidae includes a relatively large number of well-known predatory mite species that are already in use or have a considerable potential for use in biological control of herbivorous pest mites and insects on many crops including coconut palm (e.g. McMurtry 1982; Helle and Sabelis 1985; McMurty and Croft 1997; Sabelis 1996; de Moraes and Zacarias 2002; Gerson et al. 2003).

The present work is embedded in the framework of a multi-institutional project with the broad objective of developing a biological control program against *A. guerreronis* in Africa and elsewhere. *Aceria guerreronis* has been recently shown to be most probably of South American origin (Navia et al. 2005). Augmentative or classical biological control may hence offer a sustainable solution to the problem caused by this pest in South America, Africa and Asia (Moore 2000; de Moraes and Zaccarias 2002). Brazil is the largest coconut producer in South America (FAO 2005) and falls within the likely native home of *A. guerreronis*. Recent surveys of natural enemies of *A. guerreronis* conducted on coconut palms in Brazil revealed *Neoseiulus paspalivorus* DeLeon (Phytoseiidae) and *Proctolaelaps bickleyi* Bram (Ascidae) as two of the most frequently found predatory mites (Lawson-Balagbo et al. 2007a). However, neither of those predatory mites has been subjected to life history studies when offered *A. guerreronis* as prey. Studying life history is one of the basic requirements for evaluating the potential of natural enemies to be effective bio-control agents. Life history tests provide insights about the ability of a predator to persist and multiply with given food/prey types and with that allow predicting its population dynamics, in particular its numerical response to and impact on pest populations (e.g. McMurtry 1983, Bellows et al. 1992).

The objective of this work was to determine the life history parameters of *N. paspalivorus* and *P. bickleyi* with *A. guerreronis* as prey by comparing survival, development and reproduction on the latter with other food items under controlled laboratory conditions.

Additional food items tested were those found on coconut fruits apart from *A. guerreronis*, i.e. *Steneotarsonemus furcatus* DeLeon (Acari: Tarsonemidae), coconut pollen, and the fungus *Rhizopus cf. stolonifer* Lind (Mucorales: Mucoraceae), and the two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae). *Rhizopus cf. stolonifer* was included based on the observation by E. S. Silva (ESALQ-USP unpublished) that *P. bickleyi* develops well on hyphae of this fungus commonly found on old coconuts. *Tetranychus urticae* was included because this spider mite, if suitable prey, could be used for mass rearing purposes, and because it is the most common prey species tested with other phytoseiids.

## Material and method

### Rearing and experimental units

Stock colonies of *N. paspalivorus* and *P. bickleyi* were established with individuals collected from coconut fruits in September 2005, in Acarau in the State Ceará and Itamaracá in the State Pernambuco, respectively. The stock colonies were maintained on arenas each consisting of a sheet of dark PVC (12 cm diameter for *N. paspalivorus* and 10 × 6 cm for *P. bickleyi*) laid on a water saturated foam mat placed in a Petri dish (15 cm diameter and 2.5 cm height) for *N. paspalivorus* and in a plastic tray (15 × 10 cm and 4 cm height) for *P. bickleyi*. The margins of the sheet were covered by moist cotton wool serving as drinking water source and preventing the mites from escaping. A narrow strip of an adhesive (Tanglefoot™) was applied along the centre of the cotton wool to further prevent the mites from escaping. Colonies of *N. paspalivorus* and *P. bickleyi* were reared on *A. guerreronis* offered on small pieces of infested meristematic tissue of coconut fruits replaced every third day. Those pieces also served as oviposition sites. Eggs and other life-stages were collected from the old pieces before they were discarded. Mites were transferred to new arenas every 2 weeks. The rearing units were stored at ambient laboratory conditions.

All experiments were carried out on arenas each consisting of a piece of Jack bean leaf (5 × 4 × 4 cm), *Canavalia ensiformis* (L.) DC, placed upside down on water saturated foam mat covered with moist filter paper, inside a plastic tray (7 × 6 × 5 cm). The edges of the bean leaf were covered with strips of moist tissue paper to keep the leaf alive and provide access to free water. Each experimental arena was furthermore surrounded by a strip of Tanglefoot as described in the previous section. Mites were transferred to new units every third day. Experimental units were stored in a climatic chamber at 25 ± 0.1°C, 70–90% RH and 12:12 h L:D photoperiod.

### Food types tested

All life-stages of *A. guerreronis*, *S. furcatus* and *T. urticae* were offered ad libitum as prey to the predators. *Aceria guerreronis* and *S. furcatus* were supplied by introducing a piece of about 1 cm<sup>2</sup> of infested meristematic coconut fruit tissue to each arena. In this way the longevity of the eriophyids and tarsonemids was enhanced and the piece of coconut fruit also served as oviposition site for the predators. Coconut pollen was obtained from branches of inflorescences bearing female flower-buds and male flowers collected from coconut palms in Itamaracá. *Tetranychus urticae* was obtained from stock colonies maintained on *C. ensiformis*. Coconut pollen and *T. urticae* were introduced in the arenas

using a fine hair brush. *Rhizopus cf. stolonifer* was inoculated according to a methodology developed by E. S. Silva (unpublished). For such, small pieces of “dog food” (Pedigree<sup>®</sup> Complete) were moistened and inoculated with the fungus collected from old coconut fruits and cultured in agar-agar growing medium in the laboratory. Inoculated pieces were incubated 2 days in the climatic chamber to permit the development of the fungus before introduction into the experimental unit. All food types were replenished every third day.

### Life history studies

Fifty gravid females from the stock colony were confined on a rearing arena as described above and offered *A. guerreronis* as prey. Eggs laid within 12 h were singly transferred to experimental units. Each individual was observed every 8 h to determine the duration of each immature stage until reaching adulthood. For the tests on adult longevity and reproduction, thirty newly moulted female deutonymphs were taken from the stock colony and singly isolated in experimental units. Upon reaching adulthood, each female was paired with a male randomly withdrawn from the stock colony. The male was removed as soon as oviposition started. Survival of the experimental female and number of eggs laid were recorded every 24 h until natural death of the female. Eggs were collected and reared to adulthood on separate arenas for the determination of the offspring sex ratio.

### Statistical analyses

Separate analyses were run for each predator species. SPSS 12.0 (SPSS Inc., 2003) was used for all statistical analyses. Differences in the mean duration of the total developmental time among food types were compared by univariate ANOVA with sex as covariate and subsequent Bonferroni multiple comparison tests. Juvenile survival with the different food types was compared using chi-square tests. Female longevity, fecundity and oviposition rate were compared among food types using univariate ANOVA and subsequent Bonferroni multiple comparison tests. Before analysis, longevity and fecundity data of *N. paspalivorus* were log-transformed to correct for heterogeneity of the variances. Offspring sex ratios (percent female offspring) were compared between food types using pairwise chi-square analyses of the actual counts. Jackknife estimates of life table parameters (Birch 1948) and their variances were calculated as described by Hulting et al. (1990). Student's *t*-tests were used to compare the intrinsic rate of natural increase ( $r_m$ ) and the net reproductive rate ( $R_0$ ) between food items. All analyses were conducted at  $P < 0.05$  significance level.

## Results

### Juvenile survival and development

*Neoseiulus paspalivorus* developed successfully on *A. guerreronis*, *S. furcatus* and coconut pollen but was unable to reach adulthood when reared on *Rhizopus* and *T. urticae* (Table 1). The mite developed the fastest when reared on *A. guerreronis* and the slowest on coconut pollen (Table 1). Total developmental time of *N. paspalivorus* differed significantly among food items and was influenced by sex (Table 2). Developmental time of males was shorter ( $5.5 \pm 0.18$ ;  $6.5 \pm 0.24$ ;  $7.2 \pm 0.34$ , days  $\pm$  SE) than that of females ( $5.7 \pm 0.15$ ;

**Table 1** Mean duration (days  $\pm$  SE) of the life-stages of *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi* on different food types at  $25 \pm 0.1^\circ\text{C}$ , 70–90% RH and 12 h photophase

Food	N	Egg	Larva	Protonymph	Deutonymph	Egg to adult <sup>1</sup>
<i>N. paspalivorus</i>						
<i>A. guerreronis</i>	30	1.6 $\pm$ 0.97	1.3 $\pm$ 0.09	1.4 $\pm$ 0.05	1.2 $\pm$ 0.06	5.6 $\pm$ 0.16a
<i>S. furcatus</i>	28	1.9 $\pm$ 0.15	1.3 $\pm$ 0.07	1.5 $\pm$ 0.08	1.9 $\pm$ 0.12	6.8 $\pm$ 0.16b
Coconut pollen	24	1.7 $\pm$ 0.14	1.7 $\pm$ 0.11	2.1 $\pm$ 0.13	2.0 $\pm$ 0.07	7.5 $\pm$ 0.18c
<i>P. bickleyi</i>						
<i>A. guerreronis</i>	30	1.3 $\pm$ 0.09	1.0 $\pm$ 0.03	1.1 $\pm$ 0.02	1.1 $\pm$ 0.05	4.4 $\pm$ 0.11a
<i>Rhizopus</i>	30	1.4 $\pm$ 0.08	1.1 $\pm$ 0.05	1.1 $\pm$ 0.04	1.2 $\pm$ 0.07	4.9 $\pm$ 0.04b

<sup>1</sup> Different letter denotes significant difference within species (ANOVA followed by Bonferroni tests,  $P < 0.05$ ).

**Table 2** Univariate ANOVAs of the influence of food and sex (covariate) on total developmental time of *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi* at  $25 \pm 0.1^\circ\text{C}$ , 70–90% RH and 12 h photophase

Source of variation	df	Mean of squares	F	P level
<i>N. paspalivorus</i>				
Sex (covariate)	1	0.016	5.14	0.026
Food	2	0.117	36.84	0.001
Error	78	0.003		
<i>P. bickleyi</i>				
Sex (covariate)	1	0.705	3.56	0.064
Food	1	3.531	17.81	0.001
Error	57	0.198		

7.2  $\pm$  0.29; 7.7  $\pm$  0.21, days  $\pm$  SE) on *A. guerreronis*, *S. furcatus* and coconut pollen, respectively. The proportion of immature stages reaching adulthood was 100% when reared on *A. guerreronis* and significantly higher than that on coconut pollen (80%) ( $\chi^2 = 6.67$ ,  $P < 0.01$ ). No significant differences were found in survival of immature mites reared on *A. guerreronis* and *S. furcatus* (93%) ( $\chi^2 = 2.07$ ,  $P = 0.15$ ) as well as between immature stages reared on *S. furcatus* and those reared on coconut pollen ( $\chi^2 = 2.31$ ,  $P = 0.13$ ).

*Proctolaelaps bickleyi* developed the fastest on *A. guerreronis* but failed to complete juvenile development when fed *S. furcatus*, *T. urticae* and coconut pollen (Table 1). The total developmental time of *P. bickleyi* differed significantly between the food types *A. guerreronis* and *Rhizopus* and was not influenced by sex (Table 2). Developmental time was  $4.01 \pm 0.25$  (days  $\pm$  SE) for males and  $4.56 \pm 0.10$  (days  $\pm$  SE) for females reared on *A. guerreronis*, whereas it was  $4.86 \pm 0.06$  for males and  $4.87 \pm 0.07$  (days  $\pm$  SE) for females on *Rhizopus*. All immature *P. bickleyi* reached adulthood on both *A. guerreronis* and *Rhizopus*.

#### Adult female longevity, fecundity and oviposition rate

Mean female longevity of *N. paspalivorus* did not significantly differ among food types ( $F_{2,57} = 0.51$ ,  $P = 0.60$ ) (Table 3). In contrast, female fecundity differed significantly

**Table 3** Female longevity (days), fecundity (eggs/female), oviposition rate (eggs/female/day) (mean  $\pm$  SE) and sex ratio (%female offspring) of *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi* on different food types at  $25 \pm 0.1^\circ\text{C}$ , 70–90% RH and 12 h photophase

Food	N	Longevity <sup>1</sup>	Fecundity <sup>1</sup>	Oviposition rate <sup>1</sup>	Sex ratio <sup>2</sup>
<i>N. paspalivorus</i>					
<i>A. guerreronis</i>	28	16.5 $\pm$ 1.30a	24.7 $\pm$ 2.35a	1.7 $\pm$ 0.09a	75a
<i>S. furcatus</i>	13	13.1 $\pm$ 0.84a	11.1 $\pm$ 1.08ab	1.1 $\pm$ 0.07b	59b
Coconut pollen	19	14.5 $\pm$ 1.56a	11.9 $\pm$ 1.74b	1.0 $\pm$ 0.09b	64b
<i>P. bickleyi</i>					
<i>A. guerreronis</i>	30	11.0 $\pm$ 0.77a	52.4 $\pm$ 4.23a	7.0 $\pm$ 0.34a	77a
<i>Rhizopus</i>	30	11.8 $\pm$ 0.87a	32.9 $\pm$ 4.01b	3.6 $\pm$ 0.31b	83b

Separate statistical analysis for each species.

Different letters within columns denote significant differences ( $P < 0.05$ ) (<sup>1</sup>results of ANOVA followed by Bonferroni tests, with longevity and fecundity of *N. paspalivorus* log-transformed prior to analysis; <sup>2</sup>results of chi-square analysis).

among the three food types ( $F_{2,57} = 5.23$ ,  $P = 0.008$ ). Fecundity was the highest with *A. guerreronis* (24.7  $\pm$  2.35 SE eggs/female/life) and less than half and similar with *S. furcatus* and coconut pollen as food (Table 3). The percentage of female offspring (sex ratio) on *A. guerreronis* ( $n = 486$ ) was significantly different from the percentages on *S. furcatus* ( $n = 103$ ) ( $\chi^2 = 10.39$ ,  $P = 0.001$ ) and coconut pollen ( $n = 129$ ) ( $\chi^2 = 6.56$ ,  $P = 0.01$ ) (Table 3). No difference was found in the sex ratio of mites reared on *S. furcatus* and coconut pollen ( $\chi^2 = 0.46$ ,  $P = 0.50$ ) (Table 3). Longevity of adult *P. bickleyi* females did not differ between *A. guerreronis* and *Rhizopus* ( $F_{1,58} = 0.47$ ,  $P = 0.49$ ), whereas fecundity was strongly influenced by food ( $F_{1,58} = 11.22$ ,  $P = 0.001$ ) (Table 3). The sex ratios on *A. guerreronis* ( $n = 1573$ ) and *Rhizopus* ( $n = 987$ ) differed significantly ( $\chi^2 = 13.26$ ,  $P < 0.001$ ) (Table 3).

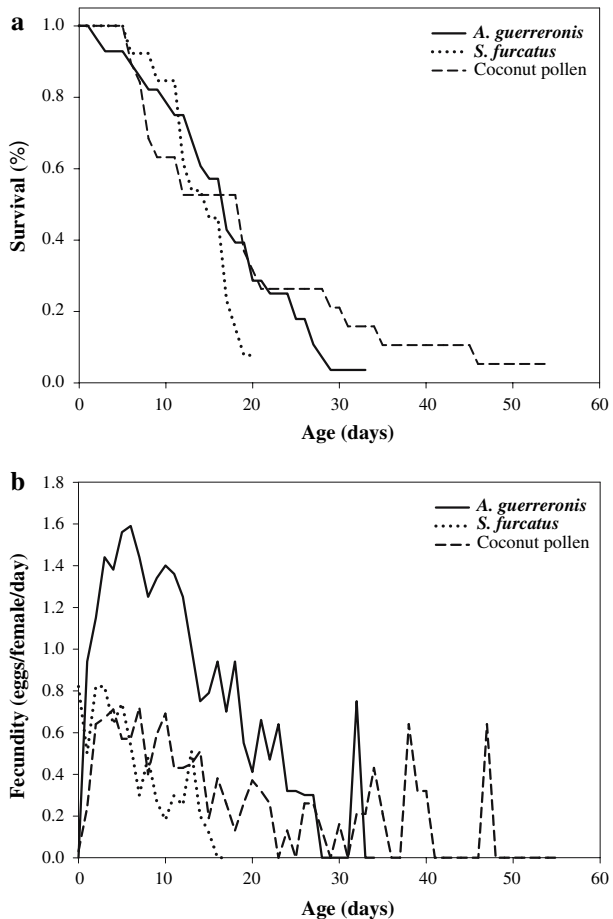
Adult female survival of *N. paspalivorus* exceeded 80% during the first week on all three food types. After 2 weeks the survival percentage declined sharply in adult females reared on *S. furcatus* and reached zero after  $\sim 20$  days. About 20% of adult females reared on *A. guerreronis* and coconut pollen survived longer than 25 days (Fig. 1a). Mean daily oviposition rate of *N. paspalivorus* differed significantly among food types ( $F_{2,57} = 21.66$ ,  $P < 0.001$ ). The oviposition rate of *N. paspalivorus* remained at a level of  $\sim 2$  eggs per day on *A. guerreronis* during the first week and declined steadily after 2 weeks (Table 3, Fig. 1b). The daily mean oviposition rate was  $\sim 1$  egg per day on *S. furcatus* and coconut pollen, which was significantly lower than that reached on *A. guerreronis* (Table 3, Fig. 1b).

Adult female survival of *P. bickleyi* declined sharply in the second week of life and reached zero after  $\sim 20$  days on both food types (Fig. 2a). The oviposition rate of *P. bickleyi* was significantly higher on *A. guerreronis* than on *Rhizopus* ( $F_{1,58} = 59.86$ ,  $P < 0.001$ ). The peak oviposition rate was reached during the first week of oviposition with up to 7 eggs per female per day on *A. guerreronis* (Fig. 2b).

#### Life table parameters

The pre- and post-oviposition periods of *N. paspalivorus* did not significantly differ among food types ( $F_{2,57} = 2.45$ ,  $P = 0.095$  and  $F_{2,57} = 0.93$ ,  $P = 0.399$ , respectively). In contrast,

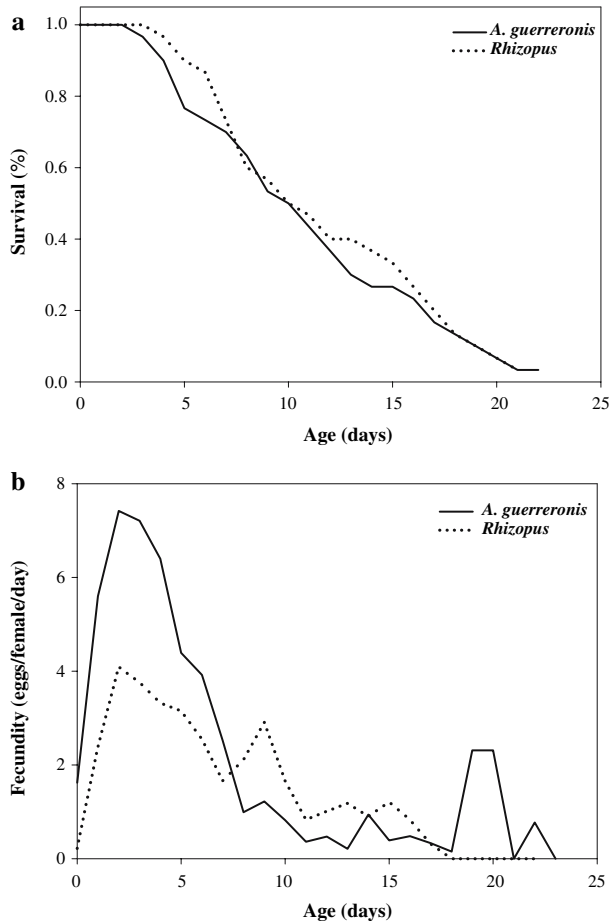
**Fig. 1** Age-specific survival (a) and fecundity (b) of *Neoseiulus paspalivorus* reared on *Aceria guerreronis*, *Steneotarsonemus furcatus* and coconut pollen



the oviposition period differed significantly among food types ( $F_{2,57} = 3.54$ ,  $P = 0.035$ ) (Table 4). The oviposition period was longer on *A. guerreronis* and shorter on coconut pollen (Table 4). *Neoseiulus paspalivorus* reared on *A. guerreronis* reached a significantly higher intrinsic rate of increase ( $r_m$ ) than those fed *S. furcatus* ( $T_{39} = 45.12$ ,  $P < 0.001$ ) and coconut pollen. ( $T_{45} = 61.7$ ,  $P < 0.001$ ) (Table 4). The  $r_m$  values of mites reared on *S. furcatus* and coconut pollen differed significantly ( $T_{30} = 10.94$ ,  $P < 0.001$ ). The  $R_0$  of *N. paspalivorus* reared on *A. guerreronis* was significantly higher than that of mites reared on *S. furcatus* ( $T_{39} = 28.26$ ,  $P < 0.001$ ) and coconut pollen ( $T_{45} = 32.14$ ,  $P < 0.001$ ). There was no difference between the latter two food types ( $T_{39} = 1.47$ ,  $P = 0.15$ ) (Table 4). The mean generation time of *N. paspalivorus* was shorter on *A. guerreronis* and *S. furcatus* (11–12 days) than on coconut pollen (~16 days). The finite rate of increase varied between 1.1 (on *S. furcatus* and coconut pollen) and 1.3 (on *A. guerreronis*) per female/day (Table 4).

The pre-oviposition, post-oviposition and oviposition periods of *P. bickleyi* did not differ between the two food types ( $F_{1,58} = 2.52$ ,  $P = 0.118$ ;  $F_{1,58} = 0.08$ ,  $P = 0.774$ ;  $F_{1,58} = 0.62$ ,  $P = 0.434$ , respectively) (Table 4). The first eggs were laid shortly after mating and the oviposition period lasted ~8 days with both food types (Table 4).

**Fig. 2** Age-specific survival (a) and fecundity (b) of *Proctolaelaps bickleyi* reared on *Aceria guerreronis* and *Rhizopus*



*Proctolaelaps bickleyi* reached a quite high intrinsic rate of increase on both *A. guerreronis* and *Rhizopus*, with the  $r_m$  on the former prey being significantly higher than the  $r_m$  reached on the latter ( $T_{58} = 49.57$ ,  $P < 0.001$ ) (Table 4). Similarly, the  $R_0$  was significantly higher on *A. guerreronis* than on *Rhizopus* ( $T_{58} = 15.4$ ,  $P < 0.001$ ). The mean generation time ranged between 8 days and 9 days on both food types. The finite rate was 1.4 (on *Rhizopus*) and 1.6 (on *A. guerreronis*) (Table 4).

## Discussion

Our study shows that *A. guerreronis* is a suitable prey and of high nutritional value for *N. paspalivorus* and *P. bickleyi* resulting in a short developmental time, high oviposition rate and with that high intrinsic rate of increase ( $r_m$ ). All other food types tested were inferior to *A. guerreronis*. However, *S. furcatus* and coconut pollen may be considered alternative food sources (sensu Overmeer 1985) for *N. paspalivorus* and the fungus *Rhizopus* for *P. bickleyi*.



**Table 4** Life table parameters of *Neoseiulus paspalivorus* and *Proctolaelaps bickleyi* on different food types at 25 ± 0.1°C, 70–90% RH and 12 h photophase

Food	N	Pre-oviposition <sup>1</sup> (days)	Oviposition period <sup>1</sup> (days)	Post-oviposition <sup>1</sup> (days)	$r_m^2$	$R_0^2$	T	$\lambda$
<i>N. paspalivorus</i>								
<i>A. guerreronis</i>	28	1.5 ± 0.19a	12.8 ± 1.18a	2.2 ± 0.32a	0.232 ± 0.007a	17.2 ± 1.64a	12.3	1.3
<i>S. furcatus</i>	13	2.3 ± 0.17a	8.1 ± 0.86b	2.7 ± 0.40a	0.126 ± 0.007b	4.1 ± 0.40b	11.3	1.1
Coconut pollen	19	1.9 ± 0.29a	9.7 ± 1.43ab	2.9 ± 0.51a	0.096 ± 0.008c	4.4 ± 0.68b	15.6	1.1
<i>P. bickleyi</i>								
<i>A. guerreronis</i>	30	0.7 ± 0.12a	7.2 ± 0.59a	3.1 ± 0.47a	0.489 ± 0.010a	40.4 ± 3.26a	7.6	1.6
<i>Rhizopus</i>	30	0.9 ± 0.12a	7.9 ± 0.71a	2.9 ± 0.51a	0.361 ± 0.010b	27.3 ± 3.33b	9.2	1.4

Separate analysis for each species.

N: number of observations.

Different letters within columns denote significant differences ( $P < 0.05$ ) (¹ results of ANOVA followed by Bonferroni tests; ² results of pairwise student's *t*-tests).

$r_m$ : jackknife estimates of intrinsic rate of increase (±SE);  $R_0$ : net reproductive rate (female progeny per female, ±SE); T: mean generation time (days);  $\lambda$ : finite rate of increase.

Both predatory mites showed characteristics of type III/IV generalist predatory mites as described by McMurtry and Croft (1997). Many type III/IV generalist mites (McMurtry and Croft 1997) are commonly found on/in different plants/habitats in association with eriophyoid mites and are considered the primary agents in natural and biological control of these mites (e.g. Sabelis 1996). With only a few exceptions all eriophyoid mites tested proved to be suitable prey for generalist phytoseiid predators (McMurtry et al. 1970; Sabelis 1996). However, the nutritional value of eriophyoid mites for phytoseiid mites is not self-evident. The citrus rust mite *Phyllocoptruta oleivora* (Ashmead) (Eriophyidae) is an inadequate prey for *Amblyseius largoensis* Muma (Kamburov 1971) but suitable for *Amblyseius swirskii* Athias-Henriot (Swirskii et al. 1967). Likewise, the tomato russet mite *Aculops lycopersici* Masee (Eriophyidae) is an inadequate prey for *Euseius* (= *Amblyseius*) *victoriensis* (Womersley) (James 1989) but suitable for *Euseius concordis* (Chant) (de Moraes and Lima 1983). Abou-Awad et al. (2001) showed that *Aceria dioscoridis* (Soliman and Abou-Awad) contains important polypeptides, which enhanced the fertility of *Lasioseius athiasae* Nawar and Nasr (Ascidae) when reared on that prey in comparison to *T. urticae* or the nematode *Meloidogyne incognita* Chitwood. Similarly, deficiency in certain nutrients may explain the unsuitability of *T. urticae* as prey observed in our study. The intrinsic rate of increase ( $r_m$ ) of *P. bickleyi* on *A. guerreronis* is probably the highest recorded for ascid mites (Nawar 1992; Abou-Awad et al. 2001; Gerson et al. 2003) and that of *N. paspalivorus* among the highest for phytoseiids on a diet of eriophyoid mites (e.g. Dicke et al. 1990; Schausberger 1992; Engel and Ohnesorge 1994). Both predatory mites thrived on *A. guerreronis* making them promising biocontrol agents of that pest.

The availability of alternative foods on coconut palms such as coconut pollen, tarsonemid mites and *Rhizopus* may help to sustain the populations of both predatory mites when *A. guerreronis* is scarce (Onzo et al. 2005; Sabelis and van Rijn 2005). The rather high intrinsic rate of increase of *P. bickleyi* reached with *Rhizopus* could be highly favourable for mass-rearing and augmentative release purposes. Our method of cultivation of *Rhizopus* is simple and cheap. The composition in proteins, carbohydrates, minerals, vitamins and fibres of commercially available dry dog food make it a perfect media for cultivating the fungus (E. S. Silva unpublished). Ascid mites and especially species in the genus *Proctolaelaps* are generally known to be able to reach very high population densities within a short period of time (Nawar 1992; Abou-Awad et al. 2001). Some ascid mites such as *Blattisocius keegani* (Fox) and *B. tarsalis* (Berlese) are known as efficacious biocontrol agents of moth, beetle eggs and acarid mites in stored products (Gerson et al. 2003). Nawar (1992) observed that *Proctolaelaps deleoni* Nawar developed well on the fungi *Fusarium oxysporum* Snyder and Hansen and *Aspergillus flavus* Teigh but failed to lay eggs.

Interestingly, both *N. paspalivorus* and *P. bickleyi* failed to reach adulthood when fed *T. urticae*. This contrasts sharply with observations by K. Negloh (unpublished), who successfully reared populations of *N. paspalivorus* from Benin and Brazil on washed eggs of *T. urticae*. This discrepancy may be due to profound differences in the experimental procedures such as the use of a different host plant for rearing *T. urticae* and washing the *T. urticae* eggs. Washing eggs of *T. urticae* may have removed cues and webbing and consequently allowed feeding by the predatory mite. Spider mite webbing has been reported to disturb some generalist predators in searching behaviour (de Moraes and Lima 1983) and/or to entrap the mites (e.g. Schausberger 1992). Our experimental protocol of brushing mixed stages of *T. urticae* on the experimental units allowed the formation of webbing and may have interfered with prey search and capture by *N. paspalivorus* and *P. bickleyi*. Juvenile mortality is usually the highest in the first feeding stage, which is,

depending on the species, the larva or the protonymph (Zhang and Croft 1994; Schausberger and Croft 1999). Our results indicate that both *N. paspalivorus* and *P. bickleyi* may have an obligatory feeding larval stage since the mites were unable to moult to the protonymphal stage without food (Lawson-Balagbo personal observation). Apart from the genus *Euseius* obligatory feeding larvae are relatively rare in phytoseiid mites (Zhang and Croft 1994; McMurtry and Croft 1997; Schausberger and Croft 1999). *Neoseiulus paspalivorus* is the first recorded species in the genus *Neoseiulus* with an obligatory feeding larval type. Similarly to phytoseiid mites, ascid larvae may or may not have to feed to reach the protonymphal stage. In contrast to *P. bickleyi*, larvae of *L. athiasae* are facultative feeders (Abou-Awad et al. 2001).

Our study is the first documentation of the life history of *N. paspalivorus* and *P. bickleyi* on the various food types occurring on coconut fruits. This is an important step in developing biological or integrated control strategies against the coconut mite *A. guerreronis*. In related studies Lawson-Balagbo et al. (2007a, b) observed that both predators may co-occur on coconut fruits but occupy separate micro-niches under the perianth. The larger *P. bickleyi* adults seem to have more difficulties in accessing the tightest areas under the perianth than *N. paspalivorus* adults. Together, these works suggest that both predatory mites are promising candidates for biological control of *A. guerreronis* and both will be subjected to further investigations. Before investigating the potential impact of both predatory mites singly and/or in combination on *A. guerreronis* under field conditions, small scale studies on population dynamics and intraguild interactions (spatial avoidance and predation) will be studied under controlled laboratory conditions.

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