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Original Article

Life history of the two predacious mites species, *Amblyseius swirskii*, and *Neoseiulus cucumeris* (Acari: Phytoseiidae), as biological control agents of the date palm mite, *Oligonychus afrasiaticus* (Acari: Tetranychidae)

História de vida de duas espécies de ácaros predadores, *Amblyseius swirskii e Neoseiulus cucumeris* (Acari: Phytoseiidae), como agentes de controle biológico do ácaro da tamareira, *Oligonychus afrasiaticus* (Acari: Tetranychidae)

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Abstract

The date palm mite, *Oligonychus afrasiaticus* (McGregor) (Acari: Tetranychidae), is a serious pest of dates in the Middle East and North Africa, inflicting severe economic damage if not controlled early. As predaceous mites are known to be potential biocontrol agents against several pests, so predation capacity, life table, reproduction, and survival of *Amblyseius swirskii* Athias-Henriot and *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae), collected from date palm farms in Qassim Saudi Arabia, were studied under laboratory conditions (25 °C, 30 °C, 35 °C and 50 ± 5% RH) against all motile stages of *O. afrasiaticus*. For both predators, mean developmental time, oviposition period, and longevity were inversely related to temperature from 25 to 35 °C. Various parameters were studied for *A. swirskii* and *N. cucumeris* at 25 °C, 30 °C and 35 °C, i.e. the female developmental time, 9.37, 7.29, 5.56, and 10.67, 8.38, 6.45 d; oviposition period, 19.77, 16.18, 13.94 and 15.90, 13.84, 10.64 d; longevity, 29.39, 24.79, 20.64 and 25.42, 21.94, 17.39 d; fecundity, 31.91, 37.10, 42.16 and 21.75, 26.84, 30.56 eggs per female, respectively. The maximum daily predation rate for both the predators was recorded at 35 °C during the oviposition period. The total predation of *A. swirskii* and *N. cucumeris* female was 370.86, 387.54, 405.83, 232.14, 263.32, 248.85 preys at 25 °C, 30 °C and 35 °C respectively. The maximum reproduction rate of *A. swirskii* and *N. cucumeris* (3.02, 2.87 eggs/♀/day) was recorded at 35 °C while the minimum (2.00, 1.36 eggs/♀/day) was recorded at 25 °C. The life table parameters were estimated as net reproductive rate (R_o) 21.68, 25.94, 29.52 and 18.95, 20.25, 22.78; the mean generation time (T) 24.92, 21.82, 18.24 and 26.30, 23.60, 20.56 d; the intrinsic rate of increase (r_m) 0.181, 0.232, 0.248 and 0.170, 0.185, 0.196; the finite rate of increase (λ) 1.365, 1.551, 1.706 and 1.126, 1.324, 1.428 for *A. swirskii* and *N. cucumeris* at 25 °C, 30 °C and 35 °C respectively. The results of this study suggested that the two phytoseiid species are promising biological control agents of *O. afrasiaticus* at a wide range of temperatures.

Keywords: biological control, predacious mites, predation capacity, *Oligonychus afrasiaticus*.

Resumo

O ácaro da tamareira, *Oligonychus afrasiaticus* (McGregor) (Acari: Tetranychidae), é uma praga grave das tâmaras no Médio Oriente e Norte de África, causando graves danos econômicos se não for controlado precocemente. Como os ácaros predadores são conhecidos por serem potenciais agentes de biocontrole contra diversas pragas, também a capacidade de predação, tabela de vida, reprodução e sobrevivência de *Amblyseius swirskii* Athias-Henriot e *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae), coletados em fazendas de tamareiras em Qassim Arábia Saudita, foram estudados em condições de laboratório (25 °C, 30 °C, 35 °C e 50 ± 5% UR) contra todos os estágios móveis de *O. afrasiaticus*. Para ambos os predadores, o tempo médio de desenvolvimento, o período de oviposição e a longevidade foram inversamente relacionados à temperatura de 25 °C a 35 °C. Vários parâmetros foram estudados para *A. swirskii* e *N. cucumeris* a 25 °C, 30 °C e 35 °C, ou seja, o tempo de desenvolvimento feminino, 9,37, 7,29, 5,56 e 10,67, 8,38, 6,45 d; período de oviposição, 19,77, 16,18, 13,94 e 15,90, 13,84, 10,64 d; longevidade, 29,39, 24,79, 20,64 e 25,42, 21,94, 17,39 dias; fecundidade, 31,91, 37,10, 42,16 e 21,75, 26,84, 30,56 ovos por fêmea, respectivamente. A taxa máxima de predação diária para ambos os predadores foi registrada a 35 °C durante o período de oviposição. A predação total de fêmeas de *A. swirskii* e *N. cucumeris* foi de 370,86, 387,54, 405,83, 232,14, 263,32, 248,85 presas a 25 °C, 30 °C e 35 °C respectivamente. A taxa máxima de reprodução de *A. swirskii* e *N. cucumeris* (3,02; 2,87 ovos/♀/dia) foi registrada a 35 °C, enquanto a mínima (2,00; 1,36 ovos/♀/dia) foi registrada

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a 25 °C. Os parâmetros da tabela de vida foram estimados como taxa reprodutiva líquida (Ro) 21,68, 25,94, 29,52 e 18,95, 20,25, 22,78; o tempo médio de geração (T) 24,92, 21,82, 18,24 e 26,30, 23,60, 20,56 d; a taxa intrínseca de aumento (rm) 0,181, 0,232, 0,248 e 0,170, 0,185, 0,196; a taxa finita de aumento (λ) 1,365, 1,551, 1,706 e 1,126, 1,324, 1,428 para *A. swirskii* e *N. cucumeris* a 25 °C, 30 °C e 35 °C respectivamente. Os resultados deste estudo sugerem que as duas espécies de fitoseídeos são promissores agentes de controle biológico de *O. afrasiaticus* em uma ampla faixa de temperaturas.

Palavras-chave: controle biológico, ácaros predadores, capacidade de predação, *Oligonychus afrasiaticus*.

1. Introduction

The date palm mite, *Oligonychus afrasiaticus* (McGregor) (Acari: Tetranychidae), is a serious pest of the dates in the Middle East and North Africa. It causes severe economic damage by feeding and constructing complex dense webs on the fruit bunches and causing reductions of 30-100% in yields if not controlled at an early stage (Palevsky et al., 2004; Ben Chaaban et al., 2011). The traditional control of *O. afrasiaticus* has relied heavily on chemical options (Al-Dosary, 2010). Although chemical pesticides used to control phytophagous mites show effective results in a short time over longer terms, they cause some significant health and environmental problems. These include the killing of beneficial organisms (Liang et al., 2010), the development of resistance in mites to miticides (Wang et al., 2020; Zhang et al., 2022), and environmental contamination (Hernández et al., 2011; Hoai et al., 2011). Because of the aforementioned concerns, a strategy that reduces the use of chemical pesticides should be considered, like use of the biocontrol agents for the management of phytophagous mites and other pests of date palms. Biocontrol has been one of the most environmentally safe and economical strategies of pest management for farmers and a potential method of reducing the cost of chemical pesticide applications and preventing resistance (Cock et al., 2010; Bi et al., 2016).

The exploitation of indigenous natural enemies that occur in and around date palm orchards are the key elements of biocontrol programs against spider mites and are essential for sustainability and food security. In particular, phytoseiid mites play a major role in controlling phytophagous mites in several countries around the world (Palevsky et al., 2009; McMurtry et al., 2013; Pérez-Sayas et al., 2018; Al-Azzazy, 2021). *Amblyseius swirskii* Athias-Henriot is an important species from the perspective of biocontrol. Being a polyphagous predator, it feeds on a broad range of prey, including tarsonemids (Onzo et al., 2012), pollen as food (Goleva and Zebitz, 2013), spider mite, *Tetranychus urticae* Koch (Xiao et al., 2013), thrips (Xu and Enkegaard, 2010; Delisle et al., 2015), whiteflies (Cavalcante et al., 2015), and eriophyids (Al-Azzazy and Alhewairini, 2020). Like *A. swirskii*, *Neoseiulus cucumeris* (Oudemans) is a generalist foliar predator and an effective biocontrol agent against broad mites (Weintraub et al., 2003), thrips (Arthurs et al., 2009), spider mites (Easterbrook et al., 2001), eriophyid mites (Al-Azzazy et al., 2018), immature stages of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Al-Azzazy et al., 2022) and cereal mite, *T. putrescentiae* (Wei et al., 2023). The natural occurrence of these predators was reported in different regions of Saudi Arabia (Fouly and Al-Rehiaya, 2011; Al-Atawi, 2011). In addition, a preliminary experiment to maintain the stock culture of *A. swirskii* and *N. cucumeris* in the laboratory using *O. afrasiaticus* as prey was very successful and formed a basis for further trials. Other than that, no accessible data on the potential of *A. swirskii* or *N. cucumeris* feed on *O. afrasiaticus* as a food source in Saudi Arabia. Therefore, this study evaluated the life-table parameters and predatory potential efficiency of *A. swirskii* and *N. cucumeris* on the date palm mite, *O. afrasiaticus*.

2. Materials and Methods

2.1. Collection and rearing of predators

Amblyseius swirskii and *N. cucumeris* were obtained from unsprayed date palm orchards at the Agricultural Experiments Station, Qassim University, Al-Mulida district (26.297875°N, 43.790684°E), Saudi Arabia. *Amblyseius swirskii* was collected from *Cynodon dactylon* (Poaceae) while *N. cucumeris* was collected from *Convolvulus arvensis* (Convolvulaceae), and *O. afrasiaticus* was obtained from severely infested date palm trees. Colonies of predatory mites were maintained separately on rearing arenas made of kidney bean (*Phaseolus vulgaris* L.) leaves, which were placed upside down on water-saturated cotton in plastic trays (10 × 20 cm in length, 2 cm height), in an incubator at 32 °C, 55-65% RH and 16L:8D photoperiod. The two predator mites were transferred to new rearing arenas after 4-6 days (d). Water was added to the plastic trays daily to keep the level of water stable and to maintain leaf freshness. The edges of bean leaves were covered with strips of wet tissue paper to prevent mites from escaping and causing contamination of other mites. The predatory mites were continuously fed on a mixture of different stages of *O. afrasiaticus* according to (Negm et al., 2014). Predator eggs were collected from the stock colony and transferred individually to the new rearing units to obtain cohorts of individuals of the same age for the subsequent experiments. Twenty microscope slides were prepared with each species to confirm their identification. Identification of both predators was confirmed according to (McMurtry and Bounfour, 1989; Beard, 1999; Chant and McMurtry, 2003, 2005, 2007).

2.2. Experimental units and conditions

The development, survival, predation rate, and fecundity of *A. swirskii* and *N. cucumeris* against *O. afrasiaticus* were monitored at three constant temperatures (25 °C, 30 °C and 35 °C), Light: Dark (L:D) = 8:16 (h) photoperiod and 50 ± 5% relative humidity (RH). The predatory mites were reared individually on bean leaf disks (3 cm in diameter), which were placed upside down on moist cotton wool, in an uncovered Pyrex® Petri dish (6 cm in diameter × 2 cm high) In addition, distilled water was added daily to the Petri dishes to maintain moisture in cotton. Similarly, every 5 or 6 days, the predators were relocated to new rearing arenas. Mite eggs, laid within a 7 h period, were collected for the life table study. Forty eggs were obtained randomly from each predator and transferred individually into new rearing units with a fine hairbrush (000). After the emergence of protonymphs, mixed stages of *O. afrasiaticus* were supplied daily as food. Preliminary trials confirmed that immature stages of *N. cucumeris* and *A. swirskii* rarely fed on *O. afrasiaticus* adult females; thus, this prey phase was ignored. In addition, the number of preys supplied to each predator was determined based on these experiences. Different numbers of *O. afrasiaticus* were supplied to different stages of *A. swirskii* and *N. cucumeris*: 10 preys of different mobile stages for protonymph, 15 for deutonymph, and 40 for an adult pair (male and female), for 24 hours after which the number of preys consumed was recorded. Observations were carried out every 12 hours, and developmental times of egg, larva, nymphs, and survivorship were recorded for both females and males. The survival rate to the adult stage was calculated. Death of individuals was set at the mid-point between the first record of death and the last observation alive. Observations were made using a stereo microscope (Olympus Optical, Japan). After the emergence of adults, females and males were paired for mating and checked daily to record pre-oviposition, oviposition, and post-oviposition periods, reproduction, longevity, and fecundity. To ensure that multiple mattings were successful, the pair were kept together until their deaths. To separate the consumption capacity of males from females, the consumption rate of 25 males was tested under similar conditions. Then, the number of preys devoured by males was deducted from the average prey consumed by the couples (Moghadasi et al., 2014). To test the sex ratio, 30 eggs of each predator were obtained and transferred individually into separate rearing units with a fine camel hairbrush, and the hatched larvae were reared till their adult stage. Then, each individual was mounted on a slide for sex determination.

2.3. Data analysis

To assess the developmental time of immature stages, generation, pre-oviposition and post-oviposition periods, total fecundity, adult longevity, predation, and life span of *N. cucumeris* and *A. swirskii* and the effect of three constant temperatures on these parameters, data were compared with analysis of variance (ANOVA) using SAS computer program version 9.2 (SAS Institute, 2008). Means were separated by Duncan's Multiple Range Test (DMRT) at P<0.05. The means of survival rates were separated using Tukey's Honestly Significant Difference test (Tukey's HSD test). Observations on the development times, survival, fecundity, and adult longevity of *N. cucumeris* and *A. swirskii* were used to construct a time-specific life table under laboratory conditions. Life table parameters for both predators were measured based on Birch (1948). The sex ratio for both predators was analyzed using a Chi-square test.

3. Results

3.1. Development of immatures, survival rate and adult longevity of A. swirskii and N. cucumeris

Amblyseius swirskii and *N. cucumeris* successfully preyed on *O. afrasiaticus* and reached maturity over all the tested temperatures (25-35 °C). The developmental time was significantly related to temperatures between 25 °C and 35 °C for all the developmental stages. With increase in temperature, the duration of each developmental stage and the total immature period for both predators decreased i.e. egg-to-adult development of *A. swirskii* was maximum at 25 °C (9.03 days for males and 9.37 days for females) and minimum at 35 °C (5.41 days for males and 5.56 days for females); while for *N. cucumeris,* it decreased from 10.21 days for males and 10.67 days for females at 25 °C to 6.25 days for males and 6.45 days for females at 35 °C (Table 1). For both the predators, more than 95% of eggs hatched at 25-35 °C, and there was no significant difference among temperatures. Further, at all temperatures tested, survival rate of *A. swirskii* from larvae to adult was more than 96%, while for *N. cucumeris* it decreased from 91.40% at 35 °C to 84.62% at 25 °C (Table 2). Increase in temperature, from 25 °C to 35 °C, had a significant effect on generation period and female longevity.

At 25 °C, the generation period and female longevity lasted 13.19 and 29.39 days for *A. swirskii* whereas it was 14.93 and 25.42 days for *N. cucumeris* (Table 3). At 35 °C, the corresponding periods were 7.72 and 20.64 days for *A. swirskii* and 8.35 and 17.39 days for *N. cucumeris*. At all temperatures between 25 °C and 35 °C, all emerging females laid eggs within 3.82-2.16 days for *A. swirskii* and 4.26-1.90 days for *N. cucumeris* (pre-oviposition period). Likewise, the oviposition period was significantly influenced by an increase in temperature. The maximum oviposition periods (19.77 and 15.90 days) were recorded at 25 °C, while the minimum oviposition periods (13.94 and 10.64 days) were recorded at 35 °C for *A. swirskii* and *N. cucumeris*, respectively. The post-oviposition periods of *A. swirskii* and *N. cucumeris* did not differ between the three temperatures studied. The life span period also followed the same trend on the three different temperatures.

3.2. Reproduction

Temperature exerted the greatest effect on the reproductive behavior of *A. swirskii* and *N. cucumeris*. An increase in temperatures from 25 °C to 35 °C progressively increased the daily rate of reproduction. The number of total eggs laid by each female of *A. swirskii* and *N. cucumeris* at 25 °C was significantly lower than that at 30 °C and 35 °C (Table 4). *N. cucumeris* laid significantly fewer eggs than *A. swirskii* over all the tested temperatures (25-35 °C). The maximum fecundity (42.16 eggs/♀) was recorded for *A. swirskii* while it was 30.56 eggs/♀ for *N. cucumeris* at 35 °C, while the minimum (31.91 and 21.75 eggs/♀) was at 25 °C for *A. swirskii* and *N. cucumeris*, respectively. At all temperatures studied, *A. swirskii* laid more eggs than *N. cucumeris* (Table 4). Furthermore, raising the temperature from 25 to 35 °C increased the oviposition rate. The maximum oviposition (3.02 and

Table 1. Developmental periods (days) of life stages of *A. swirskii* and *N. cucumeris* fed on date palm mite *O. afrasiaticus* at 25, 30 and 35 °C and 50 ± 5% RH.

Predator species	Temperature (°C)	Sex	Life stage duration, days: Egg	Larva	Protonymph	Deutonymph	Developmental time
Amblyseius swirskii	25 ± 1	Female	3.80 ± 0.16a	1.65 ± 0.10a	2.04 ± 0.16a	1.88 ± 0.12a	9.37 ± 0.82a
		Male	3.75 ± 0.14a	1.57 ± 0.12a	1.97 ± 0.12a	1.74 ± 0.14a	9.03 ± 0.74a
	30 ± 1	Female	3.22 ± 0.15b	1.10 ± 0.07b	1.53 ± 0.10b	1.44 ± 0.06b	7.29 ± 0.36b
		Male	3.15 ± 0.10b	1.05 ± 0.08b	1.48 ± 0.12b	1.39 ± 0.04b	7.07 ± 0.42b
	35 ± 1	Female	2.50 ± 0.18c	0.90 ± 0.02c	1.05 ± 0.04c	1.11 ± 0.02c	5.56 ± 0.23c
		Male	2.49 ± 0.12c	0.80 ± 0.04c	1.05 ± 0.03c	1.07 ± 0.02c	5.41 ± 0.32c
						F= 0.938;	P=0.475
Neoseiulus cucumeris	25 ± 1	Female	3.95 ± 0.20a	1.70 ± 0.16a	2.21 ± 0.18a	2.81 ± 0.12a	10.67 ± 0.74a
		Male	3.80 ± 0.20a	1.62 ± 018a	2.07 ± 0.16a	2.72 ± 0.11a	10.21 ± 0.68a
	30 ± 1	Female	3.42 ± 0.10b	1.12 ± 0.20b	1.58 ± 0.16b	2.26 ± 0.14b	8.38 ± 0.56b
		Male	3.32 ± 0.18b	1.10 ± 0.16b	1.53 ± 0.14b	2.17 ± 0.09b	8.12 ± 0.84b
	35 ± 1	Female	2.61 ± 0.20c	0.95 ± 0.08c	1.17 ± 0.08c	1.72 ± 0.08c	6.45 ± 0.59c
		Male	2.57 ± 0.16c	0.90 ± 0.08c	1.10 ± 0.04c	1.68 ± 0.06c	6.25 ± 0.67c
						F= 1.29;	P=0.391

Different letters in each column denote significant differences (ANOVA followed by Duncan's multiple range test: P < 0.05).

Table 2. Survival percentage of immature stages of *A. swirskii* and *N. cucumeris* feeding on date palm mite *O. afrasiaticus* at 25, 30 and 35 °C and 50 ± 5% RH.

Predator Species	Temperature (°C)	Stage specific survival (% ± SE)				Survival to Adulthood (% ± SE)
		Egg	Larva	Protonymph	Deutonymph	
A. swirskii	25 ± 1	95.00 ± 4.51 a	93.51 ± 3.66 a	95.77 ± 3.60 a	97.14 ± 2.82 a	96.21 ± 3.61a
	30 ± 1	96.87 ± 3.63 a	97.21 ± 3.63 a	94.52 ± 4.08 a	100 a	97.50 ± 3.65a
	35 ± 1	98.42 ± 4.57 a	96.22 ± 4.11 a	96.00 ± 3.95 a	95.70 ± 5.36 a	98.11 ± 3.82 a
N. cucumeris	25 ± 1	95.00 ± 2.45 a	94.59 ± 2.58 a	90.64 ± 2.94 a	88.19 ± 2.45 b	84.62 ± 3.46b
	30 ± 1	95.82 ± 3.46 a	94.44 ± 3.25 a	90.10 ± 3.77 a	100 a	90.25 ± 3.98a
	35 ± 1	97.50 ± 4.77 a	95.50 ± 4.68 a	91.12 ± 4.23 a	91.46 ± 3.08 a	91.40 ± 3.12 a

Means in the same column followed by the different letters are significantly different (P < 0.05) according to Tukey's HSD test.

2.87 eggs/♀/day) was recorded at 35 °C, while the minimum (2.00 and 1.36 eggs/♀/d) was at 25 °C for *A. swirskii* and *N. cucumeris*, respectively. As shown in Table 5, the sex ratio at different temperatures ranged from 60 to 80%. There were insignificant differences between 30 and 25 °C, but the maximum female-biased sex ratio was 80%, which was recorded for *A. swirskii* at 35 °C. For each predatory mite species, the female-to-male offspring ratio was 2:1, 2:1, and 2.4:1 (*A. swirskii*, 1.8:1, 1.9:1 and 2.2:1 for *N. cucumeris*, at 25, 30 and 35 °C respectively (Table 5).

3.3. Predation of A. swirskii and N. cucumeris on O. afrasiaticus

The larvae of both predators were inactive and did not feed during the experiment, and the feeding activity started immediately after the predators entered the protonymphal stages. For both predators, the predation rate increased by increasing the temperatures and the stage of the predator, so the adults consumed more prey compared with the nymph stages. Data analysis showed a significant effect of temperature on the total and daily predation rates of *A. swirskii* and *N. cucumeris*. The total number of *O. afrasiaticus* prey devoured by *A. swirskii* and *N. cucumeris* in immature and adult stages under different temperatures are shown in Tables 6, 7 and 8. Immature females of *A. swirskii* significantly consumed a higher number of prey (21.87, 23.80, and 18.01) than *N. cucumeris* (17.46, 18.99, and 17.73) at 25, 30 and 35 °C respectively. Likewise, at 35 °C, *A. swirskii* significantly devoured more prey (308.68) than *N. cucumeris* (173.43) throughout the oviposition duration (Table 8). The highest means for the daily consumption rate of females were observed

Table 3. Mean duration (days) of oviposition periods, longevity, and life Span of *A. swirskii* and *N. cucumeris* adults feeding on date palm mite *O. afrasiaticus* at 25, 30 and 35 °C and 50 ± 5% RH.

Predator species	Temperature (°C)	Pre oviposition	Oviposition	Post oviposition	Longevity		Life span	
					Female	Male	Female	Male
Amblyseius swirskii	25 ± 1	3.82 ± 0.20a	19.77 ± 0.1.40a	5.80 ± 0.70a	29.39 ± 1.30a	26.55 ± 1.19a	38.76 ± 1.20a	35.58 ± 2.46a
	30 ± 1	2.95 ± 0.17b	16.18 ± 0.80b	5.66 ± 0.28a	24.79 ± 0.87b	22.11 ± 1.22b	32.08 ± 1.61b	29.18 ± 1.58b
	35 ± 1	2.16 ± 0.12c	13.94 ± 0.84c	4.54 ± 0.38b	20.64 ± 0.92c	18.89 ± 0.75c	26.20 ± 1.14c	24.30 ± 1.34c
							F= 0.912;	P=0.467
Neoseiulus cucumeris	25 ± 1	4.26 ± 0.38a	15.90 ± 0.78a	5.26 ± 0.41a	25.42 ± 1.18a	23.74 ± 1.33a	36.09 ± 1.47a	33.95 ± 1.76a
	30 ± 1	3.15 ± 0.27b	13.84 ± 73b	4.95 ± 0.36a	21.94 ± 1.25b	20.78 ± 1.42b	30.32 ± 1.45b	28.90 ± 1.62b
	35 ± 1	1.90 ± 0.20c	10.64 ± 0.54c	4.85 ± 0.32a	17.39 ± 0.85c	15.11 ± 0.98c	23.84 ± 1.06c	21.36 ± 1.18c
							F= 1.18;	P=0.386

Different letters in each column denote significant differences (ANOVA followed by Duncan's multiple range test: P<0.05).

Table 4. Fecundity of *A. swirskii* and *N. cucumeris* feeding on date palm mite *O. afrasiaticus* at 25, 30 and 35 °C and 50 ± 5% RH.

Temperature (°C)	*Amblyseius swirskii*		*Neoseiulus cucumeris*	
	Average of eggs ± SD	Daily egg-laying rate	Average of eggs ± SD	Daily egg-laying rate
25 ± 1	31.91 ± 1.45 Aa	2.00	21.75 ± 1.62 Ab	1.36
30 ± 1	37.10 ± 1.88 Bb	2.68	26.84 ± 1.14 Bc	1.93
35 ± 1	42.16 ± 1.53 Cc	3.02	30.56 ± 1.90 Cd	2.87

The capital letter denotes the significance within the same column and the small letter denotes the significance within the same row at P<0.05. SD means standard deviation.

Table 5. Life Table Parameters of *A. swirskii* and *N. cucumeris* fed on *O. afrasiaticus* at 25, 30, 35 °C and 50 ± 5% RH.

Parameters	25 ± 1 °C; 50% RH		30 ± 1 °C; 50% RH		35 ± 1 °C; 50%RH	
	A. swirskii	*N. cucumeris*	*A. swirskii*	*N. cucumeris*	*A. swirskii*	*N. cucumeris*
Net reproduction rate (R_o)	21.68	18.95	25.94	20.25	29.52	22.78
Mean generation time, t (days)	24.92	26.30	21.82	23.60	18.24	20.56
Intrinsic rate of increase (r_m)	0.181	0.170	0.232	0.185	0.248	0.196
Finite rate of increase (λ)	1.365	1.126	1.551	1.324	1.706	1.428
50% mortality (in day)	35	32	28	26	22	20
Sex ratio (Female/total)	24/30	18/30	20/30	19/30	20/30	22/30

Table 6. Predation rate by different stages of *A. swirskii* and *N. cucumeris* feeding on date palm mite *O. afrasiaticus* at 25 °C and 50 ± 5% RH.

Predatory stage	Sex	*A. swirskii*		*N. cucumeris*	
		No. of attacked mite individuals			
		Total average mean ± SD	Daily rate, mean ± SD	Total average mean ± SD	Daily rate, mean ± SD
Protonymph	Female	9.40 ± 0.61	4.60 ± 0.24	6.30 ± 0.28	2.85 ± 0.20
	Male	9.45 ± 0.52	4.79 ± 0.32	5.95 ± 0.30	2.87 ± 0.28
Deutonymph	Female	12.47 ± 0.62	6.63 ± 0.46	11.16 ± 0.42	3.97 ± 0.40
	Male	11.55 ± 0.76	6.63 ± 0.69	10.75 ± 0.45	3.95 ± 0.24
Total	Female	21.87 ± 1.14a	5.57 ± 0.62a	17.46 ± 0.80b	3.47 ± 0.30b
	Male	21.00 ± 0.98	5.66 ± 0.57	16.70 ± 0.38	3.48 ± 0.35
Pre-oviposition	Female	40.25 ± 1.30	10.53 ± 0.78	29.96 ± 1.54	7.03 ± 0.45
Oviposition	Female	267.46 ± 3.61a	13.52 ± 0.45a	162.97 ± 2.75b	10.24 ± 0.62b
Post-oviposition	Female	41.28 ± 1.22	7.11 ± 0.88	21.75 ± 1.24	4.13 ± 0.25
Longevity	Female	348.99 ± 3.64a	11.87 ± 0.65a9.15 ± 0.41a	214.68 ± 2.78b	8.44 ± 0.60b
	Male	243.18 ± 2.17a		148.61 ± 2.79b	6.26 ± 0.42b
Life span	Female	370.86 ± 4.28a	9.56 ± 0.29a	232.14 ± 3.66b	6.83 ± 0.28b
	Male	264.18 ± 2.54a	7.42 ± 1.58a	165.31 ± 2.45b	4.58 ± 0.22b

Means followed by different letters in each row for total average and daily rate separately denote significant differences (ANOVA followed by Duncan's multiple range test: P<0.05). SD means standard deviation.

throughout the oviposition period, with the female of *A. swirskii* devoured an average of 13.52, 16.86, and 22.14, while with the female of *N. cucumeris* devoured an average of 10.24, 13.11, and 16.58 at 25, 30 and 35 °C respectively. Therefore, the optimal temperature for predation of *A. swirskii* and *N. cucumeris* was about 35 °C. Thereafter, daily consumption of predators fed on *O. afrasiaticus* decreased with age. The highest number of preys consumed during the life span was reported for *A. swirskii* females at 35 °C (405.83 prey) while for *N. cucumeris,* it was 248.85 prey. So, it could be concluded that *A. swirskii* performance was better than *N. cucumeris* against *O. afrasiaticus*.

Table 7. Predation rate by different stages of *A. swirskii* and *N. cucumeris* feeding on date palm mite *O. afrasiaticus* at 30 °C and 50 ± 5% RH.

Predatory stage	Sex	*A. swirskii*		*N. cucumeris*	
		No. of attacked mite individuals			
		Total average mean ± SD	Daily rate, mean ± SD	Total average mean ± SD	Daily rate, mean ± SD
Protonymph	Female	10.05 ± 0.22	6.56 ± 0.32	6.32 ± 0.20	4.00 ± 0.18
	Male	9.76 ± 0.36	6.59 ± 0.25	6.02 ± 0.26	3.93 ± 0.24
Deutonymph	Female	13.75 ± 0.41	9.54 ± 0.28	12.67 ± 0.36	5.60 ± 0.32
	Male	13.08 ± 0.26	9.41 ± 0.36	11.85 ± 0.20	5.46 ± 0.28
Total	Female	23.80 ± 0.74a	8.01 ± 0.88a	18.99 ± 0.42b	4.94 ± 0.22b
	Male	22.84 ± 0.60	7.95 ± 0.72	17.87 ± 0.52	4.82 ± 0.31
Pre-oviposition	Female	41.65 ± 1.40	14.11 ± 0.50	32.09 ± 1.52	10.18 ± 0.60
Oviposition	Female	272.89 ± 2.56a	16.86 ± 0.75a	181.56 ± 2.35b	13.11 ± 0.54b
Post-oviposition	Female	49.20 ± 1.58	8.69 ± 0.43	30.68 ± 0.72	6.19 ± 0.22
Longevity	Female	363.74 ± 3.50a	14.67 ± 0.55a	244.33 ± 3.40b	11.13 ± 0.59b
	Male	247.11 ± 2.42a	11.17 ± 0.36a	169.35 ± 2.44b	8.14 ± 0.35b
Life span	Female	387.54 ± 3.49a	12.08 ± 0.26a	263.32 ± 4.15b	8.68 ± 0.36b
	Male	264.18 ± 2.28a	8.46 ± 0.22a	187.22 ± 2.30b	6.47 ± 0.28b

Means followed by different letters in each row for total average and daily rate separately denote significant differences (ANOVA followed by Duncan's multiple range test: P<0.05). SD means standard deviation.

Table 8. Predation Rate by Different Stages of *A. swirskii* and *N. cucumeris* Feeding on *O. afrasiaticus* at 35 °C and 50 ± 5% RH.

Predatory stage	Sex	*A. swirskii*		*N. cucumeris*	
		No. of attacked mite individuals			
		Total average mean ± SD	Daily rate, mean ± SD	Total average mean ± SD	Daily rate, mean ± SD
Protonymph	Female	8.35 ± 0.10	7.95 ± 0.28	5.71 ± 0.24	4.88 ± 0.20
	Male	7.74 ± 0.18	7.37 ± 0.20	5.20 ± 0.18	4.72 ± 0.26
Deutonymph	Female	9.66 ± 0.30	8.70 ± 0.32	12.02 ± 0.20	6.98 ± 0.30
	Male	9.53 ± 0.26	8.90 ± 0.40	11.50 ± 0.18	6.84 ± 0.22
Total	Female	18.01 ± 0.35a	8.33 ± 0.64a	17.73 ± 0.56a	6.13 ± 0.34b
	Male	17.27 ± 0.30	8.14 ± 0.60	16.70 ± 0.46	6.00 ± 0.28
Pre-oviposition	Female	39.42 ± 1.05	18.25 ± 0.75	25.59 ± 1.13	13.46 ± 0.72
Oviposition	Female	308.68 ± 3.47a	22.14 ± 0.68a	173.43 ± 2.77b	16.58 ± 0.60b
Post-oviposition	Female	39.72 ± 1.18	8.74 ± 0.35	32.10 ± 0.65	6.61 ± 0.34
Longevity	Female	387.82 ± 4.66a	18.78 ± 0.74a	231.12 ± 3.55b	13.29 ± 0.36b
	Male	271.58 ± 2.92a	14.37 ± 0.51a	158.94 ± 2.85b	10.51 ± 0.38b
Life span	Female	405.83 ± 4.72a	15.48 ± 0.68a	248.85 ± 3.54b	10.43 ± 0.45b
	Male	288.85 ± 3.11a	11.88 ± 0.28a	175.64 ± 2.21b	8.22 ± 0.51b

Means followed by different letters in each row for total average and daily rate separately denote significant differences (ANOVA followed by Duncan's multiple range test: P<0.05). SD means standard deviation.

3.4. Effect of O. afrasiaticus on life table parameters of A. swirskii and N. cucumeris

The foregoing conclusions are consistent with the life table parameters. Both predators performed much preferably at relatively higher temperatures because of their rapid population growth rate; therefore, high oviposition (R_0) and short mean generation time (T) in contrast with low temperatures. Net reproductive rate (R_0) was 21.68, 25.94, and 29.52 females per female for *A. swirskii* and 18.95, 20.25 and 22.78 for *N. cucumeris* at 25, 30 and 35 °C respectively (Table 5). The intrinsic rate of increase (r_m) and the finite rate of increase (λ) reached the maximal value at 35 °C. The value of r_m varied from 0.181 to 0.248, 0.170 to 0.196 ♀/♀/day, and the finite rate of increase (λ) from 1.365 to 1.706, 1.126 to 1.428 at 25 °C and 35° C for *A. swirskii* and *N. cucumeris*, respectively. The mean generation time (*T*) for *A. swirskii* and *N. cucumeris* was longer at 25 °C than at 35 °C.

4. Discussion

This study is the first documentation of the life history characteristics and predation capacity of *A. swirskii* and *N. cucumeris* on the date palm mite with *O. afrasiaticus* as prey. However, several studies have been carried out on both predators when fed on mites, insects, plant pollen, and artificial foods. The current study showed that both predators, *A. swirskii* and *N. cucumeris,* developed and reproduced successfully when fed on *O. afrasiaticus* with few developmental mortalities at the three tested temperatures. For both predators, larvae developed to the protonymphal stages without feeding. Non-feeding larvae behavior may be beneficial for reducing intra-species competition or a mechanism to eschew sibling cannibalism. Similar results were obtained for other predacious phytoseiid species (Zhang and Croft, 1994). In an evaluation of the development of *A. swirskii* at 30 °C on *Phyllocoptruta oleivora* (Ashmead) and *Eutetranychus orientalis* (Klein), the shortest life cycle was observed when *A. swirskii* fed on *P. oleivora* (Al-Azzazy and Alhewairini, 2020). The developmental time of female immatures of *A. swirskii* fed on *Cenopalpus irani* Dosseand *Eotetranychus frosti* (McGregor) (Bazgir et al., 2018) were very close to the present results against *O. afrasiaticus*. A longer life cycle (22.1 days) was recorded when *A. swirskii* fed on cattail (*Typha latifolia* L.) pollen (Lee and Gillespie, 2011). This decrease in developmental rate might be attributable to variances in the nutritional value of the prey provided. Overall, faster development is essential for biocontrol agents of phytophagous mites. On the other hand, development of *N. cucumeris* immature females was relatively longer in our study (10.67 days at 25 °C) than reported when fed on *Tetranychus urticae* Koch eggs (6.4 d at 25 °C) (Li and Zhang, 2016), slightly longer than the 26 °C (6.25 days) when *N. cucumeris* were fed with *T. urticae* eggs (Kolodochka, 1985). However, the developmental time of female immatures of this predator preying on acarid mite, *Tyrophagus curvipenis* eggs and eggs of *T. urticae* (Li and Zhang, 2016; Li et al., 2021) was close to the present findings against *O. afrasiaticus*. Moreover, *N. cucumeris* were also reported to develop faster when fed on *Aculops lycopersici*, shorter than on the mixed stage of *T. urticae* in the study conducted by (Al-Azzazy et al., 2018). Temperatures ranging from 25 to 35 °C were more appropriate for the survival of *N. cucumeris* and *A. swirskii*. The survival rate of *A. swirskii* from larvae to adult was more than 96% while for *N. cucumeris* it decreased from 91.40% at 35 to 84.62% at 25. The findings of Al-Azzazy and Alhewairini (2020) support our results. They revealed that the survival rate of *A. swirskii* during the immature phases exceeded 90% at all temperatures between 16 °C and 30 °C. Also, the survival rate of *N. cucumeris* was similar to the findings obtained when fed on *T. urticae* eggs (Li and Zhang, 2016). Pre-oviposition periods of *A. swirskii* and *N. cucumeris* were very close to those stated by (Ranabhat et al., 2014; Bazgir et al., 2018). The oviposition duration and adult female longevity of *A. swirskii* were parallel to the findings reported by Abou-Awad et al. (1999), Bazgir et al. (2018) and Al-Azzazy and Alhewairini (2020) for *A. swirskii* feeding on *Rhyncaphytoptus fucifoliae* Keifer and *Aceria ficus* (Cotte), *E. frosti* and *C. irani* and *E. orientalis* and *P. oleivora*. When *Cydnoseius negevi* (Swirski and Amitai) was evaluated against *O. afrasiaticus* (Negm et al., 2014), female longevity was higher (31.80 d) than that of *A. swirskii* (29.39 d). This may be due to the lower humidity level applied for *C. negevi*. The oviposition duration and adult female longevity of *N. cucumeris* (15.90, 25.42 at 25 °C and 10.64, 17.39 at 35 °C) against *O. afrasiaticus* were close to the one stated against *Aleuroglyphus ovatus* (Troupeau) (16.40, 26.40 at 25 °C) (Ji et al., 2007) and (14.02, 18.36 at 35 °C) when the predatory mite, *N. cucumeris* fed on *T. urticae* (Al-Azzazy et al., 2018). In this work, the highest oviposition was obtained when *A. swirskii* fed on *O. afrasiaticus* (42.16 eggs/female at 35 °C). This value was higher when compared to mites that fed on *A. ficus* (28.20 eggs/female at 29 °C) and *R. ficifoliae* (20.40 eggs/female at 29 °C) (Abou-Awad et al., 1999), on Cattail pollen, *Typha latifolia* L. (23.30 eggs/female at 30 °C) (Lee and Gillespie, 2011), on dried fruit mite (*Carpoglyphus lactis* L.) (29.03 eggs/female at 23 °C) (Nguyen et al., 2014), *E. frosti* (34.69 eggs/female at 26 °C) (Bazgir et al., 2018). Furthermore, the findings of Goleva and Zebitz (2013) and Al-Azzazy and Alhewairini (2020) for *A. swirskii* fed on *Schlumbergera hybrid* pollens (50.85 eggs/female at 25 °C) and *P. oleivora* (47.99 eggs/female at 30 °C) respectively, were higher than that obtained in our finding. In this study, the maximum fecundity of *N. cucumeris* was 30.56 eggs at 35 °C which was higher than that reported by (Al-Shemmary, 2018) (25.06 eggs) with feeding on *Anagasta kuehniella* (Zeller) eggs at 27 °C. In addition, *N. cucumeris* has shown total fecundity of 29.4 eggs at 22 °C on the cereal mite, *Tyrophagus putrescentiae* (Schrank) (Ji et al., 2007). On the other hand, the findings of Zilahi-Balogh et al. (2007), Ranabhat et al. (2014) and Al-Azzazy et al. (2018) for this predator fed on *Frankliniella occidentalis* (Pergande), (83.0 eggs/ female at 24 °C), tulip pollen (89.48 eggs/ female at 25 °C) and *A. lycopersici* (60.44 eggs/ female at 35 °C) respectively, were considerably higher than the value estimated in the current study. The high fecundity for both predators in the current study might be due to multiple-mated incidence. In *Kampimodromus aberrans*, Pappas et al. (2007) showed that the females paired with a male during the lifespan with multiple mating gave the greatest fertility (28-30 eggs/female), while females with single mating had the lowest fertility (12 eggs/ female). The sex ratio of predatory phytoseiid mites is characterized by a female bias (Sabelis, 1985). This agrees with the current results of *A. swirskii* and *N. cucumeris* in addition to other previous studies (Dyer and Swift, 1979; Al-Azzazy and Alhewairini, 2020). During immature stages of *A. swirskii* and *N. cucumeris*, predation rate increased with increasing temperature from 25 to 35 °C. *Amblyseius swirskii* immature females devoured 23.80 preys of *O. afrasiaticus*at at 30 °C, while they devoured 25.27 individuals of *E. frosti* and 29.92 of *C. irani*, respectively at 25 °C (Bazgir et al., 2018), and 31.54 individuals of *E. orientalis* nymphs and 111.13 individuals of *P. oleivora*, respectively at 30 °C (Al-Azzazy and Alhewairini, 2020). Therefore, it could be concluded that the optimum temperature for predation of *A. swirskii* ranged from 25-35 °C.

Neoseiulus cucumeris immature females devoured 18.99 preys of *O. afrasiaticus* at 30 °C in this work, while they devoured 26.54 individuals of *T. urticae* and 123.67 of *A. lycopersici*, respectively at 30 °C (Al-Azzazy et al., 2018), and 15.69 individuals of *Tetranychus atlanticus* McGregor at 26 °C (Popov and Kondryakov, 2008). Data obtained from predation of *N. cucumeris* on *T. urticae* (Sarwar et al., 2009) are close to that reported in this work against *O. afrasiaticus*. The findings of Zaher et al. (1969) and Al-Azzazy and Alhewairini (2020) support our results. They showed that an increase in temperature leads to a positive influence on predation rate until the optimum temperature is reached. Ganjisaffar et al. (2011) also reported that more preys is devoured as the temperature increases from 15 to 35 °C. Many biological studies have confirmed that the nutritional quality of food sources resulted in higher values in life table parameters (Bouras and Papadoulis, 2005; Park et al., 2011; Jial et al., 2016). The rates of population growth were promising for *A. swirskii* fed on *O. afrasiaticus*. This is proven by (r_m) which was 0.248 at 35 °C. The reported intrinsic rate of natural increase for predatory mite, *A. swirskii* on *T. urticae* (0.167 at 26 °C) (El-Laithy and Fouly, 1992), *F. occidentalis* (0.138 at 25 °C) and *T. tabaci* (0.139 at 25 °C) (Wimmer et al., 2008), *T. latifolia* (0.133 at 34 °C) (Lee and Gillespie, 2011), *E. frosti* (0.179 at 25 °C), *C. irani* (0.140 at 25 °C). (Bazgir et al., 2018), *E. orientalis* (0.204 at 30 °C) (Al-Azzazy and Alhewairini, 2020) was lower than that obtained in the current study when *A. swirskii* fed on *O. afrasiaticus*. Rahmani Piyani et al. (2021) estimated an r_m of 0.396 and 0.291 for *A. swirskii* fed on date palm pollen and *Tetranychus turkestani* at 25 °C respectively. Also, (Al-Azzazy and Alhewairini, 2020) estimated an r_m of 0.280 for *A. swirskii* fed on *P. oleivora*. This is somewhat higher than our estimate. The values of (R_o), (r_m) and (λ) of *A. swirskii* at 25 °C and 50% RH are higher than those reported for *Euseius scutalis* against *O. afrasiaticus* at 25 °C and 70% RH (Al-Shemmary, 2010). *A. swirskii* performed better on *O. afrasiaticus* than on *E. scutalis*, and this could be due to the moderate humidity level used according to (Al-Azzazy and Alhewairini, 2020). Considering this, *A. swirskii* could be a useful biological control agent for *O. afrasiaticus*. In case of *N. cucumeris* against *T. urticae* and *T. putrescentiae* at 25 °C, the life table parameters (r_m, λ, R_o) values were 0.164, 1.179, 18.39 and 0.096, 1.100, 15.16, respectively (Yazdanpanah et al., 2022a); on date palm pollen (DPP), at 25 °C, these parameters were 0.152, 1.165, 14.93 (Yazdanpanah et al., 2021); and on eriophyid mite, *A. lycopersici*, at 25 °C, 0.211, 1.321, 20.47 (Al-Azzazy et al., 2018). While in the current study, they were 0.170, 1.126, and 18.95 at 25 °C. This indicates that *N. cucumeris* performs well on *O. afrasiaticus*, as a generalist phytoseiid predator.

5. Conclusion

In summary, these results show that both predatory mites thrived on *O. afrasiaticus* making them promising biocontrol agents of that pest. Both species can also feed on the date palm pollen (Rahmani Piyani et al., 2021; Yazdanpanah et al., 2022a, b). In a biocontrol context, the existence of alternative foods on date palms like date palm pollen may help to enhance the population densities of both predatory mites and allow predatory mites to increase when *O. afrasiaticus* are rare or absent and thus prevent severe declines in predatory mite populations during scarcities of primary prey. This can further contribute to the control of *O. afrasiaticus*. Finally, the results discussed above will help gain a better understanding of the effectiveness of *A. swirskii* and *N. cucumeris* as facultative predators in biological control programs of *O. afrasiaticus*. Hence, further trials should be performed to examine the performance of these predatory mites in combination and/or singly on *O. afrasiaticus* under field conditions.

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