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Predation by *Anthocoris minki pistaciae* Wagner (Hemiptera: Anthocoridae) on *Agonoscena pistaciae* Burckhardt and Lauterer (Hemiptera: Psyllidae) at different temperatures

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Abstract

Pistachio is one of the most common tree nuts in Iran and in the world, and *Agonoscena pistaciae* Burckhardt and Lauterer (Hemiptera: Psyllidae) is propounded as a considerable pest of pistachio trees. Among the numerous predators, *Anthocoris minki pistaciae* Wagner (Hemiptera: Anthocoridae) was found as a common species in pistachio orchards of Kerman Province, Iran. The consumption rate index is essential to determine the prey-predator interaction and efficiency for biological control. On the other hand, temperature as an abiotic environmental factor has an important influence on population parameters of insects. Thus, predation rate of *A. minki pistaciae* feeding on *A. pistaciae* was evaluated at three different temperatures (17, 26, and 30 ± 2 °C) with a 16L:8D photoperiod and $55 \pm 5\%$ R.H. All of the data were analyzed by the age-stage, two-sex consumption rate, MS Chart software (Ver. 2017.05.28). Obtained results showed that the highest net predation rate (C_0) and the transformation rate from prey population to predator offspring (Q_p) occurred at 30 °C (1309.13 and 54.67 prey nymphs, respectively). Moreover, the highest value for the mean prey consumption of adult insects was (1300.15 psyllid nymphs) and the highest daily mean consumption rate was calculated at this temperature. Thereupon, 30 °C is the best temperature for feeding *A. minki pistaciae* under the laboratory conditions.

Keywords: *Agonoscena pistaciae*, *Anthocoris minki pistaciae*, Prey consumption, Temperature

Background

Pistachio is globally valuable due to its nutritional value, economic significance, and important role in health (Kashaninejad and Tabil 2011). Kerman Province (in the southern part of Iran) is the largest pistachio-producing area in Iran (FAO 2016). The specific climatic conditions for the cultivation of pistachio (such as wilderness and dry areas with long and hot summers, cold winters, and low-quality soil, and salted water) have resulted in the spread of pests in pistachio orchards (Hosseinifard et al. 2008). Many phytophagous

(herbivore) arthropod pests attack pistachio trees, causing considerable damages to the crop (Zohdi et al. 2015). Among these pests, the common pistachio psyllid (CPP), *Agonoscena pistaciae* Burckhardt and Lauterer (Psyllidae), is the most adverse pest which was first reported on pistachio trees in Iran by Kiriukhin (1946) (Mehrnejad 2001).

Both nymphs and adults of CPP suck the leaves' sap and produce large amounts of dried and crystallized honeydew. Their damage to the plant leads to the fall of leaves, buds, and fruits which finally leads to yield reduction (Alizadeh et al. 2011). This pest produces several generations each year and is generally inhibited by applying chemical insecticides belonging to various classes multiple times per year (Hassani 2009). The use of insecticides failed to prevent the outbreak of this pest, and

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frequent use of these compounds has led to the development of pesticide resistance (CPP resistance occurs due to its high reproductive capacity and short life cycle) (Alizadeh et al. 2011). Due to such problems, integrated pest management (IPM) programs, especially biological control, are considered a suitable approach for controlling CPP (Mehrnejad 2001).

Some species of anthocorids including *Anthocoris nemorum* (L.), *A. nemoralis* (Fabricius), *Orius vicinus* (Ribaut), *O. minutus* (L.), and *O. majusculus* Reuter (Hemiptera: Anthocoridae) can effectively control psyllid species in infested pear orchards (Sigsgaard et al. 2006). Souliotis et al. (2002) reported *A. nemoralis* as a successful bio-control agent of CPP in Greece. Few studies have been found on its potential in pistachio orchards of Iran (Linnavuori and Hosseini 2000). Some aphid and psyllid species including *Forda* sp. (Hemiptera: Aphidoidea), *Slavum* sp. (Hemiptera: Aphidoidea), and *Psyllopsis fraxini* (L.) (Hemiptera: Psyllidae) have been recorded as preys of *A. minki pistaciae* (Falamarzi et al. 2009). Pourali et al. (2010) reported *A. minki pistaciae* as a well-known predator of *A. pistaciae* in pistachio orchards in Iran.

Anthocoris minki pistaciae is found from April to October in pistachio orchards in Kerman Province, Iran. Nowadays, the population of this predator in pistachio orchards (may be due to the use of large amounts of insecticides) is limited (Mehrnejad 2010; Yanik and Unlu 2011).

Among the known factors that influence the capacity of predators to consume prey is the temperature, as it affects the rate of growth, development, prey consumption, behavior, life cycles, population dynamics, and geographical distribution of insects (Islam and Chapman 2001). Rajabi (2004) reported that temperature increases boost metabolic interactions and then heighten the need for nutrition. So, before using biological control agents in new areas, it is necessary to know the thermal requirements of the agent (Pilkington and Hoddle 2006).

Previous studies showed benefits of using the age-stage, two-sex life table in food consumption of insect predators (Atlihan and Chi 2008).

The main purpose of this study was to investigate the influence of different temperatures on the predation rate of *A. minki pistaciae* when feeding on *A. pistaciae* as prey during immature and adult stages under laboratory conditions.

Materials and methods

Predator's collection

Samples of the anthocorids were collected from the wild and cultivated pistachio trees located in Kerman Province, Iran (Sirjan and Rafsanjan orchards, between 53° 26' E and 25° 55' N and 59° 29' E and 32° N) by using sweeping nets and aspirator, during May 2016. Collected bugs were transferred to the laboratory of Kerman Agricultural and Natural Resources Education and Research

Center and identified by the taxonomical keys of Linnavuori and Hosseini (2000) and Falamarzi et al. (2009), then *A. minki pistaciae* individuals were separated.

Insect rearing

Adult insects of the bugs were kept in a growth chamber at 25 ± 1 °C, $55 \pm 5\%$ R.H., and a photoperiod of 16 h:8 h (L:D). They were fed on psyllids. In order to rear this predatory bug, the Leaf-disk method was used (Mehrnejad 1998). In this method, to retain the moisture and to keep the pistachio leaves healthy, the Petri dishes were filled with 5-mm-thick layer of 8% Agar gel, and one healthy and clean pistachio leaf was cut to the size of the Petri dish diameter (52 mm) and the back of the leaf was placed on Agar gel in each Petri-dish, then placed into the plastic box (25 cm × 20 cm × 10 cm). A ventilation hole (0.2 mm and 3 cm diameter) was made in the middle of the lids of the Petri dish and box, respectively. Then it was covered by 50 mesh nets, and the relative humidity was controlled by placing saturated magnesium nitrate salt inside the box. The nymph and adult predators were fed on the nymphs of *A. pistaciae*, which were collected daily from the pistachio orchards.

Predation rate of *A. minki pistaciae* during immature stages

In order to determine the predation capacity of *A. minki pistaciae* during the nymphal stage, the food consumption of all nymphal instars was investigated in a pre-test separately. According to the results of the pre-test, the food consumption of the bugs was 50 CPPs (fourth instar nymphs). In the main test, newly emerged nymphs of 3 h-old *A. minki pistaciae* (first instar nymphs) were released individually on a Leaf-disk, and each individual was provided by 50 CPPs (fourth instar nymphs). Leaf-disks were checked daily, the number of consumed and alive psyllids was recorded, and the nymphs of the bug were moved to a new Leaf-disk containing nymphs of CPP. The experiments were continued for second, third, fourth, and fifth nymphal instars until the nymphs reached adult stage. Molting status, survival rate, and developmental durations of predator nymphs (the five nymphal instars) were recorded daily to determine the time spent in each nymphal stage.

In order to determine the total amount of consumed prey, this experiment was carried out with 15 replications, and the amount of consumed prey was recorded daily from the first nymphal instar to the adult stage of this predator. These experiments were performed at three constant temperatures (17 , 26 , and 30 ± 2 °C), relative humidity ($55 \pm 5\%$), and photoperiods of 16L:8D.

Predation rate of *A. minki pistaciae* during adult stage

After the adult emergence, the male and female individuals aged less than 1 day (0–24 h-old) were allowed to mate and

then transferred to experimental Leaf-disks as described earlier. According to the results of the pre-test, the food consumption of adults in each Petri dish was estimated to be 200 CPPs (100 nymphs of the fourth nymphal stage of CPP for each bug) before the main experiment. The number of the consumed psylla and the laid eggs were counted daily until the death of adults; also, the survival rate and longevity of adults were calculated.

To determine the predation sex rate, the consumption rate of ten males was estimated under the same conditions, and to calculate the female daily consumption rate, the daily predation rate of males was subtracted from the average predation rate of the pairs. During the first week of the experiment, each dead male was replaced by an alive individual (Farhadi et al. 2011).

Evaluation of predation rate

In the age-stage, two-sex life table (Chi and Liu 1985), the age-specific survival rate (l_x), and the age-specific fecundity (m_x) for an individual of age x are calculated as:

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

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

where β is the number of life stages. The age-stage-specific survival rate (s_{xj}) is the probability that a neonate survives to age x and stage j , and the age-stage-specific fecundity (f_{xj}) means the mean number of offspring produced by individual *A. minki pistaciae* of age x and stage j per day.

The age-specific predation rate (k_x) is the mean number of the fourth nymphal instar of *A. pistaciae* consumed by *A. minki pistaciae* at age x :

$$k_x = \frac{\sum_{j=1}^{\beta} s_{xj} c_{xj}}{\sum_{j=1}^{\beta} s_{xj}}$$

By using s_{xj} , the age-stage-specific net consumption rate (q_x) gives the weighted number of *A. pistaciae* consumed by *A. minki pistaciae* of age x and is calculated as:

$$q_x = k_x l_x$$

The net consumption rate (C_0) is the total amount of *A. pistaciae* consumed by an average individual during its longevity. This parameter shows the predation capacity of a predator population (both sexes and all individuals that died before the adult stage), where δ is the last age of the population:

$$C_0 = \sum_{x=0}^{\delta} q_x = \sum_{x=0}^{\delta} k_x l_x = \sum_{x=0}^{\delta} \sum_{j=1}^{\beta} s_{xj} c_{xj}$$

Table 1 Mean consumption capacity, C_0 , and Q_p of *Anthocoris minki pistaciae* fed on *Agonoscaena pistaciae* at three different temperatures under laboratory conditions

Developmental stage	17 °C		26 °C		30 °C	
	N	Mean ± SE*	N	Mean ± SE	N	Mean ± SE
Egg	15	0	15	0	15	0
1 st nymphl instar	15	14.6 ± 0.46 ^b	15	8.73 ± 0.27 ^c	15	15.07 ± 0.21 ^a
2 nd nymphl instar	14	22.57 ± 0.44 ^a	14	11.86 ± 0.54 ^c	14	20.57 ± 0.4 ^b
3 rd nymphl instar	14	38.64 ± 0.69 ^a	13	24.62 ± 0.29 ^c	13	35.15 ± 0.27 ^b
4 th nymphl instar	14	63.36 ± 0.74 ^a	13	39 ± 0.45 ^c	13	56.85 ± 0.36 ^b
5 th nymphl instar	14	80.21 ± 4.96 ^{b***}	13	91.69 ± 1.01 ^a	13	79.38 ± 0.64 ^b
Total nymphal stage	15	205.73 ± 14.34 ^a	15	154.4 ± 14.63 ^c	15	182.8 ± 16.64 ^b
Adult male	5	803.4 ± 22.8 ^b	4	839.75 ± 95.26 ^b	4	994.75 ± 11.95 ^a
Adult female	9	1086 ± 15.27 ^c	9	1281.44 ± 31.63 ^b	9	1435.89 ± 27.09 ^a
Adult mean	14	985.07 ± 39.49 ^c	13	1145.54 ± 67.99 ^b	13	1300.15 ± 61.38 ^a
Net predation rate (C_0)	–	1125.32 ± 84.28 ^b	–	1147.22 ± 127.5 ^b	–	1309.13 ± 140.43 ^a
Transformation rate (Q_p)	–	36.45 ± 7.97 ^b	–	39.05 ± 7.1 ^b	–	54.67 ± 10.67 ^a

Mean consumption capacity—mean number (± SE) of nymphs of *Agonoscaena pistaciae* eaten by different stage/sex of *Anthocoris minki pistaciae*; C_0 —the net predation rate; Q_p —the transformation rate from prey population to predator offspring at three different temperatures (17, 26, and 30 °C)

*The SEs were estimated using 10,000 bootstraps and compared by Tukey's test (comparison of 95% CI)

**Within rows, values followed by the same letters do not significantly different.

^{a,b,c}Represent quantities' numbers. ^aShows the highest level of significance. ^cShows the lowest level of significance

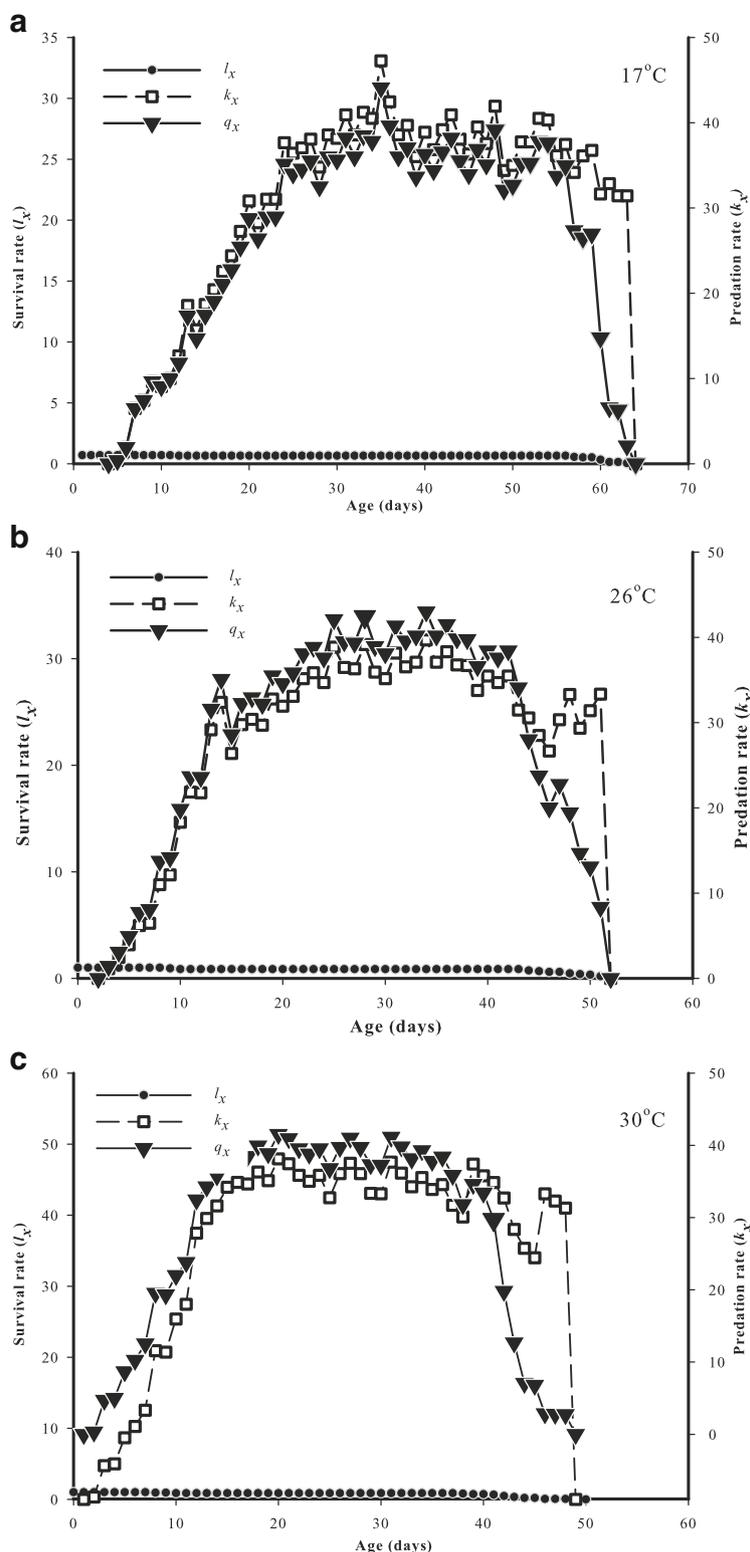


Fig. 1 Age-specific survival rate (l_x), age-specific predation rate (k_x), and age-stage-specific net predation rate (q_x) of *Anthocoris minki pistaciae* fed with *Agonoscena pistaciae* at three different temperatures under laboratory conditions. l_x , the age-specific survival rate; k_x , the age-specific predation rate; and q_x , the age-stage-specific net predation rate ($l_x k_x$) of *Anthocoris minki pistaciae* feeding on *Agonoscena pistaciae* nymphs at three different temperatures. **a** 17 °C. **b** 26 °C. **c** 30 °C

The transformation rate from food mass to pest offspring (Q_p) is the ratio of the net consumption rate to the net reproductive rate (R_0). Q_p gives the quantity of food needed for the production of an offspring and is calculated as:

$$Q_p = \frac{C_0}{R_0}$$

The age-stage-specific consumption rate (c_{xj}) surveys the differentiation of stage and the variable predation rate among individuals. This item gives the average amount of *A. pistaciae* consumed by an individual of *A. minki pistaciae* of age x and stage j (Chi and Yang 2003).

Data analysis

The daily predation rate of 15 individuals was analyzed according to Chi and Yang (2003) by the age-stage, two-sex consumption rate, MS Chart software (Chi 2017) (Ver. 2017.05.28). The standard errors of the consumption parameters were also calculated, using both the bootstrap method ($n = 10,000$) and Tukey’s test (0.05); also, the figures were drawn with Sigma Plot (Ver. 13.0, Systat software Inc.).

Results and discussion

This is the first research conducted to investigate the age-stage, two-sex predation rate of *A. minki pistaciae*.

The net predation rates (C_0) of *A. minki pistaciae* at different temperatures are shown in Table 1. The (C_0) increased by increasing the temperature. At 30 °C, it was significantly higher than those at 17 and 26 °C. The C_0 was equal to the area under the curve of $l_x k_x$ (Fig. 1).

The transformation rates from the prey population to predator offspring (Q_p) are shown in Table 1. The Q_p obtained a demographic estimation for the relationship between the reproduction rate and predation rate of the predator. A survey of the Q_p indicated that the highest and lowest values were obtained at 30 and 17 °C, respectively. This parameter increased significantly as temperature increased. In other words, *A. minki pistaciae* required 54.67 and 36.45 nymphs of CPP to produce a single egg at 30 and 17 °C, respectively.

At three temperatures, the predation rate estimated was higher in adult stage compared with the immature stage. Food consumption rate of the female was significant at the three temperatures (1086 ± 15.27 , 1281.44 ± 31.63 , and 1435.89 ± 22.09 nymphs) at 17, 26, and 30 °C, respectively. The results showed that the predation rate of females was higher than that of males. This difference could be due to the bigger size of females compared with the males, and the females need higher energy to lay eggs. Predation of adults gradually decreased with

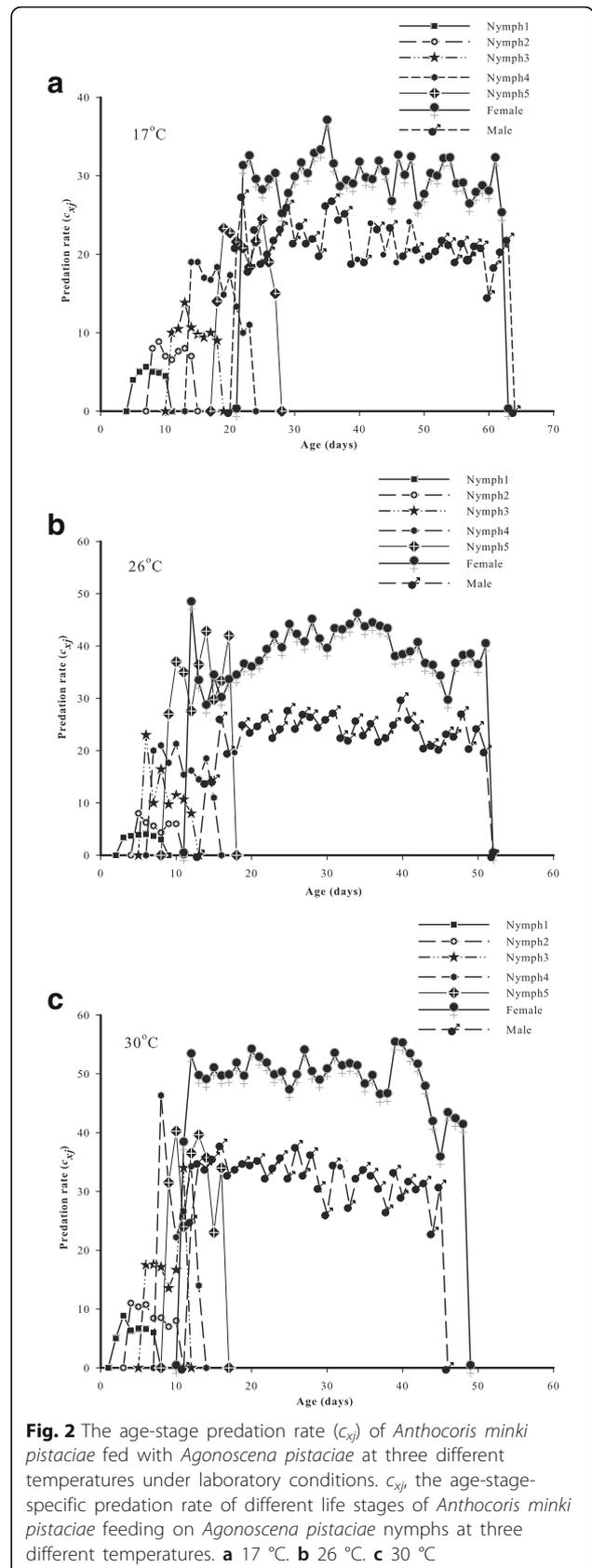


Fig. 2 The age-stage predation rate (c_{xj}) of *Anthocoris minki pistaciae* fed with *Agonosцена pistaciae* at three different temperatures under laboratory conditions. c_{xj} , the age-stage-specific predation rate of different life stages of *Anthocoris minki pistaciae* feeding on *Agonosцена pistaciae* nymphs at three different temperatures. **a** 17 °C. **b** 26 °C. **c** 30 °C

aging as well declined the number of eggs produced by females (Table 1).

The age-specific survival rate (l_x), the age-specific predation rate (k_x), and the age-stage-specific net consumption rate (q_x) at different temperatures were illustrated in Fig. 1. The age-stage-specific net predation rate (q_x) of the nymphs increased at first and then gradually decreased with the age-specific survival rate (l_x). The highest k_x and q_x were observed at 30 °C on the 20th day, at 26 °C on the 34th day, and at 17 °C on the 20th day. However, the highest age-stage-specific net predation rate of male and female adults was recorded at 30 °C (Fig. 1).

The age-stage-specific predation rate (c_{xj}) of *A. minki pistaciae* on the fourth instar nymphs of CPP is shown in Fig. 2. This parameter stated the trend in age-stage-specific predation rate, i.e., the mean number of psyllids eaten by nymphs and adults of the predator of age x and stage j . The daily consumption data for all individuals (males, females, and those died before reaching the adult stage) were used to calculate this item. The highest value for c_{xj} is observed at 30 °C.

Obtained results showed that the temperature was effective on mean consumption capacity of the nymphal stage, and it increased by increasing temperature, but due to a longer nymphal period at 17 °C the highest mean numbers of eaten prey at this temperature. Then, this quantity increased as temperature raised from 26 to 30 °C.

The adults and all nymphal instars of *A. minki pistaciae* had the highest daily mean consumption rate of CPP at 30 °C (Table 2).

Weighting coefficient showed the effect of different stages of predator life in controlling the prey's population quantitatively. If the weighting coefficient of adult females is one, the obtained weighting coefficients of adult males and fifth and fourth nymphal instars were 0.7, 0.7, and 0.5, respectively (Table 2).

The present study showed that the predation rate of adults of *A. minki pistaciae* is closely associated with temperature

rise. This result is in accordance with the results of the studies of Simonsen et al. (2009) and Zhang et al. (2012).

Among the nymphal stages, the fifth instar showed the highest food consumption at the three temperatures. This result was similar to those of Yanik and Unlu (2010). They reported that the food consumption of pre-adults of *A. minki* feeding on *Ephestia kuehniella* Zell. (Lepidoptera: Pyralidae) was affected by temperature, and the corresponding value was 123.1, 94.1, and 99.4 eggs at 20, 25, and 30 °C, respectively. Obviously, this trend is similar to the results of immature stages in the present study.

At all temperatures tested, the prey consumption of adult females was more than that of males. Similar data has also been presented by Yanik and Unlu (2011) for *A. minki* feeding on *A. pistaciae*. Yanik and Unlu (2010) reported the highest prey consumption of females and males of *A. minki* fed with *E. kuehniella* egg was at 30 °C and 40% R.H. (309.7 and 108.8, respectively). The contradiction between these data and the obtained results could be due to the difference in the nutritional quality of the hosts and experimental conditions. Yanik and Unlu (2011) stated that 631 and 303.5 nymphs of *A. pistaciae* were consumed by females and males of *A. minki* at 25 ± 1 °C. In the present study, this item for females and males of *A. minki pistaciae* was higher compared to the results of Yanik and Unlu (2011). This difference was due to the age of prey used in the test. Yanik and Ugur (2004) reported that the females of *A. nemoralis* consumed totally 1936 eggs of *E. kuehniella* at 25 ± 1 °C. The difference than obtained results may be pertained to the difference in types of prey.

Conclusions

The present study demonstrated that temperature affected the predation capacity of *A. minki pistaciae*. According to the results, despite the fact that 30 °C decreased longevity, it was the best temperature for

Table 2 Age-specific net consumption rate (q_x), daily mean consumption rate, and weighting coefficient of *Anthocoris minki pistaciae* fed with *Agonoscena pistaciae* at three different temperatures under laboratory conditions

Developmental stage	Age-stage-specific net consumption rate (q_x)			Daily mean consumption rate			Weighting coefficient		
	17 °C	26 °C	30 °C	17 °C	26 °C	30 °C	17 °C	26 °C	30 °C
Egg	0	0	0	0	0	0	0	0	0
1 st nymphal instar	14.6	8.73	15.06	5.09	3.74	7.06	0.17	0.09	0.14
2 nd nymphal instar	21.06	11.06	19.2	7.52	5.72	9.93	0.25	0.14	0.19
3 rd nymphal instar	36.06	21.33	30.46	11.04	12.31	17.58	0.37	0.31	0.35
4 th nymphal instar	59.13	33.8	49.26	16.74	17.48	29.56	0.56	0.44	0.59
5 th nymphal instar	74.86	79.46	68.8	21.19	35.06	35.59	0.71	0.89	0.71
Adult male	267.8	223.93	265.26	21.71	23.99	32.88	0.73	0.61	0.65
Adult female	651.6	768.86	861.53	29.71	39.09	49.9	1	1	1

q_x —the age-stage-specific net consumption rate; daily mean consumption rate and weighting coefficient of different stage/sex of *Anthocoris minki pistaciae* feeding on the common pistachio psylla *Agonoscena pistaciae* at three different temperatures (17, 26, and 30 °C)

feeding adults of *A. minki pistaciae* under the laboratory conditions because at this temperature, the highest net predation rate (C_0) and the transformation rate from the prey population to predator offspring (Q_p) (1309.13 ± 140.3 and 54.67 ± 10.67 prey nymphs, respectively) were achieved. Moreover, the maximum mean prey consumption of adult insects (1300.15 ± 61.38 psyllid nymphs) was calculated at 30 °C.

With regard to the climate and high temperature of Kerman Province, the predation activity of the main predators of CPP including ladybirds and lacewings decreases as temperature increases (Zohdi 2016). On the contrary, the obtained results may suggest that *A. minki pistaciae* can increase the population density and cause greater efficiency (under laboratory conditions) at 30 °C than at other temperatures tested in this study.

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Availability of data and materials

The datasets supporting the conclusions of this article are included within the article (and its additional files). Also the datasets supporting the conclusions of this article are available in the Zenodo repository in <https://zenodo.org/record/1217757#.WtBPj2997Z5> and <https://zenodo.org/record/1217761#.WtBPrm997Z4>

Authors' contributions

MS participated in the design of the study, conducted the experiments, prepared the manuscript, and performed the statistical study. MG and SH helped to improve this paper. HZ, the consultant of this project, contributed to this study design. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

- Alizadeh A, Talebi K, Hosseinaveh V, Ghadamyari M (2011) Metabolic resistance mechanisms to phosalone in the common pistachio psyllid, *Agonoscaena pistaciae* (Hemiptera: Psyllidae). *Pestic Biochem Physiol* 101:59–64. <https://doi.org/10.1016/j.pestbp.2011.07.005>
- Atlihan R, Chi H (2008) Temperature-dependent development and demography of *Scymnus subvillosus* (Coleoptera: Coccinellidae) reared on *Hyalopterus pruni* (Homoptera: Aphididae). *J Econ Entomol* 101:325–333
- Chi H (2017) CONSUME- MSChart: a computer program for consuming rate analysis based on the age stage, two-sex life table. <http://140.120.197.173/Ecology>. Accessed 20 Jan 2017
- Chi H, Liu H (1985) Two new methods for the study of insect population ecology. *Bull Inst Zool Acad Sin* 24:225–240
- Chi H, Yang T (2003) Two-sex life table and predation rate of *Propylaea japonica* Thunberg (Coleoptera: Coccinellidae) fed on *Myzus persicae* (Sulzer) (Homoptera: Aphididae). *Environ Entomol* 32:327–333. <https://doi.org/10.1603/0046-225X-32.2.327>
- Falamarzi S, Asadi G, Hosseini R (2009) Species inventory, preys and host plants of Anthocoridae sensu lato (Hemiptera: Heteroptera) in Shiraz and its environs (Iran, Fars province). *Acta Entomol Musei Nationalis Pragae* 49(1):33–42
- FAO (2016) Food and Agriculture Organization of the United Nations, FAOSTAT3: Core production data. <http://www.Faostat3.fao.org>. Accessed 17 May 2017
- Farhadi R, Allahyari H, Chi H (2011) Life table and predation capacity of *Hippodamia variegata* (Coleoptera: Coccinellidae) feeding on *Aphis fabae* (Hemiptera: Aphididae). *Biol Control* 59(2):83–89. <https://doi.org/10.1016/j.biocontrol.2011.07.013>
- Hassani MR (2009) Bioecology and economic injury level of *Agonoscaena pistaciae* (Hemiptera: Psyllidae) in Rafsanjan region of Iran. Ph.D. Thesis, University of Islamic Azad, Tehran, p 105
- Hosseinfard J, Salehi MH, Esfandiari pour I, Mohammadi J (2008) Spatial variability of groundwater quality and its relationship with pistachio yield in Anar region, Iran. *Appl Sci* 8(20):3697–3702
- Islam SS, Chapman RB (2001) Effect of temperature on predation by Tasmanian lacewing larvae. *Proceedings of the New Zealand plant protection conference. N Z Plant Prot Soc* 54:244–247
- Kashaninejad M, Tabil L (2011) Pistachio (*Pistacia vera* L.), postharvest biology and technology of tropical and subtropical fruits. *Woodhead Publ Ser Food Sci Technol Nutr* 4(11):218–246. <https://doi.org/10.1533/9780857092618.218>
- Kiriukhin G (1946) Les insectes nuisibles au Pistacier en Iran. *Ent Phytopath Appl* 18–24
- Linnavuori R, Hosseini R (2000) Heteroptera of Guilan with remark on species of the adjacent areas, 2nd edn. Guilan University Press, Rasht, p 95
- Mehrnejad MR (1998) Evaluation of the parasitoid *Psyllaephagus pistaciae* (Hymenoptera: Encyrtidae) as a biological agent of the common pistachio psylla, *Agonoscaena pistaciae*. Ph.D. Thesis, University of London, London, p 271
- Mehrnejad MR (2001) The current status of pistachio pests in Iran. *J Econ Entomol* 56:315–322
- Mehrnejad MR (2010) Potential biological control agents of the common pistachio psylla, *Agonoscaena pistaciae*, a review. *Entomofauna* 31(21):317–340
- Pilkington LJ, Hoddle MS (2006) Use of life table statistics and degree-day values to predict the invasion success of *Gonatocerus ashmeadi* (Hymenoptera: Mymaridae), an egg parasitoid of *Homalodisca coagulata* (Hemiptera: Cicadellidae) in California. *Biol Control* 37:276–283
- Pourali Z, Kheradmand K, Mehrnejad MR, Ghajarieh H (2010) Development and thermal requirement of *Anthocoris minki pistaciae* (Hemiptera: Anthocoridae) at different temperatures. *Acta Entomol Sin* 53(4):474–478
- Rajabi GR (2004) Insect ecology, 2nd edn. Ministry of Jihad-e-Agriculture, Agricultural Research and Education Organization, Tehran, p 622
- Sigsgaard L, Esbjerg P, Philipsen P (2006) Experimental releases of *Anthocoris nemoralis* F. and *Anthocoris nemorum* (L.) (Heteroptera: Anthocoridae) against the pear psyllid *Cacopsylla pyri* L. (Homoptera: Psyllidae) in pear. *Biol Control* 39(1):87–95. <https://doi.org/10.1016/j.biocontrol.2006.02.008>
- Simonsen MLR, Enkegaard A, Bang CN, Sigsgaard L (2009) Temperature effect on the predation rate of *Anthocoris nemorum* (Heteroptera: Anthocoridae) on cabbage aphids (Homoptera: Aphididae). *J Appl Entomol* 133(3):198–200
- Souliotis C, Markoyiannaki Printziou D, Lefkaditis F (2002) The problems and prospects of integrated control of *Agonoscaena pistaciae* (Homoptera: Sternorrhyncha) in Greece. *J Appl Entomol* 126:384–388. <https://doi.org/10.1046/j.1439-0418.2002.00678.x>
- Yanik E, Ugur A (2004) Consumption of *Cacopsylla pyri* (L.) (Homoptera: Psyllidae) and *Ephesia kuehniella* Zell. (Lepidoptera: Pyralidae) eggs by predator *Anthocoris nemoralis* (F.) (Heteroptera: Anthocoridae) under laboratory and natural conditions. *Plant Prot Bull* 44:47–67
- Yanik E, Unlu L (2010) The effects of different temperatures and relative humidity on the development, mortality and nymphal predation of *Anthocoris minki*. *Phytoparasitica* 38(4):327–335
- Yanik E, Unlu L (2011) Biological traits and prey consumption of *Anthocoris minki* fed on *Agonoscaena pistaciae* and *Brachycaudus amygdalinus* (Thuleaphis). *Phytoparasitica* 39(4):333–342. <https://doi.org/10.1007/s12600-011-0165-5>

- Zhang SC, Zhu F, Zheng XL, Lei C, Zhou XM (2012) Survival and developmental characteristics of the predatory bug *Orius similis* (Hemiptera: Anthocoridae) fed on *Tetranychus cinnabarinus* (Acari: Tetranychidae) at three constant temperatures. *Eur J Entomol* 109:503–508
- Zohdi H (2016) Molecular detection of pistachio psylla in the gut contents of ladybirds in pistachio orchards and determination of the role of alternative hosts on the efficacy and interaction of dominant ladybirds with *Agonoscena pistaciae*. Ph.D. Thesis, University of Guilan, Guilan, p 195
- Zohdi H, Hosseini R, Sahragard A, Mohammadi AH (2015) Molecular detection of common pistachio psylla (*Agonoscena pistaciae* Burckhardt and Lauterer) in the gut contents of *Oenopia conglobata* beetles. *J Entomol Zool Stud* 3:77–83

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