

Cosmolaelaps keni a Polyphagous Predatory Mite on Various Insect and Mite Species (Acari: Laelapidae)

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The predatory mite *Cosmolaelaps keni* is a native laelapid mite in Egypt. Development and adult longevity durations as well as fecundity of *C. keni* reared on five types of prey, *Bactrocera zonata*, *Spodoptera littoralis* and *Coreyra cephalonica* eggs (as insects prey), *Aceria dioscoridis* and *Caloglyphus rodriguez* (as mites prey) were determined under laboratory conditions. *Cosmolaelaps keni* was able to feed, develop and sustain oviposition on all examined insect and mite species. The mean developmental period of *C. keni* on *B. zonata* and *S. littoralis* eggs was significantly shorter than those fed *C. cephalonica* eggs and both mite species. Deutonymphs of *C. keni* were consumed similar number of insect eggs, while during the oviposition period, more *B. zonata* eggs were consumed. A diet of *C. rodriguez* provided the shortest oviposition period and longevity, while *C. cephalonica* eggs showed the longest period in this respect. During the oviposition period, preying on *B. zonata* and *C. cephalonica* eggs gave the highest fecundity rates for the predatory mite compared to *S. littoralis* and *C. rodriguez*. The sex ratio of *C. keni* progeny was in female-biased. *Bactrocera zonata* eggs as a prey gave the highest rate of oviposition as shown by the maximum fertility, net reproductive rate and gross reproductive rate as well as the shortest generation time compared to other tested prey; therefore *B. zonata* eggs were appropriate factitious prey for oviposition and mass rearing of the predatory mite *C. keni*.

Keywords: *Cosmolaelaps keni*, polyphagous predator, biological control, factitious prey.

The family Laelapidae consists of predators of invertebrate soil organisms (Beaulieu, 2009). Some species of laelapid mites proved that they may play an important role in biological control of eggs and larvae of micro-arthropods/nematodes (Walter and Proctor, 1999).

For example, *Cosmolaelaps simplex* Berlese and *Cosmolaelaps qassimensis* Fouly and Abdel-Baky are efficient biocontrol agents against the nematodes *Tylenchulus semipenetrans* (Cobb), *Meloidogyne javanica* Treub and *M. incognita* Chitwood as well as the acarid mites, *Caloglyphus rodriguez* Samsinak and *Tyrophagus putrescentiae* (Schrank) (Al-Rehiyani and Fouly, 2005; Fouly and Abdel-Baky, 2015). Moreira et al. (2015) designated the role of *Cosmolaelaps jaboticabalensis* Moreira, Klompen and Moraes in controlling *Franklinella occidentalis* (Pergande) under laboratory conditions.

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One of the main inhibitions for the applied use of augmentative biological control in the managements of mite/insect enemies is the high price of commercially produced natural enemy (De-Clercq et al., 1998). Providing only unnatural (factitious) prey for rearing predatory mites/insects may be more inexpensive than using the expensive one (natural prey). For example, unnatural prey increase the economic cost of marketable production systems as predators can be reared in bulk in a rearing component (Zhang, 2003).

Although there is ample literature of factitious and alternative food for phytoseiid predatory mites, no information is available for the suitability of these foods for *Cosmolaelaps keni* Hafez, El-Badry and Nasr. For example, the eriophyid mite, *Aceria dioscoridis* (Soliman and Abou-awad) (Acari: Eriophyidae) infested the weed banker plant *Pluchea dioscoridis* L. was performed as a perfect unnatural prey for various predatory mites of the family Ascidae and Phytoseiidae (Momen et al., 2011, 2014).

A few astigmatine species have been found to be suitable factitious food for several rhodacarid, ascid, phytoseiid and laelapid predatory mites (Castilho et al., 2009; Moreira et al., 2015; Massaro et al., 2016; Barbosa and de Moraes, 2016). In (2003), van Lenteren designated that the egg stage of few lepidopteran species have been used as factitious prey by some commercial insectaries to produce generalist predators van Lenteren, 2003. Many lepidopterans can be reared effectively on diets that are devoid of living plant materials (Riddick, 2009). Several other species can be produced simply on relatively cheap food, such as wheat flour or grains. Eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) was proved to be an excellent factitious food for several predatory mites of the family Phytoseiidae and Laelapidae (Momen and El-Laithy, 2007; Vangansbeke et al., 2014; Moreira et al., 2015; Navarro-Campos et al., 2016).

As the predators and their factitious prey do not coexist in a natural habitat, it is important to test and acknowledge the values of the predator-prey relationship in this artificially created system. Grenier and De Clercq (2003) pointed out that, whereas measures of development and reproduction of an arthropod natural enemy on an unnatural diet are revealing for the value of the diet for rearing purposes, the vital quality parameter of an artificially reared natural enemy is its predation efficacy.

Here we presume that *C. keni* can feed, oviposited and increases in great numbers on various factitious prey, then, selection of the best performed one on which it can be reared easily to support its populations in augmentative release programs. So, the scope of this investigation was to evaluate the potential of *C. cepalonica*, *S. littoralis* and *B. zonata* eggs and *C. rodriguez* and *A. dioscoridis* as factitious prey sources for rearing the predatory mite *C. keni*.

Materials and Methods

Rearing and experimental unit

Stock colony of *C. keni* was obtained from soil associated with very wet roots of tomato plants (*Lycopersicon esculentum*) L. at Tanta Province, Gharbia Governorate, Egypt during February 2015. *Cosmolaelaps keni* was cultured on *B. zonata* eggs in plastic cells (2.5 cm in diameter and 2 cm in depth) containing a floor of plaster of Paris and charcoal (mixed in a 9 : 1 ratio) were used. For biological experiments, small plastic cells (1.0 cm in diameter and 0.8 cm in depth) were used. A large heavy glass cover was used for each

cell to prevent mites from escaping. Activated plaster floor kept humid by daily addition of water. *Bactrocera zonata* eggs were added daily to the predator as the sole food. Feeding experiments were conducted in the laboratory at 28 ± 1 °C and 70-75% relative humidity (RH). The newly deposited eggs by female's *C. keni*, were singly removed from cultures in large cells to the small one for different biological tests.

Prey types tested

Five different factitious prey belonging to two broad categories (insects and mites species) were evaluated for their effects on development, survival and fecundity as well as life table parameters.

Bactrocera zonata and *C. cephalonica* eggs were obtained in accordance with the methods of Nasr et al. (2015) and Momen et al. (2016). Egg batches of *S. littoralis* were collected from the farm of the Faculty of Agriculture, Cairo University, and transferred (on small pieces of the host leaf) to rearing arenas for feeding experiments. The grass eriophyid mite, *A. dioscoridis* was obtained from galls of the weed ploughman's spikenard *P. dioscoridi* grown year-round and being found in several agro-ecosystems in Cairo such as tomato and eggplants; while the acarid mite *C. rodiguez* collected from wheat stores near Tanta Province and cultured with a mixture of 50% yeast and 50% wheat germ. All handling of insect eggs and mites was performed with a very fine moistened squirrel-hair brush.

Life history studies and demographic parameters

A newly laid single egg of *C. keni* was transferred to small experimental cell. For each prey, a total 25-30 eggs were used. Each larva and subsequent stages of the predatory mite was provided with additional insect eggs/mite species (more than that consumed daily). The number of consumed insect eggs and mites was calculated daily. Fresh insect eggs and mites were offered daily.

The developmental periods of different stages of *C. keni* were recorded every 12h. Newly emerged females of the predator were allowed to copulate with males. The experimental cells were examined every 24h to determine the duration of various physiological periods, daily consumption and oviposition rates as well as sex ratio of the progeny being calculated also. All experiments were conducted under laboratory conditions (28 ± 1 °C and 70-75% RH).

Statistical analysis and life table

The mean duration of each stage, also total immature phases duration and all physiological stages, longevity and fecundity on various prey were submitted to analyses of variance using One Way ANOVA and means compared by Tukey HSD ($P=0.05$ level) using SPSS computer program. Data were fitted with the assumption of normality, not transformed, and differences were compared for the predator female between all prey species. Fertility life table (Birch, 1948) was constructed for the predator reared on each prey and calculated by using the computer program "TWOSEX-MSChart" for life table analysis by Huang and Chi (2013).

Results

Influence of insects and mites prey on the life history of Cosmolaelaps keni

Cosmolaelaps keni larva is a non-feeding stage. The durations of larval stage were similar on the various prey species (Table 1). The developmental time of protonymphs and deutonymphs was significantly influenced by prey. Female deutonymphs reared on *B. zonata* eggs took significantly less time to develop to adulthood than those fed on other prey (Table 1). Total developmental time (from egg to adult) of females offered *C. rodriguez* or *C. cephalonica* eggs was significantly longer, followed by *A. dioscorides* than on *S. littoralis* and/or *B. zonatae* eggs ($F_{4,84} = 36.890$, $P = 0.0001$) (Fig. 1). The consumption rates of *C. keni* females are summarized in (Table 2). Prey type significantly affected the predation of females. Protonymphs and deutonymphs of *C. keni* were consumed similar amount of insect eggs, while they consumed about 25.94 individuals of *C. rodriguez* to develop to adulthood (Table 2, Fig. 2). Prey significantly influenced the duration of the pre-oviposition and oviposition periods (Table 1). Females fed on *B. zonata* eggs had significantly shorter pre-oviposition period than those fed on other prey, but insignificant differences were observed when fed on *S. littoralis* eggs or *C. rodriguez*. Mean oviposition period and female longevity were statistically shorter on *C. rodriguez* (oviposition

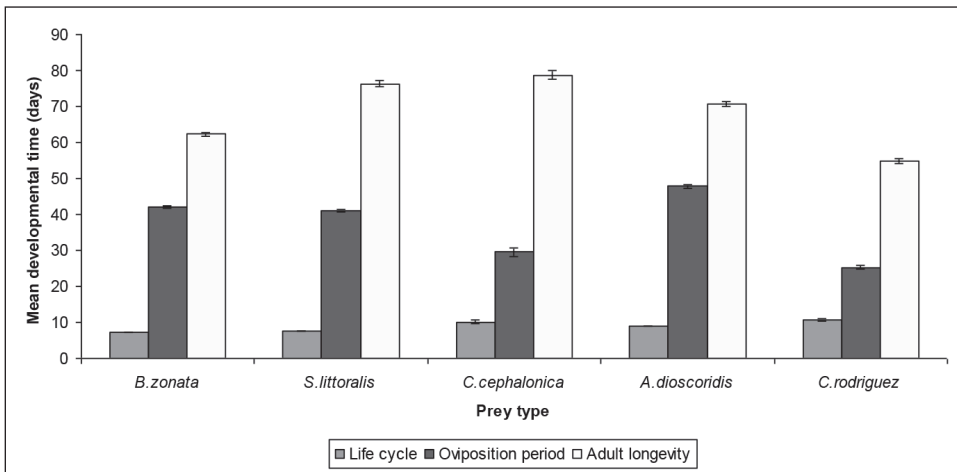


Fig. 1. Mean developmental and oviposition periods and female longevity of *Cosmolaelaps keni* fed various factious prey

period: $F_{4,84} = 368.865$, $P = 0.0001$ and female longevity: $F_{4,84} = 139.164$, $P = 0.0001$), whereas insignificant female longevity being noticed on *S. littoralis* and *C. cephalonica* eggs (Fig. 1). The post-oviposition period was statistically the same on *B. zonata* eggs and *A. dioscorides* but longer on *C. cephalonica* eggs ($F_{4,84} = 137.145$, $p = 0.0001$) (Table 1). Among the insects prey, the consumption rate was significantly higher during the oviposition periods on *B. zonata* (176.83 eggs) followed by *C. cephalonica* (146.11eggs) and *S. littoralis* (135.44 eggs) ($F_{3,68} = 56.80$, $P = 0.0001$) (Table 2, Fig. 2).

Table 1
 Developmental periods (Mean ± SE in days) of *Cosmolaelaps keni* females fed *Bactrocera zonata*, *Spodoptera littoralis* and *Coryca cephalonica* eggs, *Aceria dioscoridis* and *Caloglyphus rodriguez* at 28 ± 1 °C and 70 ± 5 % R.H.

Developmental stages	Insect and mite species				Calculated (F) value	
	<i>B. zonata</i> (18) ^z	<i>S. littoralis</i> (18)	<i>C. cephalonica</i> (18)	<i>A. dioscoridis</i> (17)		<i>C. rodriguez</i> (18)
Egg	2.00 ± 0.00 ay	1.56 ± 0.12 b	2.33 ± 0.16 a	2.00 ± 0.00 a	2.00 ± 0.00 a	9.299**
Larva	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	0.000 NS
Protonymph	2.00 ± 0.00 c	2.00 ± 0.00 c	2.50 ± 0.00 b	3.00 ± 0.00 a	2.055 ± 0.12 b	23.973**
Deutonymph	2.28 ± 0.10 c	3.00 ± 0.00 b	4.61 ± 0.26 a	2.88 ± 0.08 b	5.17 ± 0.26 a	49.725**
Life cycle	7.28 ± 0.11 c	7.55 ± 0.12 c	10.17 ± 0.46 a	8.88 ± 0.08 b	10.72 ± 0.26 a	36.890**
Pre-oviposition	1.17 ± 0.09 d	3.00 ± 0.00 c	6.17 ± 0.33 a	3.70 ± 0.11 b	3.00 ± 0.00 c	121.716**
Oviposition	42.2 ± 0.38 c	41.11 ± 0.39 c	59.55 ± 1.15 a	47.82 ± 0.47 b	25.28 ± 0.46 d	368.865**
Post-oviposition	18.94 ± 0.39 c	32.28 ± 0.72 a	12.94 ± 0.61 d	19.41 ± 0.58 c	26.50 ± 0.80 b	137.145**
Female longevity	62.33 ± 0.53 c	76.33 ± 0.88 a	78.67 ± 1.24 a	70.70 ± 0.53 b	54.78 ± 0.81 d	139.164**
Life span	69.61 ± 0.45 d	84.39 ± 0.81 b	88.83 ± 1.23 a	79.59 ± 0.56 c	65.50 ± 0.78 e	146.045**

Z Numbers between parentheses represent the number of replicates; **highly significant at $P = 0.05$; df = 4, 84; NS = insignificant
 y Means within a row followed by the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$)

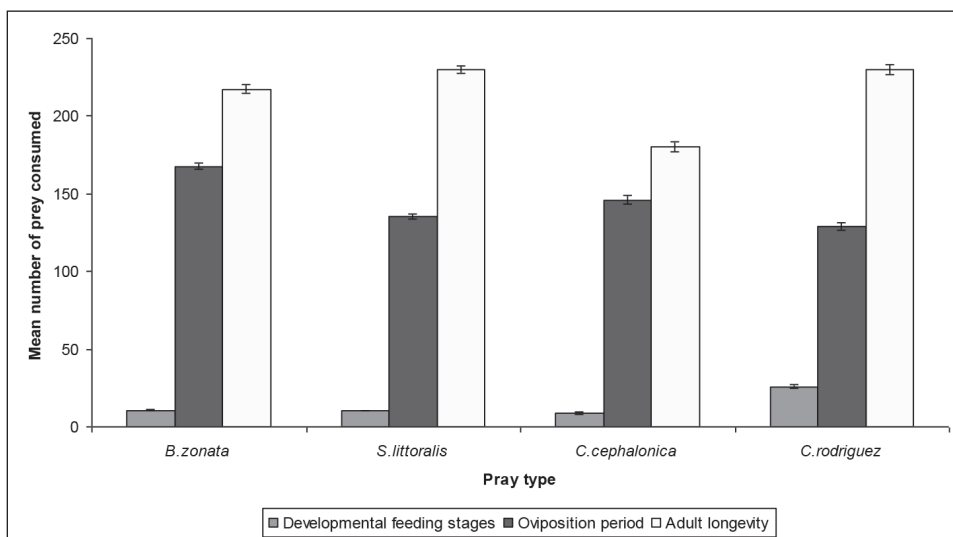


Fig. 2. Mean total consumption rate of *Cosmolaelaps keni* during developmental and oviposition periods and female longevity when fed various factious prey

Table 2

Total numbers (Mean \pm SE) of consumed *Bactrocera zonata*, *Spodoptera littoralis* and *Corcyra cephalonica* eggs and *Caloglyphus rodriguez* during the developmental periods and adult longevity of the predatory mite *Cosmolaelaps keni* females at 28 ± 1 °C and 70 ± 5 % R.H.

Female stages	Insect and mite species				Calculated (F) value
	<i>B. zonata</i> (18) z	<i>S. littoralis</i> (18)	<i>C. cephalonica</i> (18)	<i>C. rodriguez</i> (18)	
Larva	Non-feeding stage				
Protonymph	3.55 \pm 0.12by	3.00 \pm 0.00b	2.17 \pm 0.20c	6.22 \pm 0.42a	52.19**
Deutonymph	6.89 \pm 0.38b	7.61 \pm 0.24b	6.50 \pm 0.43b	19.72 \pm 1.04a	110.11**
Feeding stages consumption	10.44 \pm 0.38b	10.51 \pm 0.24b	8.72 \pm 0.58b	25.94 \pm 1.09a	150.03**
Pre-oviposition	4.78 \pm 0.38 d	10.22 \pm 0.20c	14.00 \pm 0.95b	16.67 \pm 0.19a	94.51**
Oviposition	167.83 \pm 1.99a	135.44 \pm 1.59c	146.11 \pm 2.97b	128.94 \pm 2.21c	56.80**
Post-oviposition	44.72 \pm 1.13b	83.83 \pm 1.76a	20.17 \pm 0.87c	84.72 \pm 2.72a	317.85**
Adult longevity	217.33 \pm 2.70b	230.00 \pm 2.42a	180.28 \pm 3.38c	230.22 \pm 3.21a	63.74**

Z Numbers between parentheses represent the number of replicates; ** Highly significant at $P = 0.05$; $df = 3, 68$.
y Means within a row followed by the same letter are not significantly different (Tukey HSD, $\alpha = 0.05$)

Influence of insects and mites prey on the female fecundity and demographic parameters

Total fecundity was significantly influenced by different unnatural prey (Table 3). Results revealed that the mean total fecundity was significantly higher on *B. zonata* eggs (97.11 eggs/ female) followed by *C. cephalonica* eggs than for those maintained on *C. rodriguez* (37.06 eggs/female) or *S. littoralis* eggs (73.06 eggs/female) and *A. dioscoridis* (75.71 eggs/female) ($F_{4,84} = 2622.126$, $P = 0.0001$) (Table 3). The sex ratio of the offspring determined by rearing the eggs deposited by the predator females to adulthood with each prey appeared in Table (3). The sex ratio of *C. keni* offspring was with a proportion of females ranging from 0.58 to 0.69%.

Life-table parameters of *C. keni* on five prey species are presented in Table (3). There were significant differences among prey species for all parameters measured (R_o , r_m , T , λ , GRR) ($P < 0.05$). The results showed that the net reproductive rate (R_o), intrinsic rate of natural increase (r_m) finite rate of increase (λ) and gross reproductive rate (GRR) were significantly highest on *B. zonata* eggs and lowest on *C. rodriguez* (Table 3). Generation time (T) was significantly shorter for females offered *B. zonata* eggs versus the other prey.

Discussion

The present study revealed that there are significant differences in performance of the predatory mite towards five prey types. Different prey had notable effects on all valuable parameters of fertility life table and all calculated parameters (R_o , r_m , λ , T and GRR) ($P < 0.05$). *Cosmolaelaps keni* showed an excellent performance towards *B. zonata* eggs than other prey, due mainly to short generation time, high total egg production and intrinsic rate of natural increase. The lower performance of *C. keni* towards *C. rodriguez* may be due to absence of certain nutrients required for predator oviposition.

Total developments of *C. keni* differed significantly among five prey insects and mites, where they were shortest on *B. zonata* and *S. littoralis* eggs and longest on *C. cephalonica* and *C. rodriguez* eggs. Results on the short life cycle were comparable with *Cosmolaelaps vacua* (Michael) on *Rhizoglyphus echinopus* (Fum. and Rob.) nymphs and *Musca domestica* L. eggs (Abou-Awad et al., 1989), and nearly twice shorter in case of *C. simplex* on *M. javanica* (Al-Rehiayani and Fouly, 2005) and *C. qassimensis* on *M. incognita* and *C. rodriguez* (Fouly and Abdel-Baky, 2015). Moreira et al. (2015) reported a comparable female longevity for *C. jabolicabalensis* fed *F. occidentalis* (57.7 days) with that of *C. keni* fed *C. rodriguez*. Much longer female longevity was mentioned by Enkegaard et al. (1997) for *Hypoaspis miles* (109.6 days) on *T. putrescentiae*, which approximately 2 times longer of the corresponding period of *C. keni* fed *C. rodriguez*.

The immature stages of *C. keni* consumed similar number of various insect eggs and nearly 26.0 individuals of *C. rodriguez*. Because of the difficulty of counting the minute eriophyid mite *A. dioscoridis*, here, we should take into account the size of various types of the tested food; one can expect that *A. dioscoridis* being the smallest was the easiest to capture by the predator. Abou-Awad et al. (1989) reported a higher consumption rate (more than twice) by *H. vacua* on *R. echinopus* than those of *C. keni* on *C. rodriguez* also (more than 1.5 times) on *Musca domestica* L. eggs versus the former on *B. zonata*

Table 3
Fecundity and life table parameters (Mean ± SE) of *Cosmolaelaps keni* females fed *Bactrocera zonata*, *Spodoptera littoralis* and *Coryca cephalonica* eggs and *Aceria dioscoridis* and *Caloglyphus rodriguez* at 28 ± 1 °C and 70 ± 5 % R.H.

Life table parameters	Insect and mite species					F-value
	<i>B. zonata</i> (18)z	<i>S. littoralis</i> (18)	<i>C. cephalonica</i> (18)	<i>A. dioscoridis</i> (17)	<i>C. rodriguez</i> (18)	
Fecundity (no. eggs/female)	97.11 ± 1.94ay	73.06 ± 0.76d	84.33 ± 2.05 b	75.71 ± 0.88c	37.06 ± 0.60e	2622.126 **
Intrinsic rate of increase (r_m)	0.31 ± 0.01 a	0.25 ± 0.01 b	0.19 ± 0.01 d	0.22 ± 0.01 c	0.18 ± 0.01 e	4649.830 **
Net reproductive rate (R₀)	83.24 ± 7.89 a	62.62 ± 5.45 c	72.29 ± 7.68 b	61.35 ± 6.09 c	31.76 ± 2.86 d	1039.551 **
Generation time (T)	14.47 ± 0.17 e	16.62 ± 0.22 d	22.78 ± 0.55 a	19.22 ± 0.19 b	18.72 ± 0.28c	9940.169 **
Finite rate of increase (λ)	1.36 ± 0.01 a	1.28 ± 0.01 b	1.21 ± 0.01 d	1.24 ± 0.01 c	1.20 ± 0.01 e	4725.747 **
Gross reproductive rate (GRR)	83.24 ± 7.09 a	62.62 ± 5.45 c	72.29 ± 7.68 b	64.35 ± 6.09 c	31.76 ± 2.86 d	1039.551 **
Sex ratio (females/total) %	0.69	0.61	0.64	0.69	0.58	

Z Numbers between parentheses represent the number of replicates
y Means within a row followed by the same letter are not significantly different, the stander error in case of life table parameters calculated according to Huang and Chi (2013), **highly significant at P=0.05; df = 4, 84

eggs. These variations could be attributed to different predators and prey studied and the environmental factors.

The present study has revealed that the mean predation rate of *C. keni* on insect eggs is considerably high, and this result supports the probability that *C. keni* is able to feed positively and reach a very high population under certain condition. Among the insects prey, *S. littoralis* eggs were more consumed by the predator than other preys, possibly because *B. zonata* or *C. cephalonica* eggs had higher biomass compared with the other one, which could be clarified *C. keni* need to feed on a greater number of *S. littoralis* eggs to get the same amount of nutrients. The oviposition rate of *C. keni* on *B. zonata* eggs was higher than that of *C. jabolicabalensis* on *F. occidentalis* (natural food) (Moreira et al. 2015), while *Stratiolaelaps scimitus* (Berlese) on the acarids *Aleuroglyphus ovatus* (Troupeau) and *T. putrescentiae* (Barbosa and de Moraes, 2016) being superior to that of *C. keni* on *C. rodriguez*.

The life table parameters, especially intrinsic and finite rates of increase reflect the nutritional value of a diet under specific conditions. Southwood (1978) indicated that the intrinsic rate of natural increase is an important parameter, describing the growth potential of a population under climatic and food conditions, because it reflects the overall effects of temperature and food on development, reproduction and survival characteristics of the population.

The significant differences in our r_m and R_o values showed extensive variation among prey types in terms of suitability for *C. keni*.

The relatively high rates of increase resulting in a short doubling time show that *B. zonata* eggs are of good nutritional value to *C. keni* compared with other tested prey. In our study, the intrinsic and finite rates of increase and net reproductive rate are higher than that of *C. jabolicabalensis* and *C. qassimensis* on *T. putrescentiae* (Moreira et al., 2015; Fouly and Abdel-Baky, 2015), *C. simplex* on *C. rodriguez* (Al-Rehiyani and Fouly, 2005). This difference may be due to the food types and different predators studied.

In the present study, the rapid developmental rate, short generation time and higher fecundity and net reproductive rates of *C. keni* were on *B. zonata* eggs. Consequently, *B. zonata* can be easily and inexpensively reared (Momen et al., 2016) and that could be a good candidate as a factitious prey for rearing *C. keni* and support its population in augmentative release programs. According to Nguyen et al. (2014) food nutritional deficiencies may only show after several generations of rearing. Therefore, further research will have to be done in order to draw meaningful conclusions regarding the suitability of the food types tested in the present study to sustain oviposition and development of *C. keni* over several generations.

Conclusion

In conclusion, the results of the present study indicate the possibility of using some insect eggs as factitious foods for mass-rearing of *C. keni*, potentially reducing production costs and fostering wider use of this biological control agent. Eggs of *B. zonata* proved to be an excellent prey and of high nutritional value for *C. keni* mass rearing.

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