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Biological performance of the predatory mite *Neoseiulus barkeri* Hughes (Phytoseiidae): a candidate for controlling of three mite species infesting grape trees

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Summary

The life history and predation rate of *Neoseiulus barkeri* (Phytoseiidae) feeding on *Colomerus vitis* (Eriophyidae), *Tetranychus urticae* (Tetranychidae) and *Brevipalpus lewisi* (Tenuipalpidae) were determined in the laboratory at constant temperatures of 25, 30 and 35 °C, relative humidity of 50 ± 5 % and a photoperiod of 16:8 h (light:dark). Within the temperature range studied, the increase of temperature from 25-35 °C led to a shortened development period and an increased total predation rate and reproduction. Survival during immature stages development surpassed 94 % at all the temperatures from 25 to 35 °C. The highest fecundity (59.50, 48.25 and 35.30 eggs per female) was recorded at 35 °C, while the minimum (40.25, 31.00 and 20.50 eggs per female) was at 25 °C when *N. barkeri* fed on *C. vitis*, *T. urticae* and *B. lewisi*, respectively. It is demonstrated in the life table parameters that when the predatory mite *N. barkeri* is fed on *C. vitis*, the highest reproduction rates (r_m = 0.195, 0.210 and 0.232 females/female/day) are obtained, while feeding on *B. lewisi* gave the minimum of reproduction rates (r_m = 0.095, 0.105 and 0.115) at 25 °C, 30 °C and 35 °C, respectively. The population of *N. barkeri* multiplied 20.45, 22.63 and 24.89 times in a generation time of 16.80, 14.75 and 12.50 days when fed on *C. vitis* at the same temperatures mentioned above, respectively, while *N. barkeri* multiplied 10.70, 12.88 and 14.36 times in a generation time of 23.20, 21.11 and 18.08 days when fed on *B. lewisi* at the same temperatures, respectively. This shows that *N. barkeri* is a promising control agent for *C. vitis*, *T. urticae* and *B. lewisi* on grape trees.

K e y w o r ds: *Neoseiulus barkeri;* predation rate; biological control; phytophagous mites; grapes.

Introduction

Grapevine (*Vitis vinifera* L.), is one of the common fruit in most continents covering an area of 7,437,143 ha producing around 67 Mio. t (OIV 2019). While total area reached 11.676 ha producing around 145,000 t in Saudi Arabia. Over the past decade, the area cultivated with grapes in this country expanded by about 15 % (FAO STAT 2012). Most of the cultivars planted in Saudi Arabia are highly susceptible to mite infestations (Al-Azzazy and Alhewairini 2020). The phytophagous mites (Eriophyidae, Tetranychidae and Tenuipalpidae) were of minor importance before the extensive use of synthetic pesticides. Largely due to the negative effects of acaricides on populations of predatory mites, plant-feeding mites are now the most dangerous pests of grapes in many regions of the world (James and Whitney 1993). Eriophyid mites cause serious direct damage to economically important plants by sucking cell contents from leaves and fruits leading to economic loss of the yield (Takayama *et al.* 2013) and lead to indirect injury as vectors of plant viruses (Oldfield and Proeseler 1996). *Colomerus vitis* (Pagenstecher), erineum strain is a global grape key pest, it can cause severe risks for grapevine (Ferragut *et al.* 2008). Being a vector of Grapevine 'Pinot Gris' virus rendered it to be a serious grape orchard pest (Malagnini *et al.* 2016, Javadi Khederi *et al.* 2018b). Among the species of tetranychid mites infesting plants, the two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acarina: Tetranychidae) is widely considered one of the most notable dangerous pest species due to its voracious appetite and wide geographic distribution and can infest hundreds of plant species (Yano *et al.* 2001). *T. urticae* causes severe loss in grape orchards (Candolfi *et al.* 1992). Severe infestation of *T. urticae* causes leaf damage, reduction in sugar content and ultimately affects plant growth (Hluchý and Pospîšil 1992) and yield (Prischmann *et al.* 2002). Tenuipalpid mites can undoubtedly cause severe crop loss. In addition, some species inject viruses into bud tissues, stem, fruit and leaf of host plants (Childers *et al.* 2003). *Brevipalpus lewisi* McGregor (Tenuipalpidae) is considered a serious pest of grape (Buchanan *et al.* 1980). It is reported to be widely distributed in Saudi Arabia and throughout the world (Dowling *et al.* 2012, Khan *et al.* 2019). However, in 2019, *B. lewisi* was found for the first time infesting grape plants (*Vitis vinifera* L) and inflicting considerable economic damage to the cities of Buraydah, Al-Asulabiyah, and Al Bukayriyah in northcentral Saudi Arabia. The use of broad-spectrum acaricides to manage

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phytophagous mites resulted in the destruction of natural enemies, environmental pollution, evolved resistance of mites to acaricides, pesticide residues in crops and public health problems (Ribeiro *et al.* 2014, Alhewairini and Al-Azzazy 2019). Therefore, these problems primarily necessitate the development of alternative pest control strategies, such as biocontrol agents for the management of phytophagous mites (Nicetic *et al.* 2001). Mites infesting grapes are attacked by many species of beneficial arthropods, including predatory insects and mites. Healthy populations of predacious mites keep phytophagous mite densities below economic thresholds in grape orchards (Camporese and Duso 1996).

Phytoseiidae is an important family of predacious mites that have been used extensively in biocontrol programs to regulate phytophagous mite populations in agricultural crops in different countries (Mailloux *et al.* 2010). Several species of predatory mites (e.g. Neoseiulus, Amblyseius and Typhlodromus species) feed on phytophagous mites and their eggs (Metwally *et al.* 2005, Al-Azzazy and Alhewairini 2020). The predatory mite, *Neoseiulus barkeri* Hughes (Phytoseiidae) is a widely distributed predator in many countries (Fan and Petitt 1994) including Saudi Arabia (Alatawi *et al.* 2017, Al-Shemmary 2018) *N. barkeri* is a predatory mite, feeding on a wide range of foods such as eriophyid mites, spider mites, storage mites, broad mites, thrips, whitefly eggs, Fungi and nematodes (e.g., Fan and Petitt 1994, Nomikou *et al.* 2001, Fernando *et al.* 2004, Xia *et al.* 2012, Negm *et al.* 2014, Al-Shemmary 2018, Li *et al.* 2018, Si-Hua Yang *et al.* 2020). Due to its unique biological traits, such as short life cycle, high fecundity, polyphagy, a wide prevalence, mobility and ease of rearing, *N. barkeri* is now considered as one of the most valuable and successful biocontrol agents for phytophagous mites. In the present study, we evaluated the potential efficiency of *N. barkeri* in biocontrol of the grape erineum mite, *C. vitis*, *T. urticae* and *B. lewisi*. The biological responses of *N. barkeri* have been planned to be used for getting its life-table parameters and to assess the possible application as biocontrol agents.

Material and Methods

Stock culture of predator: The effectiveness of *N. barkeri* as a predator was tested in the Acarology Laboratory of the Department of Plant Production and Protection, Qassim University, Saudi Arabia. Colonies of *N. barkeri* were established with individuals collected from commercial grape orchards in Al-Asulabiyah region (26°50′42.72″N 43°0′17.47″E), in northcentral Saudi Arabia, and were acclimated and propagated on kidney bean seedlings infested with *T. urticae* for approximately three months before the experiments described in this article in plant growth room at 32 ± 2°C, 50 % ± 5 % RH and 12:12 (L: D) photoperiod.

Preys and stock cultures: *Colomerus vitis*, *T. urticae* and *B. lewisi* were used as preys during the current study. Grape leaves infested with *C. vitis*, *T. urticae* and *B. lewisi* were collected from grape orchards in Al-Asulabiyah region (26°50′42.72″N 43°0′17.47″E), in northcentral Saudi Arabia. The three mite species were transferred to the acarology laboratory and reared on grape seedlings (*Vitis vinifera* L.), as a permanent source of preys, kept in a plant growth room at 32 ± 2 °C, 50 % ± 5 % RH and 12:12 (L:D) photoperiod.

Experimental units and conditions: The development, survival, predation rate and fecundity of *N. barkeri* were monitored at three constant temperatures (25, 30 and 35 °C), 50 ± 5 % RH and 12:12 (L: D) photoperiod. Nymphs of *T. urticae*, *B. lewisi* and motile stage of *C. vitis* collected from grape orchards or from stock cultures of prey (as a backup resource) were offered as food. For the experiments the predatory mites were reared individually on bean leaf disks (4 cm in diameter), which were placed upside down on moist cotton wool, inside plastic Petri dishes (7 cm in diameter). In addition, water was added daily to the Petri dishes to maintain moist cotton. Likewise, every 4 or 5 d, the predators were relocated to new rearing arenas.

Life history parameters: The developmental time, survival rate, adult fecundity, longevity and life table parameters of *N. barkeri* were determined by feeding them with *C, vitis*, *T. urticae* and *B. lewisi*. To determine the developmental time and to acquire same aged cohorts of predator eggs for the different biological tests, 80 gravid females of *N. barkeri* from the stock culture were deposited in the rearing arenas with about 2,000 spider mites, *T. urticae* as prey. These mite rearing arenas were maintained at 30 ± 1 °C, 12:12 h L: D photoperiod, and 50 % RH. After one day, eggs deposited by *N. barkeri* were transferred singly onto new rearing arenas, and the newly hatched larvae (60 per treatment) were supplied with the food resource to be evaluated (three preys). Observation of immature stages of *N. barkeri* were performed every 12 h to check on development, survival, and egg laying. After appearance of larvae, suitable densities of prey nymphs (30 individuals of *T. urticae* or *B. lewisi*) were added every day to the rearing arenas. A small disc (0.50 cm in diameter) of host leaves was attentively inspected to record the number of eriophyid mites per grape leaf disc before putting it onto the rearing arenas, due to the hardship in transferring the individuals of *C. vitisa*. For each treatment, after the deutonymph moult of *N. barkeri* female, a single male was put in the new female's leaf disc for mating and with a 1 cm long piece of cotton as the oviposition place. The couple was kept together until their death to ensure successful multiple mating. To separate consumption rate of females from males, the consumption rate of 40 males was tested under same conditions. Then, the mean of consumption rate of male was deducted from the average consumption rate of the couples (Moghadasi *et al.* 2014). The sex-ratio [females/(females + males)] of the predator was calculated from the developmental experiment. To test the sex ratio, 30 eggs were transferred separately to a new arena and the hatched larvae were reared until adulthood and their sex was established.

Predation rate: The predation rate of *N. barkeri* was determined using nymphs of *T. urticae*, *B. lewisi* and motile stages of *C. vitis*. The same kinds of experimental rearing arenas were used for the predation rate test. To determine the predation rate by various stages of *N. barkeri*, 40 nymphs prey of *T. urticae*, *B. lewisi* and 120 of *C. vitis* were added every day onto the discs. The quiescent stages

were removed before introducing discs into the arenas. The number of prey individuals consumed was recorded every 24 h. During the oviposition period, the number of eggs laid by the predator females were recorded every day, while eggs and prey residues were removed from the arenas to calculate the prey consumption.

Statistical analysis: One-way ANOVAs followed by Least Significant Difference (LSD) tests were used to assess the effect of temperature and prey type on development, adult longevity, fecundity and predation rates. The means of survival rates were separated according to Tukey's honestly significant difference test (Tukey's HSD test). Examinations on the development times, survival, fecundity and longevity of *N. barkeri* were used to construct a time-specific life table under laboratory rearing conditions. Sex ratios of the progeny were compared with crosstab test. Life table parameters for *N. barkeri* [mean generation time (T= Ln R_0/r_m), net reproduction rate ($R_0 = \sum l_x m_x$), intrinsic rate of increase (r_m = Ln R_0/T), finite rate of increase ($\lambda = e^{rm}$) and doubling time (DT = $ln2/r_m$] were calculated according to Birch (1948) using a BASIC computer software program developed by Abou-Setta *et al.* (1986). The Pearson's correlation coefficient of daily predation and oviposition was calculated using bivariate correlation analysis.

Results

Immature development: *Neoseiulus barkeri* completed the development from egg to adult over all temperatures studied (25, 30 and 35 °C). Successful development from egg to adult in *N. barkeri* occurred when the motile stages of *C. vitis* and nymphs of *T. urticae* and *B. lewisi* were supplied as prey. Development time of immatures significantly decreased as temperature increased. Likewise, the developmental time of immature stages fed on *C. vitis* prey was shorter than that of those fed on *T. urticae* and *B. lewisi*. The mean incubation period for eggs ranged from 4.88 d at 25 °C to 2.06 d at 35 °C. Developmental time of the larval, protonymph and deutonymph were lower than the egg incubation period at temperatures between 25 °C and 35 °C. From egg to adult, the females required 11.69, 8.46, 5.43 d on *C. vitis*, 12.70, 9.33, 5.90 d on *T. urticae* and 13.35, 9.90, 6.34 days on *B. lewisi* at the previously stated temperatures, respectively (Tab. 1). The survival rate of all stages in *N. barkeri* is shown in Tab. 3. Hatching percentage of eggs was only slightly affected by temperatures. Nearly 96.50 % of the eggs hatched at temperatures between 25 and 35 °C. Mortality of immature phases of *N. barkeri* was very low at all temperatures studied, and the results showed no trends with temperature. Nearly 97.00 % of larvae developed to adult stage at temperatures between 25 and 35 °C. At 25 °C, the generation period and adult longevity lasted (15.89 and 37.11 d), (17.11 and 36.81 d) and (18.01 and 37.41 d), respectively. At 35 °C, the corresponding periods were (7.43 and 26.40 d), (8.08 and 26.08 d) and (8.75 and 25.15 d) when *N. barkeri* fed on *C. vitis*, *T. urticae* and *B. lewisi*, respectively (Tab. 2). The same period of the male has been always shorter than those of female. As shown in Tab. 8, sex ratio (percentage daughters) at the different temperatures ranged from 56.66 to 80.00 %. There were insignificant differences among 25 and 30 °C, but female ratio was highest at 35 °C when females fed on *C. vitis* and lowest at 25 °C when females fed on *B. lewisi*.

Reproduction: Temperature had a significant effect on the reproductive parameters of *N. barkeri*. The interaction between temperature and predatory mite was significant for all parameters excluding for post-oviposition period (Tab. 2). Pre-oviposition period (POP, from moulting to adult to first oviposition) was longer at 25 °C than at 30 and 35 °C. Likewise, the POP was the longest (4.46 d) when reared on *B. lewisi*, while the POP did not differ significantly among *N. barkeri* reared on *C. vitis* or *T. urticae*. Oviposition periods were similar at both temperatures 30 and 35 °C, but a low temperature of 25 °C resulted in a 29.33 % longer oviposition period than 30 and 35 °C. However, the total number of eggs deposited per female at 25 °C was significantly lower than at 30 and 35 °C. *Neoseiulus barkeri* had a long oviposition period, which corresponded to about 72.90 % (70.97-74.84 %) of its total adult longevity (25.15-37.61 d) at all three temperatures (Tab. 2).

There were significant effects of prey type on the daily fecundity. *N. barkeri* females reared on *C. vitis* had a significantly greater total fecundity ($P < 0.05$) than *N. barkeri* females reared on *T. urticae* and *B. lewisi* (Tab. 4). Moreover, raising the temperature from 25 to 35 °C increased oviposition rate by about 64.13 %. The maximum reproduction (3.04, 2.54 and 1.97 eggs/♀/day) was recorded at 35 °C, while the minimum (1.42, 1.15 and 0.75 eggs/♀/d) was at 25 °C when *N. barkeri* fed on *C. vitis*, *T. urticae* and *B. lewisi*, respectively. At 25, 30 and 35 °C, the daily egg production peaked on days 29, 21, and 16 of life, 30, 26, and 17 and 32, 23, and 18, when *N. barkeri* fed on *C. vitis*, *T. urticae* and *B. lewisi*, respectively; the daily oviposition rates gradually reduced thereafter. Whereas the proportion of female progeny in *N. barkeri* was similar for the two prey *C. vitis* and *T. urticae*, a significantly lower percentage of female progeny was obtained when *N. barkeri* fed on flat mite, *B. lewisi* for the three temperature regimes.

Predation rate: The larvae of *N. barkeri* were sedentary and did not move far from where they hatched. No feeding nor colouration in the gut indicative of feeding was ever watched on the tested prey species. *N. barkeri* larvae developed to the first nymph stage without feeding, and predation activity started just after the mites entered the proto nymph stage. During immature stages of *N. barkeri*, predation rates increased with increasing temperatures from 25 °C to 35 °C. likewise, the age-phase-specific predation rate increased by increasing the phase of *N. barkeri* for three preys, so the adults consumed more preys compared with the nymphs. The numbers of *C. vitis*, *T. urticae* and *B. lewisi* prey consumed by female and male predators under various conditions are shown in Tabs 5, 6 and 7. The daily average consumption for females was 44.90, 57.96 and 77.02 *C. vitis*, 7.32, 11.18 and 18.31 *T. urticae* and 9.86, 12.04 and 21.18 *B. lewisi* at 25 °C, 30 °C and 35 °C and 50 % RH, respectively, during the immature stages. Data analysis showed a significant effect of temperature on the daily and total predation rates of *N. barkeri* protonymphs. The numbers of *C. vitis*, *T. urticae* and *B. lewisi* prey con-

Table 1

Average duration of the immature stages of *Neoseiulus barkeri* feeding on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at 25, 30 and 35 °C and 50 ± 5 % RH

Mite species	Temperature (°C)	Sex	Egg	Larva	Protochrysalis	Protonymph
Colomerus vitis	25 ± 1	♀	4.35 ± 0.20a	2.15 ± 0.12a	0.40 ± 0.06a	2.05 ± 0.14a
		♂	4.05 ± 0.20a	2.08 ± 0.12a	0.40 ± 0.08a	2.00 ± 0.20a
	30 ± 1	♀	3.20 ± 0.24b	1.66 ± 0.22b	0.26 ± 0.08b	1.50 ± 0.10b
		♂	3.00 ± 0.20b	1.30 ± 0.20b	0.22 ± 0.07b	1.25 ± 0.14b
	35 ± 1	♀	2.18 ± 0.22c	1.04 ± 0.08c	0.16 ± 0.06c	0.80 ± 0.12c
		♂	2.06 ± 0.22c	1.00 ± 0.06c	0.13 ± 0.05c	0.75 ± 0.10c
Tetranychus urticae	25 ± 1	♀	4.75 ± 0.36a	2.25 ± 0.20a	0.44 ± 0.07a	2.22 ± 0.19a
		♂	4.18 ± 0.32a	2.20 ± 022a	0.42 ± 0.06a	2.15 ± 0.18a
	30 ± 1	♀	3.64 ± 0.24b	1.82 ± 0.14b	0.30 ± 0.06b	1.61 ± 0.12b
		♂	3.33 ± 0.28b	1.42 ± 0.16b	0.27 ± 0.07b	1.33 ± 0.11b
	35 ± 1	♀	2.35 ± 0.28c	1.10 ± 0.11c	0.18 ± 0.05c	0.95 ± 0.04c
		♂	2.14 ± 0.24c	1.05 ± 0.09c	0.16 ± 0.04c	0.80 ± 0.04c
Brevipalpus lewisi	25 ± 1	♀	4.88 ± 0.42a	2.35 ± 0.14a	0.50 ± 0.10a	2.34 ± 0.22a
		♂	4.32 ± 0.30a	2.31 ± 0.11a	0.44 ± 0.08a	2.25 ± 0.20a
	30 ± 1	♀	3.75 ± 0.20b	1.88 ± 0.12b	0.32 ± 0.08b	1.75 ± 0.10b
		♂	3.28 ± 0.22b	1.45 ± 0.10b	0.30 ± 0.08b	1.45 ± 0.10b
	35 ± 1	♀	2.38 ± 0.22c	1.25 ± 0.06c	0.21 ± 0.05c	1.05 ± 0.10c
		♂	2.35 ± 0.24c	1.11 ± 0.08c	0.19 ± 0.04c	1.00 ± 0.10c

Mite species	Temperature (°C)	Sex	Deutochrysalis	Deutonymph	Teleiochrysalis	Developmental time
Colomerus vitis	25 ± 1	♀	0.32 ± 0.09a	2.10 ± 0.20a	0.32 ± 0.06a	11.69 ± 0.50a
		♂	0.30 ± 0.08a	2.00 ± 0.18a	0.30 ± 0.06a	11.13 ± 0.64a
	30 ± 1	♀	0.20 ± 0.08b	1.43 ± 0.09b	0.21 ± 0.06b	8.46 ± 0.44b
		♂	0.20 ± 0.08b	1.22 ± 0.10b	0.20 ± 0.06b	7.39 ± 0.66b
	35 ± 1	♀	0.10 ± 0.02c	1.05 ± 0.02c	0.10 ± 0.02c	5.43 ± 0.32c
		♂	0.10 ± 0.03c	1.00 ± 0.02c	0.10 ± 0.03c	5.13 ± 0.30c
					F = 0.814	P = 0.432
Tetranychus urticae	25 ± 1	♀	0.38 ± 0.09a	2.30 ± 0.18a	0.36 ± 0.07a	12.70 ± 0.54a
		♂	0.34 ± 0.07a	2.15 ± 0.18a	0.34 ± 0.06a	11.78 ± 0.60a
	30 ± 1	♀	0.22 ± 0.04b	1.50 ± 0.12b	0.24 ± 0.04 b	9.33 ± 0.58b
		♂	0.22 ± 0.05b	1.35 ± 0.11b	0.24 ± 0.05 b	8.17 ± 0.50b
	35 ± 1	♀	0.12 ± 0.05c	1.09 ± 0.08c	0.11 ± 0.05 c	5.90 ± 0.50c
		♂	0.12 ± 0.05c	1.05 ± 0.08c	0.11 ± 0.05 c	5.43 ± 0.38c
					F = 0.955	P = 0.495
Brevipalpus lewisi	25 ± 1	♀	0.42 ± 0.11a	2.45 ± 0.22a	0.41 ± 0.08a	13.35 ± 0.75a
		♂	0.40 ± 0.10a	2.31 ± 0.20a	0.35 ± 0.08a	12.38 ± 0.60a
	30 ± 1	♀	0.28 ± 0.10b	1.63 ± 0.10b	0.29 ± 0.06b	9.90 ± 0.71b
		♂	0.28 ± 0.09b	1.42 ± 0.11b	0.26 ± 0.05b	8.44 ± 0.60b
	35 ± 1	♀	0.16 ± 0.04c	1.15 ± 0.10c	0.14 ± 0.05c	6.34 ± 0.66c
		♂	0.14 ± 0.05c	1.10 ± 0.10c	0.12 ± 0.05c	6.01 ± 0.47c
					F = 1.035	P = 0.492

Different letters within the same column denote to a significant difference (ANOVA followed by Duncan's $P < 0.05$).

sumed daily by the protonymphs increased with increasing temperatures, from 37.02, 5.78 and 8.39 prey/d at 25 °C to 54.04, 11.57 and 14.54 prey/d at 35 °C. The predation rate of deutonymphs followed a similar trend as protonymphs. The predation increased from pre-oviposition to oviposition periods and decreased in the post-oviposition period.

The highest means for the daily and total prey consumption of females were recorded throughout the oviposition period, with the female consuming an average of 133.51, 150.50, and 167.69 *C. vitis*, 18.31, 21.99 and 25.77 *T. urticae* and 22.08, 26.94 and 29.28 *B. lewisi* individuals at 25 °C, 30 °C and 35 °C and 50 % RH, respectively, showing a preference for *C. vitis*. Therefore, the optimal temperature for predation of *N. barkeri* was about 35 °C. However, the total prey consumption of predators in the life span was highest at 35 °C (4127.75, 630.69 and 720.71) prey for female ($P = 0.191$), and 2817.14, 387.40 and 553.12 prey for male ($P = 0.221$) on *C. vitis*, *T. urticae* and *B. lewisi*, respectively. Daily consumption of predators fed on *C. vitis*, *T. urticae* and *B. lewisi* decreased with age.

Life table parameters: The life table are consistent with the aforementioned findings (Tab. 8). *N. barkeri*

Table 2

Average duration of *Neoseiulus barkeri* adults feeding on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at 25, 30 and 35 °C and 50 ± 5 % RH

Mite species	Temperature (°C)	Pre oviposition	Generation	Oviposition	Post oviposition
Colomerus vitis	25 ± 1	4.20 ± 0.24a	15.89 ± 0.66a	28.15 ± 0.91a	5.26 ± 0.32a
	30 ± 1	3.08 ± 0.20b	11.54 ± 0.50b	19.79 ± 0.84b	4.98 ± 0.30a
	35 ± 1	2.00 ± 0.09c	7.43 ± 0.46c	19.53 ± 0.70b	4.87 ± 0.41a
Tetranychus urticae	2 5± 1	4.41 ± 0.20a	17.11 ± 0.75a	26.90 ± 0.85a	5.50 ± 0.31a
	30 ± 1	3.29 ± 0.24b	12.62 ± 0.64b	19.07 ± 0.75b	5.02 ± 0.52a
	35 ± 1	2.18 ± 0.20c	8.08 ± 0.44c	18.95 ± 0.90b	4.95 ± 0.49a
Brevipalpus lewisi	25 ± 1	4.66 ± 0.28a	18.01 ± 0.80a	27.10 ± 1.32a	5.65 ± 0.34a
	30 ± 1	3.50 ± 0.22b	13.40 ± 0.75b	20.22 ± 1.25b	5.10 ± 0.20a
	35 ± 1	2.41 ± 0.24c	8.75 ± 0.46c	17.85 ± 0.90b	4.89 ± 0.25a

Mite species	Longevity		Life span (egg to death/days)	
	♀	♂	♀	♂
Colomerus vitis	37.61 ± 2.09a	34.20 ± 0.80a	49.30 ± 2.70a	45.33 ± 1.77a
	27.85 ± 1.12b	26.07 ± 1.20b	36.31 ± 1.64b	33.46 ± 1.21b
	26.40 ± 0.89b	23.19 ± 0.66b	31.83 ± 1.08c F = 0.902	28.32 ± 0.80c P = 0.504
Tetranychus urticae	36.81 ± 1.45a	35.40 ± 1.59a	49.51 ± 1.39a	47.18 ± 2.10a
	27.38 ± 2.12b	28.55 ± 2.23b	36.71 ± 1.58b	35.55 ± 1.60b
	26.08 ± 1.05b	24.98 ± 1.35b	31.98 ± 0.90c F = 1.121	30.41 ± 1.25c P = 0.442
Brevipalpus lewisi	37.41 ± 1.52a	36.25 ± 2.02a	50.76 ± 2.10a	48.63 ± 2.14a
	28.82 ± 1.25b	28.05 ± 1.37b	38.72 ± 1.60b	36.49 ± 2.22b
	25.15 ± 0.95b	24.05 ± 1.45b	31.49 ± 1.74c F = 0.758	30.06 ± 1.75c P = 0.463

Different letters within the same column denote to a significant difference (ANOVA followed by Duncan's $P < 0.05$).

Table 3

Survival of immature stages of *Neoseiulus barkeri* feeding on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at different temperatures and 50 % RH

Mite species	Temperature (°C)	Stage specific survival (% ±SE)				Survival to Adulthood (%)
		Egg	Larva	Protonymph	Deutonymph	
C. vitis	25 ± 1	$96.50 \pm 4.25_a$	$96.25 \pm 3.75_a$	100_a	$98.25 \pm 4.10_a$	$99.20 \pm 2.66_a$
	30 ± 1	$97.25 \pm 5.33_a$	$98.50 \pm 2.20_a$	100_a	100_a	100_a
	35 ± 1	$98.00 \pm 3.00_a$	100_a	100_a	100_a	100_a
T. urticae	25 ± 1	$95.75 \pm 5.20_a$	$95.50 \pm 4.25_a$	$97.50 \pm 2.75_a$	$98.65 \pm 3.05_a$	$96.00 \pm 2.00_a$
	30 ± 1	$96.20 \pm 4.25_a$	$95.30 \pm 3.75_a$	100_a	$99.00 \pm 2.10_a$	$97.25 \pm 3.75_a$
	35 ± 1	$95.00 \pm 2.75_a$	$97.25 \pm 5.15_a$	100_a	100_a	$98.00 \pm 3.44_a$
B. lewisi	25 ± 1	$95.50 \pm 4.00_a$	$94.75 \pm 5.25_a$	$93.20 \pm 3.30_a$	$94.25 \pm 5.08_a$	$94.00 \pm 4.66_a$
	30 ± 1	$96.90 \pm 5.50_a$	$95.25 \pm 4.15_a$	$94.75 \pm 4.15_a$	$95.15 \pm 2.85_a$	$95.80 \pm 3.45_a$
	35 ± 1	$97.25 \pm 3.58_a$	$96.12 \pm 2.50_a$	$95.44 \pm 5.12_a$	$96.00 \pm 3.00_a$	$97.10 \pm 2.88_a$

Means within the same column followed by the same subscript letters are not significantly different according to (Tukey HSD test).

performs much preferably at high temperatures because of its rapid growth rate therefore short mean generation time (T) and high oviposition (R_o), in contrast with low temperatures. A population of *N. barkeri* could multiply (20.45, 22.63 and 24.89), (15.56, 17.25 and 19.57) and (10.70, 12.88 and 14.36 times) in a generation time of (16.80, 14.75, and 12.50), (19.76, 17.54, and 15.46) and (23.20, 21.11 and 18.08 d) when *N. barkeri* fed on *C. vitis*, *T. urticae* and *B. lewisi* at 25 °C, 30 °C and 35 °C and 50 % RH, respectively. It was also found that under these conditions, the intrinsic rate of increase (r_m) was (0.195, 0.210 and 0.232), (0.111, 0.120 and 0.145) and (0.095, 0.105 and 0.115), respectively. Net reproductive rate (R_0) was the highest at 35 °C when *N. barkeri* fed on *C. vitis* and the lowest at 25 °C when *N. barkeri* fed on *B. lewisi*. The finite rate of increase (λ) reached the largest value 1.340 when *N. barkeri* fed on *C. vitis* at 35 ± 1 °C.

The life-table parameters derived from these data indicate that the rate of reproduction of the eriophyid mite, *C. vitis* was the highest at the higher temperature.

Table 4

Fecundity of females of *Neoseiulus barkeri* fed on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at different temperatures and 50 % RH

Temperature	*Neoseiulus barkeri*					
	Colomerus vitis		*Tetranychus urticae* nymphs		*Brevipalpus lewisi* nymphs	
	Average of eggs ± SD	Daily egg-laying rate	Average of eggs ± SD	Daily egg-laying rate	Average of eggs ± SD	Daily egg-laying rate
25 °C	40.25 ± 1.45 Aa	1.42	31.00 ± 1.25 Ab	1.15	20.50 ± 0.75 Ac	0.75
30 °C	49.66 ± 2.05 Bb	2.50	39.75 ± 1.11 Bc	2.08	28.70 ± 0.90 Bd	1.41
35 °C	59.50 ± 2.50 Cc	3.04	48.25 ± 2.10 Cd	2.54	35.30 ± 1.44 Ce	1.97

The capital letter denotes the significance within the same column and small letter denotes the significance in the same row at $P < 0.05$, $P < 0.01$.

Table 5

Predation rate of *Neoseiulus barkeri*, fed on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at 25 °C and 50 ± 5 % RH

Predatory stage	Sex	No. of attacked mite individuals					
		Colomerus vitis motile stages		*Tetranychus urticae* nymphs		*Brevipalpus lewisi* nymphs	
		Total average mean ± SD	Daily rate mean ± SD	Total average mean ± SD	Daily rate, mean ± SD	Total average mean ± SD	Daily rate mean ± SD
Protonymph	♀	75.90 ± 3.10	37.02 ± 1.12	12.85 ± 0.34	5.78 ± 0.24	19.64 ± 0.24	8.39 ± 0.39
	♂	70.25 ± 2.75	35.12 ± 2.24	11.70 ± 0.40	5.44 ± 0.28	16.88 ± 0.30	7.50 ± 0.24
Deutonymph	♀	110.45 ± 3.55	52.59 ± 2.35	20.25 ± 0.80	8.80 ± 0.74	27.61 ± 0.60	11.26 ± 0.40
	♂	101.63 ± 2.24	47.26 ± 1.21	18.64 ± 0.44	8.66 ± 0.48	21.79 ± 0.54	9.43 ± 0.36
Total	♀	$186.35 \pm 5.22_a$	$44.90 \pm 1.65_a$	$33.10 \pm 1.45_b$	$7.32 \pm 0.41_b$	$47.25 \pm 0.56_c$	$9.86 \pm 0.64_c$
	♂	171.88 ± 4.15	42.97 ± 1.88	30.34 ± 0.85	7.05 ± 0.32	38.67 ± 0.24	8.48 ± 0.50
Pre-oviposition	♀	514.90 ± 5.10	122.59 ± 3.70	70.25 ± 2.59	15.92 ± 0.55	86.67 ± 1.08	18.59 ± 0.65
Generation	♀	$701.25 \pm 5.60_a$	$44.13 \pm 2.55_a$	$103.35 \pm 2.11_b$	$6.04 \pm 0.30_b$	$134.19 \pm 2.38_c$	$7.45 \pm 0.30_c$
Oviposition	♀	$3758.40 \pm 12.39_a$	$133.51 \pm 7.30_a$	$492.75 \pm 5.80_b$	$18.31 \pm 2.04_b$	$598.55 \pm 5.45_c$	$22.08 \pm 1.49_c$
Post-oviposition	♀	288.45 ± 4.11	54.83 ± 2.89	38.90 ± 1.05	7.07 ± 0.40	56.70 ± 0.88	10.03 ± 0.64
Longevity	♀	$4561.75 \pm 13.79_a$	$121.29 \pm 4.88_a$	$601.9 \pm 6.05_b$	$16.35 \pm 0.50_b$	$741.92 \pm 5.25_c$	$19.83 \pm 0.86_c$
	♂	$3120.40 \pm 12.45_a$	$91.23 \pm 4.36_a$	$375.22 \pm 4.75_b$	$10.59 \pm 0.33_b$	$512.77 \pm 4.38_c$	$14.14 \pm 1.09_c$
Life span	♀	$4748.10 \pm 16.33_a$	$96.31 \pm 4.70_a$	$635.00 \pm 6.12_b$	$12.82 \pm 0.55_b$	$789.17 \pm 5.35_c$	$15.54 \pm 1.34_c$
	♂	$3292.28 \pm 14.85_a$	$72.62 \pm 4.08_a$	$405.56 \pm 3.60_b$	$8.59 \pm 0.30_b$	$551.44 \pm 4.28_c$	$11.33 \pm 1.06_c$

Different subscript letters within each row for daily rate and total average separately denote significant differences (F test, $P < 0.01$).

Table 6

Predation rate of *Neoseiulus barkeri*, fed on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at 30 °C and 50 ± 5 % RH

Predatory stage	Sex	No. of attacked mite individuals					
		Colomerus vitis motile stages		*Tetranychus urticae* nymphs		*Brevipalpus lewisi* nymphs	
		Total average mean ± SD	Daily rate mean ± SD	Total average mean ± SD	Daily rate mean ± SD	Total average mean ± SD	Daily rate mean ± SD
Protonymph	♀	70.42 ± 3.45	46.94 ± 2.85	14.64 ± 0.30	9.09 ± 0.40	17.81 ± 0.24	10.17 ± 0.38
	♂	52.25 ± 1.51	41.80 ± 1.10	11.23 ± 0.63	8.44 ± 0.34	14.35 ± 0.30	9.89 ± 0.40
Deutonymph	♀	99.43 ± 3.60	69.53 ± 2.20	20.15 ± 0.74	13.43 ± 0.52	22.89 ± 0.45	14.04 ± 0.68
	♂	79.30 ± 1.68	65.00 ± 2.74	16.55 ± 0.44	12.25 ± 0.82	17.69 ± 0.51	12.00 ± 0.72
Total	♀	$169.85 \pm 3.12_a$	$57.96 \pm 2.70_a$	$34.79 \pm 1.25_b$	$11.18 \pm 0.32_b$	$40.70 \pm 0.75_b$	$12.04 \pm 0.46_b$
	♂	131.55 ± 3.30	53.25 ± 2.05	27.78 ± 0.80	10.36 ± 0.24	32.04 ± 1.21	11.16 ± 0.50
Pre-oviposition	♀	428.54 ± 4.66	139.13 ± 3.69	60.22 ± 2.45	18.30 ± 0.75	79.58 ± 2.54	22.73 ± 1.23
Generation	♀	$598.39 \pm 4.11_a$	$51.85 \pm 2.24_a$	$95.01 \pm 3.88_b$	$7.52 \pm 0.30_b$	$120.28 \pm 3.80_c$	$8.97 \pm 0.50_c$
Oviposition	♀	$2978.50 \pm 8.76_a$	$150.50 \pm 6.18_a$	$419.37 \pm 5.60_b$	$21.99 \pm 1.15_b$	$544.76 \pm 7.86_c$	$26.94 \pm 2.48_c$
Post-oviposition	♀	348.26 ± 3.55	69.93 ± 3.62	45.28 ± 1.41	9.01 ± 0.50	75.67 ± 3.57	14.83 ± 0.75
Longevity	♀	$3755.30 \pm 12.50_a$	$134.84 \pm 5.88_a$	$524.87 \pm 4.35_b$	$19.16 \pm 0.90_b$	$700.01 \pm 11.28_c$	$24.28 \pm 2.35_c$
	♂	$2721.49 \pm 12.35_a$	$104.39 \pm 4.60_a$	$339.76 \pm 3.55_b$	$11.90 \pm 0.76_b$	$518.97 \pm 10.58_c$	$18.50 \pm 1.10_c$
Life span	♀	$3925.15 \pm 13.38_a$	$108.10 \pm 4.24_a$	$559.66 \pm 5.60_b$	$15.24 \pm 0.82_b$	$740.71 \pm 10.73_c$	$19.12 \pm 1.40_c$
	♂	$2853.04 \pm 12.76_a$	$85.26 \pm 3.96_a$	$367.54 \pm 4.82_b$	$10.33 \pm 0.95_b$	$551.01 \pm 6.48_c$	$15.10 \pm 1.25_c$

Different subscript letters within each row for daily rate and total average separately denote significant differences (F test, $P < 0.01$).

Table 7

Predation rate of *Neoseiulus barkeri*, fed on *Colomerus vitis*, *Tetranychus urticae* and *Brevipalpus lewisi* at 35 °C and 50 ± 5 % RH

Predatory stage	Sex	No. of attacked mite individuals					
		Colomerus vitis motile stages		*Tetranychus urticae* nymphs		*Brevipalpus lewisi* nymphs	
		Total average, mean ± SD	Daily rate mean ± SD	Total average mean ± SD	Daily rate mean ± SD	Total average mean ± SD	Daily rate mean ± SD
Protonymph	♀	67.55 ± 2.96	54.04 ± 2.08	11.00 ± 0.28	11.57 ± 0.44	15.27 ± 0.45	14.54 ± 0.40
	♂	66.81 ± 3.62	50.10 ± 2.09	8.55 ± 0.20	10.68 ± 0.25	13.90 ± 0.66	13.90 ± 0.35
Deutonymph	♀	74.94 ± 3.81	77.94 ± 4.22	26.36 ± 0.50	24.18 ± 0.38	32.72 ± 0.75	28.45 ± 0.80
	♂	67.25 ± 2.78	67.25 ± 3.67	19.39 ± 0.42	18.46 ± 0.75	27.28 ± 0.90	24.80 ± 0.66
Total	♀	$142.49 \pm 4.15_a$	$77.02 \pm 2.17_a$	$37.36 \pm 2.59_b$	$18.31 \pm 0.65_b$	$47.99 \pm 1.14_c$	$21.18 \pm 1.36_c$
	♂	134.06 ± 4.56	76.60 ± 2.25	27.94 ± 1.02	15.10 ± 0.45	41.18 ± 2.18	19.60 ± 1.60
Pre-oviposition	♀	324.70 ± 4.12	162.35 ± 4.85	52.73 ± 3.25	24.18 ± 0.90	68.66 ± 3.54	28.48 ± 2.09
Generation	♀	$467.19 \pm 5.68_a$	$62.87 \pm 2.95_a$	$85.32 \pm 3.00_b$	$10.56 \pm 0.75_b$	$116.65 \pm 3.26_c$	$13.33 \pm 0.76_c$
Oviposition	♀	$3275.10 \pm 11.20_a$	$167.69 \pm 8.85_a$	$488.53 \pm 4.98_b$	$25.77 \pm 2.16_b$	$522.65 \pm 6.75_c$	$29.28 \pm 3.48_c$
Post-oviposition	♀	385.46 ± 4.53	79.14 ± 5.12	52.07 ± 2.11	10.52 ± 0.65	81.41 ± 3.45	16.64 ± 1.25
Longevity	♀	$3985.26 \pm 10.45_a$	$150.95 \pm 7.15_a$	$593.33 \pm 6.15_b$	$22.75 \pm 1.14_b$	$672.72 \pm 9.35_c$	$26.74 \pm 2.55_c$
	♂	$2683.08 \pm 11.76_a$	$115.70 \pm 8.55_a$	$359.46 \pm 4.29_b$	$14.38 \pm 0.78_b$	$511.94 \pm 8.67_c$	$21.28 \pm 1.25_c$
Life span	♀	$4127.75 \pm 12.81_a$	$129.68 \pm 6.28_a$	$630.69 \pm 4.90_b$	$19.72 \pm 1.08_b$	$720.71 \pm 9.28_c$	$22.88 \pm 1.65_c$
	♂	$2817.14 \pm 10.45_a$	$99.47 \pm 6.89_a$	$387.40 \pm 3.45_b$	$12.73 \pm 1.27_b$	$553.12 \pm 7.44_c$	$18.40 \pm 1.44_c$

Different subscript letters within each row for daily rate and total average separately denote significant differences (F test, $P < 0.01$).

Table 8

Effect of different prey species on the life table parameters of *Neoseiulus barkeri* at different temperatures and 50 % RH

Parameters	25 ± 1 °C			30 ± 1 °C			35 ± 1 °C		
	C. vitis	*T. urticae*	*B. lewisi*	*C. vitis*	*T. urticae*	*B. lewisi*	*C. vitis*	*T. urticae*	*B. lewisi*
Net reproduction rate (*Ro*)	20.45	15.56	10.70	22.63	17.25	12.88	24.89	19.57	14.36
Mean generation time, *t* (days)	16.80	19.76	23.20	14.75	17.54	21.11	12.50	15.46	18.08
Intrinsic rate of increase (r_m)	0.195	0.111	0.095	0.210	0.120	0.105	0.232	0.145	0.115
Finite rate of increase (λ)	1.223	1.110	1.020	1.275	1.30	1.050	1.340	1.151	1.077
50 % mortality (in day)	40	38	37	28	27	30	26	25	24
Sex ratio (Female/total)	22/30	21/30	17/30	23/30	22/30	21/30	24/30	23/30	21/30

Discussion

This study was the first to evaluate the predatory efficiency of *N. barkeri*, against *C. vitis* and *B. lewisi* as preys. Our results indicate that *N. barkeri* can grow and reproduce successfully on three mite species infesting grape orchards at 25-35 °C, with few developmental mortality at any of the temperatures tested. The development of *N. barkeri* on *C. vitis* was reached in shorter times than on *T. urticae* and *B. lewisi*.

The immature developmental time of *N. barkeri* fed on *C. vitis* (5.43 d) was shorter than that measured on the eriophyid mite, *Aceria guerreronis* Keifer (Fernando *et al.* 2004), *Eriophyes dioscoridis* at 25 °C (Momen 1995), *Oligonychus afrasiaticus* (McGregor) at 35 °C (Negm *et al.* 2014), onion thrips (*Thrips tabaci* Lindeman) at 25 °C (Bonde 1989) and *T. urticae* at 25 °C (Jafari *et al.* 2010). These results indicate that *C. vitis* provides *N. barkeri* with higher reproductive capability than does *T. urticae*. So, we presumed that it is worth studying *N. barkeri* on *C. vitis* for mass production purposes which may give encouraging results. On the other hand, the reported developmental time for *N. barkeri* fed on *Aleuroglyphus ovatus* Toupeau (Acaridae) was 5.0 d at 32 °C (Xia *et al.* 2012), which is shorter than that reported in our finding. Temperatures ranging from 25 to 35 °C were more appropriate for the survival of the predatory mite, *N. barkeri*. This information on its life history will be useful for its rearing and release in open field. Like in other phytoseiid mites, where sex ratios are characterized by female bias (Toyoshima and Amno 1998), the sex ratio of predatory mite *N. barkeri* under all temperatures tested favored the female (59.66-80.00 %). This ratio was in agreement with the 70 % ratio reported by Negm *et al.* (2014) for *N. barkeri* fed on date mite *O. afrasiaticus*, as well as by Momen (1995). In the present study, sex ratio was higher at 35 °C than at 25 and 30 °C.

Therefore, higher temperatures may be more useful to control mites in grape orchards with *N. barkeri*. This difference might owe to some other reasons, such as food type. On two preys *C. vitis* and *T. urticae*, sex ratio of the progeny of *N. barkeri* reared at three temperatures was higher than 70 % [females/ (females + males)] at 25, 30 and 35 °C, but

only 56.66 on *B. lewisi* at 25 °C, suggesting a potential disturbance of the pseudo-arrhenotoky mechanism of predators reared at low temperature and fed an apparently unsuitable prey, resulting in the production of relatively higher number of males (Sabelis and Nagelkerke 1988). Pre-oviposition periods of *N. barkeri* were very close to those recently stated by Negm *et al.* (2014) at the same temperature.

The oviposition period and female longevity of *N. barkeri* were parallel to the findings reported by Momen (1995), Jafari *et al.* (2010) and Negm *et al.* (2014) for *N. barkeri* fed on individuals of *T. urticae*, *E. dioscoridis* and *O. afrasiaticus*. When *Neoseiulus cucumeris* was evaluated against *Aculops lycopersici* (Al-Azzazy *et al.* 2018), female longevity was shorter (21.99 d) than that of *N. barkeri* (27.85 d). This may be due to the higher moisture percentage applied for *N. cucumeris*. In the present study, the total number of eggs and daily egg production per female at 35 °C were higher than at the other two temperatures indicating that 35 °C should be a suitable temperature for reproduction by *N. barkeri*. Similar findings were obtained with *N. barkeri* in that total oviposition was highest at 35 °C and 35 % Relative humidity (Negm *et al.* 2014). In the present study the highest fertility was obtained when *N. barkeri* fed on *C. vitis* (59.50 eggs per female). This rate was higher when compared to *N. barkeri* fed on *Thrips tabaci* (47.1 eggs/female at 25 °C) (Bonde 1989), *E. dioscoridis* (44.20 eggs/female at 25 °C). (Momen 1995), *Ephestia kuehniella* Zeller (50.4 eggs per female at 27 °C) (Momen and El-Laithy 2007), *A. ovatus* (20.52 eggs per female at 32 °C) (Xia *et al.* 2012) and *O. afrasiaticus* (34.8 eggs/female at 35 °C) (Negm *et al.* 2014). On the other side, the results of Bonde (1989) and Momen (1995) for this predator fed on *Thrips tabaci* (47.1 eggs/female at 25 °C) and *T. urticae* (54.84 eggs/female at 25 °C) respectively, were higher than evaluated in the percent study when *N. barkeri* fed on *T. urticae* at 25 °C. Phytoseiid mites demand multiple matings to obtain their highest reproductive potential (Jiale *et al.* 2016). Therefore, the high fecundity in the current study could be due to both multiple matings incidence and the moderate humidity level applied (50 %). The current study showed that temperature affects the feeding capacity of all life stages of *N. barkeri*, with the exception of the larval stage. *N. barkeri* larvae developed to the proto nymph without feeding. Non feeding larvae behavior may be beneficial with respect to intraspecific competition or mechanism to avert sibling cannibalism. Similar results have been stated for other predatory phytoseiid species (Amano and Chant 1977, Metwally *et al.* 2005). During immature stages of *N. barkeri*, predation rate increased with increasing temperature from 25 to 35 °C. Therefore, it could be concluded that the optimal temperature for predation of *N. barkeri* was about 35 °C. A slight decline was observed in the mean number of prey consumption at 25 ºC. The findings of (Negm *et al.* 2014) support our results. They confirmed that an increase in temperature leads to a positive effect on food consumption until the optimal temperature is reached, and then the impact of temperature becomes unfavorable.

The predation rate of *N. barkeri* on the three prey species studied indicates that the daily consumption rate increased significantly in the adult. Likewise, the females through the oviposition period consumed a significantly greater number of prey, indicating that females need to increase predation to obtain sufficient energy for egg production throughout this period. This behavior is in agreement with other results (Jiale *et al.* 2016). The decrease in daily consumption rate with age, observed in post ovipostion periods, may be explained by a low energy demand due to decrease in basal metabolism and reproduction requirements, similar to that reported in *Neoseiulus cucumeris* Oudemans by Al-Azzazy *et al.* (2018) and *Phytoseiulus persimilis* (Athias-Henriot) by Rasmy and Hussein (1996). The good performance of *N. barkeri* reared on *C. vitis* demonstrated that this prey is nutritionally more suitable than *T. urticae* and *B. lewisi*, indicating that the nutritional value of prey might affect which prey was most preferred. The predator consumed more *B. lewisi* than *T. urticae*, possibly because nymphs of *T. urticae* had higher biomass compared with nymphs of *B. lewisi*, which could be explained by *N. barkeri* need to feed on great number of *B. lewisi* immatures to get the similar quantity of nutrients. Likewise, the predatory mite *Amblyseius swirskii* preferred the larvae of *Frankliniella occidentalis*, with higher nutritional content, to the nymphal stages of *T. urticae* (Xu and Enkegaard 2010). Comparable results were obtained by Janssen and Sabelis (1992). They compared the predation rate and fertility of thirty-six species of the predacious mites, and found species with high fecundity ordinarily devoured more prey. Consequently, it seems sensible to assume that this predator will be more effective under natural ecosystems with higher diversity of prey. Generally, the present findings could serve as a guide line for mass rearing and mass production of predacious mites used in biocontrol strategies. The life table parameters such as the intrinsic rate of natural increase (r_m) are appropriate tools for measuring the increased potential of mites population under feeding conditions and prevailing environmental conditions, as a reflexion of the overall effects of prey type and temperature on the developmental time, survival, reproduction, predation and conversion rate characteristics (Jiale *et al.* 2016).

Most findings have reported that the highest quality food sources leads to highest values in life table parameters (Park *et al.* 2011, Jiale *et al.* 2016). The rates of population growth were more promising for *N. barkeri* fed on *C. vitis* compared to *T. urticae* and *B. lewisi*. This is proven by the intrinsic rate of natural increase (r_m) which was 0.232 on *C. vitis* while was 0.145 on *T. urticae* and 0.105 on *B. lewisi* at 35 °C. The reported intrinsic rate of increase for *N. barkeri* on *Thrips tabaci* (0.22 at 25 °C) (Bonde 1989), *E. kuehniella* (0.14 at 27 °C) (Momen and El-Laithy 2007), *T. urticae* (0.221 at 25 °C) (Jafari *et al.* 2010), *A. ovatus* (0.17 at 32 °C) (Xia *et al.* 2012) and *O. afrasiaticus* (0.16 at 35 °C) (Negm *et al.* 2014) was lower than that obtained in the present study when *N. barkeri* fed on *C. vitis*. In view of this, *N. barkeri* could be a useful biological control agent for *C. vitis*, *T. urticae* and *B. lewisi* on grapes under most of the prevailing climatic conditions in Saudi Arabia, and the presented results will be significant in the management of these pests in grape orchards.

References

Abou-Setta, M. M.; Sorrell, R. W.; Childers, C. C.; 1986: Life 48: a BASIC computer program to calculate life table parameters for an insect or mite species. Florida Entomol. **69**, 690-697. DOI: https://doi.org/10.2307/3495215

Alatawi, F. J.; Basahih, J.; Kamran, M.; 2017: The superfamily Phytoseioidea (Acari: Mesostigmata) from Saudi Arabia: a new species, new records and a key to the reported species. Acarologia **57**, 275-294. DOI: https://doi.org/10.1051/acarologia/20164154

Al-Azzazy, M. M.; Alhewairini, S. S.; 2020: A life table analysis to evaluate biological control of four mite species associated with olive trees using the predatory mite *Phytoseius plumifer* (Acari: Phytoseiidae) in Saudi Arabia. Pak. J. Agric. Sci. **57**, 299-305. DOI: https://doi.org/10.21162/PAKJAS/20.9469

Al-Azzazy, M. M.; Alhewairini, S. S.; 2020: An Alternative control strategy for grape erineum mites. Pak. J. Agri. Sci. **57**, 609-614. DOI: https://doi.org/10.21162/PAKJAS/19.844

Al-Azzazy, M. M.; Al-Rehiayani, S. M.; Abdel-Baky, N. F.; 2018: Life tables of the predatory mite *Neoseiulus cucumeris* (Acari: Phytoseiidae) on two pest mites as prey, *Aculops lycopersici* and *Tetranychus urticae*. Arch. Phytopathol. Plant Protect. **51**, 637-648. DOI: https://doi.org/10.1080/03235408.2018.1507013

Alhewairini, S. S.; Al-Azzazy, M. M.; 2019: Evaluation of the side effects of Oxamyl and Hymexazol of five species of soil-dwelling predatory mites. Pak. J. Agri. Sci. **56**, 531-536. DOI: https://doi.org/10.21162/PAKJAS/19.8345

Al-Shemmary, K. A.; 2018: The availability of rearing *Neoseiulus cucumeris* (Oud.) and *Neoseiulus barkeri* (Hughes) (Acari: Phytoseiidae) on three insect egg species. Egypt. J. Biol. Pest Control **28**, 1-7. DOI: https://doi.org/10.1186/s41938-018-0084-6

Amano, H.; Chant, D. A.; 1977: Life history and reproduction of two species of predacious mites *Phytoseiulus persimilis* A.-H. and *Amblyseius andersoni* (Chant) (Acari: Phytoseiidae). Can. J. Zool. **55**, 1978-1983. DOI: https://doi.org/10.1139/z77-255

Birch, L. C.; 1948: The intrinsic rate of natural increase of an insect population. J. Animal Ecol. **17**, 15-26. DOI: https://doi.org/10.2307/1605

Bonde, J.; 1989: Biological studies including population growth parameters of the predatory mite *Amblyseius barkeri* at 25 °C in the laboratory. Entomophaga **34**, 275-287. DOI: https://doi.org/10.1007/BF02372676

Buchanan, G. A.; Bengston, M.; Exley, E. M.; 1980: Population growth of *Brevipalpus lewisi* McGregor (Acarina: Tenuipalpidae) on grapevines. Aust. J. Agric. Res. **31**, 957-965. DOI: https://doi.org/10.1071/AR9800957

Camporese, P.; Duso, C.; 1996: Different colonization patterns of phytophagous and predatory mites (Acari: Tetranychidae, Phytoseiidae) on three grape varieties: a case study. Exp. Appl. Acarol. **20**, 1-22. DOI: https://doi.org/10.1007/BF00051473

Candolfi, M. P.; Boller, E. F.; Wermelinger, B.; 1992: Influence of the two spotted spider mite, *Tetranychus urticae*, on the gas exchange of Pinot noir grapevine leaves. Vitis **31**, 205-212. DOI: https://doi.org/10.5073/vitis.1992.31.205-212

Childers, C. C.; French, J. V.; Rodrigues, J. C. V.; 2003: *Brevipalpus californicus*, *B. obovatus*, *B. phoenicis*, and *B. lewisi* (Acari: Tenuipalpidae): a review of their biology, feeding injury and economic importance. Exp. Appl. Acarol. **30**, 5-28. DOI: https://doi.org/10.1023/B:APPA.0000006543.34042.b4

Dowling, A. P. G.; Ochoa, R.; Beard, J. J.; Welbourn, W. C.; Ueckermann, E. A.; 2012: Phylogenetic investigation of the genus *Raoiella* (Prostigmata: Tenuipalpidae): diversity, distribution, and world invasions. Exp. Appl. Acarol. **57**, 257-269. DOI: https://doi.org/10.1007/s10493-011-9483-z

Fan, Y.; Petitt, F. L.; 1994: Functional response of *Neoseiulus barkeri* Hughes on two-spotted spider mite (Acari: Tetranychidae). Exp. Appl. Acarol. **18,** 613-621. DOI: https://doi.org/10.1007/BF00051724

FAO STAT; 2012: FAOSTAT: Statistical Database. 10 February. (http://faostat.fao.org).

Fernando, L. C. P.; Aratchige, N. S.; Kumari, S. L. M. L.; Appuhamy, P. A. L. D.; Hapuarachchi, D. C. L.; 2004: Development of a method for mass rearing of *Neoseiulus baraki*, a mite predatory on the coconut mite, *Aceria guerreronis*. Cocos **16**, 22-36. DOI: https://doi.org/10.4038/cocos.v16i0.2194

Ferragut, F.; Gallardo, A.; Ocete, R.; López, M. A.; 2008: Natural predatory enemies of the erineum strain of *Colomerus vitis* (Pagenstecher) (Acari, Eriophyidae) found on wild grapevine populations from southern Spain (Andalusia). Vitis **47**, 51-54. DOI: https://doi.org/10.5073/vitis.2008.47.51-54

Hluchý, M.; Pospíšil, Z.; 1992: Damage and economic injury levels of eriophyid and tetranychid mites on grapes in Czechoslovakia. Exp. Appl. Acarol. **14**, 95-106. DOI: https://doi.org/10.1007/BF01219102

Jafari, S.; Fathipour, Y.; Faraji, F.; Bagheri, M.; 2010: Demographic response to constant temperatures in *Neoseiulus barkeri* (Phytoseiidae) fed on *Tetranychus urticae* (Tetranychidae). Syst. Appl. Acarol. **15**, 83-99. DOI: https://doi.org/10.11158/saa.15.2.1

James, D. G.; Whitney, J.; 1993: Mite populations on grapevines in south-eastern Australia: Implications for biological control of grapevine mites (Acarina: Tenuipalpidae, Eriophyidae). Exp. Appl. Acarol. **17**, 259-270. DOI: https://doi.org/10.1007/BF02337275

Janssen, A.; Sabelis, M. W.; 1992: Phytoseiid life-histories, local predator-prey dynamics, and strategies for control of tetranychid mites. Exp. Appl. Acarol. **14**, 233-250. DOI: https://doi.org/10.1007/BF01200566

Javadi Khederi, S.; Khanjani, M.; Gholmi, M.; de Lillo, E.; 2018b: Impact of the erineum strain of *Colomerus vitis* (Acari: Eriophyidae) on the development of plants of grapevine cultivars of Iran. Exp. Appl. Acarol. **74**, 347-363. DOI: https://doi.org/10.1007/s10493-018-0245-z

Jiale, L. V.; Yang, K.; Wang, E.; Xuenong, X. U.; 2016: Prey diet quality affects predation, oviposition and conversion rate of the predatory mite *Neoseiulus barkeri* (Acari: Phytoseiidae). Syst. Appl. Acarol. **21**, 279-287. DOI: https://doi.org/10.11158/saa.21.3.3

Khan, E. M.; Kamran, M.; Alatawi, F. J.; 2019: Flat mites (Acari: Tenuipalpidae) from Saudi Arabia: two new species, new records and key to all known species. J. Nat. Hist. **53**, 185-208. DOI: https://doi.org/10.1080/00222933.2019.1581294

Li, L.; Jiao, R.; Yu, L.; He, X. Z.; He, L.; Xu, C.; Zhang, L.; Liu, J.; 2018: Functional response and prey stage preference of *Neoseiulus barkeri* on *Trasonemus confuses*. Syst. Appl. Acarol. **23**, 2244-2258. DOI: https://doi.org/10.11158/saa.23.11.16

Maghadasi, M.; Saboori, A.; Allahyari, H.; Golpayegani, A.; 2014: Life table and predation capacity of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) feeding on *Tetranychus urticae* (Acari: Tetranychidae) on rose. Int. J. Acarol. **40**, 501-508. DOI: https://doi.org/10.1080/01647954.2014.962084

Mailloux, J.; Le Bellec, F.; Kreiter, S.; Tixier, M. S.; Dubois, P.; 2010: Influence of ground cover management on diversity and density of phytoseiid mites (Acari: Phytoseiidae) in Guadeloupean citrus orchards. Exp. Appl. Acarol. **52**, 275-290. DOI: https://doi.org/10.1007/s10493-010-9367-7

Malagnini, V.; De Lillo, E.; Saldarelli, P.; Beber, R.; Duso, C.; Raiola, A.; Zanotelli, L.; Valenzano, D.; Giampetruzzi, A.; Morelli, M.; Ratti, C.; Causin, R.; Gualandri, G.; 2016: Transmission of grapevine Pinot gris virus by *Colomerus vitis* (Acari: Eriophyidae) to grapevine. Arch. Virol. **161**, 2595-2599. DOI: https://doi.org/10.1007/s00705-016-2935-3

Metwally, A. M.; Abou-Awad, B. A.; Al-Azzazy, M. M.; 2005: Life table and prey consumption of the predatory mite *Neoseiulus cydnodactylon* Shehata and Zaher (Acari: Phytoseiidae) with three mite species as prey. Z. Pflanzenkrankh. Pflanzensch. **112**, 276-286. DOI: https://www.jstor.org/stable/45154911

Momen, F. M.; 1995: Feeding, development and reproduction of *Amblyseius barkeri* (Acarina: Phytoseiidae) on various kinds of food substances. Acarologia **36**, 101-05 (https://www1.montpellier.inra.fr/CBGP/acarologia/article.php?id=2286).

Momen, F. M.; El-Laithy, A. Y.; 2007: Suitability of the flour moth *Ephestia kuehniella* (Lepidoptera: Pyralidae) for three predatory phytoseiid mites (Acari: Phytoseiidae) in Egypt. Int. J. Trop. Insect. Sci. **27**, 102-107. DOI: https://doi.org/10.1017/S1742758407777160

Negm, M. W.; Alatawi, F. J.; Aldryhim, Y. N.; 2014: Biology, Predation, and Life Table of *Cydnoseius negevi* and *Neoseiulus barkeri* (Acari: Phytoseiidae) on the Old World Date Mite, *Oligonychus afrasiaticus* (Acari: Tetranychidae). J. Insect. Sci. **14**, 1-6. DOI: https://doi.org/10.1093/jisesa/ieu039

Nicetic, O.; Watson, D. M.; Beattie, G. A. C.; Meats, A.; Zheng, J.; 2001: Integrated pest management of two-spotted mite *Tetranychus urticae*

on greenhouse roses using petroleum spray oil and the predatory mite *Phytoseiulus persimilis*. Exp. Appl. Acarol. **25**, 37-53. DOI: https://doi.org/10.1023/A:1010668122693

Nomikou, M.; Janssen, A.; Schraag, R.; Sabelis, M.W.; 2001: Phytoseiid predators as potential biological control agents for *Bemisia tabacci*. Exp. Appl. Acarol. **25**, 271-291. DOI: https://doi.org/10.1023/A:1017976725685

OIV.; 2019: State of the vitiviniculture world report. O I V (Off. Int. Vigne Vin), Paris (http://www.oiv.int).

Oldfield, G. N.; Proeseler, G.; 1996: Eriophyoid mites as vectors of plant pathogens. World Crop Pests **6**, 259-275. DOI: https://doi.org/10.1016/S1572-4379(96)80017-0

Park, H. H.; Shipp, L.; Buitenhuis, R.; Ahn, J. J.; 2011: Life history parameters of a commercially available *Amblyseius swirskii* (Acari: Phytoseiidae) fed on cattail (*Typha latifolia*) pollen and tomato russet mite (*Aculops lycopersici*). J. Asia-Pac. Entomol. **14**, 497-501. DOI: https://doi.org/10.1016/j.aspen.2011.07.010

Prischmann, D. A.; Croft, B. A.; Luh, H. K.; 2002: Biological control of spider mites on grape by phytoseiid mites (Acari: Tetranychidae, Phytoseiidae): emphasis on regional aspects. J. Econ. Entomol. **95**, 340-347. DOI: https://doi.org/10.1603/0022-0493-95.2.340

Rasmy, A. H.; Hussein, H. E.; 1996: Effect of mating on rate of predation of two species of predacious mites, *Agistemus exsertus* Gonz. and *Phytoseiulus persimilis* Ath-Hen. Anzeiger Schädlingskunde Pflanzensch. Umweltsch. **69**, 88-89. DOI: https://doi.org/10.1007/BF01908437

Ribeiro, L. P.; Zanardi, O. Z.; Vendramin, J. D.; Yamamoto, P. T.; 2014: Comparative toxicity of an acetogenin-based extract and commercial pesticides against citrus red mite. Exp. Appl. Acarol. **64**, 87-98. DOI: https://doi.org/10.1007/s10493-014-9810-2

Sabelis, M. W.; Nagelkerke, C. J.; 1988: Evolution of pseudo-arrhenotoky. Exp. Appl. Acarol. **4**, 301-318. DOI: https://doi.org/10.1007/BF01196192

Si-Hua Yang; Wan-Qin Zhou; Dong-Wei Wang; Chun-Ling Xu; Hui Xi; 2020: Evaluation of *Neoseiulus barkeri* (Acari: Phytoseiidae) for the control of plant parasitic nematodes, *Radopholus similis* (Tylenchida: Pratylenchidae) and *Meloidogyne incognita* (Tylenchida: Heteroderidae). Biocontrol Sci. Technol. **30**, 201-211. DOI: https://doi.org/10.1080/09583157.2019.1698713

Takayama, K.; Iyoki, S.; Takahashi, N.; Nishina, H.; Van Henten, E. J; 2013: Plant diagnosis by monitoring plant smell: detection of russet mite damages on tomato plants. IFAC Proc. **46**, 68-70. DOI: https://doi.org/10.3182/20130327-3-JP-3017.00018

Toyoshima, S.; Amano, H.; 1998: Effect of prey density on sex ratio of two predacious mites, *Phytoseiulus persimilis* and *Amblyseius womersleyi* (Acari: Phytoseiidae). Exp. Appl. Acarol. **22**, 709-723. DOI: https://doi.org/10.1023/A:1006093424452

Xia, B.; Zou, Z.; Li, P. X.; Lin, P.; 2012: Effect of temperature on development and reproduction of *Neoseiulus barkeri* (Acari: Phytoseiidae) fed on *Aleuroglyphus ovatus*. Exp. Appl. Acarol. **56**,33-41. DOI: https://doi.org/10.1007/s10493-011-9481-1

Xu, X.; Enkegaard, A.; 2010: Prey preference of the predatory mite, *Amblyseius swirskii* between first instar western flower thrips *Frankliniella occidentalis* and nymphs of the two-spotted spider mite *Tetranychus urticae*. J. Insect. Sci. **10**, 764-800. DOI: https://doi.org/10.1673/031.010.14109

Yano, S.; Takabayashi, J.; Takafuji, A.; 2001: Trade-offs in performance on different plants may not restrict the host plant range of the phytophagous mite, *Tetranychus urticae*. Exp. Appl. Acarol. **25**, 371-381. DOI: https://doi.org/10.1023/A:1017926017081

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