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Research Article

Biological and life table parameters of the mealy almond aphid, *Hyalopterus amygdali*, on five commercial cultivars of almonds under laboratory conditions

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Abstract: The mealy almond aphid, *Hyalopterus amygdali* (Hemiptera: Aphididae), is an important pest that causes severe damage to almond in Iran. This research studied the life table and population growth parameters of *H. amygdali* on five almond cultivars: 'Mamaei', 'Rabie', 'Ferragnes', 'Shahrood 7', and 'Shahrood 21'. The experiment was conducted in an incubator at 25 ± 1 °C, 50 ± 5% RH, and a photoperiod of 14:10 hours (L:D). The data were analyzed using the Two-Sex MSChart program. Based on the results, the longest lifespan of the adult aphid was recorded on 'Mamaei' (4.11 days), while the shortest was on 'Shahrood 21'cultivar (1.89 days). The net reproductive rate (R_0) ranged from 6.42 for 'Mamaei' to 0.2 nymphs per individual in 'Shahrood 21'. 'Mamaei' cultivar showed the highest values of the intrinsic rate of increase (r_m) and the finite rate of increase (λ) (0.245 and 1.278 day^{-1}, respectively), along with the shortest duration of the immature stages (5.79 days). In contrast, 'Shahrood 21' showed the lowest values of r_m and λ (-0.183 and 0.832 day^{-1}, respectively) and the longest duration of the immature stages (7.72 days). Based on the findings, 'Mamaei' and 'Shahrood 21' cultivars were considered the most suitable and unsuitable hosts for the development and reproduction of *H. amygdali*, respectively.

Keywords: *Hyalopterus amygdali*, Population growth, Reproduction, *Prunus dulcis*, Two-sex analysis

Introduction

Among the various tree nuts, almond *Prunus dulcis* (Mill) D. A. Webb is the second most-consumed worldwide. The United States of America and Spain are the world's main producers of this crop, whereas Iran ranks fifth, with a cultivation area of 182,000 hectares and production of 142,000 tons (DPEIC, 2019).

This crop is infested with various aphid species. Among the 21 aphid species that feed on almond trees worldwide, *Hyalopterus amygdali* (Blanchard, 1840) is described as the dominant species (Blackman and Eastop, 2024). The almond trees in Iran are greatly affected by this

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pest, which primarily feeds on the undersides of leaves, reducing shoot growth, causing leaf deformations, and producing excessive honeydew (Ghorbali *et al*., 2008). The primary hosts of *H. amygdali* are stone-fruit plants, including plum *Prunus domestica* L., peach *P. persica* (L.) Batsch, almond *P. dulcis* (Mill.) D. A.Webb, and apricot *P. armeniaca* L. The aphid exhibits cyclic parthenogenesis and heteroecious behavior throughout most of its life cycle, producing multiple asexual generations during the spring. From the second decade of June, winged females are produced and migrate to secondary hosts, typically perennial reed grasses (*Phragmites* species) (Ghorbali *et al*., 2008). In the autumn, aphids return to their primary hosts, where a single sexual generation occurs and overwintering eggs are laid (Blackman and Eastop, 2000). This aphid causes plant damage directly through feeding and indirectly through sooty mold that grows on honeydew, as well as through the transmission of plant viruses such as *plum pox virus* (Isac *et al*., 1998; Elibuyuk, 2003).

Evaluating the influence of host plants on pest population development and investigating the interactions between pests and their host plants can indicate the susceptibility or resistance of different cultivars to pests (Safuraie-Parizi *et al*., 2014). One crucial step in pest management is the use of resistant plants, which affect insects' biology and development (Chen *et al*. 1996). According to Stenberg (2017), using insect-resistant host plants is an economically, ecologically, and environmentally advantageous control method within any IPM program. Previous studies have suggested using resistant cultivars to control *H. amygdali* (Özgökçe and Atlıhan, 2005; Jafarlou, 2017).

Life table analysis is a useful method for investigating the resistance and susceptibility of host plants to pests by obtaining data on the biology and population parameters of the pests (Smith, 2005). A life table is a significant tool in entomological studies as it provides the foundation for categorizing age-specific mortality and insect survival, along with precise information about a given cohort of insects (Carey, 2001). Pests cause greater damage to susceptible host plants than to resistant ones due to higher population growth rates (Panda and Khush, 1995). This study aims to investigate the biology and population parameters of *H. amygdali* across different almond cultivars using the age–stage, two-sex life table theory to reveal the susceptibility of these cultivars to this pest. Identifying resistant varieties and employing them in the integrated management of *H. amygdali* is an environmentally safe method to reduce pest population and damage in almond orchards.

Materials and Methods

Plant materials

In this experiment, five cultivars of almonds, including 'Mamaei', 'Rabie', 'Shahrood 7', 'Shahrood 12' ('Ferragnes'), and 'Shahrood 21' were used. These cultivars were obtained from the Department of Horticulture and planted at the Chahar-Takhteh station of the Agricultural and Natural Resources Research and Education Center, Chaharmahal va Bakhtiari province, Iran. They were grafted onto 'GF677' rootstock and arranged in a completely randomized block design with three replicates of 10 plants each. Fertilizers, including micro- and macroelements, were applied according to soil analysis (Department of Soil Sciences, Agricultural and Natural Resources Research and Education Center, Chaharmahal va Bakhtiari province, Iran). The trees were irrigated once a week, and weeds were controlled mechanically.

Insect sources and identification

The initial populations of *H. amygdali* were collected from an almond orchard (var. 'Mamaei') at the Agricultural and Natural Resources Research and Education Center in Shahre-Kord, Chahrmahal, and Bakhtiari province, in the first week of May 2022. Microscope slides were prepared from the aphid samples and identified using keys provided by Rezwani (2001) and Blackman and Eastop (2024). The stock colony was maintained on almond seedlings of var. 'Mamaei' grafted onto 'GF677' rootstock and planted in plastic pots (40

× 60 cm). The stock colony was kept under greenhouse conditions at 25 ± 3 °C, 50 ± 10% RH, and a 12:12 (L: D) photoperiod. Before starting the experiments, the aphids were fed on each cultivar for 10 days (at least one generation).

Life table experiment

Life table parameters of *H. amygdali* were studied on the leaves from young branches of different almond varieties following Nourbakhsh *et al.* (2007). The experimental units were kept in a growth chamber at 25 ± 1 °C and 50 ± 5% RH. The photoperiod was 14:10 (L:D) h, which was provided by fluorescent lamps yielding 175 μEs−1 m−2.

The aphid individuals were not able to settle on leaf substrates. Therefore, single-leafed almond twigs were used to establish the experimental units (Nourbakhsh *et al.*, 2007; Saeidi and Nemati, 2017). Forty twigs 10 cm in length, from different almond cultivars were separated and placed in cylindrical plastic containers (5 cm in height, 2.5 cm in diameter). An 8 mm-diameter, 3 cm-high plastic tube was placed in the center of each cylindrical container to support the stem. The cylindrical containers were filled with water up to a height of 4.5 cm to prevent aphids from escaping while watering the stem. The tested almond twigs were replaced during the experiments when the leaves became discolored. Before starting the experiment, five females of *H. amygdali* were placed on fresh almond twigs of each cultivar for 24 h. Then, newly born nymphs of *H. amygdali* were placed separately in the experimental units. Each experiment was replicated 40 times for each cultivar. Nymph development was recorded every 12 h until the adult stage, and the survivorship of the different immature stages was monitored. After the emergence of the adults, the number of nymphs produced by each female was recorded daily. Observations and data collection continued until all adults died.

Data analysis

The collected data were analyzed according to the age-stage, two-sex life theory (Chi, 1988; Chi, 2020) using the TWOSEX-MSChart software. The mean and standard error of the measured parameters were estimated using the bootstrap method (Huang and Chi, 2012) with 100,000 bootstrap samples. Bootstrapping produced a normal frequency distribution, which was essential for subsequent analyses and comparisons. Differences among the cultivars were assessed using a paired bootstrap test (Polat-Akköprü *et al.*, 2015). All diagrams were produced using SigmaPlot 15.0.

According to this method, the growth parameters, such as the net reproductive rate (R_0), intrinsic population growth rate (r_m), finite rate of increase (λ), mean generation times (T) and other parameters, including age-stage specific survival rate (s_{xj}: the probability of a newborn nymph surviving to age x and stage j), age-stage specific fecundity (f_{xj}: daily number of nymphs produced per female of age x), the age-specific survival rate (l_x: the probability of a newborn nymph reaching to age x), the age-specific fecundity (m_x: daily number of nymphs produced per individual), the life expectancy (e_{xj}: the time that an individual of age x and stage j is expected to be alive) and the age-stage-specific reproductive value (v_{xj}) were calculated.

Results

The effect of different almond cultivars on the duration of various mealy almond aphid stages is presented in Table 1. There were significant differences in the development time of each pre-adult instar and in adult longevity among the studied cultivars. The longest adult longevity was 4.11 days for 'Mamaei', while the shortest (1.89 days) was observed in 'Shahrood 21'. The pre-adult period was significantly affected by cultivar. The longest pre-adult duration was recorded in 'Shahrood 21' (7.72 days), whereas the shortest was for the 'Mamaei' cultivar (5.79 days). The same trend was observed for the first to fourth instars (Table 1).

Pre-adult survival rates were 0.475, 0.575, 0.275, 0.35, and 0.225 on 'Mamaei', 'Rabie', 'Shahrood 7', 'Shahrood 12' ('Ferragnes'), and 'Shahrood 21', respectively. The fecundity of

H. amygdali on 'Mamaei' (13.53 nymphs per female) was significantly higher than that on the other cultivars, followed by 'Rabie' cultivar (6.61 nymphs/female). The lowest fecundity (0.89 nymphs per female) was observed on the 'Shahrood 21' cultivar. The longest and shortest oviposition periods were observed on 'Mamaei' and 'Shahrood 21' cultivars, respectively (Table 2).

Based on the analysis, population growth parameters varied significantly among the studied cultivars. The net reproductive rate (R_0) was highest for 'Mamaei' and lowest for 'Shahrood 21' (6.425 and 0.20 nymphs, respectively). The aphids on 'Mamaei' had the highest intrinsic rate of increase (r_m) (0.245 day^{-1}), while 'Shahrood 21' had the lowest (-0.183 day^{-1}). Moreover, there was a significant difference in the finite rate of increase (λ). The highest and lowest values were obtained for 'Mamaei' and 'Shahrood 21', respectively. The mean generation time (T) significantly differed among the cultivars, with the highest value on 'Shahrood 21' and the lowest on 'Rabie' (Table 3).

The curves of age-stage survival rate (s_{xj}) estimate the probability that a newly born nymph survives to age x and stage j. The probabilities that a newly born nymph reaching the adult stage were 0.661, 0.563, 0.159, 0.201, and 0.034 for 'Mamaei', 'Rabie', 'Shahrood 7', 'Ferragnes', and 'Shahrood 21', respectively (Fig. 1).

Table 1 Mean comparison (± SE) of different stage durations of *Hyalopterus amygdali* reared on different almond cultivars under laboratory condition.

Cultivar	Nymph I (day)	Nymph II (day)	Nymph III (day)	Nymph IV (day)	Pre-adult (day)	Adult longevity (day)	Total life span (day)
'Mamaei'	1.27 ± 0.04 cd	1.34 ± 0.04 d	1.32 ± 0.05 bc	1.61 ± 0.05 e	5.79 ± 0.08 de	4.11 ± 0.09 a	6.29 ± 0.57 a
'Rabie'	1.38 ± 0.03 c	1.33 ± 0.04 de	1.36 ± 0.04 b	1.76 ± 0.05 bd	5.89 ± 0.09 d	3.13 ± 0.18 bcd	7.01 ± 0.43 a
'Shahrood 7'	1.50 ± 0.00 b	1.50 ± 0.00 c	1.59 ± 0.05 a	1.82 ± 0.08 bc	6.32 ±0.07 c	3.41 ± 0.20 b	5.65 ± 0.46 ab
'Shahrood 12'	1.50 ± 0.00 b	1.57 ± 0.04 b	1.68 ± 0.06 a	1.86 ± 0.06 b	6.64 ± 0.12 b	3.14 ± 0.22 bc	5.41 ± 0.54 abc
'Shahrood 21'	1.95 ± 0.03 a	1.85 ± 0.06 a	1.75 ± 0.07 a	2.00 ± 0.00 a	7.72 ± 0.09 a	1.89 ± 0.11 e	4.97 ± 0.46 abcd

*Means followed by the same letters in t each column are not significantly different (paired bootstrap test at 5% significance level).

Table 2 The mean (± SE) fecundity, oviposition and pre-adult survival rate of *Hyalopterus amygdali* reared on different almond cultivars under laboratory condition.

Cultivar	Fecundity (Nymphs/Female)	Oviposition day (day)	Pre-adult survival rate
'Mamaei'	13.53 ± 0.85 a	2.53 ± 0.14 a	0.475 ± 0.079 a
'Rabie'	6.61 ± 0.59 b	1.57 ± 0.10 b	0.575 ± 0.078 a
'Shahrood 7'	5.82 ± 0.58 bc	2.14 ± 0.18 a	0.275 ± 0.071 bc
'Shahrood 12'	3.64 ± 0.25 d	1.36 ± 0.12 bc	0.350 ± 0.075 ab
'Shahrood 21'	0.89 ± 0.20 e	0.57 ± 0.07 d	0.225 ± 0.066 bcd

*Means followed by the same letters in t each column are not significantly different (paired bootstrap test at 5% significance level).

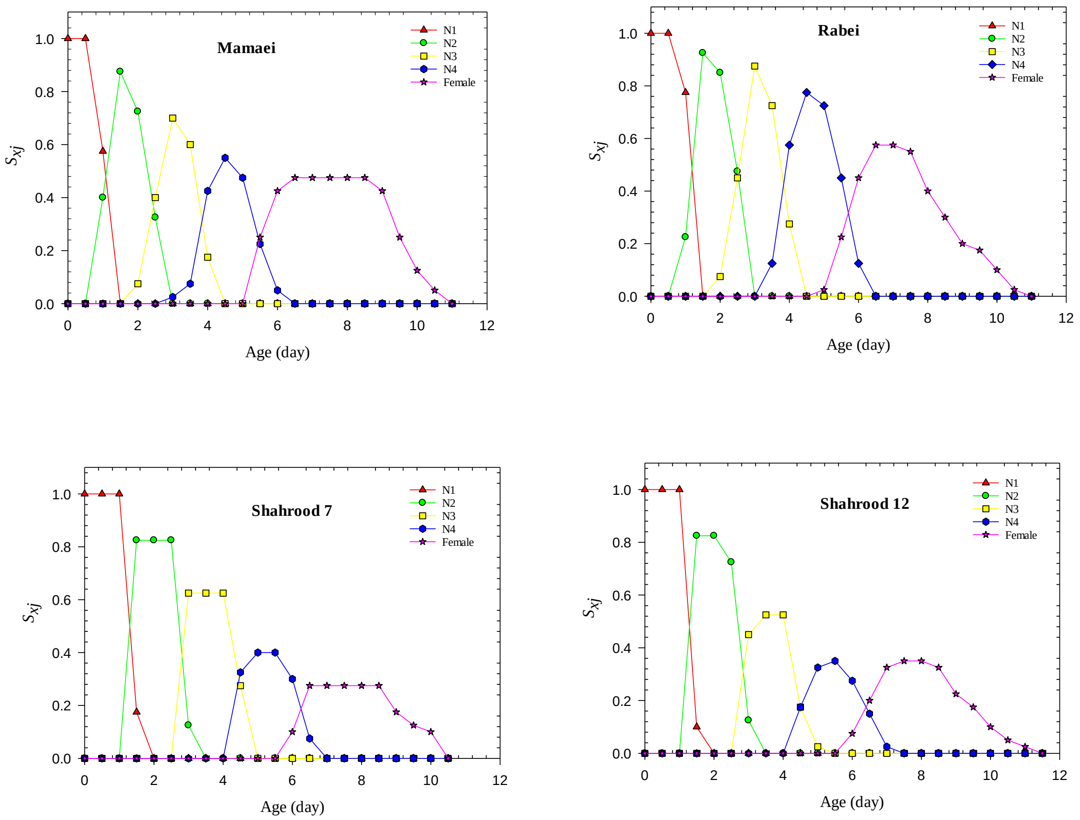
Table 3 Mean comparison (± SE) of life table parameters of *Hyalopterus amygdali* on different almond cultivars under laboratory condition.

Cultivar	R_0 (offspring/individual)	r_m (day^{-1})	λ (day^{-1})	T (day)
'Mamaei'	6.425 ± 1.137 a	0.246 ± 0.025 a	1.279 ± 0.032 a	7.566 ± 0.135 bc
'Rabie'	3.800 ± 0.610 b	0.181 ± 0.022 a	1.198 ± 0.027 a	7.385 ± 0.143 cd
'Shahrood 7'	1.600 ± 0.440 c	0.059 ± 0.037 b	1.061 ± 0.039 b	7.981 ± 1.184 ab
'Shahrood 12'	1.275 ± 0.287 cd	0.029 ± 0.028 bc	1.030 ± 0.029 bc	8.209 ± 1.995 a
'Shahrood 21'	0.200 ± 0.073 e	-0.183 ± 0.047 d	0.832 ± 0.041 d	8.767 ± 0.203 a

***** R_0: Net Reproductive rate; *rm:* Intrinsic rate of increase; λ: Finite rate of increase, *T:* Mean generation time.
Means followed by the same letters in each column are not significantly different (paired bootstrap test at 5% significance level).

The curves of l_x (the age-specific survival rate of all individuals), m_x (the age-specific fecundity of the total population), and l_xm_x (the age-specific maternity) display trends in survival and fecundity of *H. amygdali* on different hosts (Fig. 2).

The highest age-specific fecundity (m_x) peaks were 2.21, 1.56, 1.09, 1, and 0.33 nymphs per female on 'Mamaei', 'Rabie', 'Shahrood 7', 'Ferragnes', and 'Shahrood 21', respectively.



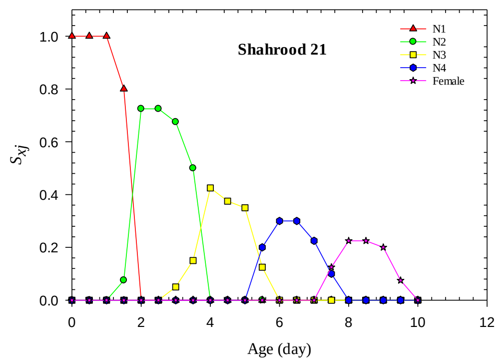
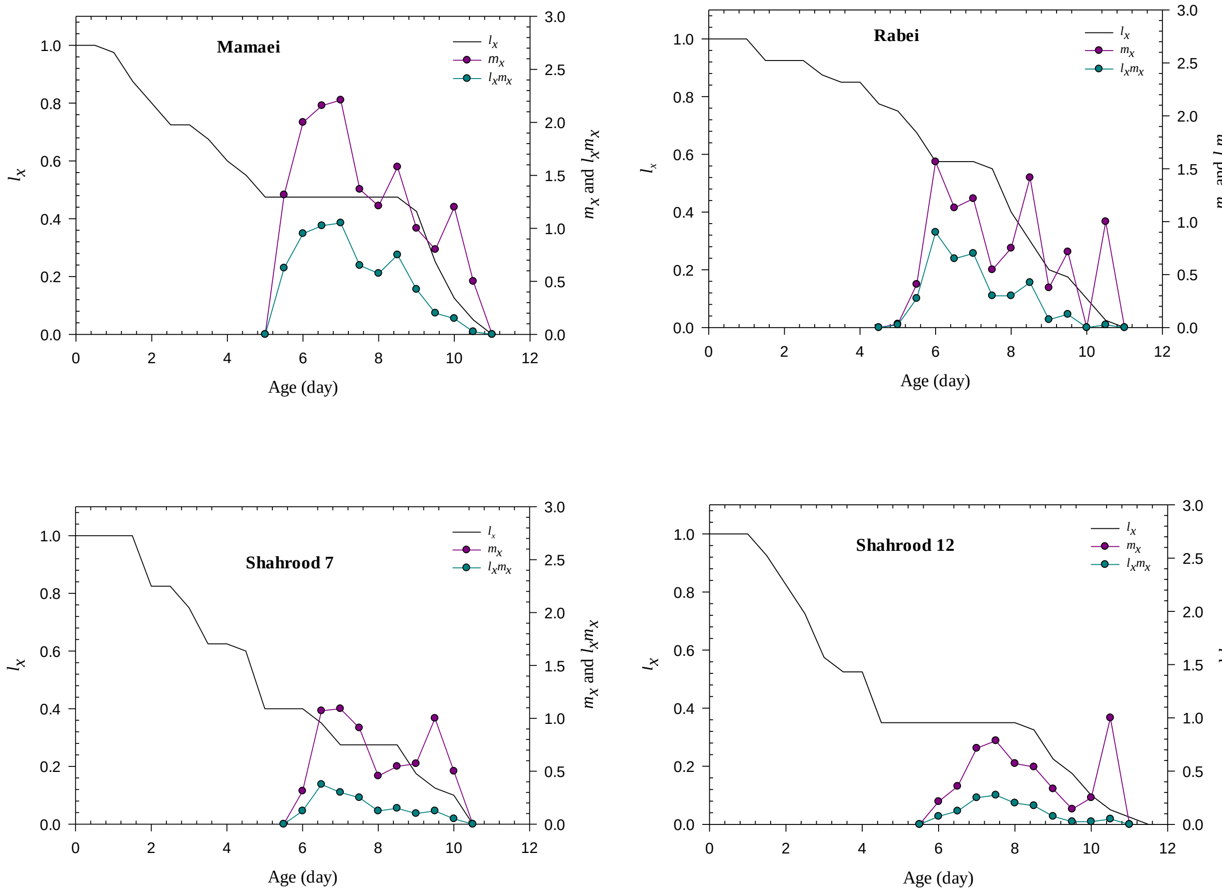


Figure 1 Age-stage specific survival rate (s_{xj}) of *Hyalopterus amygdali* reared on different almond cultivars.



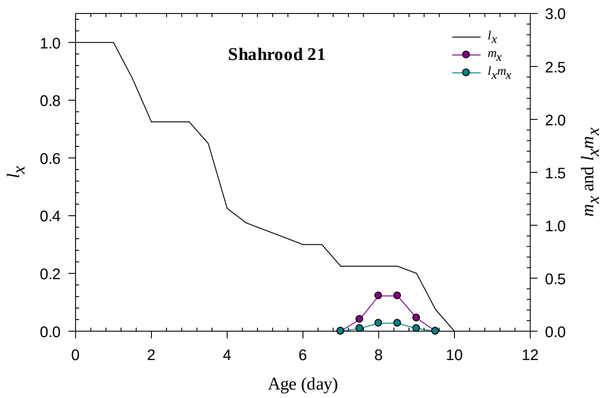


Figure 2 Age-specific survival rate (l_x), age-stage specific maternity (l_xm_x), and age-specific fecundity (m_x) of *Hyalopterus amygdali* reared on different almond cultivars.

The life expectancy (e_{xj}) of adult aphids was lowest on 'Shahrood 21' compared to the other varieties (Fig. 3). The peak of age-stage-specific reproductive values (v_{xj}) occurred at 5.5, 5, 6, 6, and 7.5 days on 'Mamaei', 'Rabie', 'Shahrood 7', 'Ferragnes', and 'Shahrood 21', respectively (Fig. 4).

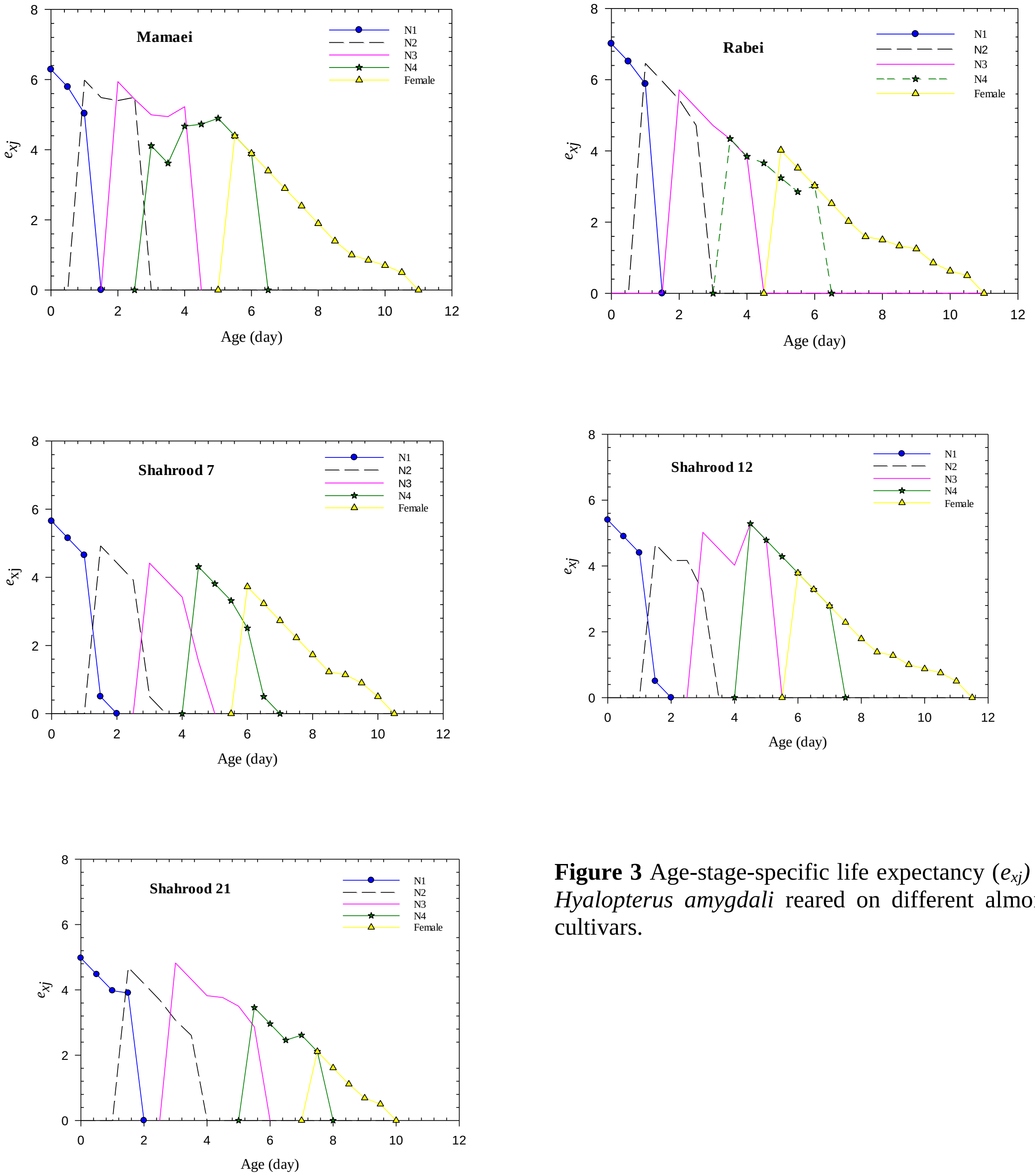


Figure 3 Age-stage-specific life expectancy (e_{xj}) of *Hyalopterus amygdali* reared on different almond cultivars.

Discussion

Hyalopterus amygdali is one of the most important pests in almond orchards in different parts of Iran, significantly reducing crop growth and yield (Nourbakhsh *et al.*, 2007; Ghorbali *et al.*, 2008; Jafarlou, 2017). Despite using mineral oils and both contact and systemic pesticides, successful control has not been achieved over many years. Additionally, the alternative management program is essential due to the challenges associated with chemical control, especially the development of resistance, as well as the economic losses caused by this pest.

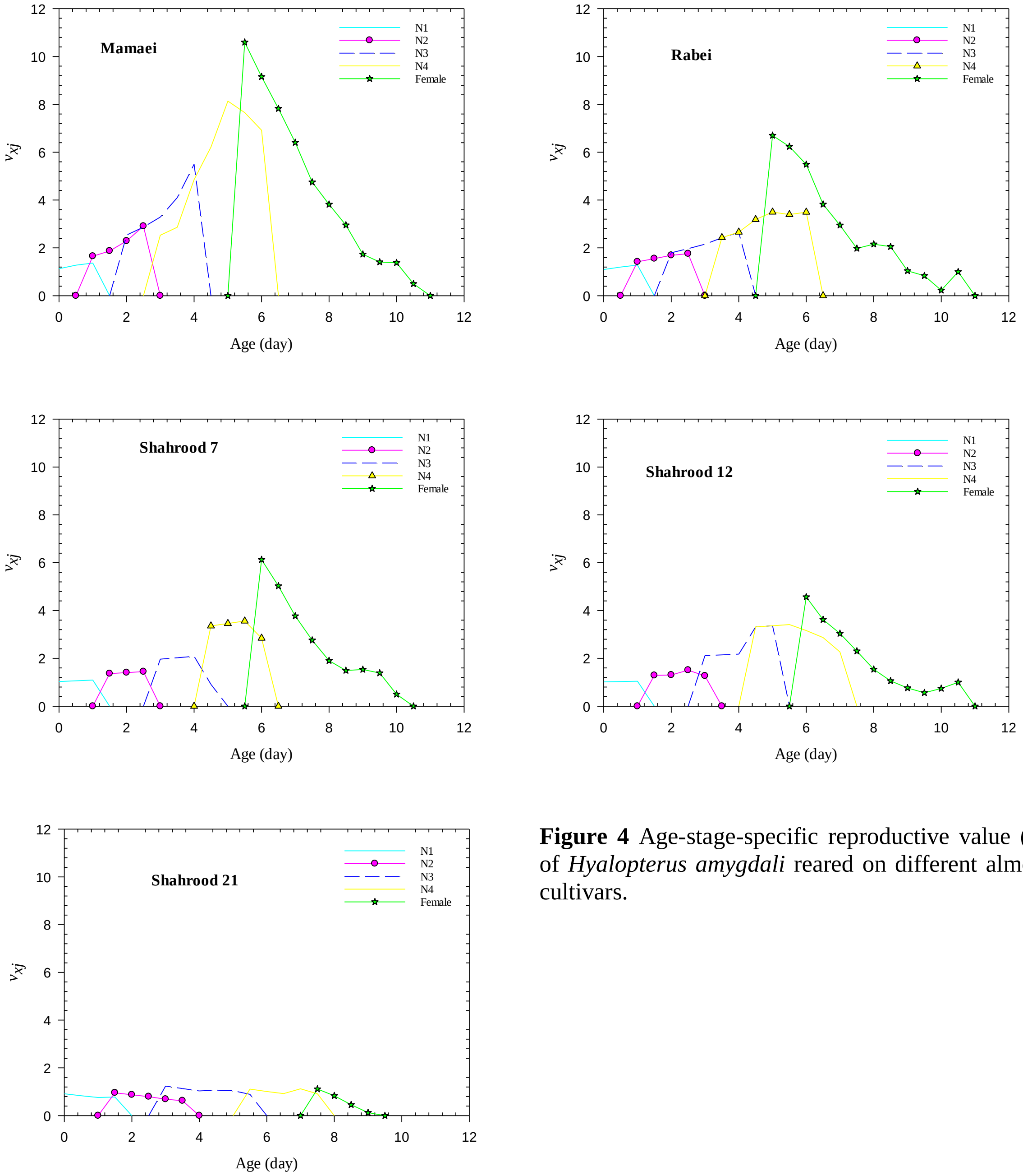


Figure 4 Age-stage-specific reproductive value (v_{xj}) of *Hyalopterus amygdali* reared on different almond cultivars.

Host plant resistance, a key component of integrated pest management (IPM), offers an alternative to reduce pesticide applications and address challenges in pest management systems (Panda and Khush, 1995).

In this study, we evaluated the effects of different almond cultivars on the demography and life table parameters of the mealy almond aphid under laboratory conditions to assess antibiosis resistance. The results showed that the host plant had a considerable effect on the development, survival, and fecundity of the mealy almond aphid. 'Mamaei' was the most suitable cultivar for *H. amygdali* in terms of development time, survival rate, fecundity, and population growth. Our findings are consistent with those of Özgökçe and Atlıhan (2005) and Jafarlou (2017), who reported significant effects of different almond and apricot cultivars on the development, survival, and reproduction of aphids. According to Jafarlou (2017), among the five almond cultivars ('Sahand', 'Shekoofe', 'Azar', 'Ferragnes', and 'Ne Plus Ultra') tested under field conditions (in a cage), 'Shekoofe' was more susceptible, whereas 'Sahand' was considered a relatively resistant cultivar to the mealy almond aphid, *H. amygdale,* compared to the other cultivars. Another study by Özgökçe and Atlıhan (2005) on four apricot cultivars ('Tyrinte', 'Sakıt', 'Colomer', and 'Bebeco') showed that the population of the mealy plum aphid, *Hyalopterus pruni*, on the susceptible 'Tyrinte' cultivar was considerably higher than on the other tested cultivars. They also recorded the shortest (9.4 days) and the longest (10.2 days) immature periods on the 'Tyrinte' and 'Bebeco' cultivars, respectively.

Plant defenses directly influence life-table parameters, especially the intrinsic rate of increase, of phytophagous insects and mites (Krips *et al*., 1998; Agrawal, 2000; Saeidi *et al*., 2021). Therefore, many researchers have used life table parameters to evaluate the susceptibility or resistance of host plants to various pests. In the current study, we analyzed the most important life-table parameters for describing the population growth of *H. amygdali* on almond cultivars. The R, rm, and λ values were higher on 'Mamaei' than on the other tested cultivars. These higher values on 'Mamaei' were due to greater survival to adulthood, a higher daily rate of offspring production, and the highest total fecundity. Although there was no significant difference between the r_m and λ values obtained on 'Mamaei' and 'Rabie', the values of adult longevity, oviposition period, and fecundity were higher on 'Mamaei' than on 'Rabie'. According to Saeidi *et al.* (2021), among the nine almond cultivars tested against the spider mite, *Schizotetranychus smirnovi* Wainstein, 'Mamaei', 'Nonpareil', and 'Rabie' supported shorter developmental times, higher fecundity and growth rates, and lower mortality rates. In contrast, 'Shekoofe' and 'Shahrood$_{21}$', resulted in longer developmental times, lower fecundity, and lower mortality and growth rates, leading them to be classified as resistant cultivars to *S. smirnovi*. According to Özgökçe and Atlıhan(2005), *H. pruni* showed the highest intrinsic rate of increase and net reproductive rate on 'Tyrinte' compared to other apricot cultivars. The low adult longevity and reduced fecundity of the aphid on 'Shahrood 21' observed in the present study may be attributed to antibiosis in this cultivar. Studies indicate that the chemical composition of host plant leaves significantly influences pest development rates, mortality, and reproductive potential (Toros, 1974; Van de Vrie *et al*., 1972).

Plant resistance has been recognized as a fundamental tool for integrated pest management programs (Zehnder *et al*., 2007). Therefore, the different resistance levels observed in this study may provide valuable information for managing *H. amygdale* in almond orchards. Among the tested cultivars, 'Mamaei' appeared to be the most favorable, whereas 'Shahrood 21' was the most unsuitable host for the mealy almond aphid. Our findings may provide useful insights for IPM programs targeting mealy almond aphids, helping minimize pest damage and reduce pesticide use. Further studies are suggested to identify the morphological or phytochemical barriers that adversely affect *H. amygdale* growth and development on resistant almond cultivars.

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Declaration of conflicting interests

The authors declare that they have no conflict of interest.

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بررسی ویژگی‌های زیستی و جدول زندگی شته آردی بادام *Hyalopterus amygdali* روی پنج رقم تجاری بادام در شرایط آزمایشگاهی

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چکیده: شته آردی بادام *Hyalopterus amygdali* یکی از آفات مهمی است که هر ساله خسارت زیادی به بادام در ایران وارد می‌کند. در این پژوهش تأثیر پنج رقم بادام شامل: مامایی، ربیع، شاهرود ۷، شاهرود ۱۲ (فرانیس) و شاهرود ۲۱ روی جدول زندگی و پارامترهای رشد جمعیت شته آردی بادام بررسی شد. آزمایش در انکوباتور در دمای ۱ ± ۲۵ درجه سلسیوس، رطوبت نسبی ۵ ± ۵۰ درصد و دوره نوری ۱۰:۱۴ ساعت (تاریکی: روشنایی) انجام شد. داده‌ها با استفاده از برنامه Two-Sex MChart تجزیه و تحلیل شدند. براساس نتایج، بیشترین طول عمر شته بالغ مربوط به نمونه‌های تغذیه شده از رقم مامایی (۴/۱۱ روز) و کم‌ترین آن مربوط به نمونه‌های تغذیه شده از شاهرود ۲۱ (۱/۸۹ روز) بود. نرخ خالص تولیدمثلی (R_0) از ۶/۴۲ برای مامایی تا ۰/۲ پوره به‌ازای هر فرد در مورد شاهرود ۲۱ متغیر بود. رقم مامایی بیشترین مقدار نرخ ذاتی افزایش جمعیت (r) و نرخ متناهی افزایش جمعیت (λ) (به‌ترتیب ۰/۲۴۵ و ۱/۲۷۸ بر روز) و کوتاه‌ترین زمان مرحله نابالغ (۵/۷۹ روز) را نشان داد، درحالی‌که رقم شاهرود ۲۱ کم‌ترین مقدار r و λ (به‌ترتیب ۰/۱۸۳- و ۰/۸۳۲ بر روز) و طولانی‌ترین زمان مرحله نابالغ (۷/۷۲ روز) را نشان داد. براساس نتایج ارقام مامایی و شاهرود ۲۱ به‌ترتیب مناسبترین و نامناسب‌ترین میزبان برای این آفت بودند.

واژگان کلیدی: *Hyalopterus amygdali*، تولیدمثل، بادام، رشدونمو، تجزیه دوجنسی