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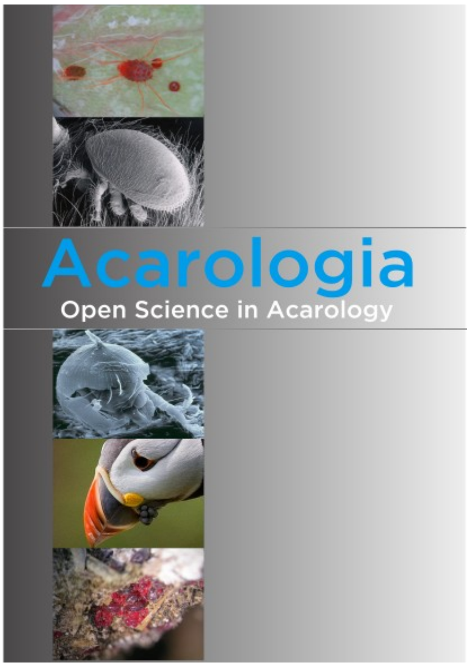

ISSN 0044-586X (print), ISSN 2107-7207 (electronic)

The digitalization of Acarologia papers prior to 2000 was supported by Agropolis Fondation under the reference ID 1500-024 through the « Investissements d'avenir » programme (Labex Agro: ANR-10-LABX-0001-01)

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Comparison of natural prey *Tetranychus turkestani*, date palm pollen, and bee pollen diets on development, reproduction, and life table parameters of the predator *Amblyseius swirskii*

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Original research

ABSTRACT

The predatory mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) is produced commercially for biological control of insects and mites on crop plants around the world. The aim of this study was to compare the effects of a diet of natural prey, *Tetranychus turkestani* Ugarov and Nikolskii (Acari: Tetranychidae), date palm pollen, or bee-collected pollen on *A. swirskii* development, reproduction, and life table parameters. Completely randomized, no-choice experiments were conducted in replicated experimental units, i.e., 3 x 3 cm plastic sheets inside Petri dishes. A life table analysis was also conducted. Results indicated that diet type did not affect *A. swirskii* preimaginal survival; it ranged from 97-100% on *T. turkestani* and both pollen diets. However, total development time was significantly shorter for *A. swirskii* females fed date palm pollen than *T. turkestani* or bee pollen. Adult females fed *T. turkestani* lived longer, had longer oviposition periods, and produced more eggs. The intrinsic rate of natural increase (0.396 d<$^{-1}$) was higher for *A. swirskii* fed date palm pollen than *T. turkestani* or bee pollen. The finite rate of increase, net reproductive rate, and gross reproductive rate did not differ significantly between *A. swirskii* fed date palm pollen or *T. turkestani*. Mean generation time (7.56 d) and population doubling time (1.043 d) were shorter for *A. swirskii* fed date palm pollen than *T. turkestani* or bee pollen. This study suggests that the *T. turkestani* diet or date palm pollen diet is suitable for *A. swirskii*. Date palm pollen has great potential as a cost effective diet to mass produce *A. swirskii* in the absence of natural prey. Future research could determine whether long-term rearing on date palm pollen reduces the ability of *A. swirskii* to locate, capture, and consume *T. turkestani* or other *Tetranychus* species on crop plants.

Keywords agricultural acarology; biological control; life table analysis; nutrition; rearing

Received 05 May 2021
Accepted 12 October 2021
Published 21 October 2021

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Academic editor
Palevsky, Eric

https://doi.org/10.24349/G9ed-QB9h

ISSN 0044-586X (print)
ISSN 2107-7207 (electronic)

Introduction

Amblyseius swirskii Athias-Henriot (Acari: Phytoseiidae) is a type III generalist predatory mite, which has a wide diet range including insect and mite prey, pollen, plant exudates, and honeydew (McMurtry *et al.* 2013). More specifically, laboratory studies indicate that *A. swirskii* develops and reproduces on a diet of tetranychid mites (Riahi *et al.* 2017b), eriophyid

How to cite this article Rahmani Piyani A. *et al.* (2021), Comparison of natural prey *Tetranychus turkestani*, date palm pollen, and bee pollen diets on development, reproduction, and life table parameters of the predator *Amblyseius swirskii*. **Acarologia 61(4): 890-900.** https://doi.org/10.24349/G9ed-QB9h

mites (Park *et al.* 2010), tenuipalpid mites (Peña *et al.* 2009), tarsonemid mites (Abou-Awad *et al.* 2014), psyllids (Juan-Blasco *et al.* 2012), whiteflies (Medd and Greatrex 2014), thrips (Messelink *et al.* 2006), and plant pollen (Nemati *et al.* 2019). *Amblyseius swirskii* is used in augmentative biological control of pests on greenhouse-grown crops such as cucumber *Cucumis sativus* L., and sweet pepper *Capsicum anuum* L. in more than 50 countries (Knapp *et al.* 2018).

Amblyseius swirskii was first discovered along the eastern Mediterranean coast but has expanded its natural range throughout the Middle East and neighboring regions (Calvo *et al.* 2014). It is a candidate for augmentative biological control of the strawberry spider mite *Tetranychus turkestani* Ugarov and Nikolskii (Acari: Tetranychidae) on crop plants in greenhouses and fields in Khuzestan province, southwestern Iran, and elsewhere. *Tetranychus turkestani* is an important pest of crop plants in multiple families in the southwestern region of Iran (Mossadegh and Kocheili 2003; Sohrabi and Shishehbor 2008) and other countries including Russia (Popov 1981), USA (Jeppson *et al.* 1975), China (Li *et al.* 2014), India and some European countries (Migeon and Dorkled 2021). Characterized by frequent outbreaks coupled with acaricide resistance, this mite poses a threat to field and glasshouse crop producers (Sohrabi and Shishehbor 2008). *Tetranychus turkestani* has several generations during the growing season, tolerates high temperatures and low humidity, and has a short generation time of approximately 6 to 7 days (Sohrabi and Shishehbor 2008). Different developmental stages initially feed on the lower leaf surface but can cover an entire plant as populations increase. Early damage symptoms appear as chlorotic stipples on leaves, but large areas will turn yellow as feeding damage builds-up. Leaves may also become bronzed, and the plant can defoliate. Webbing is often very evident, giving a bright appearance to the plant (Jeppson *et al.* 1975).

Developing or improving techniques to mass produce *A. swirskii* for augmentative releases against *T. turkestani* are needed. In efforts to reduce rearing costs, factitious prey, e.g., *Carpoglyphus lactis* (L.) (Acari: Carpoglyphidae), has been used to rear *A. swirskii* (San *et al.* 2020). Yet, additional time, labor, and space will be required to maintain *C. lactis* colonies. Hence, the incorporation of a non-prey diet would be most cost-effective. Research has tested the utility of non-prey diets, e.g., plant pollen, in lieu of natural prey. For example, pollen from cattail *Typha latifolia* L., almond *Prunus amygdalus* Batsch, date palm *Phoenix dactylifera* L., castor bean *Ricinus communis* L., maize *Zea mays* L., and apricot *Prunus armeniaca* L. are potential plant pollen diets for mass rearing *A. swirskii* (Riahi *et al.* 2017a). Bee-collected pollen (from unidentified plant sources) is less suitable for *A. swirskii* development and reproduction (Goleva and Zebitz 2013; Calvo *et al.* 2014), but this is not always the case if the nutritional content of bee pollen exceeds that of date palm pollen (Khanamani *et al.* 2017). If plant pollen is readily obtained from plants grown locally or purchased from a supplier in the region, *A. swirskii* mass production could become more time and cost efficient. Culturing of tetranychids requires more time and labor because host plants must also be cultured to provide food for the tetranychids. Currently, there are no suitable artificial diets for continuous mass rearing of tetranychids (Van der Geest *et al.* 1983; He *et al.* 2019).

Although biological characteristics of *A. swirskii* fed tetranychids such as *Tetranychus urticae* Koch (Fadaei *et al.* 2018), *Panonychus citri* (McGregor) (Ji *et al.* 2013), *Eotetranychus frosti* (McGregor) (Bazgir *et al.* 2018), and *Eutetranychus orientalis* (Klein) (All-Azzazy and Alhewairini 2020) have been studied previously, no information is available on *A. swirskii* attacking or feeding on *T. turkestani* in Iran or elsewhere. Therefore, the objectives of this study were to compare the effects of natural prey *T. turkestani*, date palm pollen, and bee pollen diets on *A. swirskii* development, reproduction, and life table parameters.

Material and methods

Spider mite and predatory mite colonies

The *T. turkestani* used in this study originated from field bindweed *Convolvulus arvensis* L. (Solanales: Convolvulaceae) growing on the premises of the Faculty of Agriculture, Shahid Chamran University of Ahvaz, Ahvaz, Iran. A stock colony of *T. turkestani* was maintained on seedlings of cowpea *Vigna unguiculata* (L.) Walp. (Fabales: Fabaceae) grown from seeds and transplanted into compost in plastic pots (20 cm diam.) in a laboratory of the Department of Plant Protection. Infested plants were held in wooden framed rearing cages (120 × 60 × 60 cm) covered with nylon mesh, 210 µm aperture. The cages were maintained in a laboratory at 25 ± 2 °C, 50 ± 5% RH and a 16: 8 (L: D) h with illumination (4000 lux) provided by fluorescent lamps. New plants were introduced as required.

The *A. swirskii* population was obtained from laboratory colonies at Bu-Ali Sina University, Hamedan, Iran, which had been purchased from Koppert Biological Systems (Berkel en Rodenrijs, The Netherlands) in 2012. It was reared on *T. urticae* at Bu-Ali Sina University. At Shahid Chamran University, Department of Plant Protection, the *A. swirskii* colony was maintained in a laboratory in rearing units comprised of a plastic sheet (11 x 7 x 0.1 cm) on a foam mat maintained in humid conditions (approximately 70% RH) with distilled water in a Plexiglas box (as described by Wazler and Schausberger 1999). To provide food, cowpea leaves infested with *T. turkestani* were added to the units twice a week. Date palm pollen was also made available to immature and adult *A. swirskii* in the rearing units for several generations when *T. turkestani* immatures and adults were in short supply. The *A. swirskii* colony was reared for several generations prior to commencing the experiments.

Pollen

Date palm production is a major industry in Ahaz city, Iran. Very fresh date palm pollen of the Stamaran cultivar was harvested directly from a tree growing in Ahvaz city in April 2019. Even if date palm pollen was not harvested from the field, it could have been purchased at a low price. In a previous study, date palm pollen sheaths were obtained from a rural supplier in Ahvaz at a cost of 3.0-3.5 USD per kg (equivalent to four sheaths); approximately 6 g of pollen grains were within each kg of sheath (Ebrahimifar *et al.* 2021). Commercial bee-collected pollen (of unknown plant origin) was purchased from a rural supplier in Ahvaz city. The average price of bee pollen was 12.0 USD per kg in Ahvaz (PS, *personal observations*). Bee pollen was stored in a freezer at -18 °C for up to four months, before experimentation.

Experimental setup

Experimental units were prepared according to the method described by Riahi *et al.* (2017a) with some modifications. Each experimental unit was comprised of a green plastic sheet (3 x 3 cm) located on a thick foam pad, cut to a similar size (3 x 3 cm), in a plastic Petri dish (9 cm diam., 2 cm high) that was half-filled with distilled water (Figure 1). The edges of the plastic sheet were covered with moist tissue paper to prevent *A. swirskii* from escaping. In addition, a few cotton threads were placed on each plastic sheet to serve as shelter and oviposition substrates for *A. swirskii*. Eggs of *A. swirskii* (less than 24 h old) were transferred individually to each experimental unit using a fine squirrel-hair brush. After emergence of the larvae, mites were fed according to treatments, i.e., *T. turkestani* prey, date palm pollen, or bee pollen. The experimental units were monitored daily, and developmental duration and survival of immature stages were recorded. Molting was confirmed by the presence of exuviae in the experimental units. After adult emergence, each newly emerged female and male (less than 24 h old) was coupled and transferred to a new experimental unit provided with the same food they were fed in immature stages. The experimental units were checked daily and pre-oviposition period, oviposition period, post-oviposition period, adult longevity, and total fecundity were recorded. The experiments were carried-out in a completely randomized design to test the effects of diet

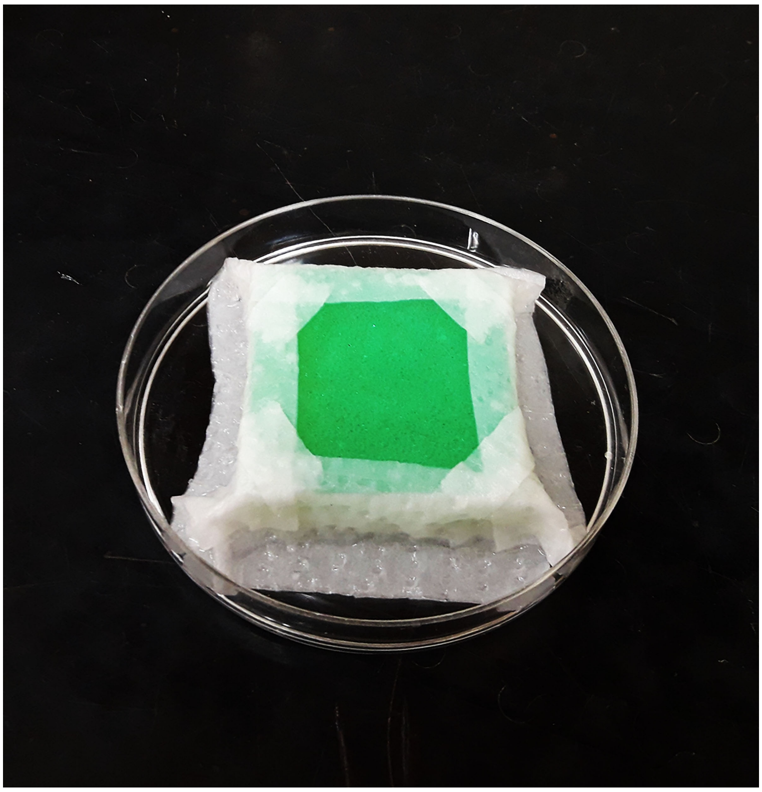

Figure 1 Experimental rearing unit to test the effects of diet treatments on *A. swirskii* development and reproduction.

treatment type on *A. swirskii* life history parameters. All experiments were conducted in a growth chamber at 25 ± 1 °C, 65 ± 5% RH and a 16L: 8D h photoperiod.

Approximately 5 mg of date palm pollen or bee pollen was added to respective treatment dishes with a single *A. swirskii* male or female. Every other day, old pollen was replaced with new pollen. In the prey treatment, live *T. turkestani* immatures and adults were added to dishes with a single *A. swirskii* male or female. Every other day, dead and uneaten *T. turkestani* were replaced with live *T. turkestani* from the stock colony. Sample sizes for female development and immature survival tests were 25, 35, and 33 individuals in *T. turkestani*, date palm pollen, and bee pollen treatments, respectively. Sample sizes for male development and immature survival tests included 20, 9, and 11 individuals in *T. turkestani*, date palm pollen, and bee pollen treatments, respectively. Sample sizes for reproduction and longevity tests included 25, 35, and 33 individuals in *T. turkestani*, date palm pollen, and bee pollen treatments, respectively. Number of replications (n) for immature development (female and male), reproduction and longevity (female and male) of diet treatments are listed in Tables 1, 2, and 3.

Statistical analysis

The datasets were first verified for normal distribution by the Kolmogorov-Smirnov test. Developmental time, immature survival, preoviposition period, oviposition period, postoviposition period, adult longevity, and total fecundity of *A. swirskii* fed different diets were analyzed using a one-way analysis of variance (one-way ANOVA). Immature survival data were arcsine transformed to homogenize variances prior to the one-way ANOVA. Means were separated using Tukey's Honestly Significant Difference (HSD) test at α = 0.05. SPSS version 22 statistical software (SPSS for windows, SPSS Institute Inc., Chicago, IL, USA.) was used for data analysis.

Life table parameters are important in defining the effects of external factors on populations (Birch 1948). Life table parameters can confirm which diets are most suitable for predator life history parameters (Grenier and De Clercq 2003). In the context of this study, they were used to confirm results obtained from experiments determining the effects of three diets on *A. swirskii* development and reproduction. An age-stage, two-sex life-table procedure (Chi and Liu 1985) was selected for data analysis to account for variable development rates among individuals and stages of development of *A. swirskii* fed different diets. Life table, i.e., population growth parameters including net reproductive rate (R_0), gross reproductive rate (*GRR*), intrinsic rate of natural increase (r_m), finite rate of increase (λ), and mean generation time (*T*) were calculated with the TWOSEX-MSChart program (Chi 2018). Population doubling time (*DT*), the number of days required for the *A. swirskii* population to double in numbers, was also calculated $DT = \ln(2)/r_m$. Standard error (SE) of the population growth parameters was obtained using the bootstrap technique and multiple comparisons were made by the paired bootstrap test with 100,000 samples (Maia *et al.* 2000).

Results

Immature development and survival rate

The time in the egg stage was shortest for *A. swirskii* in the date palm pollen treatment than the *T. turkestani* or bee pollen treatments. Parental females and males in the stock colony had exposure to date palm pollen, *T. turkestani*, but not bee pollen. The protonymph stage was shorter for females and males in the date palm pollen treatment than the *T. turkestani* treatment. Total developmental time of *A. swirskii* females and males was affected significantly by diet type (females: F = 40.83; df = 2, 90; P < 0.001; males: F = 6.64; df = 2, 37; P = 0.003) (Tables 1 and 2). Total development time was significantly shorter for females fed date palm pollen than *T. turkestani* or bee pollen (Table 1). It was significantly shorter for males fed date palm pollen than *T. turkestani* or bee pollen (Table 2). Diet type had no significant effect on percent survival rate of males and females, combined (F = 1.50; df = 2, 6; P = 0.29); it was 100 ± 0.00a, 98.22 ± 1.82a, and 97.78 ± 1.81a for *A. swirskii* fed *T. turkestani*, date palm pollen, and bee pollen, respectively.

Diet type had a significant effect on pre-oviposition (F = 31.64; df = 2, 90; P < 0.001), oviposition (F = 43.12; df = 2, 90; P < 0.001) and post-oviposition (F = 12.66; df = 2, 90; P < 0.001) periods of *A. swirskii* females (Table 3). Pre-oviposition period was longest for females fed bee pollen rather than date palm pollen or *T. turkestani*. Oviposition and post-oviposition periods were longest for females fed *T. turkestani* than date palm pollen or bee pollen. Diet type had a significant effect on total fecundity (F = 31.64; df = 2, 90; P < 0.001; Table 3); females fed *T. turkestani* laid 1.7 and 5.7 times more eggs than females fed date palm pollen and bee pollen, respectively.

Significant differences in longevity were observed amongst the diets (F = 65.57; df = 2, 90; P < 0.001 for females; F = 13.91; df = 2, 37; P < 0.001 for males; Table 3). Both *A. swirskii* females and males lived longer when fed the *T. turkestani* diet rather than the date palm pollen or bee pollen diet. Longevity of *T. turkestani*-fed females and males was 34.57 d and 34.15 d, respectively (Table 3). Longevity of date palm pollen-fed and bee pollen-fed females (or males) did not differ significantly.

Life table analysis

Life table analysis confirmed that diet type had significant effects on *A. swirskii* life history (Table 4). The highest intrinsic rate of natural increase (r_m) was observed for *A. swirskii* fed date palm pollen rather than *T. turkestani* or bee pollen. The finite rate of increase (λ), net reproductive rate (R_0), and gross reproductive rate (*GRR*) did not differ significantly between *A. swirskii* fed date palm pollen or *T. turkestani*. But *A. swirskii* fed bee pollen had the lowest intrinsic and finite rates of increase and the lowest net and gross reproductive rates. Mean generation time (*T*) and population doubling time (*DT*) were significantly shorter for *A. swirskii* fed date palm pollen rather than *T. turkestani* or bee pollen (Table 4). Note that *A. swirskii* fed bee pollen had the longest mean generation and population doubling times.

Discussion

Diet type had a distinct influence on immature development of *A. swirskii* in this study. Total development time was shortest when *A. swirskii* immatures were fed the date palm pollen diet. Perhaps, nutrients in date palm pollen were easier to digest or assimilate than those in bee pollen or *T. turkestani*. A comparison of macronutrients, i.e., amino acids, lipids, carbohydrates, minerals, and phytochemicals, amongst the three diets would be necessary to help explain these results. In addition, geographic origin, climatic conditions, and soil type of individual plants from which date palm pollen and bee pollen originated could have influenced nutritional quality. The plant origin of bee pollen in this study was unknown. The plant species represented in the bee-collected pollen can have important consequences on its nutritional quality, i.e., amino acid profile and content (Taha *et al.* 2019).

The developmental time of 4.20 d for *A. swirskii* females fed date palm pollen in this study was short when compared to 9.09 d reported by Riahi *et al.* (2017a) and 8.3 d reported by Nemati *et al.* (2019). The developmental time of 5.79 d for females fed bee pollen in this study was also short in comparison to 10.38 d reported by Riahi *et al.* (2017a). Note that almond pollen, castor bean pollen, and date palm pollen were superior to bee-collected pollen as a diet to support the development of the phytoseiid *Neoseiulus cucumeris* (Oudemans) (Yazdanpanah *et al.* 2021). The authors indicated that bee pollen had the lowest nutritional value for *N. cucumeris*. In contrast, Khanamani *et al.* (2017) indicated that date palm pollen was inferior to bee pollen (collected from unidentified plant species), probably because the proportion of protein, lipids, and sugars were significantly lower in date palm pollen.

Prior research has not tested the effects of a diet of *T. turkestani* on development time of *A. swirskii*. Total development time of *A. swirskii* fed *T. turkestani* (at 25 °C, 5.97 d for females and 5.50 d for males) in this study was shorter than for *A. swirskii* fed *T. urticae* (7.60 d, Riahi *et al.* 2017a), *T. urticae* (6.89 d, Fadaei *et al.* 2018), *E. frosti* (6.94 d, Bazgir *et al.* 2018), and *E. orientalis* (11.17 d, All-Azzazy and Alhewairini 2020). Also, *T. turkestani*-fed *A. swirskii* developed faster than their prey. For example, development time of *T. turkestani* was approximately 10 d at 25°C (Bazazzadeh *et al.* 2020). Development time of *A. swirskii* fed *T. turkestani* in this study was also shorter than the development time reported for potential insect prey such as *Bemisia tabaci* (Gennadius) Bet-Dagen strain (Homoptera: Aleyrodidae) (6.3 d, after modification, Nomokou *et al.* 2001), and two thripids *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) and *Thrips tabaci* Lindeman (7.8 d at 25°C, Wimmer

Table 1 Mean (± SE) immature development time (d) of *Amblyseius swirskii* females fed different diets.

Parameters	Natural prey and pollen diets		
	T. turkestani (n = 25)	Date palm pollen (n = 35)	Bee pollen (n = 33)
Egg incubation period (d)	1.96 ± 0.08 a	1.59 ± 0.08 b	1.83 ± 0.05 a
Larva (d)	0.86 ± 0.05 a	0.70 ± 0.04 b	0.70 ± 0.04 b
Protonymph (d)	1.86 ± 0.10 a	1.01 ± 0.04 b	1.80 ± 0.08 b
Deutonymph (d)	1.28 ± 0.09 a	0.97 ± 0.05 a	1.86 ± 0.08 a
Total (d)	5.97 ± 0.13 a	4.20 ± 0.08 b	5.79 ± 0.16 a

Values in rows followed by the same small letter are not significantly different, using the Tukey test at 5% significance level. n = number of individuals reaching the adult stage.

Table 2 Mean (± SE) immature development time (d) of *Amblyseius swirskii* males fed different diets.

Parameters	Natural prey and pollen diets		
	T. turkestani (n = 20)	Date palm pollen (n = 9)	Bee pollen (n = 11)
Egg incubation period (d)	2.05 ± 0.10 a	1.56 ± 0.53 c	1.84 ± 0.09 b
Larva (d)	0.95 ± 0.06 a	0.72 ± 0.16 ab	0.67 ± 0.07 b
Protonymph (d)	1.45 ± 0.10 a	0.89 ± 0.22 b	1.50 ± 0.19 a
Deutonymph (d)	1.06 ± 0.11 a	0.84 ± 0.25 b	1.38 ± 0.17 a
Total (d)	5.50 ± 0.18 a	4.13 ± 0.13 c	5.11 ± 0.42 b

Values in rows followed by the same small letter are not significantly different, using the Tukey test at 5% significance level. n = number of individuals reaching the adult stage.

et al. 2008). The ability of *A. swirskii* to develop faster than prey species has profound implications for augmentative biological control. It suggests that augmentative releases of *A. swirskii* could eliminate pest populations in the greenhouse or open field.

Diet type had a distinct effect on reproduction (fecundity) in this study. The observation that *A. swirskii* produced more progeny, i.e., more eggs, when fed the *T. turkestani* diet (rather than the date palm pollen or bee pollen diet) could suggest that the quantity or quality of macronutrients necessary for ovary (gonad) development and egg maturation are greater in *T. turkestani*. Unfortunately, the macronutrient profile in *T. turkestani* is unknown and specific nutrients that could stimulate *A. swirskii* oviposition have not been reported. Note that *A. swirskii* reproduction (fecundity) was greatest on a diet of *T. turkestani* (this study) than on a diet of *T. urticae* (Abou-Awad *et al.* 1992; Riahi *et al.* 2017a, b; Fadaei *et al.* 2018), *E. frosti* (Bazgir *et al.* 2018), *E. orientalis* (All-Azzazy and Alhewairini 2020), *B. tabaci* (Nomokou *et al.* 2001), *F. occidentalis*, or *T. tabaci* (Wimmer *et al.* 2008). These observations suggest that a diet of *T. turkestani* is suitable for *A. swirskii* reproduction.

Although the *T. turkestani* diet was best for *A. swirskii* reproduction, this observation does not diminish the value of the date palm pollen diet. In prior research, *A. swirskii* fecundity was greatest on a diet of date palm pollen rather than eggs of two scale insects *Insulaspis pallidula* (Green) and *Phoenicococcus marlatti* Cockerell (Homoptera: Diaspididae) (Abou-Elella *et al.* 2013). Similarly, *A. swirskii* fecundity was greater on a diet of date palm pollen than a diet of *T. urticae* eggs or immatures, but less than on a diet of *E. orientalis* immatures or adults (Ali and Zaher 2007). Date palm pollen contains sterols, saponins, flavonoids, fatty acids, amino

Table 3 Mean (± SE) pre-oviposition, oviposition, post-oviposition, longevity, and fecundity of *Amblyseius swirskii* adults fed different diets.

Parameters	Natural prey and pollen diets		
	T . turkestani (n = 25)	Date palm pollen (n = 35)	Bee pollen (n = 33)
Pre-oviposition period (d)	2.24 ± 0.09 b	1.71 ± 0.15 b	5.00 ± 0.5 a
Oviposition period (d)	20.40 ± 1.60 a	10.29 ± 0.60 b	11.69 ± 1.02 b
Post-oviposition period (d)	5.96 ± 1.24 a	1.83 ± 0.74 b	1.94 ± 0.25 b
Female longevity (d)	34.57 ± 1.34 a	26.64 ± 0.75 b	24.33 ± 1.65 b
Male longevity (d)	34.15 ± 1.85 a	23.83 ± 1.65 b	21.83 ± 1.63 b
Total fecundity (eggs/fem)	45.52 ± 1.51 a	25.77 ± 1.56 b	7.97 ± 0.66 c

Values in rows followed by the same small letter are not significantly different, using the Tukey test at 5% significance level. n = number of reproducing females observed.

Table 4 Estimated life table parameters of *Amblyseius swirskii* fed different diets. Values are expressed as means ± SE.

Parameters	Natural prey and pollen diets		
	T. turkestani	Date palm pollen	Bee pollen
Intrinsic rate of increase (r_m)(d^{-1})	0.291 ± 0.014 b	0.396 ± 0.013 a	0.159 ± 0.123 c
Finite rate of increase (λ) (d^{-1})	1.338 ± 0.019 a	1.486 ± 0.021 a	1.123 ± 0.015 b
Net reproductive rate (R_0) (offspring)	25.28 ± 3.48 a	20.04 ± 1.99 a	5.67 ± 0.71 b
Gross reproductive rate (*GRR*)	28.29 ± 3.48 a	24.55 ± 1.99 a	5.88 ± 0.71 b
Mean generation time (*T*) (d)	11.09 ± 1.22 b	7.56 ± 1.12 c	12.88 ± 1.29 a
Doubling time (*DT*) (d)	1.753 ± 0.001 b	1.043 ± 0.062 c	2.394 ± 0.008 a

Values in rows followed by the same small letter are not significantly different, using the paired bootstrap test at 5% significance level.

acids, and other components that purportedly improve fertility in humans (Tahvilzadeh *et al.* 2016). The presence of these nutrients at suitable concentrations could affect the fecundity of *A. swirskii*. More research is necessary to identify the nutrients in date palm pollen and to manipulate their concentrations to maximize reproduction in *A. swirskii* and other phytoseiids in mass rearing systems.

Diet type also affected longevity (adult lifespan) of *A. swirskii* in this study; *A. swirskii* males and females lived longer when fed *T. turkestani* than date palm pollen or bee pollen. Many highly fecund arthropod species are not long-lived because energy and resources are diverted to oviposition rather than body maintenance (Hosking *et al.* 2019). The observation that the most fecund *A. swirskii* females (fed the *T. turkestani* diet) lived longer in this study does not follow this pattern. More research on the potential association between fecundity and longevity in phytoseiids is warranted. If phytoseiid females emerge as adults with only one or two mature eggs in their ovaries, it is possible that long-lived females generate more eggs than short-lived ones over time. The rate at which eggs mature in the ovaries of phytoseiids would also provide clues to whether fecundity and longevity are positively or negatively related. Research on egg maturation or ovarian dynamics in phytoseiids is scarce (Di Palma and Alberti 2001).

The benefits of date palm pollen and *T. turkestani* diets on *A. swirskii* development and reproduction was confirmed by a life table analysis. Although intrinsic rate of natural increase (r_m) was greatest for *A. swirskii* fed the date palm pollen rather than *T. turkestani*, the finite rate of increase (λ), net reproductive rate (R_0), and gross reproductive rate (*GRR*) did not differ significantly between the two diets. The observation that mean generation time (*T*) and doubling time (*DT*) were least for *A. swirskii* fed date palm pollen (rather than *T. turkestani*) suggests that *A. swirskii* will require less time to complete a generation and double in population size when fed date palm pollen.

The highest intrinsic rate of natural increase (*r*m) in this study was recorded when *A. swirskii* was fed date palm pollen (0.396 d^{-1}). This value is higher than those reported by Riahi *et al.* (2017a) (0.080 d^{-1}), Fadaei *et al.* (2019) (0.050 d^{-1}) and Nemati *et al.* (2019) (0.031 d^{-1}) for *A. swirskii* fed date palm pollen. These dissimilarities might be explained by disparities in freshness of date pam pollen or differences in date palm cultivar. A follow-up study to examine date palm pollen quality in relation to freshness, cultivar, and geographic location would be informative.

In addition, the r_m value calculated for *A. swirskii* fed date palm pollen in this study was higher than the r_m value reported for *A. swirskii* fed cattail pollen (0.158 d^{-1}), a commonly used and recommended food to maintain *A. swirskii* laboratory colonies (Lee and Gillespie 2011). Furthermore, the r_m found in this study was higher than those reported for *A. swirskii* fed *T. urticae* (0.167 d^{-1}) (El-Leithy and Fouly 1992), the western flower thrip *F. occidentalis* (0.056 d^{-1}), and onion thrip *T. tabaci* (0.024 d^{-1}) (Wimmer *et al.* 2008), and the eriophyoid fig mites

Aceria ficus (Cotte) (0.155 d^{-1}) and *Rhyncaphytoptus ficifoliae* Keifer (0.122 d^{-1}) (Abou-Awad *et al.* 2000), tomato russet mite *Aculops lycopersici* (Massee) (0.201 d^{-1}) (Park *et al.* 2011), and cotton whitefly *B. tabaci* (0.213 d^{-1}) (Nomikou *et al.* 2001).

In conclusion, date palm pollen has great potential as a diet to support *A. swirskii* in a cost-effective mass rearing system. Date palm pollen is readily available in Iran, easily harvested, amenable to cold storage, and very inexpensive to purchase. In contrast, additional labor costs and rearing space would be required to maintain a *T. turkestani* colony and host plants as food. Host plants are necessary because a satisfactory artificial diet for *T. turkestani* is not available. Although factitious prey, e.g., *C. lactis,* is available for *A. swirskii* (San *et al.* 2020), additional time, labor, and space will be required to maintain *C. lactis* colonies. Therefore, the incorporation of a non-prey diet would be most cost-effective. Although the date palm pollen diet would be more advantageous for mass rearing of *A. swirskii*, future research must determine if long-term rearing on this diet would cause any deterioration of the colony. Research is also necessary to determine if long-term rearing on date palm pollen reduces the capacity of *A. swirskii* to locate, capture, and consume natural prey, such as *T. turkestani*, on plants in greenhouses or open fields.

Acknowledgements

The authors thank the research deputy of Shahid Chamran University of Ahvaz for supporting this research. Two anonymous peer reviewers commented on a previous version of this manuscript. The U.S. Government has the right to retain a non-exclusive, royalty-free license in and to any copyright of this article. This article reports the results of research only. Mention of a commercial or proprietary product does not constitute an endorsement of the product by the U.S. Department of Agriculture or Shahid Chamran University of Ahvaz.

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