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The availability of rearing *Neoseiulus cucumeris* (Oud.) and *Neoseiulus barkeri* (Hughes) (Acari: Phytoseiidae) on three insect egg species

Koloud A Al-Shemmary

Abstract

The predatory mites, *Neoseiulus cucumeris* (Oud.) and *Neoseiulus barkeri* (Hughes) (Acari: Phytoseiidae), were collected from leaves of the kidney bean (*Phaseolus vulgaris* L.) growing at Hail District, Saudi Arabia, in 2017. Different biological aspects and life table parameters of both predators were evaluated by feeding on three insect egg species, *Anagasta* (*Ephestia*) *kuehniella* (Keller) (Pyralidae), *Sitotroga cerealella* (Oliv.) (Gelechiidae), and *Spodoptera littoralis* (Boisduval) (Noctuidae), as alternative food sources at 27 °C and 70% RH. Predators' developmental times were affected by food type. Duration of life cycle was significantly longer when *N. cucumeris* was provided with *S. cerealella* eggs (16.56 days for male and 15.42 days for female) than the other two kinds of insect eggs. Maximum time of life cycle of *N. barkeri* occurred for male fed on eggs of *S. cerealela* (18.82 days), likewise the minimum time was observed for male fed on eggs of *A. kuehniella* (9.92 days).The fecundity of both phytoseiid mites was the highest (25.06 eggs/♀, with a daily rate of 2.05 eggs/♀/day, for *N. cucumeris* and 23.26 eggs/♀, with a daily rate of 2.04 eggs/♀/day, for *N. barkeri*, respectively) by feeding on eggs of *A. kuehniella*. Fecundity was the lowest (13.37 eggs/♀, with a daily rate of 1.48 eggs /♀/ day and 10.35 eggs/♀, with a daily rate of 0.84 eggs/♀/day for the two predatory mites, respectively) on *S. cerealella* eggs. Food source affected all the life table parameters of both tested predatory mites. It was concluded that two phytoseiid mite species can be maintained successfully on the alternative food, *A. kuehniella* eggs, in lab trials whenever the natural prey types are scarce.

Keywords: Predatory mites, *Neoseiulus cucumeris*, *Neoseiulus barkeri*, Life table parameters, Insect prey eggs

Background

The spread of insecticide strains of stored-product pests and environmental problems connected with chemical control, like the effect of methyl bromide on the ozone layer, has led to intensify the researches for alternative control methods such as biological control (Rees 2003). Predatory mites of the family Phytoseiidae are of economic importance because they are efficient bio-agents that can be used against insect and mite pests in many crops in the open fields and in the greenhouses worldwide (Fouly et al. 2013).

Many phytoseiid species are facultative predators (generalists), not only on spider mites but also on other sources of food such as whiteflies, pollen (Fouly and Hassan 1991-1992; Gnanvossous et al. 2005; and Al-Shammery 2011), and thrips (van Houten et al. 2005; Messelink et al. 2005; and Winner et al. 2008). The two phytoseiid mites *Neoseiulus cucumeris* (Oud.) and *Neoseiulus barkeri* (Hughes) are known to play a natural important role in controlling the spider mites of the family Tetranychidae and Eriophyidae as well as the whiteflies and thrips on vegetables (Fouly et al. 2011).

The Mediterranean flour moth, *Anagasta* (*Ephestia*) *kuehniella* (Keller) (Pyralidae) and *Sitotroga cerealella* (Oliv.) (Gelechiidae), are serious cosmopolitan pests of stored grain products (Rees 2003). Eggs and larvae of *A. kuehniella* are widely utilized as a substitute host/prey to the laboratory-reared parasitoid and predatory species for biological control (Hamasaki and Matsui

Correspondence: kholodaqeel89@gmail.com
Department of Biology, College of Science, Hail University, Hail 1441, Kingdom of Saudi Arabia

2006 and Paust et al. 2008). The cotton leafworm, *Spodoptera littoralis* (Boisduval) (Noctuidae), is one of the most important agricultural insect pests in the Middle East. It attacks many crops including cotton, alfalfa, peanut, potatoes, lettuce, celery, pepper, and tomato (Mohamed 2003).

The present study was conducted to evaluate the potential of two phytoseiid predatory mites, *Neoseiulus cucumeris* and *N. barkeri*, of consuming alternative sources of food such as different insect eggs. The effect of insect eggs on different biological aspects as well as life table parameters of both phytoseiid predators was studied under laboratory conditions.

Materials and methods

Cultures of the phytoseiid predatory mites

Samples from both predatory mites, *N. cucumeris* and *N. barkeri*, were collected from leaves of kidney bean (*Phaseoulus vulgaris* L.), growing at a private farm at Hail District, Saudi Arabia, in 2017. Collected plant leaves were placed in cellophane bags, with small pieces of cotton wool soaked in ether and transferred directly to the laboratory of Department of Biology, College of Science, Hail University, Saudi Arabia, for direct examination, using a stereoscopic binocular. A pure culture from each of *N. cucumeris* and *N. barkeri* was maintained by feeding them on mobile stages of the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), in separate climatic rooms at 27 ± 1 °C and 65 ± 5% RH and photoperiod of 10:14 h (L:D). Predatory mites were reared on detached hibiscus leaf discs, *Hibiscus mutabilis* L. (5 cm in diameter), which were placed underside upon a wet cotton wool layer in plastic trays. The wet cotton wool prevented the mites from escaping and maintained the leaf freshness by adding drops of water when needed. The phytoseiid mite species were identified by Dr. Ahmad H. Fouly, Professor of Acarology at Faculty of Agriculture, Mansoura University, Egypt.

Cultures of *Anagasta* (*Ephestia*) *kuehniella* and *Sitotroga cerealella*

Laboratory colonies from each of *A. kuehniella* and *S. cerealella* were maintained separately in plastic cylinders, filled with 100 g of a standard diet (43.5% wheat flour, 43.5% maize meal, 3.0% yeast, and 10% glycerin). Adults naturally do not feed (Norris and Richards,1934). To establish the colonies, three pairs of moths from each species were introduced into a cylinder to lay eggs and then were deposited onto the standard diet. Two crumpled paper towels (25 × 25 cm) were placed in each cylinder for pupation. Ten cylinders/hosts were used. Eggs were collected from 20 pairs of moths in a plastic container (20 × 16 × 10 cm), lined with two porous plastic sheets (20 × 5 cm) as an ovipositional surface.

Culture of *Spodoptera littoralis*

S. littoralis colony was established by field collections from *P. vulgaris* growing in a private farm in Hail District. The larvae were fed on leaves of castor bean. Fresh clean leaves were supplied daily. Pre-pupae were removed and placed in wooden cages (70 × 90 × 50 cm) with wire gauze sides (2 mm meshes). The floor of these cages was covered by a layer of fine autoclaved coarse sawdust, to be always moist, as relatively high humidity is essential for the formation of the cocoons. Emerging adults were fed on (10% sugar) solution and offered fresh castor bean leaves to serve as an ovipositional site (Adham et al. 2009). Deposited egg batches were transferred daily to the rearing units of the predatory mites.

Experimental technique

For individual rearing, newly deposited eggs of each of *N. barkeri* and *N. cucumeris* were transferred from the culture to leaf discs of hibiscus, 1 in.^{2} each. The newly deposited eggs were collected daily for a week and divided into three groups, each with 50 eggs. The newly hatched larvae were confined singly on a leaf disc and provided with a surplus amount of one of the tested insect eggs for their whole life span. The first and second groups were provided by *S. cerealella* and *A. kuehniella* eggs, while the third one was supplied with *S. littoralis* eggs. Mites were examined daily until maturity. The numbers of immature stages reached maturity, and their sex ratio was recorded. The newly emerged females were copulated as soon as they emerged and kept at the same conditions during their life span. Number of deposited eggs of each newly adult female was recorded daily. The incubation period of each species of the predatory mites was recorded. All treatments were conducted at 27 ± 1 °C and 65 ± 5% RH.

Statistical analysis

Biological data

Developmental time, duration of female reproductive period, and number of deposited eggs of each mite female were analyzed, using one-way ANOVA, followed by means separation, using LSD test and Duncan multiple range test (Costat Software Program 1990).

Life table parameters

Duration of immature stages, mortality rates, sex ratio, and total number of deposited eggs/females (Fecundity) of *N. barkeri* and *N. cucumeris* were estimated daily and used for calculating of life table parameters according to Birch (1948) and Laing (1968) and then by using the Basic Computer Program of Abou-Setta et al. (1986),

Table 1 Duration (in days) of male developmental stages of *Neosiulus cucumeris* fed on eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 70% RH

Developmental stage	Prey species			LSD	*F*	*P*
	A. kuehniella	*S. littoralis*	*S. cerealella*			
Egg	1.92 ± 0.16 a	2.16 ± 0.11 a	1.91 ± 0.15 a	0.40	0.89	0.416
Larva	1.71 ± 0.19 c	2.41 ± 0.15 b	4.33 ± 0.22 a	0.52	49.42	0.000
1st nymph	1.92 ± 0.16 c	3.08 ± 0.15 b	4.91 ± 0.19 a	0.46	79.67	0.000
2nd nymph	2.28 ± 0.12 c	3.58 ± 0.19 b	5.41 ± 0.23 a	0.49	75.66	0.000
Total	5.91 ± 0.26 c	9.07 ± 0.29 b	14.65 ± 0.47 a	0.93	166.52	0.000
Life cycle	7.83 ± 0.33 c	11.23 ± 0.28 b	16.56 ± 0.47 a	0.99	147.21	0.000
Longevity	11.17 ± 0.38 b	11.25 ± 0.41 b	16.91 ± 0.32 a	1.03	74.50	0.000
Life span	19.00 ± 0.45 c	22.48 ± 0.49 b	33.17 ± 0.68 a	1.46	181.59	0.000

Means ± SE. Means in the same row followed by the same letter are not significantly different ($P > 0.05$)

where the intrinsic rate of natural increase r_m was estimated by the equation: $\Sigma e^{-r_m} L_x M_x = 1$, where x is the age in days, l_x the age-specific survival rate (proportion of females alive at age x), and M_x the oviposition rate at age x {(age-specific oviposition) × (proportion of females)}. The net reproductive rate (R_o) was given as $R_o = \Sigma l_x M_x$. The mean generation time (T), in days, was calculated as $T = \Sigma Xl \times Ml / \Sigma XlMl$ and then used as $T = \ln R_o / r_m$. The hatchability and survival rate at the lab conditions of 26 °C and 70% RH were used for estimating l_x. The proportions of females (number of females/total adults) were used for calculating the M_x values.

Results and discussion

Effects of prey type on predator's development period

Data presented in Table 1 indicated that insignificant differences among incubation periods of *N. cucumeris* male when fed on the three preys were found. Total duration of immature stages was significantly longer, when *N. cucumeris* was fed on *S. cerealella* eggs than on the other two egg species. In other words, duration of life cycle was significantly longer when *N. cucumeris* was provided with *S. cerealella* eggs (16.56 days for male and 15.42 days for female) than the other two kinds of insect eggs. Maximum time of life cycle of *N. barkeri* occurred for male fed on eggs of *S. cerealela* (18.82 days), likewise, the minimum time was observed for male fed on eggs of *A. kuehniella* (9.92 days). The longest life cycle (15.42 days) was obtained for *N. cucumeris* females fed on eggs of *S. cerealella*, while the shortest one (9.6 days) was recorded when female of *N. cucumeris* fed on *A. kuehniella* eggs (9.66 days) (Table 2). Therefore, it can be concluded that both *N. cucumeris* and *N. barkeri* were able to feed and complete their developmental periods on eggs of *A. kuehniella*, *S. littoralis*, and *S. cerealella* as alternative food sources. These results are supported by the findings of El-Sawi and Momen (2005) and Momen and El-Sawi (2008). Contradictory, Romeih et al. (2004) who found that *Neoseiulus* (*Amblyseius*) *californicus* (McGregor) failed to feed on *Corcyra cephalonica* eggs and could not complete its life cycle. These results also incorporated with Romeih et al. (2004) and Momen and El-Sawi (2008) who reared *Euseius scutalis* on *S. littoralis* and *S.exigua* Huber and *Agrotis ipsilon* (Hufnagel) eggs as alternative

Table 2 Duration (in days) of male developmental stages of *Neosiulus barkeri* fed on eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 70% RH

Developmental stage	Prey species			LSD	*F*	*P*
	A. kuehniella	*S. littoralis*	*S. cerealella*			
Egg	2.50 ± 0.13 a	2.66 ± 0.14 a	2.41 ± 0.15 a	0.39	0.75	0.478
Larva	2.14 ± 0.14 c	3.50 ± 0.15 b	4.50 ± 0.15 a	0.40	65.74	0.000
1st nymph	2.57 ± 0.13 c	4.18 ± 0.19 b	5.25 ± 0.22 a	0.49	56.33	0.000
2nd nymph	2.71 ± 0.12 c	4.41 ± 0.15 b	6.66 ± 0.25 a	0.49	122.47	0.000
Total	7.42 ± 0.20 c	12.09 ± 0.35 b	16.41 ± 0.44 a	0.90	189.48	0.000
Life cycle	9.92 ± 0.22 c	14.75 ± 0.14 b	18.82 ± 0.54 a	1.07	131.28	0.000
Longevity	12.42 ± 0.25 b	12.83 ± 0.27 b	17.91 ± 0.29 a	0.73	126.72	0.000
Life span	22.14 ± 0.32 c	27.58 ± 0.56 b	36.73 ± 0.68 a	1.42	106.73	0.000

Means in the same row followed by the same letter are not significantly different ($P > 0.05$)

Table 3 Duration (in days) of *Neosiulus cucumeris* females fed on eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 70% RH

Developmental stage	Prey species			LSD	*F*	*P*
	A. kuehniella	*S. littoralis*	*S. cerealella*			
Egg	2.13 ± 0.12 a	2.21 ± 0.11 a	2.56 ± 0.12 a	0.33	30.38	0.029
Larva	2.13 ± 0.08 c	2.78 ± 0.18 b	3.81 ± 0.15 a	0.40	32.19	0.000
1st nymph	2.60 ± 0.12 c	3.42 ± 0.13 b	4.22 ± 0.19 a	0.43	22.55	0.000
2nd nymph	2.80 ± 0.10 c	3.42 ± 0.13 b	4.83 ± 0.20 a	0.43	47.02	0.000
Total	7.53 ± 0.22 c	9.62 ± 0.26 b	12.86 ± 0.38 a	0.84	75.34	0.000
Life cycle	9.66 ± 0.24 c	11.83 ± 0.28 b	15.42 ± 0.44 a	0.94	70.61	0.000
Pre-oviposition	3.13 ± 0.18 c	5.27 ± 0.27 b	6.68 ± 0.12 a	0.61	65.29	0.000
Oviposition	12.26 ± 0.31 a	9.78 ± 0.32 b	8.81 ± 0.23 c	0.81	35.31	0.000
Post-oviposition	3.61 ± 0.18 c	6.21 ± 0.21 b	7.43 ± 0.26 a	0.62	73.03	0.000
Longevity	19.00 ± 0.18 c	21.71 ± 0.55 b	22.92 ± 0.37 a	1.22	23.40	0.000
Life span	28.66 ± 0.15 c	33.57 ± 0.75 b	38.34 ± 0.39 a	1.53	78.36	0.000

Means in the same row followed by the same letter are not significantly different ($P > 0.05$)

food sources and found that the total developmental time of the immature stages was the shortest on eggs of *S. littoralis.* Also, Fouly et al. (2013) noticed that *Bemisia tabaci* gave the longest life cycle of the predatory mite *E. scutalis*, followed by the immature stages of *T. urticae*, while plant pollen gave the shortest life cycle. Escudero and Ferragut (2004) found that developmental time was significantly longer when *N. californicus* and *Phytoseiulus persimilis* Athias–Henriot were fed on *Tetranychus evansi* Baker than *T. urticae*, *T. turkestani* Ugarov and Nikolski, and *T. ludeni* Zacher.

Longevity of *N. barkeri* males was likewise affected by the type of prey. It was significantly longer when the predator was fed on *S. cerealella* (17.91 days) than the other prey species. However, longevity did not show a significant difference, when the predator was supplied by *A. kuehniella* (12.42 days) or *S. littoralis* eggs (12.83 days) (Table 2).

There was a significant difference between the duration of developmental stages, where female life cycle of *N. cucumeris* was the longest (15.42 days), when it was fed on *S. cerealella*, and the shortest (9.6 days), when females were fed on *A. kuehniella* eggs (Table 3). The adult females of *N. cucumeris* started laying eggs after (3.13, 5.27, and 6.68 days), when reared on eggs of *A. kuehniella*, *S. littoralis*, and *S. cerealella*, respectively. Furthermore, ovipositional period was significantly longer, when the females of *N. cucumeris* were fed on *A. kuehniella* eggs than on the other two species. Female longevity was significantly longer (22.92 days), when

Table 4 Duration (in days) of *Neosiulus barkeri* females fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 70% RH

Developmental stage	Prey species			LSD	*F*	*P*
	A. kuehniella	*S. littoralis*	*S. cerealella*			
Egg	2.33 ± 0.12 a	2.46 ± 0.12 a	2.64 ± 0.12 a	0.34	1.38	0.260
Larva	1.60 ± 0.12 c	2.73 ± 0.11 b	3.57 ± 0.13 a	0.34	16.35	0.002
1st nymph	3.00 ± 0.16 c	3.46 ± 0.12 b	4.50 ± 0.13 a	0.39	26.25	0.000
2nd nymph	3.40 ± 0.15 c	3.93 ± 0.14 b	5.50 ± 0.17 a	0.43	43.74	0.000
Total	8.00 ± 0.28 c	10.12 ± 0.15 b	13.57 ± 0.28 a	0.66	89.03	0.000
Life cycle	10.33 ± 0.24 c	12.58 ± 0.26 b	16.21 ± 0.34 a	0.77	123.37	0.000
Pre-oviposition	3.53 ± 0.12 c	5.33 ± 0.15 b	6.07 ± 0.23 a	0.48	17.59	0.000
Oviposition	11.46 ± 0.26 b	10.46 ± 0.20 c	12.14 ± 0.20 a	0.62	12.79	0.000
Post-oviposition	4.20 ± 0.16 c	6.06 ± 0.30 b	7.71 ± 0.26 a	0.68	45.76	0.000
Longevity	19.19 ± 0.29 c	21.85 ± 0.35 b	25.92 ± 0.39 a	0.94	73.05	0.785
Life span	29.52 ± 0.40 c	34.43 ± 0.25 b	42.13 ± 0.67 a	1.26	192.87	0.000

Means in the same row followed by the same letter are not significantly different ($P > 0.05$)

Table 5 Total and daily rate of deposited eggs of *Neoseiulus cucumeris* and *N. barkeri* fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 70% RH

Fecundity	Predatory mite	Prey species			LSD	*F*	*P*
		A. kuehniella	*S. littoralis*	*S. cerealella*			
Total deposited eggs	*Neosiulus cucumeris*	25.06 ± 0.39 Aa	15.57 ± 0.33 Ab	13.37 ± 0.31 Ac	0.96	300.19	0.000
	N. barkeri	23.26 ± 0.24 Ba	16.40 ± 0.32 Ab	10.35 ± 0.54 Bc	1.03	270.53	0.000
	LSD	0.94	0.93	1.24	….	….	….
	F	14.21	2.98	26.27	…..	…..	….
	P	0.000	0.095	0.000	…..	…..	….
Daily rate of eggs	*Neosiulus cucumeris*	2.05 ± 0.05 Aa	1.67 ± 0.11 Ab	1.48 ± 0.04 Ab	0.21	15.20	0.000
	N. barkeri	2.04 ± 0.04 Aa	1.57 ± 0.08 Ab	0.84 ± 0.17 Bc	0.13	152.01	0.000
	LSD	0.15	0.23	0.135	…	…	…
	F	0.027	0.74	90.95	…	…	…
	P	0.869	0.396	0.000	…	…	…

Means have small letters that represent the differences between prey species for the same predatory mite. Means in the same row followed by the same letter are not significantly different ($P > 0.05$)

female was fed on eggs of *S. cerealella* than the other tested insect eggs.

The total duration of life cycle of *N. barkeri* female was affected by the type of food, where it averaged 16.21, 12.58, and 10.33 days, when the predator was fed on eggs of *S. cerealella*, *S. littoralis*, and *A. kuehniella*, respectively (Table 4). Adult longevity was also influenced by the type of food as it was significantly longer, when *N. barkeri* female was fed on *S. cerealella* (25.92 days) followed by *S. littoralis* (21.85 days) and *A. kuehniella* (19.19 days), respectively. The longest ovipositional period (12.14 days) was recorded, when the mite female was fed on *S. cerealella* eggs, while the shortest (10.46 days) was recorded for the female that fed on *S. littoralis.*

The data also indicated that the fecundity (no. deposited eggs/female) of *N. cucumeris* and *N. barkeri* females was highest on eggs of *A. kuehniella* (25.06 eggs/female, with a daily rate of 2.05 eggs, and 23.26 eggs/female, with a daily rate of 2.04 eggs, respectively) (Table 5). The lowest fecundity was obtained, when the predatory mites were provided by *S. cerealella* eggs. Similar results were obtained by Momen and El-Sawi (2008) who mentioned that the fecundity of *E. scutalis* was highest on eggs of *S. littoralis* and *S. exigua* and the lowest was on *A. ipsilon* eggs. Results in Table 5 also showed that there was a significant difference between the total deposited eggs of the two predatory mites by feeding on *A. kuehniella* and *S. cerealella*. There was insignificant difference between the total deposited eggs of the two predatory mites, when they were provided by the eggs of *S. littoralis*. The daily rate of deposited eggs did not show a significant difference between the two predatory mite species, when they fed on eggs of *A. kuehniella* and *S. littoralis*. Contradictory,

Table 6 Life table parameters of *Neosiulus cucumeris* and *N. barkeri* fed on three different kinds of insect eggs and incubated at 27 °C and 70% RH

Life table parameters	*Neoeiulus barkeri*			*Neoseiulus cucumeris*		
	A. kuehniella	*S. littoralis*	*S. cerealella*	*A. kuehniella*	*S. littoralis*	*S. cerealella*
T	25.80	29.69	35.37	17.42	20.37	23.45
DT	14.58	18.66	23.73	11.17	12.72	17.07
Ro	11.84	9.36	8.09	9.02	9.47	6.87
r_m	0.096	0.075	0.059	0.126	0.110	0.082
e^{rm}	1.100	1.078	1.061	1.134	1.116	1.085
GRR	20.04	19.20	23.69	11.52	16.25	12.45
Sex ratio	0.56	0.52	0.52	0.58	0.56	0.52
Survival %	90	84	80	88	86	82
No. mites	16	16	15	16	15	17

Gross reproductive rate (GRR) is the mean total number of eggs produced by a female over its life time, (GRR = ΣMx) measured in female eggs/female/generation

N. cucumeris laid more eggs than *N. barkeri* when both were supplied by *S. cerealella* eggs.

Life table parameters of *N. cucumeris* and *N. barkeri*

Obtained results showed that the survival percentages of the two phytoseiid mites, *N. cucumeris* and *N. barkerii*, reached their highest level of survival (90% and 88%), when both predators were fed on eggs of *A. kuehniella*, respectively. Feeding on eggs of *S. cerealella* caused the lowest rate of survival where it was 80% and 82% for *N. cucumeris* and *N. barkeri*, respectively (Table 6). Figures 1 and 2 illustrated that Lx values gradually decreased during the ovipositional period. Also, it was found that the type of food had insignificant effect on the sex ratio, where *A. kuehniella*, *S. littoralis*, and *S. cerealella* caused a female proportion of *N. cucumeris* of 0.58, 0.56, and 0.52%, while these values of *N. barkeri* were 0.56, 0.52, and 0.52%, respectively (Table 6).

The mean generation time (*T*) was affected by food source; therefore, data showed that the eggs of *S. cerealella* prolonged the *T* period of *N. cucumeris* (23.45 days), while *A. kuehniella* caused the shortest one (17.42 days). Correspondent values were 35.37 and 25.80 days for *N. barkeri* (Table 6). Therefore, it can be concluded that *A. kuehniella* and *S. littoralis* were more suitable as food sources for both phytoseiid mites, where they shortened the mean generation time.

Feeding on insect eggs generally caused low net reproductive rates R_o of both tested predatory mites, where eggs of *A. kuehniella* and *S. littoralis* were more favorable diets, and resulted in 9.027 and 9.470, and 11.840 and 9.360 females/female of *N. cucumeris* and *N. barkeri*, respectively. Feeding on *S. cerealella* eggs caused the lowest R_o value (6.87 and 8.09 females/female) for both predatory mites, respectively (Table 6). Although these values were the highest, they are still lower than the R_o values when both phytoseiid mites were fed on spider mites or plant pollen. Similar results were obtained by Momen and El-Sawi (2008) who mentioned that R_o of *E. scutalis* was highest on eggs of *S. littoralis* and *S. exigua*, and the lowest on *A. ipsilon* eggs. Concerning the intrinsic rate of natural increase (r_m), which is the rate of increase of an insect or mite species under specific physical conditions, in unlimited environment, the effects of increasing density do not need to be considered (Birch 1948). The present data showed that r_m is 0.126, 0.110, and 0.085 for *N. cucumeris*, when fed on *A. kuehniella*, *S. littoralis*, and *S. cerealella*, respectively. Correspondent values were 0.095, 0.075, and 0.059 females, when *N. barkeri* was provided by the aforementioned preys, respectively. Figures 3 and 4 showed the age specific fecundity (Mx) where most of the deposited eggs of both *N. barkeri* and *N. cucumeris* were laid within the first two weeks of their life.

The expected number of new females, which would add daily to the population as represented by the finite rate of increase e^{rm} (λ), showed similar results and followed the trend observed with r_m values. Again, the finite rate of

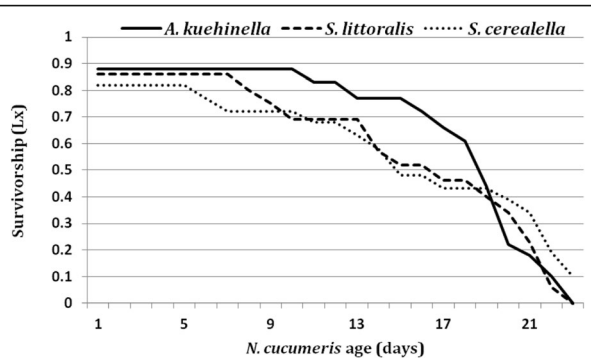

Fig. 2 Age-specific survivorship of *Neoseiulus cucumeris* fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 65% RH

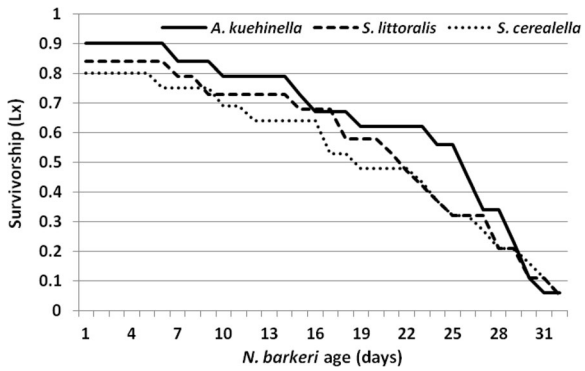

Fig. 1 Age-specific survivorship of *Neoseiulus barkeri* fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 65% RH

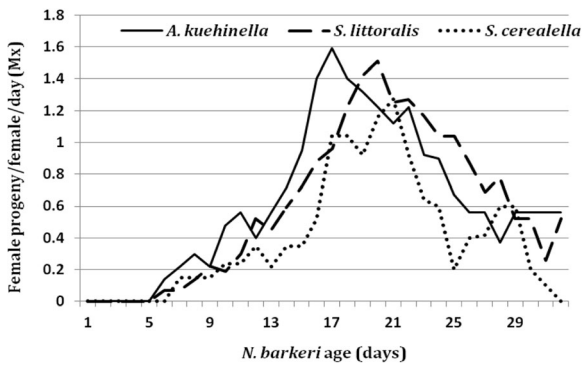

Fig. 3 Age-specific fecundity of *Neoseiulus barkeri* fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 65% RH

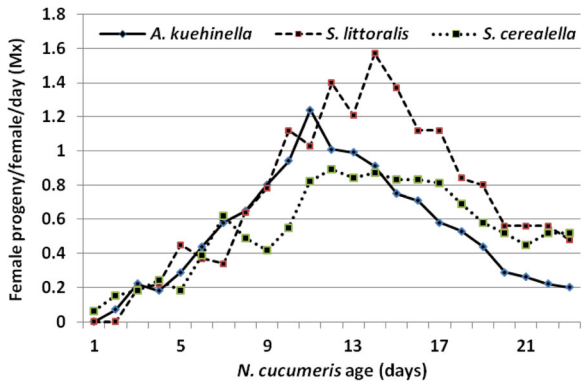

Fig. 4 Age-specific fecundity of *Neoseiulus cucumeris* fed eggs of *Anagasta kuehniella*, *Spodoptera littoralis*, and *Sitotroga cerealella* and incubated at 27 °C and 65% RH

increase was obviously affected by the type of food, where e^{rm} values were at their highest rates, when *N. cucumeris* and *N. barkeri* were fed on eggs of *A. kuehniella* (1.100 and 1.134) and decreased on *S. littoralis* to reach the lowest rate, on the eggs of *S. cerealella* (Table 6).

Several authors studied the capability of generalist phytoseiid mites to feed not only on spider mites but also on insects and pollen (Messelink et al. 2005; Winner et al. 2008; Al-Shammery 2011 and Fouly et al. 2011).

Conclusion

In conclusion, the results showed that the two phytoseiid mites, *N. cucumeris* and *N. barkeri*, which are considered promising biological control agents of some mites and insect pests, could be reared successfully under laboratory conditions by feeding them on different insect eggs as an alternative food source, especially when their natural preys are scarce.

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Authors' contributions

I declare and confirm that I have designed the idea of the present experiments and carried out the trials in the laboratory by rearing insect preys and predatory mites as well as analyzed the data. The author read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The author declares that she has no competing interests.

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References

Abou-Setta MM, Sorrell RW, Childers CC (1986) Life 48: a BASIC computer program to calculate life table parameters for an insect or mite species. Fla Entomol 69:690–697

Adham FK, Rashad EM, Shoukry IF, Nasr EE (2009) Host plants shifting affect the biology and biochemistry of *Spodoptera littoralis* (Boisd.) (Lepidoptera: Noctuidae). J Biol Sci 2(1):63–71

Al-Shammery KA (2011) Plant pollen as an alternative food source for rearing *Euseius scutalis* (Acari: Phytoseiidae). J Entomol 8(4):365–374

Birch LC (1948) The intrinsic rate of natural increase of an insect population. J Anim Ecol 17:15–26

Costat Software Program (1990) Microcomputer program analysis, version 4.20, CoHort Software, Berkley, CA, USA. https://doi.org/10.1016/j.biocontrol.2005.05.013

El-Sawi SA, Momen FM (2005) Biology of some phytoseiid predators (Acari: Phytoseiidae) on eggs of *Phothorimaea operculella* and *Spodoptera littoralis* (Lepidoptera: Gelechiidae and Noctuidae). Acarologia 46:23–30

Escudero LA, Ferragut F (2004) Life-history of predatory mites *Neosiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae) on four spider mite species as prey with special reference to *Tetranychus evansi* (Acari: Tetranychidae). Biol Control 32:378–384

Fouly AH, Al-Daghairi MA, Abdel Baky NF (2011) Effect of crowding and food level on the biology of *Typhlodromips swirskii* (Acari: Gamasida: Phytoseiidae) fed on whitefly *Bemisia tabaci* (Homoptera: Aleyrodidae). J Entomol 8(1):52–62

Fouly AH, Hassan MF (1991-1992) Effect of crowding and food level on the predaceous phytoseiid mite *Amblyseius gossipi* (El-Badry) fed on white fly *Bemisia tabaci* (Gennadius). Bull Zool Soc Egypt 40:141–146

Fouly AH, Nassar OA, Osman MA (2013) Biology and life tables of *Esieus scutalis* (A.-H.) reared on different kinds of food. J Entomol 10(4):199–206

Gnanvossous D, Yaninek JS, Toko M (2005) Comparative life history traits of three neotropical phytoseiid mites maintained on plant-based diets. Biol Control 35:32–39. https://doi.org/10.1016/j.biocontrol.2005.05.013

Hamasaki K, Matsui M (2006) Development and reproduction of an aphidophagous coccinellid, *Propylea japonica* (Thunberg) (Coleoptera: Coccinellidae), reared on alternative diet, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) eggs. Appl Entomol Zool 41:233–237

Laing JE (1968) Life history and life table of *Phytoseiulus persimilis* A.-H. Acarologia 10:578–588

Messelink G, van Steenpaal S, van Wensveen W (2005) *Typhlodromips swirskii* (Athias-Henriot) (Acari: Phytoseiidae): a new predator for thrips control in greenhouse cucumber. IOBC/wprs Bulletin 28(1):183–186

Mohamed HM (2003) Comparative studies on the host plant and growth development and fecundity of the cotton leaf worm, *Spodoptera littoralis* (Boisd.) (Noctuidae, Lepidoptera). J Egypt Ger Soc Zool 42E:183–197

Momen FM, El-Sawi SA (2008) Life-history trails of the predacious mite *Euseius scutalis* (Acari: Phytoseiidae) on eggs of three insects (Lepidoptera: Noctuidae) Acta Phytopathological et entoml. Hungarica 43:163–170

Norris MJ, Richards OW (1934) Contributions towards the study of insect fertility - III. Adult nutrition, fecundity, and longevity in the genus *Ephestia* (Lepidoptera, Phycitidae). Proc Zool Soc London 4(2):333–360

Paust A, Reichmuth C, Buttner C, Prozell S, Adler C, Scholler M (2008) Spatial effects on competition between the larval parasitoid *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae) and *Venturia canescens* (Gravenhorst) (Hymenoptera: Ichneumonidae) parasitizing the Mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). Mitteilungen Der Deutschen Gesellschaft fur Allgemeine Und Angewandte Entomologie 16: 291–294

Rees D (2003) Insects of stored products. CSIRO Publishing, London, p 181

Romeih, A.H.M.; El-Saidy, E.M.A. and El Arnaouty, S.A. (2004). Suitability of two lepidopteran eggs as alternative prey for rearing some predatory mites. 1st Arab Conference of app. Bio. Pest control, Cairo, Egypt, 5–7 April

van Houten YM, Ostilie ML, Hoogerbrugge H, Bolckmans K (2005) Biological control of western flower thrips on sweet pepper using the predatory mites *Amblyseius cucumerism Iphiseius degenerans*, *A andersoni* and *A swirskii*. IOBC/WPRS Bulletin 28(1):283–286

Winner D, Hoffmann D, Schausberger P (2008) Prey suitability of western flower thrips, *Frankliniella occidntalis* and onion thrips, *Thrips tabaci* for predatory mite, *Amblyseius swirskii*. Biocontrol Sci Tech 18(6):541–550