

The Lesser Wax Moth *Achroia grisella* (Lepidoptera: Pyralidae): A New Diet for Rearing Three Predatory Mites of the Family Phytoseiidae

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The predatory mites *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* are native phytoseiid mites in Egypt. The biology of these predators was studied using *Achroia grisella* eggs as food source. Tested phytoseiids were succeeded to develop to adulthood and sustain oviposition on *A. grisella* eggs. For *Cydnoseius negevi*, the development was slower and fecundity was lower than for *Neoseiulus barkeri* and *Amblyseius swirskii*. The predation rate during immature stages of *Cydnoseius negevi* was higher than those of *Neoseiulus barkeri* and *Amblyseius swirskii*. During oviposition period, *N. barkeri* consumed more eggs than other phytoseiids did. The higher mean fecundity was recorded for *Neoseiulus barkeri* and *Amblyseius swirskii* as opposed to the lower mean for *Cydnoseius negevi*. When *Amblyseius swirskii* fed on *Achroia grisella* eggs, the oviposition period, female longevity and mean generation time were longer than for *Cydnoseius negevi* and *Neoseiulus barkeri*. Feeding on eggs of *Achroia grisella* resulted in the lowest mean fecundity, net reproductive rate, intrinsic rate of natural increase, finite rate of increase and gross reproductive rate for *Cydnoseius negevi*. The sex ratio of all predators' progeny was in female-biased. Consequently, the moth egg was alternative food for *Neoseiulus barkeri* and *Amblyseius swirskii*, while it considers as survival prey for *Cydnoseius negevi*.

Keywords: Generalist predators, Phytoseiidae, *Achroia grisella*, biological control, alternative food.

One of the most valuable products of honey bees is the wax. It is used in the pharmacological industry, dentistry and cosmetics. Pollen and honey are very important nutrients mining from wax and is therefore attacked by various pests (Ebadi, 1975). The most economical and serious pests of wax are *Galleria mellonella* Linnaeus and *Achroia grisella* Fabricius (both Lepidoptera: Pyralidae) (Chang and Hsieh, 1992). Honeybee pests are known to cause significant losses, and to transmit viral pathogens for which therapies remain absent and continue to be difficult to eliminate (McMenamin and Genersch, 2015). In an effort to allow the production of predators at low cost, factitious items have been evaluated, i.e. alternative food sources that they would not normally found in their natural habitat. In addition, such different items of food can be useful as food supplements to support predator populations after release in the crop (Wade et al., 2008). Providing easily produced frozen, live, lyophilized insects and mites as primary food sources (fac-

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titious food) instead of natural prey that support the development and reproduction of predators may make the cost-effective rearing system economic (Zhang, 2003). Also, alternative/adequate foods which are easily offered and cheaper than the natural prey may give an increase to ease the rearing costs of natural enemies (Riahi et al., 2017a).

For example astigmatid mites and eggs of many lepidopterans have been considered useful for mass rearing predatory mites (Huang et al., 2013). This usually renders the rearing process less expensive than those using phytophagous mites as food, due to reduced requirements for space, labor and maintenance costs (Gerson et al., 2003).

The predatory mites *Neoseiulus barkeri* (Hughes), *Amblyseius swirskii* Athias-Henriot and *Cydnoseius negevi* (Swirski and Amitai) (all Acari: Phytoseiidae) are classified as members of type III generalist predators (McMurtry et al., 2013), able to develop on a wide range of natural foods like: *Tetranychus urticae* Koch (Acari: Tetranychidae), *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), *Aculops lycopersici* (Masse) (Acari: Eriophyidae) and pollen grains (Hansen, 1988; Abou-Awad et al., 1989; Momen, 1995; Momen and Abdel-Khalek, 2008; Arthurs et al., 2009) and factitious prey included *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), *Aleuroglyphus ovatus* Toupeau (Acari: Acaridae), decapsulated dry cysts of the brine shrimp *Artemia franciscana* Kellogg (Anostraca: Artemiidae), *Carpoglyphus lactis* (L.) (Acari: Carpo-glyphidae) (El-Sawi and Momen, 2005; Momen and El-Laithy, 2007; Xia et al., 2012; Nguyen et al., 2014; Ji et al., 2015).

One of the main reasons for the choice of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* is that able to target more one important prey at the same time ex: *Neoseiulus barkeri* (against thrips and spider mites), *Amblyseius swirskii* (against whiteflies, thrips, mites), *Cydnoseius negevi* (against whitefly and thrips) (van Lenteren, 2012; Negm et al., 2014). The second reason is that tested phytoseiids here are generalist commercialized predation capacity that are presently being used on worldwide scale as an augmentative biological control in many of vegetable greenhouses and fruit orchards (McMurtry et al., 2013; Buitenhuis et al., 2015).

The objective of this report was to test the acceptability of a new diet, *Achroia grisella* eggs for rearing *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi*. Our studies includes the developmental periods, predation rates, all physiological parameters, reproductive performance and fertility life table of tested phytoseiid mites fed on eggs of *Achroia grisella*.

To our knowledge present study is the first showing the potential of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* to feed and reproduce on *Achroia grisella* eggs.

Materials and Methods

Phytoseiid mites

The native phytoseiid mite, *Cydnoseius negevi* was collected from a mango orchard in Tanta Province, on March 11, 2016. *Amblyseius swirskii* and *Neoseiulus barkeri* were collected from eggplant fields in Faywam Province, on May 25, 2017. *Cydnoseius negevi*

was reared on pollen grains of castor bean *Ricinus communis* L. (Euphorbiaceae), while *Neoseiulus barkeri* and *Amblyseius swirskii* were reared on *Tetranychus urticae* supplied as prey. All cultures of predatory mites were maintained separately on excised raspberry leaves spread on water-soaked cotton in Petri dishes at $30 \text{ }^{\circ}\text{C} \pm 1$, $70 \pm 5\%$ RH and a 18:6 h (L:D) photoperiod at NRC, Egypt. Drops of water were added to cotton wool when necessary to prevent mites from escaping and to maintain leaf freshness. Raspberry leaves were replaced by fresh ones every 2 weeks.

Rearing of *Achroia grisella*

The lesser wax moth, *Achroia grisella* was reared on an artificial diet according to Sawaf (1962) with some modification. The survival rate of *Achroia grisella* on the new artificial diet used presently was 95%, respectively.

Females and males of the moth were collected from infested honey hives, and then released in plastic cups (150 ml) for mating. A sheet from toilet tissue was hanged in the plastic cups for females to lay their eggs. Female moths oviposited between layers of tissues and to isolate it, one drop of water was added on eggs patch to facilitate tissue layer to be opened without any damage to the sticky eggs. The collected eggs were placed on an artificial diet and incubated at $27 \pm 1 \text{ }^{\circ}\text{C}$ and $70 \pm 5\%$ RH. The hatched larvae were released to feed on artificial diet till pupation. Table 1 shows the main component of an artificial diet used for rearing *Achroia grisella* in the laboratory.

Table 1

Main component of an artificial diet used for rearing *Achroia grisella* at $27 \pm 1 \text{ }^{\circ}\text{C}$ and RH of $70 \pm 5\%$

Quantity	Components
440 gm	Wheat flour
40 gm	Corn flour
240 gm	Wheat bran
120 gm	Milk Powder
10 gm	Yeast
100 ml	Honey
200 ml	Glycerin

Life histories and predation of tested phytoseiid mite species

A single egg of each species of predatory mite was introduced into each rearing leaf disc. Arenas (3×3 cm) of excised raspberry leaves, placed on water saturated cotton in plastic Petri dishes, were used to confine the predators. The development of predators was observed twice daily, and the stage of development was recorded at each observation. Since all predatory larvae develop to protonymphs without feeding, prey eggs were provided after the molt to the protonymphal stage. Insect eggs were transferred carefully to the leaf disks with a fine paintbrush. To determine the prey consumption by different stages of tested predatory mites, 8–10 *Achroia grisella* eggs were added daily to each leaf disc for all predators. After every 24 h, the number of prey consumed was replaced daily by other fresh eggs to maintain an ample food supply.

A newly emerged female of each predatory species from the development experiment was mated with an unmated male for one day in the rearing discs. The male was removed at the following day. Five days later, a new male of each species was introduced to each arena for repeated mating if necessary. All physiological periods and oviposition of the predatory females were observed daily until death. After being counted daily, the eggs of each female were transferred to a separated arena where they were reared on *Achroia grisella* eggs to adulthood for sex determination. Prey eggs consumed (completely or partially deflated, respectively), were recorded daily in each experiment until the predatory females died. Every 3 / 4 days the predators were transferred to new discs. All experiments were maintained in rearing chambers under at 30 ± 1 °C and $70 \pm 5\%$ RH.

Age-stage, two-sex life table

Developmental time of all individuals, including male and female and female daily fecundity were analyzed according to the age-stage, two-sex life table theory (Chi and Liu, 1985) and the method described by Chi (1988).

The age-stage specific survival rate (s_{xj}) (where x = age in days and j = stage); the age-stage specific fecundity (f_{xj}) (daily number of eggs produced per female on age x); the age-specific survival rate (l_x); the age-specific fecundity (m_x) (daily number of eggs produced per individual, i.e. this number is divided by all individuals (males and females) of age x) and the population growth parameters (the intrinsic rate of increase (r_m); the finite rate of increase (λ) that $\lambda = e^r$; the gross reproductive rate (GRR); the net reproductive rate (R0) and the mean generation time (T)) are calculated.

The age age-specific survival rate includes both male and female, and is calculated according to Chi and Liu (1985) as:

$$l_x = \sum_{j=1}^k s_{xj}$$

and

$$m_x = \frac{\sum_{j=1}^k s_{xj} f_{xj}}{\sum_{j=1}^k s_{xj}}$$

Where k is the number of stages.

The intrinsic rate of increase is estimated by using iterative bisection method from:

$$\sum_{x=0}^w e^{-r(x+1)} l_x m_x = 1$$

With age indexed from 0 to ω (maximum age).

The mean generation time is calculated as $T = \ln R_0 / r$. The R_0 is estimated by using:

$$R_0 = \sum_{x=0}^w \sum_{j=1}^k s_{xj} f_{xj}$$

The GRR is calculated as $GRR = \sum m_x$.

Data analysis and population parameters (r_m , λ , GRR, R0 and T) were calculated by using the TWOSEX-MSChart programme (Chi, 2017). The means and standard errors of the population parameters were estimated by using the Bootstrap procedure with 100,000 re-sampling and the life table parameters of tested predatory phytoseiid mites on eggs of *Achroia grisella* were compared by using a paired bootstrap test (Huang and Chi, 2013).

Female age-specific life table

In the female life table, the number of female progeny, survival rate of immature and female adult stages, daily fecundity and sex ratio were used for the estimation of different life table parameters. The estimated parameters were the age-specific survival rate (l_x), age-specific fecundity (m_x), r_m , λ , GRR, R0, T.

The life table constructions were adopted from Birch (1948).

Statistical analysis

The mean duration of each immature and all physiological stages, longevity, predation rate and fecundity of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* on *Achroia grisella* eggs were submitted to analyses of variance using one-way ANOVA and means compared by Tukey ($P=0.01$ level) using SPSS computer program. Data were fitted with the assumption of normality, not transformed, and differences were compared for all tested predators on *Achroia grisella* eggs.

Results

Influence of Achroia grisella eggs on life histories and predation of Neoseiulus barkeri, Amblyseius swirskii and Cydnoseius negevi

The developmental times of immature stages and adult longevities periods of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnoseius negevi* fed on *Achroia grisella* eggs are demonstrated in Table 2. Pre-adult individuals of predatory species could develop to adult with *Achroia grisella* eggs. The durations of egg and larval stages of all tested predators were similar.

The duration of protonymphal stage of *Cydnoseius negevi* was significantly longer than that of *Neoseiulus barkeri* and *Amblyseius swirskii*. The significantly shortest developmental duration was observed in *Neoseiulus barkeri* (Table 2). Insignificant differences were observed in the duration of deutonymphal stage for *Amblyseius swirskii* and *Cydnoseius negevi* and also between *Neoseiulus barkeri* and *C. negevi*. The results showed that all tested predators larvae did not feed on insect eggs. The consumption rates of *Cydnoseius negevi*, *Amblyseius swirskii* and *Neoseiulus barkeri* females are summarized in Table 3. Protonymphs and deutonymphs of *Cydnoseius negevi* were consumed significantly more amount of *Achroia grisella* eggs than those of *Neoseiulus barkeri* and *Amblyseius swirskii* did. Females of *Amblyseius swirskii* had significantly longer

Table 2

Developmental periods (mean \pm SE in days) of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* females fed on *Achroia grisella* eggs at 30 ± 1 °C and $70 \pm 5\%$ R.H.

Developmental stages	Predatory phytoseiid mites			Calculated F value
	<i>Neoseiulus barkeri</i> (30) ^z	<i>Amblyseius swirskii</i> (30)	<i>Cydnoseius negevi</i> (30)	
Egg	3.00 \pm 0.00	3.00 \pm 0.00	3.00 \pm 0.00	–
Larva	1.00 \pm 0.00	1.00 \pm 0.00	1.00 \pm 0.00	–
Protonymph	2.43 \pm 0.08c ^y	3.33 \pm 0.09b	4.60 \pm 0.09a	151.057
Deutonymph	1.74 \pm 0.07b	2.17 \pm 0.07a	1.93 \pm 0.05ab	8.298
Lifecycle	8.20 \pm 0.07c	9.50 \pm 0.10b	10.53 \pm 0.09a	163.919
Pre-oviposition	1.00 \pm 0.00b	2.63 \pm 0.19a	1.33 \pm 0.09b	51.655
Oviposition	9.57 \pm 0.12b	10.73 \pm 0.27a	2.83 \pm 0.14c	508.162
Post-oviposition	1.40 \pm 0.09b	0.37 \pm 0.10c	3.20 \pm 0.17a	124.887
Adult longevity	11.97 \pm 0.16b	13.73 \pm 0.35a	7.37 \pm 0.10c	207.620
Life span	20.17 \pm 0.18b	23.23 \pm 0.35a	17.90 \pm 0.15c	118.170

^y Within a row, means followed by a common letter do not differ significantly (Tukey HSD, $\alpha=0.01$, $df=2,87$).

^z Number in brackets refers to number of replicates.

pre-oviposition and oviposition periods than that of *Cydnoseius negevi* and *Neoseiulus barkeri* ($F_{2,87}=51.655$, 508.162 , $P=0.0001$). Individuals of *Cydnoseius negevi* fed on *Achroia grisella* eggs had the shortest oviposition ($F_{2,87}=508.162$, $P=0.0001$) and longest post-oviposition periods ($F_{2,87}=124.887$, $P=0.0001$) among *Neoseiulus barkeri* and *Amblyseius swirskii*. Mean oviposition period, adult longevity and life span were statistically shorter in *Cydnoseius negevi* than for *Amblyseius swirskii* and *Neoseiulus barkeri* (oviposition period: $F_{2,87}=508.162$; adult longevity: $F_{2,87}=207.602$; life span: $F_{2,87}=118.175$, $P=0.0001$). The total predation rate increased from pre-oviposition to oviposition periods and reduced in the post-oviposition phase of *Neoseiulus barkeri* and *Amblyseius swirskii*. During female longevity, *Neoseiulus barkeri* and *Amblyseius swirskii* were consumed similar amount of *Achroia grisella* eggs and higher than those of *Cydnoseius negevi*. Among the predators, the total and daily consumption rate was significantly higher during the oviposition periods of *Neoseiulus barkeri* (47.07eggs/ ♀, 4.93 eggs/ ♀/ day) followed by *Amblyseius swirskii* (42.43 eggs/♀, 3.97 eggs/ ♀/ day) and *Cydnoseius negevi* (7.97 eggs/ ♀, 2.81/♀/ day) ($F_{2,87}=827.058$, $P=0.0001$) (Table 2).

Age-stage, two-sex life table

The age-stage specific survival rates (s_{xj}) of tested phytoseiid mites (Fig. 1) show the probability that a newborn will survive to age x and develop to stage j . These curves also show the survivorship and stage differentiation as well as the variable developmental rate. The probability that a newborn egg survived to the adult stage was 0.86, 0.86 and 0.86 for females and 0.14, 0.14 and 0.14 for males of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnoseius negevi*, respectively.

Age-specific survivorship, age and age-stage-specific fecundity

The age-specific survivorship (l_x) and age-specific fecundity (m_x) of predatory phytoseiid mites reared on *Achroia grisella* eggs are shown in Fig. 2. These curves indicate that all tested phytoseiid species completed its development and reproduced on *Achroia grisella* eggs. The mean number of offspring produced by phytoseiid individuals of the age x and stage j per day is shown with the age-stage-specific fecundity (f_{xj}) in Fig. 2. The start of oviposition of the first female of *Amblyseius swirskii*, *Cydnoseius negevi* and

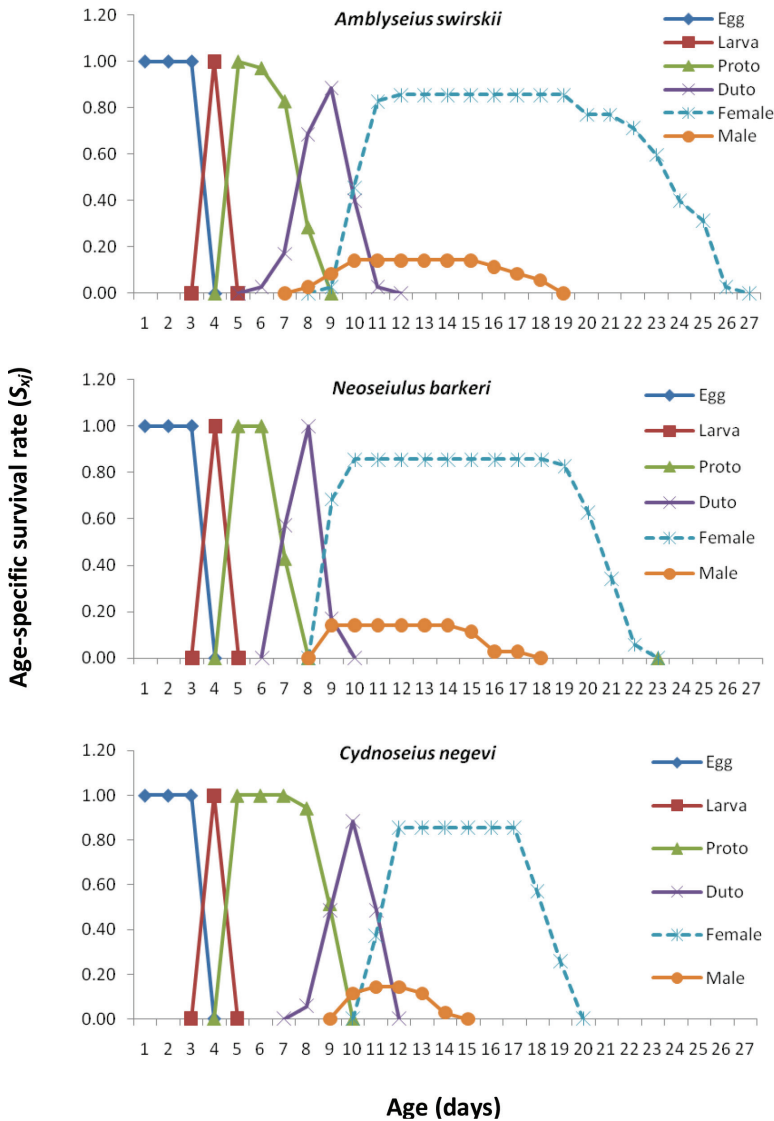


Fig. 1. Age-stage survival rate (S_{xj}) of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnoseius negevi* on *Achroia grisella* eggs

Table 3
Total and daily numbers (mean \pm SE) of consumed *Achroia grisella* eggs during the developmental periods and adult longevity of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* at 30 ± 1 °C and $70 \pm 5\%$ R.H.

Feeding stages	Predatory phytoseiid mites						Calculated <i>F</i> -value
	<i>Neoseiulus barkeri</i>		<i>Amblyseius swirskii</i>		<i>Cydnoseius negevi</i>		
	Total	Daily	Total	Daily	Total	Daily	
Larva				Non-feeding stage			
Protonymph	4.30 \pm 0.28B ^y	1.80 \pm 0.10b	1.57 \pm 0.09C	0.48 \pm 0.03c	10.40 \pm 0.18A	2.29 \pm 0.07a	518.908
Deutonymph	4.37 \pm 0.26B	2.50 \pm 0.16a	2.60 \pm 0.09C	1.23 \pm 0.06b	5.67 \pm 0.09A	3.03 \pm 0.15a	87.300
Life cycle	8.67 \pm 0.18B	2.07 \pm 0.04b	4.17 \pm 0.14C	0.77 \pm 0.03c	16.07 \pm 0.20A	2.48 \pm 0.05a	479.338
Pre-oviposition	2.47 \pm 0.09B	2.47 \pm 0.09b	10.23 \pm 0.72A	4.02 \pm 0.16a	2.40 \pm 0.10B	1.90 \pm 0.07c	111.197
Oviposition	47.07 \pm 0.77A	4.93 \pm 0.07a	42.43 \pm 0.95B	3.97 \pm 0.04b	7.97 \pm 0.41C	2.81 \pm 0.06c	827.058
Post-oviposition	3.40 \pm 0.27B	2.47 \pm 0.14a	0.90 \pm 0.26C	0.87 \pm 0.25b	9.27 \pm 0.51A	2.89 \pm 0.03a	138.429
Adult longevity	52.93 \pm 0.78A	4.43 \pm 0.06a	53.57 \pm 1.18A	3.92 \pm 0.05b	19.63 \pm 0.43B	2.66 \pm 0.04c	518.080
Life span	61.60 \pm 0.87A	3.81 \pm 0.04a	57.73 \pm 1.19B	3.00 \pm 0.04b	35.70 \pm 0.46C	2.57 \pm 0.03c	245.965

^y Within a row, means followed by the same uppercase letter (indicate the mean total consumption rate) while the lowercase letter (indicate the mean daily consumption rate) are not significantly different, Tukey HSD, $\alpha = 0.01$, $df = 2, 87$.

Neoseiulus barkeri occurred at the age 8, 10 and 8 days, respectively. The highest daily fecundity (peak of f_i , female) of above phytoseiids on insect eggs was 2.0, 1.20 and 2.30 eggs, respectively, that occurred at the age of 13.0, 11.8 and 14.0 days, respectively.

Two-sex life table parameters

The fecundity and life table parameters of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnozeius negevi* fed on *Achroia grisella* eggs is shown in Table 4.

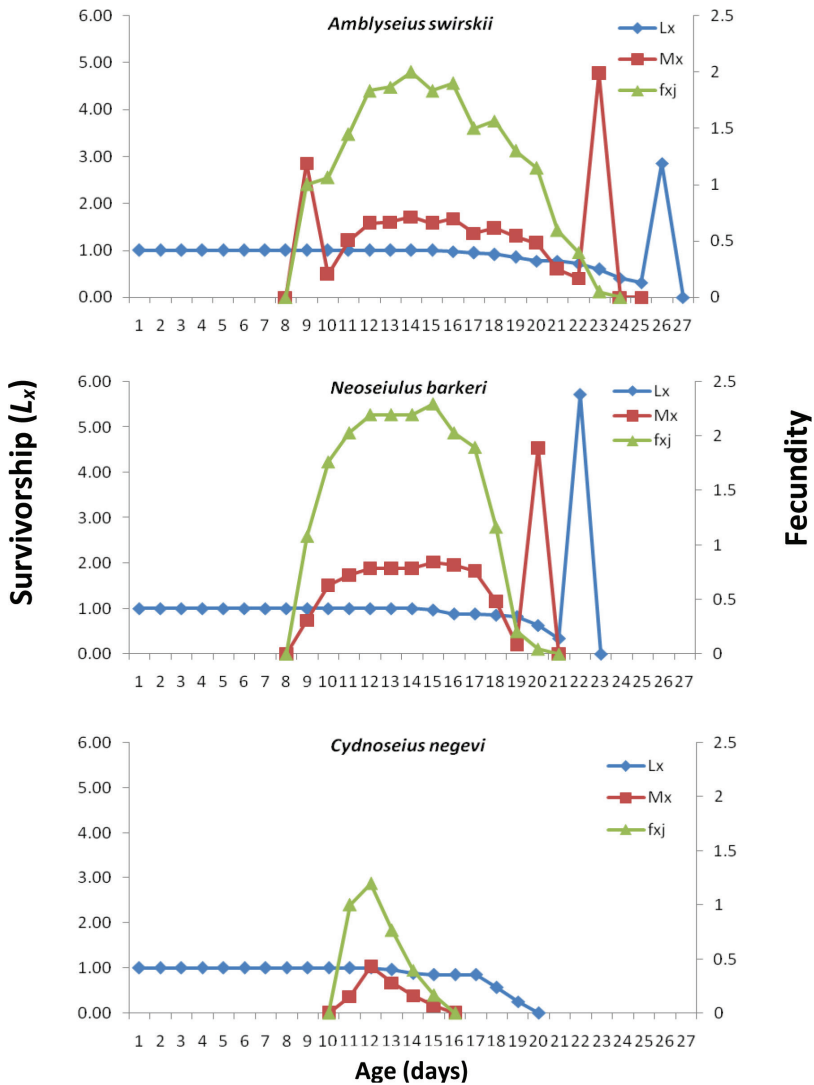


Fig. 2. Age-specific survival rate (l_x), age-stage fecundity of female (f_{xj}) and age-specific fecundity rate (m_x) of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnozeius negevi* on *Achroia grisella* eggs

Table 4

Fecundity and life table parameters (mean \pm SE) of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* fed on *Achroia grisella* eggs at 30 ± 1 °C and 70 ± 5 % R.H.

Life table parameters	Predatory phytoseiid mites			F
	<i>Neoseiulus barkeri</i> (30) ^z	<i>Amblyseius swirskii</i> (30) ^z	<i>Cydnoseius negevi</i> (30) ^z	
Mean total fecundity /♀	18.83 \pm 0.23a ^y	17.70 \pm 0.46a	3.00 \pm 0.00b	891.202
Mean daily no. of eggs /♀	1.98 \pm 0.029a	1.66 \pm 0.03b	1.13 \pm 0.055c	109.845
Net reproductive rate (R0)	16.2 \pm 1.133a	15.2 \pm 1.130b	2.543 \pm 0.177c	2800.0
Intrinsic rate of increase (r_m)	0.2150 \pm 0.006a	0.188 \pm 0.006b	0.075 \pm 0.006c	5679.0
Finite rate of increase (λ)	1.239 \pm 0.007a	1.206 \pm 0.007b	1.077 \pm 0.006c	5488.1
Mean generation time (T)	12.958 \pm 0.085b	14.987 \pm 0.135a	12.508 \pm 0.122c	2770.2
Gross reproductive rate (GRR)	16.91 \pm 0.876a	16.17 \pm 0.895b	2.63 \pm 0.147c	5128.1
Sex ratio (female/total)%	0.66	0.63	0.56	
♀: ♂	250 ♀ : 130 ♂	223 ♀ : 129♂	♀45 : ♂35	

^y Means within a row followed by common letter do not differ significantly, Tukey HSD, $\alpha = (0.01)$. $df = 2, 87$.

^z Number between parentheses represents number of replicates.

Based on the age-stage, two-sex life table, for all the measured parameters: net reproductive rate (R0), intrinsic rate of increase (r_m), mean generation time (T), finite rate of increase (λ), gross reproductive rate (GRR), the value of (R0) of *Neoseiulus barkeri* females fed insect eggs was significantly higher than that for *Amblyseius swirskii* and *Cydnoseius negevi* females. *Amblyseius swirskii* had a longer generation time than that for other predatory females. The (GRR) and (λ) were higher in *Neoseiulus barkeri* than that of *Amblyseius swirskii* and *Cydnoseius negevi*.

Age-stage reproductive value

The age-stage reproductive value (v_{xj}) is the contribution of individuals of age x and stage j to the future population. The reproductive value for a new egg (v_{01}) of *Amblyseius swirskii*, *Cydnoseius negevi* and *Neoseiulus barkeri* on *Achroia grisella* eggs is the finite rate of increase (λ) (Fig. 3). The peak reproductive (Fig. 3) was at the age of 11, 10 and 9 days for *Amblyseius swirskii*, *Cydnoseius negevi* and *Neoseiulus barkeri* fed on insect eggs, respectively. This implies that, in comparison with other ages, female individuals of the ages 11, 10 and 9 days made the highest contribution to the population when fed on *Achroia grisella* eggs, respectively. The total number of eggs deposited by *Neoseiulus barkeri* and *A. swirskii* females fed on *Achroia grisella* eggs was statistically similar and higher than that for *Cydnoseius negevi* females ($F_{2,87} = 891.202$, $P = 0.0001$). The very low fecundity of *Cydnoseius negevi* led to very low intrinsic rates of increase and net reproductive rates on insect eggs.

Discussion

The present study revealed that *Achroia grisella* eggs was accepted by different life stages of *Neoseiulus barkeri*, *Amblyseius swirskii* and *Cydnoseius negevi* females and

sustained the development and reproduction. Few studies have been carried out on the life history of tested phytoseiid predators being fed on various insects' egg. When *Amblyseius swirskii* and *Neoseiulus barkeri* were fed on natural prey such as: *Thrips tabaci*, *Tetranychus urticae*, *Eutetranychus orientalis* (Klein), *Oligonychus afrasiaticus* (McGregor), *Aculus fockeui* (Nalepa and Trouessart) (Acari: Eriophyidae), *Aculops lycopersici* and almond pollen, the developmental period of both species was considerably shorter than on *Achroia grisella* eggs in the present study (Momen, 1995; Momen and El-Borolossy, 1999; Abou-Elella, 2003; Momen and Abdel-Khalek, 2008; Momen, 2009; Negm et al., 2014; Riahi et al., 2017a). When *Cydnoseius negevi* fed on natural foods as *R. communis*, *B. tabaci*, *Aculus fockeui* (Momen, 2009; Momen et al., 2009), and the developmental

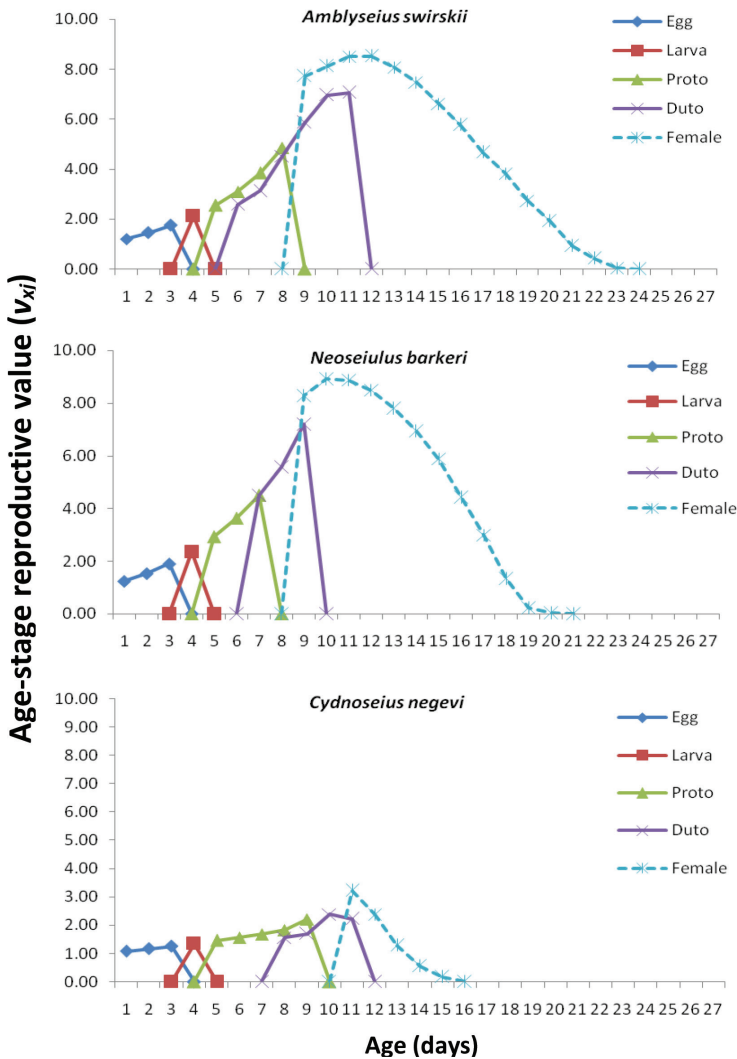


Fig. 3. Age-stage reproductive value (V_{xj}) of *Amblyseius swirskii*, *Neoseiulus barkeri* and *Cydnoseius negevi* on *Achroia grisella* eggs

period was shorter than on eggs of *Achroia grisella* tested here. Whereas *Amblyseius swirskii* and *Neoseiulus barkeri* preying on some unnatural foods ex: *Ephestia kuehniella* and *Phthorimaea operculella* eggs, *Suidasia medonensis* Oudemans (Acari: Suidasiidae), *Carpoglyphus lactis* and *Bactrocera zonata* eggs (Saunders) (Diptera: Tephritidae), the developmental period of both species was shorter than on eggs of *Achroia grisella* (El-Sawi and Momen, 2005; Momen and El-Laithy, 2007; Midthassel et al., 2013; Nguyen et al., 2014; Ji et al., 2015; Momen et al., 2016). *Cydnoseius negevi* has not cited before to feed on unnatural foods. The immature stages of *Cydnoseius negevi* consumed more than twice/four times of *Achroia grisella* eggs than those of *Neoseiulus barkeri* and *Amblyseius swirskii* did, respectively. El-Sawi and Momen (2005) reported a higher consumption rate by *Amblyseius swirskii* females on *Phthorimaea operculella* (73.9 eggs) and *Spodoptera littoralis* eggs Boisduval (Lepidoptera: Noctuidae) (78.8 eggs) than those fed *Achroia grisella* eggs. *Neoseiulus barkeri* consumed more *B. zonata* eggs (70.44 eggs/♀) during adult longevity opposed to (52.93/♀) on *Achroia grisella* eggs (Momen et al., 2016). The females longevity of *Amblyseius swirskii* was longer on *Phthorimaea operculella* (23.5 days), *S. littoralis* (29.8 days), *Ephestia kuehniella* (44.12 days) than those fed *Achroia grisella* eggs (13.73 days) (El-Sawi and Momen, 2005; Nguyen et al., 2014), respectively. Also, *Neoseiulus barkeri* had longer an adult longevity more than (2.5 times) on *Bactrocera zonata* (29.17 days) and (3 times more) on *Ephestia kuehniella* (43.0 days) than on *Achroia grisella* eggs in the present study (Momen and El-Laithy, 2007; Momen et al., 2016). These variations in developmental and physiological periods and predation rates could be attributed to different prey studied and the environmental factors. The oviposition rate and all demographic parameters of *Cydnoseius negevi* was extremely lower than that on other tested natural foods (Momen, 2009; Momen et al., 2009; Negm et al., 2014). The lower performance of *Cydnoseius negevi* towards *Achroia grisella* eggs may be due to 1) inadequacies of level of certain nutrients of eggs required for developing their ovarioles or eggs, 2) it could be caused also by the presence of an antifeeding factor in the eggs. The oviposition rate of *Amblyseius swirskii* on *Achroia grisella* eggs was higher than those fed on bee pollen (0.14 eggs/♀), date pollen (8.7 eggs/♀) and the acarid mite *Tyrophagus putrescentiae* (Schrank) (3.69 eggs/♀) and comparable with those fed on *Rhyncaphytoptus ficifoliae* Keifer (20.0 eggs/♀) (Diptilomiopidae) and the mango red spider mite *Oligonychus mangiferus* (Rahman and Sapra) (20.9 eggs/♀) (Abou-Awad et al., 1999, 2010; Riahi et al., 2017a,b). When *Neoseiulus barkeri* fed on *Eutetranychus kankitus* Ehara and *Panonychus citri* (McGregor) as natural prey, the oviposition rate was higher than those fed on *Achroia grisella* eggs presently (Ying Li et al., 2017). Fecundity of *Neoseiulus barkeri* on *Tyrophagus putrescentiae*, *Aleuroglyphus ovatus* as unnatural foods was comparable with the rate recorded on insect eggs (Xia et al., 2012; Ying Li et al., 2017).

Conclusion

In conclusion, the results of the present study indicate the possibility of using *Achroia grisella* eggs as unnatural food for mass-rearing of *Neoseiulus barkeri* and *Amblyseius swirskii*, potentially reducing production costs and encouragement wider use of these biological control agents. Therefore, *Achroia grisella* can be easily and inexpen-

sively reared according to the cheap component of used diet that could be good candidate as unnatural food for rearing above predators. The possibility of using *Achroia grisella* eggs evaluated presently for mass rearing of *Amblyseius swirskii* and *Neoseiulus barkeri*, is acceptable as of lower cost than using spider mites as natural prey, and also of the smaller space of rearing predators and reduced labor needed.

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