



Potential of a winterschmidtiiid prey mite for the production of the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae)

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Abstract

Mass rearing of the predatory mite *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) using natural (prey) methods is costly and laborious, limiting its application in the biological control of pests. A high-production, low-cost method using a prey substitute would help to relieve this problem. *Oulenziella bakeri* Hughes (Acari: Winterschmidtiiidae) could be an alternative prey source, but studies on the reproductive parameters of *N. californicus* under rearing conditions are lacking. This study evaluated the potential of *O. bakeri* as an alternative prey in *N. californicus* rearing by comparing developmental parameters among *N. californicus* reared on three diets based on an age-stage two-sex life table. We found that the preoviposition period and developmental time of *N. californicus* did not vary based on diet. The fecundity of *N. californicus* adults reared on *O. bakeri* was 29.8 eggs per female, which was lower than that of adults reared on *Tetranychus urticae* Koch (Acari: Tetranychidae) (42.9 eggs per female); there was no significant difference between *O. bakeri* and apple pollen (30.2 eggs per female). The oviposition rate of mites fed on *O. bakeri* was 69% of that fed on *T. urticae*. *Neoseiulus californicus* reared on *O. bakeri* and apple pollen showed the same intrinsic rate of increase (0.25 per day), which was 86% of the rate of those fed on *T. urticae*. Compared with predatory mites reared on natural prey, *N. californicus* reared on *O. bakeri* had a high survival rate and good oviposition and population growth parameters, suggesting that *O. bakeri* is suitable for the rearing of *N. californicus*.

Keywords Alternative prey · Life table · *Oulenziella bakeri* · Predator · *Neoseiulus californicus*

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Introduction

An increasing number of biocontrol agents is being introduced to agricultural systems, and it is important that they are mass produced in a suitable and sustainable manner as part of the foundation of enhanced biological control (King 1993). Of the predatory mite species that have been successfully commercialized (McMurtry and Scriven 1965; McMurtry and Croft 1997), more than 20 are used to control spider mites, thrips, whiteflies and aphids (van Lenteren 2012). Maintaining large-scale, low-cost production of predatory mites is crucial for their application as biocontrol agents (Song et al. 2019).

There are some established methods for the mass rearing of predatory mites. The first is the natural prey breeding method, which involves breeding natural prey and using them as a food source. This approach is mainly used for predatory mites that prey exclusively or mainly on spider mites, such as *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae). The second method is alternative (factitious) prey breeding, which uses wheat bran and other diets to rear alternative prey, including some astigmatid mites, lepidopteran eggs, and the pupae of small insects (Altieri 1992; Pina et al. 2012; Barbosa and de Moraes 2015; Ji et al. 2015). For example, *Carpoglyphus lactis* (L.) (Acari: Astigmata) are often used as a food source in rearings of predatory mites such as *Neoseiulus barkeri* (Hughes), *Amblyseius swirskii* Athias-Henriot, *Amblyseius gossipi* Elbadry (all Acari: Phytoseiidae), and *Stratiolaelaps scimitus* (Womersley) (Acari: Laelapidae) (Rasmy et al. 1987; Bolckmans and van Houten 2006). The third method is pollen breeding – some mites are specialized pollen feeders/generalist predators (so-called ‘type IV’ predators in the terminology of McMurtry et al. 2013). Finally, artificial diets may be used as substitute food sources in mass cultures of predatory mites, such as honey, tryptone, sucrose, egg yolk, and yeast extract (Nguyen et al. 2014; Janssen and Sabelis 2015).

Neoseiulus californicus (McGregor) is a predatory mite used as a biocontrol agent against the two-spotted spider mite, *Tetranychus urticae* Koch, throughout a wide range of climatic and management conditions (Greco et al. 2005; Fraulo and Liburd 2007; Fraulo et al. 2008; Palevsky et al. 2008). Based on their food habits, biological traits, and morphological traits, phytoseiid mites have been classified into four categories (McMurtry and Croft 1997): type I mites are specialist predators of *Tetranychus*, type II mites are selective (specialist) predators of tetranychid mites, type III mites are generalist predators, and type IV mites are specialized pollen feeders/generalist predators. Although *N. californicus* feeds on tetranychid mites in the field, they can either selectively prey on spider mites [selective (specialist) predators] or feed on alternative foods such as pollen or small arthropods when field prey mite populations are low [generalist predators] (Rhodes and Liburd 2005; Saber 2013; Vacacela Ajila et al. 2019). Furthermore, some non-prey foods, such as fungal spores and hyphae, pollen, artificial diets and even plant tissues, may be used as supplementary or alternative foods in *N. californicus* rearing (Overmeer et al. 1985; van Rijn and Tanigoshi 1999). Therefore, in the commercial production of *N. californicus*, a range of alternative food sources may be used.

Neoseiulus californicus has been successfully reared on a variety of astigmatid mites (Castagnoli et al. 2006; Simoni et al. 2006; Barbosa and de Moraes 2015), including the dust mites *Dermatophagoides farinae* (Hughes) and *Lepidoglyphus destructor* (Schrank). Some astigmatid mites can be easily reared in large numbers on bran, flour or similar substrates, which greatly reduces the cost of predatory mite mass-rearing compared with the use of phytophagous mites as prey (Ramakers and van Lieburg 1982; Gerson et al. 2003). However, some astigmatid mites are not practicable food sources

for predatory mites because they may trigger allergies in those that rear them (Castagnoli et al. 2006). It is well known that using spider mite-infested plants to rear phyto-seiid mites has several disadvantages, such as the need for a large space, high costs and harvesting difficulties (Nguyen et al. 2015; Vangansbeke et al. 2016; Su et al. 2019). The use of an artificial food source to rear predatory mites is also costly compared with alternative prey such as *Oulenziella bakeri* Hughes (Acari: Winterschmidtidae) (De Clercq et al. 2010). Hence, a cost-effective alternative prey for mass rearing is an essential requirement.

The fungivorous mite *O. bakeri* inhabits the leaves and fruits of rubber, jute, and citrus trees in tropical regions (Fan et al. 2012). Liu and Zhang (2016) studied the biological characteristics of *O. bakeri* and found that populations fed on yeast can become established at 25 °C. Studies have demonstrated that large numbers of *O. bakeri* can be reared on yeast alone or on combinations of yeast, flour, wheat husk, vermiculite, sawdust and other components (Jiang 2014). This is a cost-effective breeding method to maintain an *O. bakeri* population as prey. Similar to the commercial predatory mite breeding method using astigmatid mites (Ramakers and Van Lieburg 1982; Rasmy et al. 1987), most food sources of *O. bakeri* may be obtained in large numbers, are inexpensive and are easy to procure. Zhu et al. (2019) found that adult female *N. californicus* displays a type II functional response when fed on *O. bakeri* eggs and nymphs.

Although *O. bakeri* may be an alternative prey species in the large-scale commercial production of *N. californicus* (Liu and Zhang 2016; Zhu et al. 2019), to date there are no detailed data on the reproduction and development of *N. californicus* reared on *O. bakeri*. Therefore, we aimed to understand the effects of diet on *N. californicus* populations reared on *O. bakeri*, apple pollen and *T. urticae*.

Materials and methods

Mite source and rearing

The initial populations of *N. californicus* and *O. bakeri* used in this study were purchased from Fuzhou Guannong Biological Science and Technology (Fuzhou, China), and reared in the laboratory in a 60×62×172-cm climate cabinet at 27±1 °C, 75±5% RH, and L16:D8 photoperiod. Yeast was purchased from Angel Yeast Company, China, and used to rear *O. bakeri*. The arenas used to rear *N. californicus* and *O. bakeri* consisted of square plastic boxes (18×18 cm, 8 cm high) with a sponge placed at the bottom and a 12-cm-diameter Petri dish on top of the sponge. Distilled water was added to fill the box to the bottom of the Petri dish to prevent mites from escaping. Colonies of *T. urticae* were established from specimens originally collected in Guiyang city, China (26°55'N, 107°17'E). *Tetranychus urticae* colonies were reared on bean plants (*Phaseolus vulgaris* L.) in a greenhouse at 27±1 °C under natural humidity and photoperiod conditions.

Apple pollen was chosen as a natural food source because the survival rate and fecundity of *N. californicus* on apple pollen were better than on other pollen types (including apricot, camellia and loofah) according to our preliminary evaluations. Fresh apple pollen was purchased from Shandong Qingdao Jinbaolun Agricultural Technology, China, and stored at -20 °C for no more than 6 months. During the experiments, the pollen was stored in a refrigerator at ca. 4 °C for no more than 2 weeks.

Life table study

Low-quality food leads to nutrient imbalances and can affect biological parameters (such as fecundity, among others) (Lee 2007). To avoid the effects of nutrient imbalance, an experimental population of *N. californicus* was reared for five generations on *T. urticae*, *O. bakeri* and apple pollen before the initiation of the experiments, and then the newly emerged generation were used in the following experiments. The experimental unit contained a 3-cm-diameter bean leaf disc placed on top of a wet sponge in a 10-cm-diameter Petri dish containing water. The edges of the bean leaf were covered with absorbent cotton to provide moisture and prevent predators from escaping. Water was added to the tray daily to keep the cotton moist. At the beginning of the experiments, to obtain *N. californicus* eggs of the same-age, 50 pairs of males and females in the same period were transferred from the conditioned colonies onto a bean leaf disc. After 24 h, the deposited eggs were individually transferred to the experimental units, with up to 60 replicates per treatment. Sixty *N. californicus* eggs were used for each diet. After hatching, 0.1 mg of apple pollen per experimental unit or a mixture of different stages of *O. bakeri* or *T. urticae* was offered as food.

Each experimental unit was checked daily, and the survivorship and development of the various immature stages of the predators were recorded. When the predatory mites reached the adult stage, females were paired with males obtained in the same experiment. Couples were kept together through the end of the study. The number of eggs laid was recorded, and eggs were removed daily after oviposition until all the adult mites died. In the pollen tests, pollen was changed and removed every 5 days. In the mite prey tests, the amount of *O. bakeri* and *T. urticae* were observed daily and supplemented, if necessary, to ensure adequate prey for the predator. All tests were carried out at 27 ± 1 °C, $75 \pm 5\%$ RH and L16:D8 photoperiod.

Data analysis

The raw data of *N. californicus* individuals were analysed according to developmental stage and the two-sex life table using the Two Sex-MSChart program (Chi and Liu 1985; Chi 1988, 2017). The age-stage specific survival rate (S_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), age-stage specific fecundity (f_{xj}), age-stage life expectancy (e_{xj}) and growth parameters, including intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T), were calculated according to Chi and Liu (1985) and Chi (1988).

Huang and Chi (2012) indicated that the jackknife method leads to substantial errors in the pseudo-values of the net reproductive rate (R_0) and overestimates their differences. Therefore, bootstrapping with 100,000 iterations was used to estimate the means and standard errors of the life table parameters. The paired bootstrap test was used to compare differences in developmental duration in various life stages, adult longevity, total preoviposition period (TPOP; the time from hatching to the first oviposition in females), adult preoviposition period (APOP; the time between adult emergence and the first oviposition in females), oviposition days, preadult survival rate, fecundity and population parameters (r , λ , R_0 and T) among the three treatments. The significance of differences between treatments was calculated above 100,000 bootstrap and then evaluated based on the 95% confidence interval (Goodman 1982; Brandstätter 1999; Hesterberg et al. 2005). All figures were generated using SigmaPlot v.14.0 software (Systat Software, San Jose, CA, USA).

Fig. 1 Mean (+SE) preadult survival rate (%) of *Neoseiulus californicus* reared on *Oulenziella bakeri*, apple pollen, or *Tetranychus urticae*. Means capped with the same letter are not significantly different (paired bootstrap tests: $P > 0.05$)

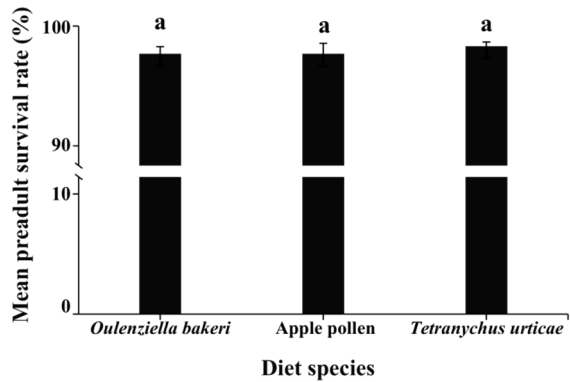


Table 1 Mean (\pm SE) development duration (days) of various life stages and the longevity of *Neoseiulus californicus* adults reared on each of three diets

Stage	<i>Oulenziella bakeri</i>		Apple pollen		<i>Tetranychus urticae</i>		
	n	Duration (days)	n	Duration (days)	n	Duration (days)	
Egg	60	1.83 \pm 0.04 a	60	1.88 \pm 0.08 a	60	1.77 \pm 0.07 a	
Larva	58	1.05 \pm 0.06 a	59	1.02 \pm 0.02 a	60	1.01 \pm 0.04 a	
Protonymph	58	1.04 \pm 0.05 a	59	1.06 \pm 0.03 a	60	1.02 \pm 0.02 a	
Deutonymph	58	1.24 \pm 0.03 a	58	1.29 \pm 0.04 a	59	1.21 \pm 0.06 a	
Adult longevity	Female	32	20.85 \pm 1.23 b	34	32.15 \pm 2.31 a	37	21.52 \pm 1.15 b
	Male	26	18.92 \pm 1.02 b	24	25.96 \pm 1.75 a	22	19.64 \pm 1.21 b
Total longevity	Female	32	26.04 \pm 1.24 b	34	37.44 \pm 6.68 a	37	26.52 \pm 1.16 b
	Male	26	24.62 \pm 0.99 b	24	30.99 \pm 1.74 a	22	24.44 \pm 1.23 b

Standard errors are calculated using the bootstrap method with 100,000 iterations. Means within a row followed by different letters are significantly different (paired bootstrap test: $P < 0.05$)

Results

Development time, preadult survival, adult longevity, and lifespan

The mean development times of the various immature life stages of *N. californicus* reared on *O. bakeri*, apple pollen, and *T. urticae* are summarized in Table 1. The durations of egg, larva, protonymph and deutonymph were not different among the three diet groups (Table 1). Female and male adult longevity in *N. californicus* reared on apple pollen were 32.15 and 25.96 days, respectively; the values were significantly higher than those of *N. californicus* fed on *O. bakeri* (female and male adult longevity were 20.85 and 18.92 days, respectively) and those reared on *T. urticae* (21.52 and 19.64 days, respectively) (Table 1). Diet had no influence on the preadult survival rate in *N. californicus* (Fig. 1). The total numbers of eggs laid by *N. californicus* reared on *T. urticae* was 42.87 per female, which was significantly higher than those fed on *O. bakeri* (29.78 eggs per female) and apple pollen (30.18 eggs per female) (Table 2).

Table 2 Mean (\pm SE) female reproductive parameters of *Neoseiulus californicus* reared on each of three diets

Parameter	<i>Oulenziella bakeri</i> (n=32)	Apple pollen (n=34)	<i>Tetranychus urticae</i> (n=37)
Adult pre-oviposition period (APOP) (days)	2.33 \pm 0.11 b	2.94 \pm 0.36 a	1.95 \pm 0.20 c
Total pre-oviposition period (TPOP) (days)	5.19 \pm 0.16 a	5.30 \pm 0.18 a	5.00 \pm 0.13 a
No. oviposition days	12.30 \pm 1.05 a	13.74 \pm 1.21 a	14.74 \pm 0.85 a
Lifetime fecundity (total no. eggs per female)	29.78 \pm 2.57 b	30.18 \pm 2.59 b	42.87 \pm 2.29 a

Standard errors are calculated using the bootstrap method with 100,000 iterations. Means within a row followed by different letters are significantly different (paired bootstrap tests: $P < 0.05$)

No difference in the TPOP was observed among the mites fed the different diets (Table 2). However, the APOP was significantly prolonged in the mites fed on apple pollen compared to the other two diets (Table 2).

Age-specific survivorship and fecundity

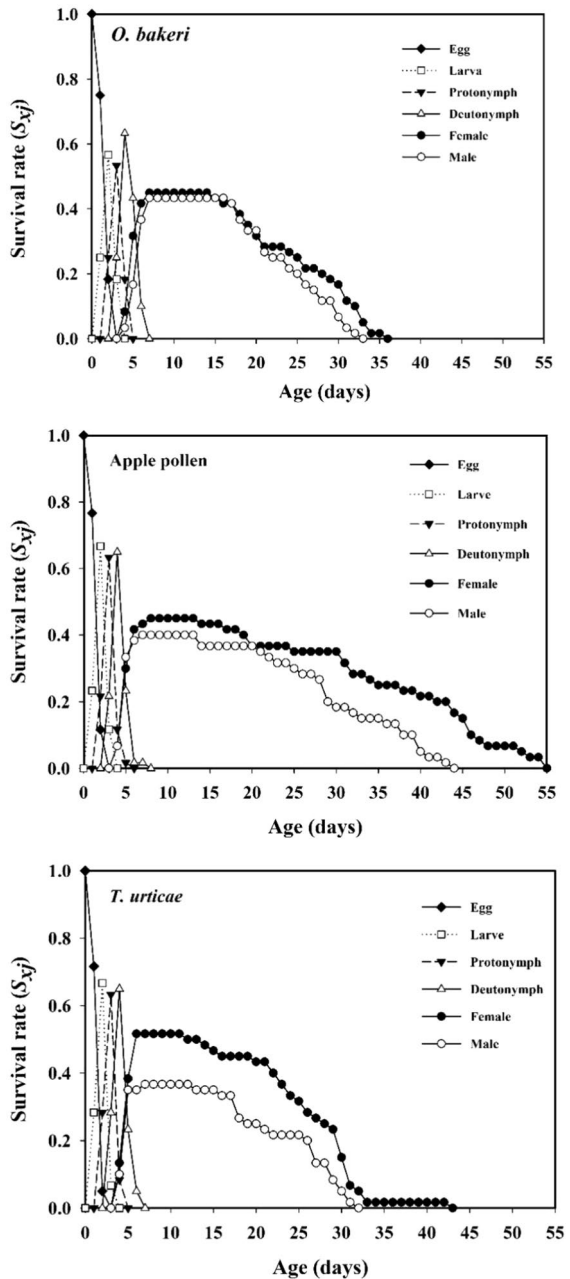
The overlap observed in the age-stage specific survival rates (S_{xj}) clearly showed a variable developmental rate among individuals (Fig. 2). The average daily egg production by *N. californicus* females reared on *T. urticae* was higher than those in mites reared on *O. bakeri* and apple pollen. Females reared on *O. bakeri*, apple pollen, and *T. urticae* achieved peak oviposition at 6, 5 and 8 days, with maximum daily egg production per female of 2.92, 2.89, and 3.48 eggs, respectively (Fig. 3).

The life expectancy at age zero (e_{01}) in individuals reared on apple pollen (30.20 days) was higher than the corresponding values for individuals reared on *O. bakeri* (22.86 days) and *T. urticae* (23.30 days) (Fig. 4). The reproductive values (v_{xj}) at age zero were 1.30, 1.28, and 1.33 day^{-1} for *N. californicus* reared on *O. bakeri*, apple pollen, and *T. urticae*, respectively (Fig. 5).

Life table parameters

The intrinsic rate of increase (r), net reproductive rate (R_0), mean generation time (T), and finite rate of increase (λ) values are listed in Table 3. There were no differences in T among *N. californicus* mites reared on the different diets (Table 3). Higher values of λ (1.34 day^{-1}), r (0.29 day^{-1}), and R_0 (22.17 offspring) of *N. californicus* were recorded on *T. urticae* as compared to *O. bakeri* ($\lambda = 1.28 \text{ day}^{-1}$, $r = 0.25 \text{ day}^{-1}$, $R_0 = 13.40$ offspring) and apple pollen ($\lambda = 1.28 \text{ day}^{-1}$, $r = 0.25 \text{ day}^{-1}$, $R_0 = 13.58$ offspring).

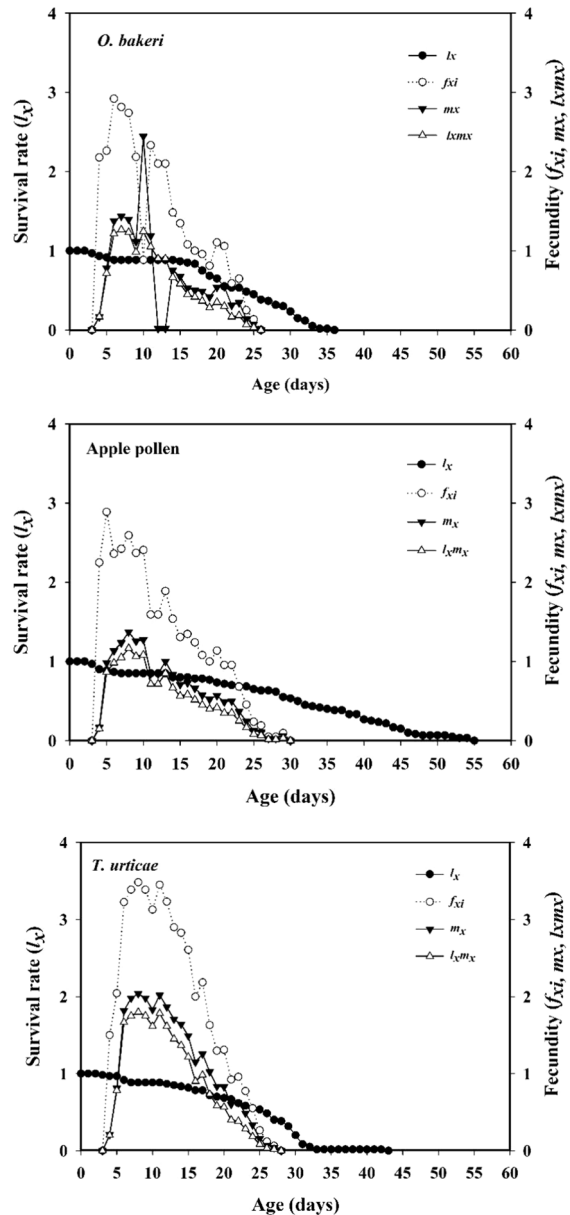
Fig. 2 Age-stage-specific survival rate (S_{xy}) of *Neoseiulus californicus* reared on *Oulenzietta bakeri*, apple pollen, or *Tetranychus urticae*



Discussion

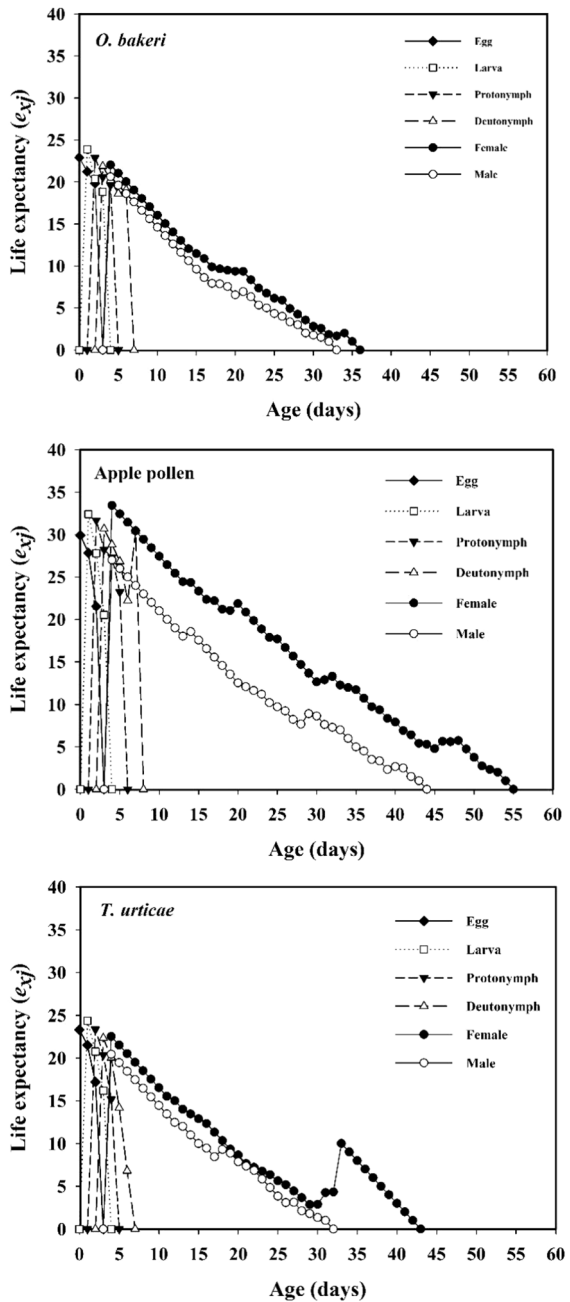
The aim of this study was to assess the use of *O. bakeri* in the rearing of *N. californicus* as an alternative food source compared to *T. urticae* and apple pollen. *Neoseiulus californicus* was reared for five generations on all three food sources, with an immature survival

Fig. 3 Age-specific survival rate (l_x), age-specific fecundity (m_x), age-stage-specific fecundity (f_{xj}), and net maternity ($l_x m_x$) of *Neoseiulus californicus* reared on *Oulenziaella bakeri*, apple pollen, or *Tetranychus urticae*



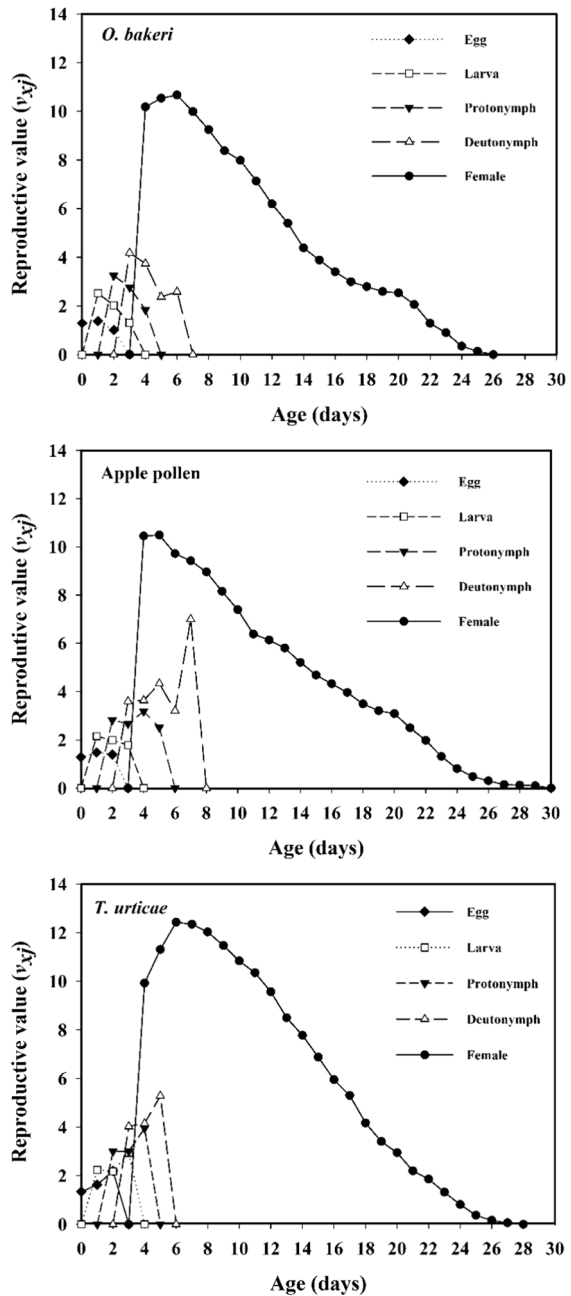
rate > 96%. *Neoseiulus californicus* reared on *O. bakeri* and apple pollen had similar development times and population growth. There were no significant differences in female and male total longevity between *N. californicus* reared on *O. bakeri* and *T. urticae*. *Oulenziaella bakeri* mites as a food source yielded a 69% oviposition rate of *N. californicus* (Table 2), approximately 60% net reproductive rate (R_0), 86% intrinsic rate of increase (r) and > 95% finite rate of increase (λ) (Table 3) compared to predatory mites reared on *T. urticae*. These results showed that *O. bakeri* holds a promise in *N. californicus* rearing.

Fig. 4 Age-specific life expectancy (e_{xj}) of *Neoseiulus californicus* reared on *Oulenzia bakeri*, apple pollen, or *Tetranychus urticae*



Pollen may positively affect multiple characteristics of predatory mites, including survival rates, body size, and/or fecundity (Castagnoli et al. 1999a, b; Khanamani et al. 2017). In this study, rearing *N. californicus* on apple pollen resulted in significantly longer total longevity in both sexes and longer APOPs in females than rearing *N. californicus*

Fig. 5 Age-stage-specific reproductive value (v_{xj}) of *Neoseiulus californicus* reared on *Oulenzia bakeri*, apple pollen, or *Tetranychus urticae*



on *O. bakeri* and *T. urticae*. However, the total number of eggs laid per female reared on apple pollen was significantly lower than that on *T. urticae*. The number of eggs laid by *N. californicus* females reared on maize pollen (34.89) was lower than that laid by females reared on *T. urticae* (38.31) (Khanamani et al. 2017). *Typhlodromus bagdasarjani* females

Table 3 Mean (\pm SE) population growth parameters of *Neoseiulus californicus* reared on each of three diets

Diet	r (day ⁻¹)	R_0 (no. offspring/female)	T (days)	λ (day ⁻¹)
<i>Oulenziella bakeri</i>	0.25 \pm 1.78 b	13.40 \pm 2.22 b	10.23 \pm 0.32 a	1.28 \pm 2.28 b
Apple pollen	0.25 \pm 1.85 b	13.58 \pm 2.25 b	10.59 \pm 0.36 a	1.28 \pm 2.35 b
<i>Tetranychus urticae</i>	0.29 \pm 1.55 a	22.17 \pm 3.00 a	10.54 \pm 0.22 a	1.34 \pm 2.07 a

Standard errors were calculated using the bootstrap method with 100,000 iterations. Means within a column followed by different letters are significantly different (paired bootstrap tests: $P < 0.05$)

fed almond pollen laid 27.59 eggs, which was more than females fed *T. urticae* (21.50 eggs per female) (Riahi et al. 2016). These differences in fecundity may be due to nutritional variability in pollen from different plant species, and predatory mite species differ in their ability to utilize pollen (Khanamani et al. 2017). Pollen, as an alternative food source, may be used to maintain the predator population when primary prey is unavailable, or to produce predatory mites on a small scale for experimental use. Nevertheless, the pollen rearing method is not feasible for large-scale rearing because pollen needs to be replaced frequently due to the potential for fungal growth during rearing.

Alternative non-mite foods, such as artificial diets, have been evaluated for their use in low-cost, effective commercial rearing of *N. californicus*. Song et al. (2019) found that the artificial diet enriched with *Ephestia kuehniella* eggs (that is, 20% *E. kuehniella* eggs, 4% honey, 4% sucrose, 4% tryptone, 4% yeast extract, 8% egg yolk, and 56% distilled water) was adequate to support long-term rearing of *N. californicus*. However, using artificial diets to rear predatory mites often leads to reduced fecundity, a reduced lifespan, an inability to locate hosts, and poor survival. Ogawa and Osakabe (2008) reared *N. californicus* on an artificial diet based on yeast, sugar, and fresh egg yolk and found that the mites successfully developed to the adult stage, but they laid few eggs. Another artificial diet consisting of honey, sucrose, tryptone, yeast extract, fresh egg yolks, and the shelled egg extract of brine shrimp, *Artemia franciscana* (Kellogg) (Nguyen et al. 2015), was used to rear *N. californicus*, yielding mites that developed to the adult stage and laid some eggs, but their offspring was unable to develop to the adult stage. *Neoseiulus californicus* is considered a selective predator of tetranychid mites, which may explain its relatively poor performance on some artificial diet (McMurtry and Croft 1997; Nguyen et al. 2015).

Previous studies on predatory mite mass rearing on other saphrophagous mites has reported encouraging results. For example, *N. barkeri* reared on the synanthropic mite *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) laid 18.20 eggs per female (Li et al. 2017), to the fecundity of predators reared on *T. urticae*. Saphrophagous mites include *Tyrollichus casei* Oudemans, *T. putrescentiae* and *Acarus farris* (Oudemans) (all Acari: Astigmata), which have been used as prey in the mass production of *Agistemus exsertus* Gonzalez (Acari: Stigmaeidae), *Amblyseius cucumeris* Oudemans (Acari: Phytoseiidae) and *N. barkeri* (Schliesske 1981).

Several other astigmatid mites have been screened as alternative prey for *N. californicus*. Castagnoli et al. (2006) found that *L. destructor* was the most suitable prey species among five astigmatid mites, as there was no phytoseiid mortality, and the development time was relatively short. In females reared on *L. destructor* at 25 °C and 80% RH, the daily fecundity rate was 2.16 eggs per female. The fecundity of *N. californicus* reared on *D. farinae* at 25 °C and 80–90% RH was 30.50 eggs per female (Castagnoli et al. 1999a). Barbosa and de Moraes (2015) reported that the fecundity of *N. californicus* reared on *Blomia tropicalis* Bronswijk and *Austroglycyphagus lukoschusi* (Fain) at 25 °C and 90% RH was

17.8 and 21.7 eggs per female, respectively. Our results showed that the fecundity of *N. californicus* reared on *O. bakeri* was 29.78 eggs per female, similar to the fecundity rates in females reared on astigmatid mites under similar environmental conditions. Li et al. (2016) assessed the dried fruit mite *C. lactis* as an alternative prey species for *N. californicus*, but this yielded a fecundity and intrinsic rate of increase (r) of only 36.7 and 56%, respectively, compared to natural prey at 25 °C and 75% RH. As mentioned above, we found that the oviposition rate and r in *N. californicus* reared on *O. bakeri* were 69 and 86% of those in *N. californicus* reared on *T. urticae*, respectively – much higher than those reported previously and high enough to sustain rapid population growth under similar environmental conditions.

Compared with those in other astigmatid mites used in the rearing of *N. californicus*, large-scale producing of *O. bakeri* with wheat bran or yeast costs very little (Jiang 2014), and no studies or reports have shown that *O. bakeri* causes human allergies. The results suggest the possible use of *O. bakeri* as an alternative prey for the mass rearing of *N. californicus*, potentially reducing production costs and enabling its widespread application. Despite these promising results, complementary studies are warranted because many factors interact during mass rearing.

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Declarations

Conflict of interest The authors declare no competing financial interests.

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