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Article

Suitability of different pollen grains and *Tetranychus urticae* as food for the predatory mite, *Amblyseius swirskii* (Acari: Phytoseiidae)

Fatemeh Kadkhodazadeh[1], Mahdieh Asadi[1*] and Mostafa Khanamani[2]

1. *Department of Plant Protection, College of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran; E-mails: fatemeh_kadkhodazadeh@yahoo.com, m.asadi@uk.ac.ir*
2. *Department of Plant Protection, Faculty of Agriculture, University of Jiroft, Jiroft, Iran; E-mail: m.khanamani@ujiroft.ac.ir*

[*] Corresponding author

ABSTRACT

The suitability of eight pollen diets (wild almond, date palm, oak, pomegranate, pistachio, peach, damask rose, and walnut) and also *Tetranychus urticae* Koch as natural diet on life table of the *Amblyseius swirskii* (Phytoseiidae) was determined at 25 ± 1 °C, 60 ± 5% relative humidity and photoperiod of 16:8 h (L: D). Results showed that damask rose pollen was not accepted as food and did not support the development of *A. swirskii* beyond the protonymphal and deutonymphal stage. The highest and lowest values of the intrinsic rate of increase (r) and finite rate of increase (λ) belonged to the pistachio (0.192 and 1.212 day^{-1}) and peach (0.022 and 1.023 day^{-1}) pollen, respectively. The net reproductive rate (R_0) values varied from 1.4 offspring for the peach pollen to 29.54 offspring for the pistachio. Furthermore, the highest and lowest fecundity rate was recorded on the pistachio (36.65 eggs/female) and peach (3.23 eggs/female) pollen, respectively. Measured life table parameters of *A. swirskii* reared on different diets revealed pistachio, and after that, date palm and pomegranate pollen grains to be the most suitable diets. These findings may introduce more suitable pollen diets for the rearing of this predatory mite.

KEY WORDS: Alternative diet; biological control; life table; pistachio; predatory mites.

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INTRODUCTION

The use of predatory mites as a safe tool in pest management programs has been increased due to the growing demand for alternatives to chemical pesticides (Gerson and Weintraub 2007). Among predatory mites, the family Phytoseiidae is well known to include predators, which have proved their efficacy against several mite and insect pests in different crops under both protected crops and field conditions (McMurtry *et al*. 2013). Currently many species of this family have been introduced for use in classical biological control programs. At least 20 species of this family have been commercially available and primarily applied to greenhouse plants (Zhang 2003). Some of these species are as follows: *Phytoseiulus persimilis* Athias-Henriot, *Amblyseius swirskii* (Athias-Henriot), *Neoseiulus cucumeris* (Oudemans), *Neoseiulus barkeri* Hughes, *Neoseiulus californicus* (McGregor), *Neoseiulus fallacis* (German), *Iphiseius degenerans* (Berlese), and *Galendromus occidentalis* (Nesbitt).

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Natural enemies would exhibit an improved biocontrol efficacy within greenhouse environments provided they could survive on alternative food sources (such as pollen) and build up populations (Khanamani *et al*. 2017a; Riahi *et al*. 2017a). Such an ability would also be enormously valuable in the rearing of predators in laboratories or their mass rearing for release purposes. The availability of an effective alternative diet for phytoseiid mites can eliminate many of the problems associated with their rearing (Overmeer 1985).

The effectiveness of non-prey food sources, such as pollen, honeydew, and microbes, in maintaining generalist predatory mite populations is widely accepted (McMurtry and Croft 1997). The utilization of non-prey food sources by predators is significant in biological control programs (Khanamani *et al*. 2021). It allows the predator to maintain its population in the event of prey scarcity; this is also extremely important in rearing of predators in laboratories or mass rearing programs for release purposes (Khanamani *et al*. 2017a).

One of the most successful phytoseiid mite species is *A. swirskii*, a generalist predator that preys on pest insects and mites such as two-spotted spider mites, whiteflies, thrips and serves as a biological control agent in many greenhouses (McMurtry *et al*. 2013). This comercialized biocontrol agent can be used in many protected cultivations, from vegetables to ornamental plants (Fathipour and Maleknia 2016). Its ability to control several major pests of a wide spectrum of crops in many countries has made this mite a popular and widely employed agent. Though this species is not native to Iran, it is widely imported and released in greenhouses; interestingly, it is well established in greenhouses of many regions of the country (personal observation).

Like many generalist phytoseiid mites, *A. swirskii* can develop, feed, and reproduce on non-prey food sources such as pollen (Van Rijn and Sabelis 1990), allowing its populations to build upon plants before the pests are present and to persist on the crops during periods of prey scarcity or absence. Also, they will be able to protect host plants from further colonization and population increase of the pest species (Riahi *et al.* 2016; Khanamani *et al.* 2017a). This mite's ability to feed on pollen extensively helps establish itself in high numbers in flowering plants, even before pests are present (Bolckmans and van Houten 2006).

Pollen from different plant species may differ in their nutritional value to the mites and affect their life table parameters. Pollen is a major source of proteins and lipids for mites; however, the concentrations of these nutrients in pollen grains can vary widely among host plant species (Khanamani *et al.* 2017b). Thus, the developmental and reproductive responses of phytoseiids to different pollen sources can vary considerably (McMurtry and Croft 1997; Van Rijn and Tanigoshi 1999; Goleva and Zebit 2013; Riahi *et al.* 2016; Khanamani *et al.* 2017a). Differences in resource quality can directly affect the development, reproduction, survival, and quality of the predator (Vaudo *et al*. 2015). Numerous studies have attempted to reveal the impact of different pollen grains (Goleva and Zebit 2013; Riahi *et al.* 2016; Khanamani *et al.* 2017a, b), natural diets (El-Laithy and Fouly 1992; Wimmer *et al.* 2008), and artificial diets (Nguyen *et al.* 2014; Khanamani *et al.* 2017c) on the bio-ecological parameters of the predatory mites. It has been demonstrated that some phytoseiid species' reproductive potential is highest on pollen, compared with natural prey (Zhimo and McMurtry 1990; Riahi *et al.* 2016; Khanamani *et al.* 2017a).

To develop an effective diet, it is necessary to understand the nutritional requirements of the predator in regards to its development and reproductive performance (McMurtry and Scriven 1966). Since the suitability of all plant pollen as alternative or supplementary food sources for *A. swirskii* is not known adequately, our study aimed to compare the suitability of different plant pollen grains and *T. urticae* (as control treatment) for mass rearing of *A. swirskii*. The quality of pollen grains was measured by their ability to promote growth and oviposition of the predator. With a comparison of eight different pollen as food sources, this study contributes to improving the knowledge of the pollen spectrum accepted by *A. swirskii*.

MATERIALS AND METHODS

Pollen collection

Pollen grains from wild almond (*Amygdalus scoparia* Spach), pistachio (*Pistacia vera* L.), date palm (*Phoenix dactylifera* L.), pomegranate (*Punica granatum* L.), oak (*Quercus brantii* Lindl.), peach (*Prunus persica* L. Batsch.), walnut (*Juglans regia* L.) and damask rose *(Rosa damascene* Mill.) were collected during the flowering season in 2018. All pollen grains were collected from trees in Kerman Province, Iran, except for oak pollen collected from oak jungles of Lorestan Province, Iran. The pollen grains were oven-dried (at 37 °C for 48 h) and then frozen at −20 °C for long-term storage or refrigerated at 4 °C for up to two weeks during the experiments.

Mite rearing

Two-spotted spider mites (TSSM), *Tetranychus urticae* Koch, were used as natural prey (control treatment) to feed the predatory mite. A laboratory colony of TSSM was established using specimens collected from infested weeds at the Faculty of Agriculture, Shahid Bahonar University of Kerman, Iran. These mites were cultured on laboratory-grown bean (*Phaseolus vulgaris* variety Khomein) plants in the greenhouse with natural conditions. These mites were used for laboratory rearing of *A. swirskii.*

The initial population of *A. swirskii* was obtained from Koppert Biological Systems. The specimens were transferred into rearing arenas and maintained in a climate room at 25 ±1 °C, 60 ± 5% RH, and a photoperiod of 16:8 h (L:D), as described by Khanamani *et al*. (2017a). Bean leaves infested with TSSM were added to the arena three times a week.

Experimental design

To determine how different plant pollen (date palm, oak, pomegranate, pistachio, wild almond, peach, damask rose, and walnut) affect basic life-history parameters of *A. swirskii*, age-stage two sex life tables were constructed, and the parameters were compared with those estimated on TSSM (as control treatment). *Amblyseius swirskii* was reared for one generation on each pollen diet before the initiation of the experiments.

At the beginning of the experiments, 20 pairs of both genders of the predators reared on the related diet were maintained on a green plastic substrate (three rearing units for each treatment) to obtain the synchronized eggs of *A. swirskii*. After 12h, the deposited eggs were transferred individually to the experimental units using a fine camel-hair brush, up to 70 replicates per treatment. The experimental units were similar to those described by Khanamani *et al*. (2017a). These eggs were checked daily, and the incubation period was recorded. After the emergence of larvae, the respective test diet (0.05 mg pollen /experimental unit; a mixture of different immature stages of TSSM for control treatment) was offered as food. These experimental units were checked daily using a stereomicroscope, and the duration of different life stages, mortality, and survivorship of the predator on different diets were monitored. The presence of exuviae from molting was used to determine the different immature life stages.

After the emergence of adults, females were coupled with males obtained from the same experiment or taken from a colony of the same diet. Each pair was transferred into new experimental units. Small cotton was placed in the center of the green plastic substrate as a shelter or oviposition site. The couple was kept together up to the end of the study, and the dead males were replaced by new ones. In daily observations, the duration of pre-oviposition, oviposition, and post-oviposition periods, as well as longevity and fecundity, were recorded until the death of all individuals. In pollen treatments, fresh pollen was offered in seven-day intervals, removing the older pollen to avoid fungi contamination. In control treatments, a mixture of different immature stages of TSSM was added daily. All experiments were performed at 25 ± 1 °C, 60 ± 5% RH, and a photoperiod of 16:8 h (L: D).

Electron microscopic studies of pollen

Morphological studies (pollen shape and exine pattern) of the pollens were conducted using a scanning electron microscope (Zeiss DSM-940, Zeiss, Oberkochen, Germany) equipped with an imaging software (Orion, version 6, PCI Image grabbing system for Windows) from Arya electronic optic company (Iran). Pollen was dispersed in small quantities with a sterile brush onto acetone-sterilized aluminum plates covered with a piece of conductive tab (type G 3347; 12 mm diameter). Subsequently, the pollen was dried for 30 min in an exsiccator (Duran, DIN 12491 DN 250; height 300 mm) using silica gel and gold-sputtered for 8 min (Balzers Union SCD 040).

Statistical analysis

According to the age-stage, two-sex life table theory, the raw demographic data of all individuals was analyzed (Chi and Liu 1985; Chi 1988). Data analyses and population parameters (r, λ, GRR, R_0 and T) were done using the TWOSEX-MSChart program (Chi 2018). Equations used in calculations of two-sex life table parameters of *A. swirskii* on different diets are presented in Table 1. The variances and standard errors of the pre-adult survival rate and population parameters were estimated by a bootstrap procedure (Efron and Tibshirani 1992). To obtain stable estimates, we used 100,000 bootstraps. The differences of life table bootstrap values among the treatments were compared using paired bootstrap test based on confidence interval. Data were tested for normality using Kolmogorov-Smirnov test before subjecting them to analyses. Differences in the duration of different life stages and fecundity of the predator on the treatments were compared using one-way analysis of variance (ANOVA). If significant differences were detected, multiple comparisons were made using the Tukey test ($p < 0.05$). Statistical analyses were carried out using SPSS 19 software.

Table 1. Equations used for calculation of two-sex life table parameters of *Amblyseius swirskii* on different tested diets.

Parameter	Unit	Description	Equation
x	day	Age class of individuals from age stage	
N_x	individual	Number of surviving individuals entering age class x	
l_x	proportion	Age-specific survivorship, the proportion of surviving individuals from birthday to age x.	$l_x = \frac{N_x}{N_0}$ & $l_x = \sum_{j=1}^{k} s_{xj}$
S_{xj}	proportion	Age-specific survival rate, the proportion of surviving individuals from birthday to age x and stage j	
m_x	egg	Age-specific fecundity, daily number of eggs produced per individual of age x	$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$
f_{xj}	egg	Age-stage fecundity, daily number of eggs produced per female of age x	
r	day^{-1}	Intrinsic rate of increase	$\sum_{x=0}^{\omega} e^{-r(x+1)} l_x m_x = 1$
λ	day^{-1}	Finite rate of increase	$\boldsymbol{\lambda} = e^r$
R_0	offspring/individual	Net reproductive rate	$R_0 = \sum^{\omega} \sum^{k} s_{xj} f_{xj}$
GRR	offspring/individual	Gross reproductive rate	$GRR = \sum^{\beta} m_x$
T	day	Mean generation time	$T = \frac{lnR_0}{r}$

* where k is the number of stages, and ω is maximum age (Chi and Liu 1985).

RESULTS

Duration of different life stages

The pollen of damask rose was not accepted as food and did not support the development of *A. swirskii* beyond the protonymphal and deutonymphal stage. Therefore, we could not evaluate the biological parameters of the predatory mite on this pollen. Duration of different immature life stages of *A. swirskii* fed on seven other plant pollen, and TSSM is presented in Table 2.

Except for the larval period, there were significant differences in duration of the other life stages of the predatory mite on different tested diets. The developmental time was significantly different among pollen diets. The predator individuals fed on the pistachio pollen experienced a longer pre-adult period. In contrast, shorter pre-adult duration was observed when the predator was fed on date palm pollen and also on oak pollen. Male and female longevity of adult *A. swirskii* was significantly affected by tested pollen diets; the shortest period of adult longevity was associated with those mites reared on peach pollen.

Table 2. Duration of different life stages (days) and fecundity (eggs) (± SE) of *Amblyseius swirskii* reared on *Tetranychus urticae* and seven different plant pollen grains.

Parameter	**Natural prey**	**Pollen diets**						
	T. urticae	**Wild-Almond**	**Date palm**	**Peach**	**Oak**	**Pistachio**	**Pomegranate**	**Walnut**
Egg	1.98 ± 0.09^{c}	2.00 ± 0.07^{bc}	1.67 ± 0.09^{d}	2.03 ± 0.07^{b}	1.97 ± 0.03^{c}	1.94 ± 0.10^{c}	2.21 ± 0.09^{ab}	2.23 ± 0.09^{a}
Larva	1.05 ± 0.09^{a}	1.1 ± 0.05^{a}	1.03 ± 0.03^{a}	1.03 ± 0.03^{a}	1.03 ± 0.03^{a}	1.03 ± 0.03^{a}	1.04 ± 0.04^{a}	1.03 ± 0.03^{a}
Protonymph	1.93 ± 0.05^{a}	1.76 ± 0.11^{abc}	1.7 ± 0.08^{bcd}	1.54 ± 0.11^{cd}	1.46 ± 0.09^{d}	1.86 ± 0.1^{ab}	1.68 ± 0.09^{bcd}	1.7 ± 0.12^{abcd}
Deutonymph	1.74 ± 0.1^{ab}	1.75 ± 0.1^{ab}	1.22 ± 0.08^{d}	1.48 ± 0.11^{bc}	1.26 ± 0.08^{cd}	1.92 ± 0.12^{a}	1.32 ± 0.1^{cd}	1.69 ± 0.13^{ab}
Pre-adult	6.5 ± 0.10^{bc}	6.65 ± 0.15^{ab}	5.57 ± 0.12^{e}	6.13 ± 0.17^{de}	5.7 ± 0.14^{e}	6.75 ± 0.16^{a}	6.25 ± 0.1^{cd}	6.69 ± 0.17^{ab}
Male longevity	34.67 ± 3.46^{a}	22.10 ± 1.49^{cd}	39.09 ± 3.39^{a}	18.09 ± 1.19^{d}	31.51 ± 1.75^{b}	42.70 ± 2.67^{a}	23.46 ± 3.45^{cd}	25.07 ± 1.27^{c}
Female longevity	37.77 ± 2.13^{bc}	25.67 ± 0.95^{d}	43.87 ± 2.49^{b}	16.77 ± 1.24^{e}	36.59 ± 1.32^{c}	53.44 ± 0.96^{a}	36.84 ± 1.03^{c}	27.52 ± 0.06^{d}
APOP	2.16 ± 0.21^{c}	3.27 ± 0.15^{a}	1.72 ± 0.13^{d}	3.20 ± 0.24^{ab}	2.47 ± 0.19^{c}	2.13 ± 0.09^{c}	2.7 ± 0.13^{b}	2.53 ± 0.18^{b}
TPOP	9.94 ± 0.18^{c}	10.2 ± 0.24^{a}	7.28 ± 0.19^{e}	9.8 ± 0.38^{ab}	8.06 ± 0.29^{d}	8.89 ± 0.17^{c}	8.95 ± 0.13^{c}	9.22 ± 0.37^{c}
Oviposition	23.22 ± 1.23^{a}	6.11 ± 0.40^{d}	23.72 ± 1.03^{a}	3.69 ± 0.46^{e}	10.47 ± 0.47^{c}	23.13 ± 0.79^{a}	12.62 ± 0.51^{b}	8.98 ± 0.61^{c}
Fecundity (eggs/female)	34.77 ± 1.83^{ab}	6.26 ± 0.59^{f}	31.22 ± 1.55^{b}	3.23 ± 0.67^{g}	14.53 ± 0.79^{d}	36.65 ± 1.26^{a}	18.33 ± 0.81^{c}	9.83 ± 0.58^{e}

[*] APOP: adult pre-oviposition period; TPOP: total pre-oviposition period (from egg to the first oviposition).
The means followed by different letters in the same row are significantly different ($P < 0.05$, Tukey).

Reproductive periods and fecundity

Reproductive periods and fecundity of *A. swirskii* fed on different diets are shown in Table 2. The shortest duration of both the adult pre-ovipositional period (APOP) and total pre-ovipositional period (TPOP) was related to *A. swirskii* reared on date palm pollen. In contrast, the longest period of the two parameters was related to the mites fed on wild almond pollen. The highest number of oviposition days was related to the individuals reared on the TSSM and date palm and pistachio pollen. The pistachio pollen was a suitable diet for the predator's oviposition and fecundity; this diet increased fecundity to the greatest extent, only to be succeeded by individuals reared on the natural prey (TSSM).

Survival and fecundity curves

The curves of age-stage-specific survival rates (s_{xj}) of *A. swirskii* (Fig. 1) show the probability that a newborn individual would survive to age x and stage j. The age specific survivorship (l_x) (Fig.

2) shows the probability that a newborn individual would survive to age *x* and is calculated by pooling of all individuals of both sexes. In addition, the stage mortality of *A. swirskii* on different pollen is presented in Table 3. According to these results, the predator's highest pre-adult mortality was on the peach pollen (of course, after damask rose pollen with 100% mortality in immature stage). At the same time, no immature mortality was observed on pistachio and pomegranate pollen grains.

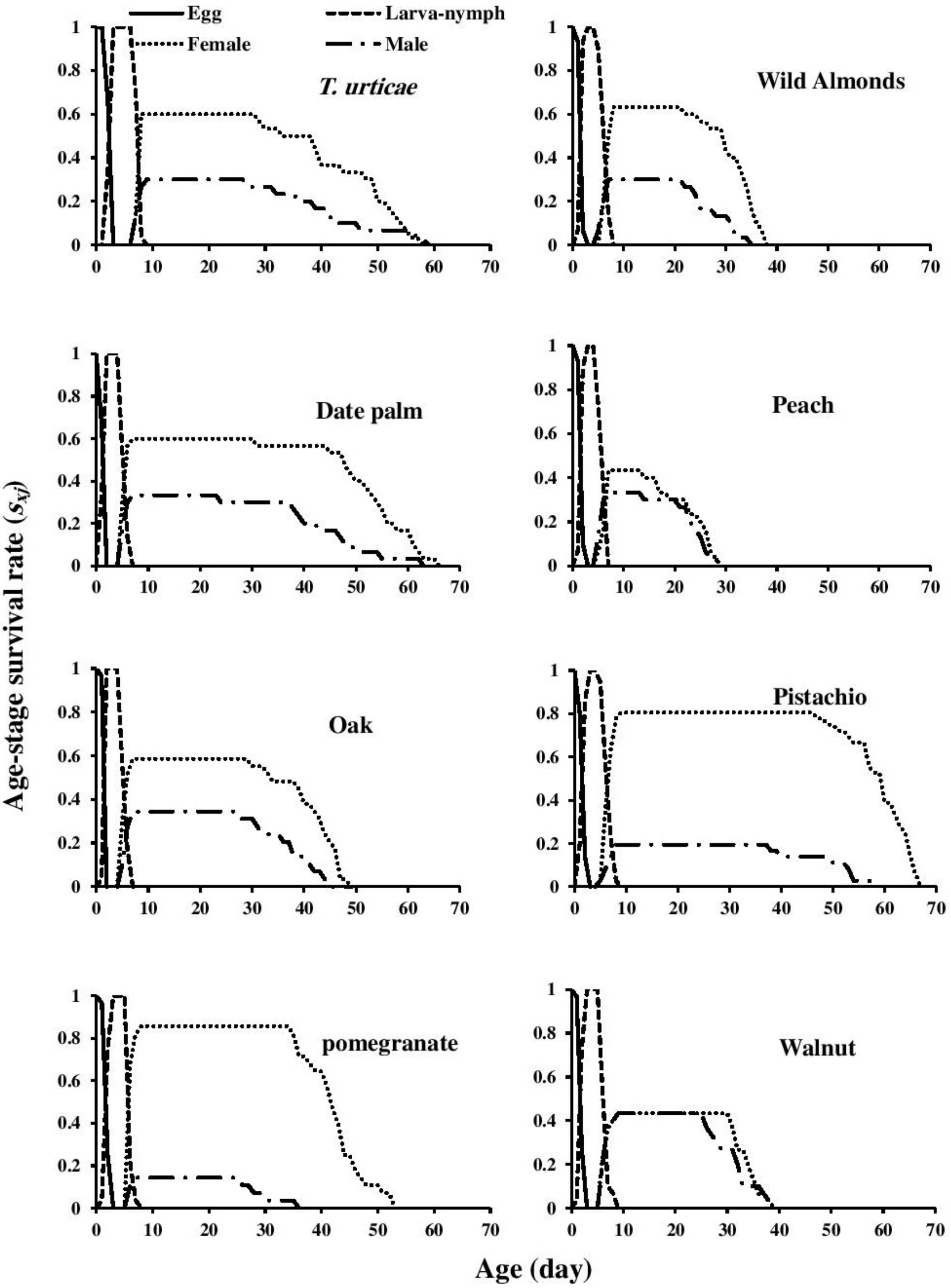

Figure 1. Age-stage-specific survival rate (s_{xj}) of *Ambluseius swirskii* fed on *Tetranychus urticae* and seven different plant pollen grains.

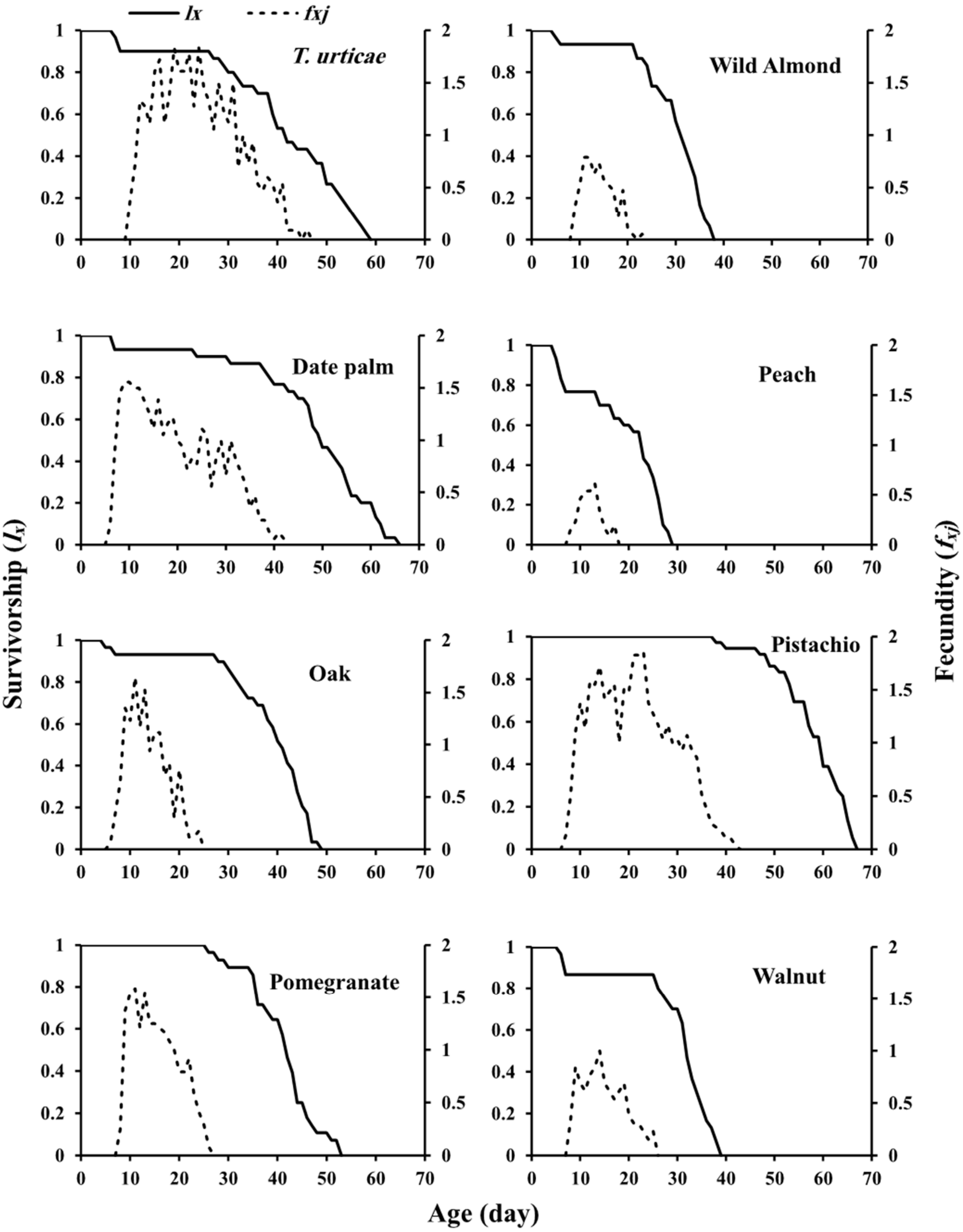

Figure 2. Age-specific survivorship (l_x), and age-stage-specific fecundity (f_{xj}) of *Ambluseius swirskii* fed on *Tetranychus urticae* and seven different plant pollen grains.

Age-stage specific fecundity values (f_{xj}) of *A. swirskii* fed on TSSM, and different plant pollen diets are shown in Figure 2. These fecundity curves showed that the predatory mite had the highest fecundity on pistachio pollen, followed by TTSM and date palm pollen, respectively. The lowest fecundity was on peach and wild almond pollen.

Table 3. Stage mortality (%) of *Amblyseius swirskii* reared on different tested diets.

Parameter	Natural prey	Pollen diets						
	T. urticae	Wild-Almond	Date palm	Peach	Oak	Pistachio	Pomegranate	Walnut
Egg	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
Larva	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
Protonymph	0.00 ± 0.00^{b}	0.03 ± 0.00^{a}	0.00 ± 0.00^{b}	0.06 ± 0.00^{a}	0.03 ± 0.00^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}
Deutonymph	0.10 ± 0.02^{a}	0.03 ± 0.01^{a}	0.07 ± 0.01^{a}	0.17 ± 0.06^{a}	0.03 ± 0.01^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.13 ± 0.05^{a}
Pre-adult	0.10 ± 0.01^{bc}	0.06 ± 0.01^{c}	0.06 ± 0.01^{c}	0.23 ± 0.04^{a}	0.07 ± 0.01^{c}	0.00 ± 0.00^{d}	0.00 ± 0.00^{d}	0.13 ± 0.01^{b}
Female	0.60 ± 0.08^{bc}	0.63 ± 0.09^{bc}	0.60 ± 0.07^{bc}	0.43 ± 0.09^{c}	0.59 ± 0.09^{bc}	0.81 ± 0.07^{ab}	0.88 ± 0.06^{a}	0.43 ± 0.09^{c}
Male	0.30 ± 0.05^{ab}	0.30 ± 0.07^{ab}	0.33 ± 0.08^{ab}	0.33 ± 0.09^{ab}	0.34 ± 0.08^{ab}	0.19 ± 0.04^{b}	0.14 ± 0.05^{b}	0.43 ± 0.09^{a}

The means followed by different letters in the same row are significantly different among treatments using the paired bootstrap test at 5% significance level.

Population growth parameters

Age-stage, two-sex life table parameters were calculated based on data of the entire cohort. Table 4 summarizes the effect of different pollen diets on the life table parameters of *A. swirskii*. The analyses of the life table parameters of *A. swirskii* indicated significant differences among different pollen diets. The data showed that gross reproductive rate (*GRR*), net reproductive rate (R_0), intrinsic rate of increase (r), and finite rate of increase (λ) of the individuals that consumed the pistachio pollen were higher than other treatments. The predator's highest growth rate was on the pistachio pollen, followed by the date palm and pomegranate pollen grains. Besides, our results revealed that the longest mean generation time (T) of this predator was obtained on the individuals reared on the walnut pollen. In contrast, the lowest values of this parameter were observed on the peach and oak pollen grains.

Table 4. The mean (± SE) two-sex life table parameters of *Amblyseius swirskii* reared on *Tetranychus urticae* and seven different plant pollen grains.

Parameter	Natural prey	Pollen diets						
	T. urticae	Wild-Almond	Date palm	Peach	Oak	Pistachio	Pomegranate	Walnut
r (day^{-1})	0.146 ± 0.009^{c}	0.094 ± 0.011^{d}	0.188 ± 0.012^{ab}	0.022 ± 0.024^{e}	0.158 ± 0.013^{bc}	0.192 ± 0.006^{a}	0.187 ± 0.006^{ab}	0.094 ± 0.015^{d}
λ (day^{-1})	1.158 ± 0.010^{c}	1.098 ± 0.013^{d}	1.208 ± 0.015^{ab}	1.023 ± 0.024^{e}	1.171 ± 0.015^{bc}	1.212 ± 0.008^{a}	1.206 ± 0.008^{ab}	1.099 ± 0.017^{d}
GRR (offspring/ individual)	24.75 ± 3.51^{ab}	4.25 ± 0.68^{e}	20.45 ± 2.97^{bc}	1.88 ± 0.51^{f}	9.14 ± 1.44^{d}	29.56 ± 2.64^{a}	15.72 ± 1.36^{c}	4.91 ± 1.003^{e}
R_0 (offspring/ individual)	20.89 ± 3.30^{b}	3.96 ± 0.66^{d}	18.70 ± 2.90^{b}	1.40 ± 0.40^{e}	8.50 ± 1.41^{c}	29.54 ± 2.64^{a}	15.71 ± 1.36^{b}	15.1 ± 0.41^{c}
T (day)	20.63 ± 0.25^{b}	14.47 ± 0.34^{d}	15.44 ± 0.36^{d}	12.61 ± 2.02^{e}	13.45 ± 0.38^{e}	17.56 ± 0.30^{c}	14.66 ± 0.22^{d}	28.80 ± 0.22^{a}

[*] The means followed by different letters in the same row are significantly different among treatments using the paired bootstrap test at 5% significance level (100000 bootstrap samples).

DISCUSSION

Information on how different diets can influence reared predatory mites' quality is essential to develop a compressive program in large-scale rearing of these mites. Pollen is a food source for numerous insects and mites, including many natural enemies' species (Goleva and Zebit 2013). The effectiveness of non-prey food items, such as pollen, in laboratory and mass-rearing phytoseiid mites is widely accepted. However, different plant species' pollen may differ in their nutritional value to different phytoseiid mite species. Life table parameters are powerful tools to analyze and understand the impact of external factors such as different diets on the quality of produced predatory mites (Khanamani *et al*. 2017a).

Our study indicated significant influences of different plant pollen on the fitness of the predatory mite, *A. swirskii*. We showed that this predatory mite could feed and develop into adults on all tested pollen grains except on damask rose pollen, improving current knowledge on pollen range accepted by this predator. Nemati *et al*. (2019) demonstrated that *A. swirskii* could develop into adult stage on different pollen grains (such as apricot, pear, opium poppy, and date palm) except for hollyhock pollen, where eggs failed to develop to maturity. Pre-adult mortality rate after damask rose pollen feeding can be due to the possible presence of toxic secondary metabolites and deficiency or absence of primary essential nutrients for growth and development in this pollen diet. The predator individuals fed on date palm pollen and oak pollen experienced shorter pre-adult duration. These two pollen grains can be considered the favorite food for the predatory mite's immature stages. The developmental time of *A. swirskii* has been reported to be 7.45–8.80 and 8.38–9.64 days on different artificial diets and factitious preys, respectively (Riahi *et al*. 2017b, c); these values are longer than the developmental time on any of the pollen studied here. Therefore, these pollen grains can be considered the favorite food for the immature stages of *A. swirskii* in production systems.

Nevertheless, there was no immature mortality on the pistachio and pomegranate pollen. The predator's highest immature mortality rate was observed on the peach pollen, indicating a low nutritional value of this pollen. Deficiency or absence of primary essential nutrients (especially proteins) in the mentioned pollen grains for development may be the root of such differences. Differences in morphological features of pollen surface and secondary metabolites can also cause such differences. The nutritional values and the quality of pollen nutrients depend on the plant species and the pollination type (Somerville and Nicol 2006).

Differences in survival rates, developmental times, and reproductive rates were reflected in the life table parameters, especially in the r-value. The highest growth rate (r) of the predator was on the pistachio pollen (0.192 day^{-1}), followed by the date palm (0.188 day^{-1}) and pomegranate (0.187 day^{-1}) pollen. These growth rates exceed the values reported on *T. urticae* (0.134 day^{-1}), eggs of *Ephestia kuehniella* Zeller (0.119), decapsulated cysts of *Artemia franciscana* Leach (0.135 day^{-1}), maize pollen (0.172 day^{-1}), date palm pollen (0.080 day^{-1}), bee-collected pollen (−0.101 day^{-1}), (Riahi *et al*. 2017a, b), and *Frankliniella occidentalis* (Pergande) (0.056 day^{-1}) and *Thrips tabaci* (Lindeman) (0.024 day^{-1}) (El-Laithy and Fouly 1992; Wimmer *et al*. 2008). The highest growth rates in this study did not show significant differences with those reported for this predator when fed on almond pollen (0.185 day^{-1}) (Riahi *et al*. 2017b) and decapsulated cysts of *A. franciscana* (0.182 day^{-1}) (Nguyen *et al*. 2014). However, r values reported on *Aculops lycopersici* (Massee) (0.201 day^{-1}) and *Bemisia tabaci* Gennadius (0.213 day^{-1}) (Nomikou *et al*. 2001; Park *et al*. 2011) were higher than those measured here. The differences between these findings may be due to the differences in the quality of nutrients in diets, source of the predator populations, rearing techniques, experimental conditions (especially temperature), and different statistical analyses.

The protein content of pollen is believed to be one of the best indicators for nutritive quality as it is closely linked to the performance of the consumers (Roulston and Cane 2000; Khanamani *et al*. 2017a, d). Khanamani *et al*. (2017a) reported that due to the higher protein content in almond pollen (*Prunus amygdalus*), the performance of the predator on this pollen was greater than on other pollen diets. Therefore, the different suitability classes presented here for different tested pollen may be related to the amount of protein content. Also, potentially toxic secondary metabolites, deficiency or absence of primary essential nutrients for growth, development, and fecundity of this mite could also be explanatory of these differences. However, the value of r on the date palm pollen in the current study was higher than the values reported by Riahi *et al*. (2017a). The date palm pollen is prepared from different palm cultivars in various provinces of the south of Iran. Our different results might be due to the different quality of palm pollen of different varieties.

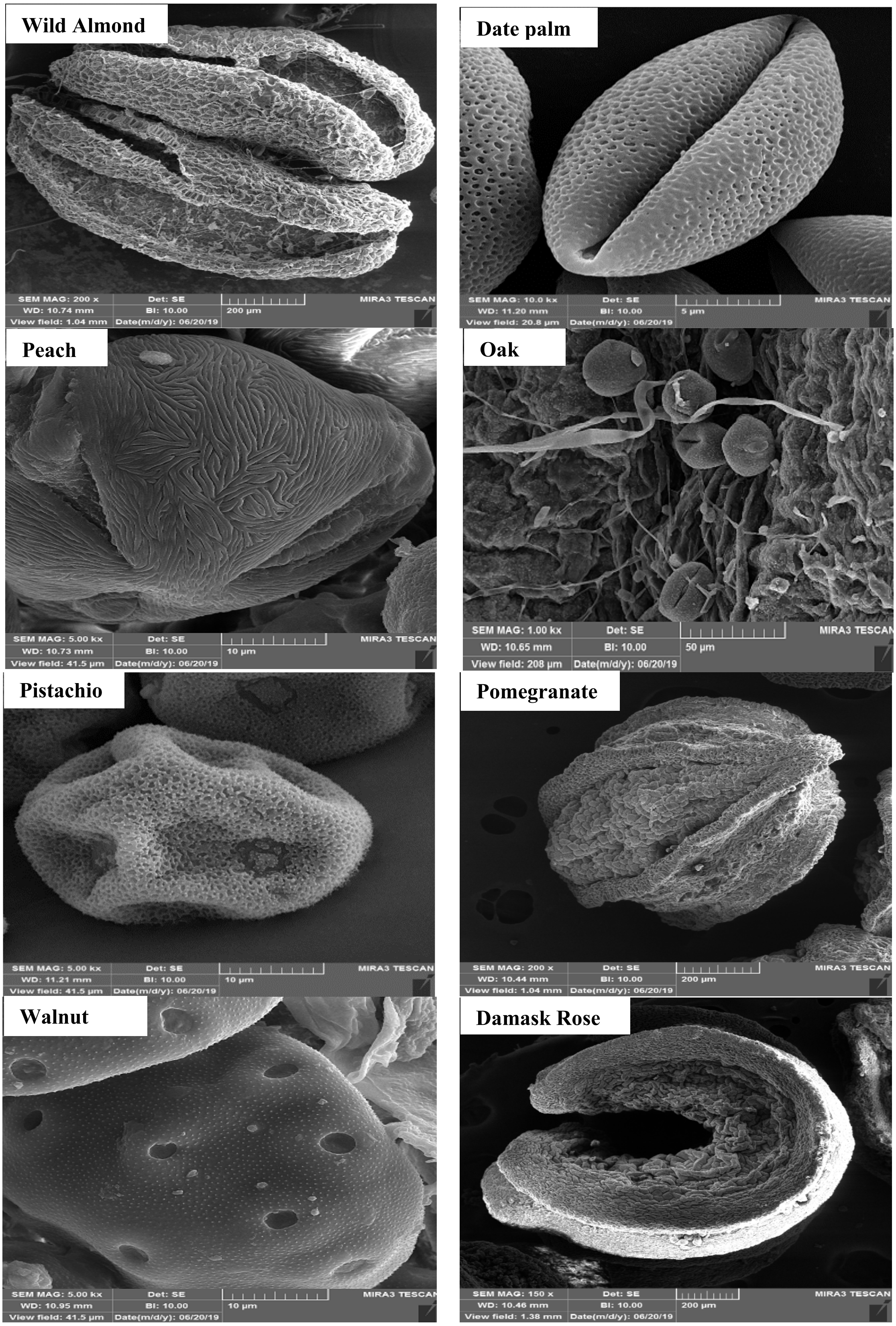

Figure 3. Pollen shape of eight different plant pollens prepared using a Scanning Electron Microscopy (SEM).

Suitability of the tested pollen grains for the reproduction of *A. swirskii* can be classified into five groups: (1) highly suitable: pistachio, date palm, and pomegranate pollen; (2) suitable: oak pollen;

(3) relatively suitable: wild almond and walnut pollen; (4) poor: peach pollen; (5) very poor or unfavorable: damask rose pollen. Our results indicated that pistachio, date palm, and pomegranate pollen are more preferable than the natural prey food (*T. urticae*) owing to higher value of *r*, and shorter mean generation times.

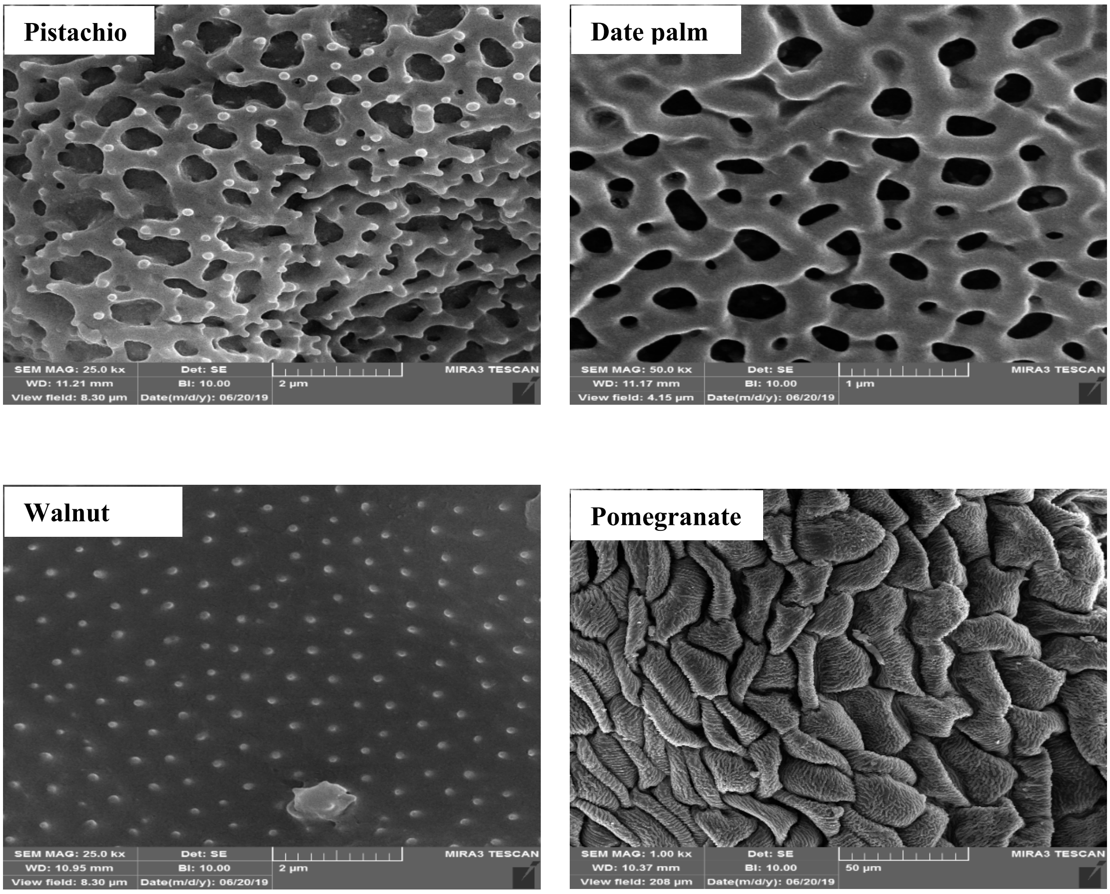

Figure 4. Exine patterns of four plant pollens prepared using a Scanning Electron Microscopy (SEM).

Finally, shape and exine patterns of pollen grains were provided in this study using a Scanning Electron Microscopy (Figs. 3, 4). As shape, size, aperture, spine and exine patterns in the pollen of different plant species are completely different, these morphological diversities can also be the reason of differences in suitability of different pollen diets tested. Exine thickness and grain hardness of different pollens, however, cannot be determined by their shapes and exine patterns. Therefore, further studies for determination of exine thickness and grain hardness of different pollens and their relationship with bioecological parameters is recommended.

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مطلوبیت گرده گیاهان مختلف و *Tetranychus urticae* برای پرورش کنهٔ شکارگر *Amblyseius swirskii* (Acari: Phytoseiidae)

فاطمه کدخدازاده[۱]، مهدیه اسدی[۱*] و مصطفی خنامانی[۲]

۱. گروه گیاهپزشکی، دانشکدهٔ کشاورزی، دانشگاه شهید باهنر کرمان، کرمان، ایران؛ رایانامه‌ها: fatemeh_kadkhodazadeh@yahoo.com؛ m.asadi@uk.ac.ir
۲. گروه گیاهپزشکی، دانشکدهٔ کشاورزی، دانشگاه جیرفت، کرمان، ایران؛ رایانامه: M.khanamani@ujiroft.ac.ir

[*] نویسنده مسئول

چکیده

مطلوبیت هشت گردهٔ گیاهی (بادام کوهی، خرما، بلوط، انار، پسته، هلو، گل محمدی، و گردو) و همچنین کنهٔ تارتن به عنوان طعمه طبیعی (شاهد) روی آماره‌های جدول زندگی کنهٔ شکارگر *Amblyseius swirskii* (Acari: Phytoseiidae) در شرایط آزمایشگاهی در دمای ۱ ± ۲۵ درجهٔ سلسیوس، رطوبت نسبی ۵ ± ۶۰ درصد و طول دوره روشنایی به تاریکی ۱۶ به ۸ ساعت، بررسی شد. نتایج نشان داد گردهٔ گل محمدی مورد پذیرش کنهٔ شکارگر واقع نشد و کنه‌های تغذیه کرده از این گرده نتوانستند به مرحلهٔ فراتر از پورهٔ سن یکم و دوم برسند. بیشترین و کمترین مقادیر ذاتی افزایش جمعیت (r) و نرخ متناهی افزایش جمعیت (λ) به ترتیب مربوط به افراد پرورش یافته روی گردهٔ پسته (۰/۱۹۲ و ۱/۲۱۲ بر روز) و گردهٔ هلو (۰/۰۲۲ و ۱/۰۲۳ بر روز) بود. مقادیر خالص تولید مثل (R_0) از ۱/٤ نتاج روی گردهٔ هلو تا ۲۹/٥٤ نتاج روی گردهٔ پسته متغیر بود. افزون براین، بیشترین و کمترین میزان باروری به ترتیب روی گردهٔ پسته (۳٦/٦٥ تخم به ازای هر ماده) و گردهٔ هلو (۳/۲۳ تخم به ازای هر ماده) ثبت شد. اندازه‌گیری آماره‌های جدول زندگی کنهٔ شکارگر *A. swirskii* پرورش یافته روی غذاهای مختلف نشان داد که گردهٔ پسته، و پس از آن گردهٔ خرما و انار مناسب‌ترین رژیم غذایی برای پرورش این کنه شکارگر هستند. یافته‌های این پژوهش ممکن است رژیم‌های غذایی مناسب گرده را برای پرورش این کنه شکارگر معرفی کند.

واژگان کلیدی: رژیم غذایی جایگزین؛ مهار زیستی؛ جدول زندگی؛ پسته؛ کنه‌های شکارگر.

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