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Original Article

Evaluation of the effectiveness of *Neoseiulus cucumeris* (Oudemans) as a predator of *Tuta absoluta* (Meyrick)

Avaliação da eficácia de *Neoseiulus cucumeris* (Oudemans) como predador de *Tuta absoluta* (Meyrick)

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Abstract

The leaf miner, *Tuta absoluta* is continue to be a serious threat to solanaceous plants, especially tomato plant worldwide. Tomato crop in Saudi Arabia has been recently affected by *T. absoluta*, which is difficult to control due to its unique biological features, such as high fecundity and its potential to develop resistance to chemical pesticides. In this article, the suitability and effectiveness of the predatory mite, *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae), an indigenous species usually found in tomato greenhouses of northcentral Saudi Arabia, has been evaluated on eggs and 1st instar larvae of *T. absoluta* in the laboratory. All experiments were conducted in an incubator at three constant temperatures of 22, 27 and 32°C ± 1°C, 50 ± 4% R.H. and L12:D12 h photoperiod. Adult females and males of *N. cucumeris* were able to feed and sustain oviposition on eggs and 1st instar larvae of *T. absoluta*, and could be an effective biocontrol agent against *T. absoluta*. The *N. cucumeris* had a clear preference for eggs compared to 1st instar larvae of *T. absoluta*. The results showed the obvious effect of the temperature on the consumption rate of the predatory mite. The maximum daily consumption rate occurred during the oviposition period, when the females of the predatory mite consumed an average of 4.26 eggs and 2.44 1st instar larvae of *T. absoluta*. In general, total fecundity was high with *T. absoluta* eggs as a food source when temperature increased from 22 to 32°C. The highest fecundity rate (42.92 and 20.97 eggs /female) was recorded at 32°C, while the lowest one (26.77 and 10.12 eggs / female) was recorded at 22°C, when *N. cucumeris* female fed on eggs and 1st instar larvae of *T. absoluta*, respectively. The results of this study indicated that the predatory mite, *N. cucumeris* can be considered a promising potential candidate for controlling the leaf miner *T. absoluta*, and further research is required to assess its effectiveness under greenhouse conditions.

Keywords: biological control, *Tuta absoluta*, predatory mite, *Neoseiulus cucumeris*.

Resumo

A traça-do-tomateiro, *Tuta absoluta*, continua sendo uma séria ameaça às plantas solanáceas, especialmente ao tomateiro em todo o mundo. A safra de tomate na Arábia Saudita foi recentemente afetada por *T. absoluta*, o qual é de difícil controle por causa de suas características biológicas únicas, como alta fecundidade e potencial para desenvolver resistência a pesticidas químicos. Neste artigo, a adequação e a eficácia do ácaro predador *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae), uma espécie indígena geralmente encontrada em estufas de tomate no centro-norte da Arábia Saudita, foram avaliadas em ovos e larvas de 1º instar de *T. absoluta* em condições de laboratório. Todos os experimentos foram conduzidos em uma incubadora em três temperaturas constantes de 22, 27 e 32°C ± 1°C, 50 ± 4% UR e fotoperíodo L12: D12 h. Fêmeas e machos adultos de *N. cucumeris* foram capazes de se alimentar e sustentar a oviposição em ovos e larvas de 1º instar de *T. absoluta*, podendo ser um agente de biocontrole eficaz contra *T. absoluta*. *Neoseiulus cucumeris* teve uma clara preferência por ovos em comparação com larvas de 1º instar de *T. absoluta*. Os resultados mostram que mais presas foram consumidas conforme a temperatura aumentou de 22°C para 32°C. A taxa máxima de consumo diário ocorreu durante o período de oviposição, quando as fêmeas consumiram em média 4,26 ovos e 2,44 larvas de 1º instar de *T. absoluta*. Em geral, a fecundidade total foi maior com ovos de *T. absoluta* como fonte alimentar e com o aumento da temperatura. A maior taxa de fecundidade (42,92 e 20,97 ovos por fêmea) foi registrada a 32°C, enquanto a mais baixa (26,77 e

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10,12 ovos por fêmea) foi a 22°C, quando *N. cucumeris* se alimentou de ovos e larvas de 1º instar de *T. absoluta*, respectivamente. Os resultados deste estudo indicam que o ácaro predador *N. cucumeris* pode ser considerado um potencial candidato para o controle da traça-do-tomateiro *T. absoluta*, e mais pesquisas são necessárias para avaliar sua eficácia em condições de estufa.

Palavras-chave: controle biológico, *Tuta absoluta*, ácaro predador, *Neoseiulus cucumeris*.

1. Introduction

The leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is the most important tomato pest in Saudi Arabia and an important factor in most agricultural economies of tomato crops in Asia, for which no sustainable practical control strategy is available yet. Currently, it is a serious threat to tomato producers in Saudi Arabia and there is evidence which shows that its proliferation has indeed decreased tomato yield with its larval feeding activity, combating this pest requires the expansion use of pesticides which increase production costs in addition to polluting the environment (Abdel-Baky and Al-Soqeer, 2017). The *T. absoluta* demonstrates a wide thermal tolerance, completing its development between 14°C and 35°C (Cherif et al., 2019). A single female can achieve a maximum lifetime fecundity of 260 eggs (Uchôa-Fernandes et al., 1995; Sylla et al., 2019). Yield losses, however, are a result of feeding activity of larvae which disrupt the plant's photosynthetic processes (Aigbedion-Atalor et al., 2019), and may serve as entry routes for bacterial diseases (Tropea Garzia et al., 2012), consequently, the pest can cause up to 85–100% yield losses in tomato crops if no control methods are used (Desneux et al., 2010). The tomato borer is a very challenging pest to control by chemical pesticides. It is due to its unique biological traits, such as: high reproduction rate in a wide range of environmental conditions, short life cycle, rapid adaptation to new environments and potential to develop resistance to pesticides (Lietti et al., 2005; Desneux et al., 2010; Roditakis et al., 2013; Martins et al., 2016; Cherif et al., 2019). The use of frequently applied conventional insecticides to manage *T. absoluta* resulted into the destruction of predators and other non-target beneficial organisms, the development of pests that become resistant to these insecticides, presence of pesticide residues in crops and the negative effects on human health (Passos et al., 2017; Giorgini et al., 2019), thus making the management strategies for the control of *T. absoluta* a more complex matter. As a result, these problems necessitate the development of alternative pest control strategies that may not result into the above mentioned negative effects, such as biocontrol agents for the management of the leaf miner, *T. absoluta*. This strategy prevents the need for insecticides and provides long-term pest control as well as preemptive protection. Generalist, predatory mites are widely recognized as significant contributors to biological control of pests, hence the exploitation of these predators as a tool in pest control is essential for sustainability and food security (Williams et al., 2004). This is demonstrated by the successful control of *Bemisia tabaci* by early release of *Amblyseius swirskii* Athias Henriot in zucchini plants (Téllez et al., 2017). Although *T. absoluta* has since long been recognized as a serious pest, research on the predatory mites of this pest has only started recently. Momen et al. (2013) reported the first promising results about *Neoseiulus barkeri*, *Cydnoseius negevi* and *Amblyseius largoensis* when exposed to *T. absoluta* eggs. These predators are able to feed and sustain oviposition on eggs of *T. absoluta*. The predatory activities of these three species have also been reported which were proven to prey on unfed, 1st instar larvae of *T. absoluta* under laboratory conditions (Metwally et al., 2015). While several researches have been carried out on predatory mite species, scarce informations are available about the effectiveness of *N. cucumeris* as a predator of *T. absoluta*, which has largely been found in infested tomato plantations in Qassim region, Saudi Arabia (Al-Azzazy et al., 2018). The *N. cucumeris* is a cosmopolitan species and a common predator inhabiting tomato and pepper greenhouses and other fruit crops in Saudi Arabia (Al-Atawi, 2011; Al-Azzazy et al., 2018; Al-Shemmary, 2018). This predator has been studied for its potential to control a wide range of pests, including thrips (Van Driesche et al., 2006; Zilahi-Balogh et al., 2007), whitefly (silver leaf) (Zhang et al., 2011), Asian citrus psyllid (Fang et al., 2013), spider mites & eriophyids (Brodeur et al., 1997; Al-Azzazy et al., 2018), broad mite (Weintraub et al., 2003), cyclamen mite (Easterbrook et al., 2001), acarid mite (Li et al., 2021), eggs of *Anagasta kuehniella*, *Spodoptera littoralis* and *Sitotroga cerealella* (Al-Shemmary, 2018), pollen (Van Rijn and Tanigoshi, 1999; Sarwar et al., 2009), the immature stages of a variety of pests (McMurtry and Croft, 1997), and other small arthropods (Van Lenteren, 2012; Knapp et al., 2018). The current study aimed to evaluate the efficiency of the predatory mite, *N. cucumeris* and its role as a biological control agent for the tomato borer, *T. absoluta*. In particular, predation rates on eggs and 1st instar larvae of *T. absoluta* and reproduction rate of the predator on this prey in the laboratory at three constant temperatures in order to evaluate if this predator can be considered a promising candidate as a biological control agent of *T. absoluta* Further study is needed to assess its effectiveness under greenhouse conditions.

2. Materials and Methods

2.1. Stock culture of predator

This research was performed at the Acarology Laboratory of the Department of Plant Production and Protection, Qassim University, Saudi Arabia. Colonies of *N. cucumeris* were collected from untreated tomato greenhouses in the Qassim region (26.3489° N, 43.7668° E), Saudi Arabia. The laboratory colony was set up using kidney bean plants (*Phaseolus vulgaris* L.) heavily infested with *Tetranychus urticae* Koch (Acari: Tetranychidae) for at least 4 months. Each bean leaf was placed upside down on a water-saturated cotton disc (diameter: 6 cm) inside plastic Petri dishes (diameter: 12 cm, 2 cm deep), with an extra cotton tape on the leaf edges to prevent the predatory mites from escaping. The Petri dishes were kept in an incubator at 32 ± 2°C, 12:12 h light: dark, and 50 ± 4% R.H.

2.2. Host plant

Tomato plants (cv. Pritchard) were grown in the experimental greenhouse in the Research Station, Qassim University under natural photoperiod of 12 h. Tomato plants were irrigated three times a week and fertilized weekly with water-soluble fertilizer. All the usual agriculture practices were followed. Plants at the beginning of the flowering stage with approximately 40–45 cm height from the soil surface were used in all the experiments.

2.3. Tuta absoluta colony and oviposition

The initial colony of *T. absoluta* used in this research was collected from tomato greenhouse in Qassim region, Saudi Arabia. Adults were reared under laboratory conditions (25°C ± 3 (range: 23 to 28°C), 50 ± 4% R.H. and 12:12 h light: dark. in PERSPEX® cages (120 cm high × 80 cm wide × 90 cm depth) each containing five tomato seedlings for egg laying. Small streaks of 50% honey solution were placed to the top sides of each cage as food source for adults. In addition to the tomato seedlings, the adults provided with tomato terminal buds and leaves with the petiole plugged into a ball of moistened cotton to delay wilting, then placed in a small glass test tube (15 ml) for oviposition. The plants were taken out of cages and eggs and 1st instar larvae of *T. absoluta* were collected under a stereoscopic microscope (SD30, Olympus, Japan) using a fine camel hair brush and placed on rearing arena used in mites feeding experiment.

2.4. Experimental units and conditions

The predation rate and fecundity of *N. cucumeris* were monitored at three constant temperatures of 22, 27and 32°C.± 1°C, 50 ± 4% R.H. and L12:D12 h photoperiod. Eggs and 1st instar larvae of *T. absoluta* collected from rearing cages (described above) or from stock cultures of the prey in tomato greenhouse (as a backup resource) were offered as food. Following the method of El-Banhawy (1977), a single predatory mite was placed on citrus leaf discs *Citrus sinensis* L.; Rutaceae (to prevent the larvae from penetrate leaves) (diameter: 3 cm), which were placed upside down on a water-saturated cotton disc (diameter: 4 cm) inside plastic Petri dishes (diameter: 8 cm). Edges of the citrus leaf disc were wrapped with moist cotton tape to prevent the predators from escaping. In addition, water was added daily to the Petri dishes to maintain moist cotton. Likewise, after every 3 or 4 days, the predators were transferred to new rearing arenas.

2.5. Life history parameters

The longevity and adult fecundity of *N. cucumeris* were determined by feeding them with eggs and 1st instar larvae of *T. absoluta*. To obtain the same-aged eggs of the female predatory mites for the different experiments, 100 gravid females of *N. cucumeris* from the stock culture were placed individually on the rearing arenas with about 1000 spider mites, *T. urticae* as prey (10 per rearing arena). These rearing arenas of the predatory mite were maintained at three constant temperatures of 22, 27 and 32°C.± 1°C, 50 ± 4% R.H. and L12:D12 h photoperiod. After one day (exposure period), the females were removed from the rearing arenas and the amount of eggs was reduced to 1 by puncturing the excess eggs with a fine needle, and the newly hatched larvae were supplied with eggs, 1st instar larvae of *T. absoluta* (The first experiment) and nymphs of *T. urticae* (The second experiment). Rearing arenas were examined daily and the predator development and survival were recorded. Survival and developmental progress were assessed every 12 h until the mites died or reached adulthood. For each treatment, after emergence of adults, suitable densities of prey (Five eggs or five, 1st instar larvae) were added every day to the rearing arenas. There were 80 replicates with both *T. absoluta* eggs 1st instar larvae (Third experiment). Females were coupled with those males obtained in the same experiment and kept together until their death to allow multiple matings (Gotoh and Tsuchiya, 2008). The males that escaped or died prior to the females were replaced with new males. To calculate the predation rate independently to males from females, the predation rate of 80 males was examined under same temperatures. Then, the mean of predation rate of male was subtracted from the average predation rate of the couples (Moghadasi et al., 2014). Pre-oviposition, oviposition and post-oviposition periods were determined to evaluate longevity, fecundity and mortality of adults until death of the last individual. Longevity was recorded separately for males and females. When females began to lay eggs, their eggs were counted and removed daily.

2.6. Predation rate

The consumption rate of *N. cucumeris* was determined using eggs and unfed 1st instar larvae of *T. absoluta*. The same kinds of experimental rearing arenas were used for the consumption rate trial. Each rearing arena was abundantly supplied with food daily. To determine the consumption rate by adult females and males of *N. cucumeris*, ten eggs or ten 1st-instar larvae of *T. absoluta* were added every day onto the discs. The numbers of both eggs and 1st instar larvae that were attacked or had clear symptoms of feeding damage were recorded every 24 h to determine consumption rates. During the oviposition period, the numbers 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.

2.7. Prey preference between eggs and first instar larvae of T. absoluta

All experiments were carried out on citrus leaf discs as described above. Ten individuals of both eggs and 1st instar larvae of *T. absoluta* were randomly chosen from the rearing cultures and carefully transferred onto the rearing arena using a fine camel hair brush for 2 hours of acclimatization. Thereafter, a single newly emerged adult female of *N. cucumeris* that had been starved for one day was then introduced into the rearing arena. All rearing arenas were kept at three constant temperatures of 22, 27 and 32°C.± 1°C, 50, ± 6% R.H. and L12:D12 h photoperiod for 24 hours after which the number of consumed preys was recorded. The experiment involving *T. absoluta* eggs was replicated 30 times with 5 control treatments (i.e., in absence of the predatory mite, *N. cucumeris*), and one involving 1st instar larvae of *T. absoluta* was replicated 30 times with 5 control treatments (i.e.,in the absence of *N. cucumeris*). The number of replicates for the control group was determined on the basis of preliminary trials in which no control mortality happened in numerous replicates among 1st-instar larvae of *T. absoluta* or among *T. absoluta* eggs using the experimental procedure outlined above. Similarly, no mortality occurred in the controls during the experiments.

2.8. Statistical analysis

To assess the pre-oviposition, oviposition and post-oviposition periods, adult longevity, fecundity, predation rate of *N. cucumeris* and the effect of temperature on these parameters, data were compared with one-way analysis of variance (ANOVA) and the difference between means was conducted using Duncan's multiple range tests (P < 0.05) (Duncan, 1955), using the SAS 9.1 program and Fisher's least significant differences (LSD). The standard errors of the fecundity, reproduction period and predation rate were estimated using the bootstrap technique (Farhadi et al., 2011; Bahari et al., 2018).

2.9. Prey preference between T. absoluta eggs and 1st-instar larvae of T. absoluta

The assessment of preference was based on the Formula 1 for Manly's preference index (Manly et al., 1972):

$$\beta_1 = \frac{Log\left(\frac{e1}{A1}\right)}{Log\left(\frac{e1}{A1}\right) + Log\left(\frac{e2}{A2}\right)} \quad (1)$$

where, β1 is the preference to prey type 1, *e1* and *e2* are the number of prey type 1 and type 2 remaining after the experiment and *A1* and *A2* are the offered number of prey type 1 and type 2 to the predator.

3. Results

In the first trial, it was shown that *N. cucumeris* failed to develop into adults when 1st instar larvae of *T. absoluta* was provided as prey at three constant temperatures (22°C, 27°C, and 32°C). On the other hand, only 5% individuals successfully emerged into adults when the predator fed on *T. absoluta* eggs at the same previous conditions. Furthermore, they showed evident difficulties preying on eggs and 1st instar larvae of *T. absoluta*. When provided with *T. urticae* nymphs, nearly all the *N. cucumeris* completed their development successfully in experiment 2. Laboratory trial showed that *N. cucumeris* was able to develop over all temperatures studied (22, 27 and 32 °C), when *T. urticae* nymphs were supplied as prey. The developmental periods of immature stages significantly decreased as temperature increased. From egg to adult, the females required 10.25, 7.81, 5.50 days when reared on *T. urticae* nymphs at the previously stated temperatures, respectively (Table 1). Hatching percentage of eggs was only slightly affected by temperatures. At each of the temperatures between 22 and 32°C, more than 96% of the eggs (range: 94–98%) hatched and there were no significant differences among temperatures. Mortality of immature stages of *N. cucumeris* was very low at all the three temperatures studied, and the results showed no trends with temperature. Approximately 95% of larvae developed to adulthood at temperatures between 22 and 32°C. On the other hand, laboratory trial showed that *N. cucumeris* was able to oviposit over all temperatures studied (22, 27 and 32°C), when eggs and 1st instar larvae of *T. absoluta* were supplied as prey in experiment 3. At all temperatures between 22°C and 32°C, all emerged females laid eggs within 1.68–5.93days (pre-oviposition period) (POP). At 22°C, the adult longevity lasted26.50 days and27.18days, respectively. At32°C, the corresponding periods were 17.35 days 18.36 days, when *N. cucumeris* fed on eggs and 1st instar larvae of *T. absoluta*, respectively (Table 1). Generally, at all temperatures, females lived at least 2 days longer than males (Table 1). The interaction between temperature and *N. cucumeris* was significant for all parameters excluding the post-oviposition period (Table 2). The maximum oviposition periods (17.64 and 17.11 days) were recorded at 22°C, while the minimum ones (11.72 and 12.73 days) were recorded at 32°C, when *N. cucumeris* fed on eggs and 1st instar larvae of *T. absoluta*, respectively. When *N. cucumeris* fed on eggs and 1st-instar larvae of *T. absoluta*, a significant difference was observed among its oviposition rates (One-way ANOVA, P < 0.01 (Table 3).

Additionally, *N. cucumeris* females fed on eggs exhibited a higher rate of fecundity than those fed on 1st instar larvae of *T. absoluta*. Moreover, an increase of temperature from 22 to 32°C, progressively increased the daily rate of reproduction. The highest fecundity (42.92 eggs /female) was recorded at 32°C, while the minimum one (26.77 eggs /female) was obtained at 22°C, when *N. cucumeris* female fed on *T. absoluta* eggs and when the predatory female fed on 1st instar larvae of *T. absoluta*, female laid 20.97 eggs at 32°C and 10.12 eggs at 22°C (Table 3). The highest amount of eggs laid by *N. cucumeris* females was on the seventh day of their oviposition-periods. Through the first ten days of the oviposition period, the number of eggs laid remained high after which the numbers of laid eggs gradually decreased. There were no effects of food type or the different temperatures on post-oviposition period.

3.1. Prey preference between T. absoluta eggs and 1st-instar larvae of T. absoluta

The predatory mite, *N. cucumeris* clearly preferred eggs to 1st instar larvae of *T. absoluta* (t = 2.996, P = 0.001, df = 21). Interestingly, female fecundity was higher when *N. cucumeris* fed on *T. absoluta* eggs than on 1st instar larvae. The results showed that *N. cucumeris* in the existence of equal densities of the two types of prey had a clear preference for *T. absoluta* eggs (preference index

Table 1. Duration (days±SD) of *N. cucumeris* immatures reared on *T. urticae* nymphs at three constant temperatures.

		Developmental stages				
Temperature (°C)	**Sex**	**Egg**	**Larva**	**Protonymph,**	**Deutonymph,**	**Developmental time**
22±1	♀	3.14±0.18a	2.42±0.20a	2.36±0.18a	2.33±0.23a	10.25±0.44a
	♂	3.11±0.16a	2.40±0.22a	2.33±0.19a	2.22±0.24a	10.06±0.58a
27±1	♀	2.85±0.20b	1.87±0.24b	1.59±0.11b	1.50±0.12b	7.81±0.40b
	♂	2.80±0.22b	1.72±0.20b	1.55±0.20b	1.47±0.21b	7.54±0.45b
32±1	♀	2.12±0.16c	1.16±0.09c	1.03±0.14c	1.19±0.05c	5.50±0.25c
	♂	2.05±0.16c	1.18±0.08c	0.98±0.12c	1.17±0.06c	5.38±0.35c
					F=1.16	P=0.483

The means followed by different letters in the same column are significantly different (ANOVA followed by Duncan's P<0.05).

Table 2. Average duration (in days±SD) of *N. cucumeris* adults feeding on eggs and 1st instar larvae of *T. absoluta* at three constant temperatures.

T. absoluta	Temperature (°C)	Pre-oviposition	Oviposition	Post-oviposition	Longevity	
					♀	♂
eggs	22±1	4.38±0.30a	17.64±1.08a	4.48±0.35a	26.50±1.29a	24.81±0.77a
	27±1	3.25±0.19b	14.41±0.76b	4.00±0.27a	21.66±1.46b	19.27±85b
	32±1	1.68±0.08c	11.72±0.80c	3.95±0.30a	17.35±0.97c F=0.867;	16.12±0.54c P=0.429
1st instar larvae	22±1	5.93±0.32a	17.11±1.10a	4.14±0.24a	27.18±2.05a	26.08±1.04a
	27±1	3.25±0.18b	14.39±0.95b	4.10±0.32a	21.74±1.46b	20.77±1.23b
	32±1	2.09±0.16c	12.73±0.61c	3.54±0.41a	18.36±1.20c F=1.243;	17.10±098c P=0.478

The means followed by different letters in the same column are significantly different (ANOVA followed by Duncan's P<0.05).

Table 3. Fecundity of females of *N. cucumeris* females fed on eggs and 1st instar larvae of *T. absoluta* at three constant temperatures.

Temperature °C	*Neoseiulus cucumeris*			
	T. absoluta eggs		1st-instar larvae of *T. absoluta*	
	Avg. of eggs ± SD	Daily egg-laying	Average of eggs ± SD	Daily egg-laying
22	26.77± 1.83 ^{Aa}	1.51	10.12± 0.72 ^{Ab}	0.59
27	33.96±1.23 ^{Bb}	2.35	14.66±0.78 ^{Bc}	1.01
32	42.92 ±1.09 ^{Cc}	3.66	20.97 ±1.74 ^{Cd}	1.64

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

β: 0.91 ± 0.04), consuming 4.85 *T. absoluta* eggs and 1.9 1st instar larvae of *T. absoluta* during the experimental periods of 24 h. The pre-oviposition periods of *N. cucumeris* were significantly faster on a diet of *T. absoluta* eggs than on 1st instar larvae. Peak of fecundity of *N. cucumeris* was 2 fold higher on *T. absoluta* eggs than on 1st-instar larvae of *T. absoluta*.

3.2. Predation of N. cucumeris on T. absoluta eggs and 1st-instar larvae of T. absoluta

The numbers of eggs and 1st instar larvae of *T. absoluta* consumed by adult females and males of *N. cucumeris* under three constant temperatures are shown in Tables 4, 5 and 6. During pre-oviposition period of *N. cucumeris* females, the daily predation rates increased with an increasing of temperatures from 22 to 32°C. The daily average consumptions for females were 2.55, 3.24, and 3.65 eggs, and 1.50, 1.75, and 2.05 1st instar larvae of *T. absoluta* at 22, 27 and 32°C, respectively.. The predation rate increased from pre-oviposition period to oviposition one and reduced in the post-oviposition period. The highest means for the daily predation rate of females were recorded during the oviposition period, with the female devoured an average of 3.07, 3.61 and 4.26 eggs, and 1.67, 1.89, and 2.44 1st

Table 4. Predation rate of *N. cucumeris* adults, fed on eggs and 1st instar larvae of *T. absoluta* at 22 °C and 50% R.H.

Predatory stage	Sex	No. of attacked mite individuals			
		Eggs of *T. absoluta*		1st-instar larvae of *T. absoluta*	
		Total average, (mean ± SD)	Daily rate, (mean± SD)	Total average (mean ± SD)	Daily rate, (mean± SD)
Pre-oviposition	♀	11.16±1.25	2.55±0.38	8.89±0.38	1.50±0.09
Oviposition	♀	54.33±2.89ᵃ	3.07±0.32ᵃ	28.57±2.33ᵇ	1.67±0.11ᵇ
Post-oviposition	♀	6.80±0.28	1.52±0.22	4.47±0.17	1.08±0.09
Longevity	♀	72.29±3.56ᵃ	2.72±0.18ᵃ	41.93±3.59ᵇ	1.54±0.13ᵇ
	♂	48.37±2.04ᵃ	1.95±0.09ᵃ	26.60±1.05ᵇ	1.02±0.08ᵇ

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

Table 5. Predation rate of *N. cucumeris* adults, fed on eggs and 1st instar larvae of *T. absoluta* at 27°C and 50% R.H.

Predatory stage	Sex	No. individuals. of attacked prey (*T. absoluta*)			
		Eggs		1st instar larvae	
		Total average (mean ± SD)	Daily rate, (mean± SD)	Total average (mean ± SD)	Daily rate, (mean± SD)
Pre-oviposition	♀	10.53±0.48	3.24±0.21	5.68±0.16	1.75±0.08
Oviposition	♀	52.02±2.77ᵃ	3.61±0.09ᵃ	27.19±1.45ᵇ	1.89±0.12ᵇ
Post-oviposition	♀	7.52±0.51	1.88±0.18	5.12±0.14	1.25±0.09
Longevity	♀	70.07±3.69ᵃ	3.23±0.14ᵃ	37.99±2.67ᵇ	1.74±0.16ᵇ
	♂	38.15±2.74ᵃ	1.98±0.15ᵃ	23.88±2.71ᵇ	1.15±0.07ᵇ

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

Table 6. Predation rate of *N.cucumeris* adults, fed on eggs and 1st instar larvae of *T. absoluta* at 32°C and 50% R.H.

Predatory stage	Sex	No. of individuals of attacked prey (*T. absoluta*)			
		Eggs		1st -instar larvae	
		Total average, (mean ± SD)	Daily rate, (mean± SD)	Total average (mean ± SD)	Daily rate, (mean± SD)
Pre-oviposition	♀	6.13±0.12	3.65±0.41	4.28±0.18	2.05±0.12
Oviposition	♀	49.92±3.85ᵃ	4.26±0.43ᵃ	31.06±2.84ᵇ	2.44±0.14ᵇ
Post-oviposition	♀	8.33±0.43	2.11±0.21	4.74±0.15	1.34±0.12
Longevity	♀	64.38±3.94ᵃ	3.71±0.22ᵃ	40.08±2.81ᵇ	2.18±0.10ᵇ
	♂	34.17±2.55ᵃ	2.12±0.18ᵃ	21.37±1.28ᵇ	1.25±0.09ᵇ

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

instar larvae of *T. absoluta* at 22, 27 and 32°C. Therefore, the optimal temperature for predation of *N. cucumeris* was about 32°C. The lowest and the highest values for the mean daily predation rate by females during their post-ovposition period were observed at 22°C (1.52 and 1.08 prey/day) and 32°C (2.11 and 1.84 prey/day), when fed on eggs and 1st instar larvae of *T. absoluta*, respectively.

4. Discussion

The work herein was the first to evaluate the effectiveness of *N. cucumeris*, against eggs and 1st instar larvae of *T. absoluta* as prey. However, many research works have evaluated the potential of *N. cucumeris* as biocontrol agent of various arthropod preys (mites and insects) and food types such as plant pollen. In this work, the phytoseiid mite, *N. cucumeris* developed when fed on *T. urticae* nymphs at the temperatures tested. In an evaluation of the developmental time of *N. cucumeris* at 27°C and 70% R.H. on eggs of three insect species, the shortest life cycle was noted when *N. cucumeris* fed on *A. kuehniella* eggs (Al-Shemmary, 2018). The developmental time of female immatures of *N. cucumeris* preying on eggs of tetranychid mite, *T. urticae* and acarid mite, *Tyrophagus curvipenis* eggs (Li and Zhang, 2016; Li et al.,

2021) was close to the present findings against *T. urticae* nymphs. A longer life cycle (15.42 days) was recorded when this predator was preying on *Sitotroga cerealella* eggs (Al-Shemmary, 2018). Furthermore, this predator was also stated to develop quicker when preying on *T. urticae* of mixed phase, much shorter than on pollen of maize (Obrist et al., 2006). The pre-oviposition periods of *N. cucumeris* were very close to those stated by Al-Azzazy et al. (2018). At 25, 30 and 35°C, the oviposition periods and female longevity of *N. cucumeris* were parallel to the findings reported by Ji et al. (2007), Sarwar et al. (2009) and Al-Shemmary (2018) for *N. cucumeris* fed on of *Aleuroglyphus ovatus*, *T. urticae*, the western flower thrips, *Frankliniella occidentalis* and eggs of three insect species (*Anagasta* (*Ephestia*) *kuehniella*, *Sitotroga cerealella*, and *Spodoptera littoralis*). When *N. cucumeris* was evaluated against *Aculops lycopersici* (Al-Azzazy et al., 2018), female longevity was shorter (19.89 day) than that of *N. cucumeris* fed on eggs and 1st instar larvae of *T. absoluta* (21.66 and 21.74 days). On the other hand, the values obtained were much lower than those reported for *N. cucumeris* when fed with seven different pollens by Ranabhat et al. (2014). In the current study, the total number of eggs and the daily egg production per female at 32°C were higher than at the other two temperatures, this indicated, that 32°C should be a suitable temperature for reproduction by *N. cucumeris*. Similar findings were obtained with *N. cucumeris* in which the total oviposition period was the highest at 35 °C and 55% R. H. (Al-Azzazy et al., 2018). In the present study the highest fertility was obtained in the event of *N. cucumeris* preying on *T. absoluta* eggs (42.92 eggs/ female). This rate was high when compared to *N. cucumeris* preying on *A. kuehniella* eggs (25.06 eggs/ female at 27°C) (Al-Shemmary, 2018), *A. ovatus* (39 eggs/ female at 27°C) (Ji et al., 2007), *T. putrescentiae* (29.4 eggs/ female at 22°C) (Lee et al., 2020). On the other side, the results of Ranabhat et al. (2014) and Al-Azzazy et al. (2018) for this predator when fed on tulip pollen (89.48 eggs/ female at 25°C) and *Aculops lycopersici* (60.44 eggs/ female at 35°C)., These results were differed from those evaluated in the current study, when *N. cucumeris* fed on *T. absoluta* eggs and 1st instar larvae at 32°C. Momen and El-Laithy (2007), Momen et al. (2013) stated that *N. barkeri* preying on eggs of *E. kuehniella* and *T. absoluta* eggs had an oviposition rates of 44.2 eggs/female and 47.39 eggs/ female in agreement with the present findings where *N. cucumeris* reared on *T. absoluta* eggs. The predatory phytoseiid mites needs multiple mating to obtain high reproductive potential (Ji et al., 2007; Jiale et al., 2016). Therefore, the highest fertility in the present study could be due mainly to both multiple mating incidence and the moderate humidity level applied (50%). The current study showed that temperature affects the feeding capacity of *N. cucumeris*. During the pre-oviposition, oviposition and post-oviposition periods of *N. cucumeris* females, the consumption rate increased with an increase of temperature from 22 to 32°C. Therefore, it could be concluded that the optimal temperature for predation of *N. cucumeris* was about 32°C. A slight decline was recorded in the predation rate at 22 ºC. The findings of (Zilahi-Balogh et al., 2007; Al-Azzazy et al., 2018: Al-Azzazy and Alhewairini, 2020), supported the present findings. They confirmed that an increase in temperature leads to a positive effect on predation rate. The predation rate of *N. cucumeris* on both prey types studied showed that, the adult females through their oviposition periods consumed significantly large numbers of preys, which explaineed that, females need to increase consumption to obtain sufficient energy for egg laying potential. This behavior is consistent with other researchers (Metwally et al., 2005 and Al-Azzazy, 2021).

The results of the present study indicated that, the predation rate of *N. cucumeris* reared on *T. absoluta* eggs was different from that of those individuals reared on 1st instar larvae of *T. absoluta*. According to Jiale et al. (2016), the quality of prey can be the reason of differences in their consumption by predators. Also, Jafari and Bazgir (2015) reported that difference in prey sizes could also be an important factor for choosing the number of prey by predatory mites. This indicates that besides the prey quality, smaller size of eggs than 1st instar larvae of *T. absoluta* could be another factor that can account for the larger consumption of this prey by *N. cucumeris*. Several researches have reported that the quality of prey leads to the highest values of reproduction rate (Jiale et al., 2016). The rates of reproduction were more promising for *N. cucumeris* when fed on eggs compared to 1st instar larvae of *T. absoluta*. This is proven by the highest fertility which was (3.66 eggs/female/day) when fed on *T. absoluta* eggs, while it was (1.64 eggs/female/day) on 1st instar larvae of the same *pest* at 32°C. These results show that *T. absoluta* eggs provide *N. cucumeris* with higher reproductive capability than does the 1st instar larvae of *T. absoluta*. Therefore, the authors assumed that by incorporating the predatory mite, *N. cucumeris* into existing biological control strategies for *T. absoluta,* may provide promising results.

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Conflict of interest

The authors declare that they have no conflict of interest.

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