Persian J. Acarol., 2024, Vol. 13, No. 1, pp. 115–130.
https://doi.org/10.22073/pja.v13i1.82742
Journal homepage: http://www.biotaxa.org/pja

ISSN 2251-8169
PERSIAN JOURNAL OF ACAROLOGY

Article

The effects of maize pollen on development and population growth potential of *Amblyseius swirskii* and *Cydnoseius negevi* (Acari: Phytoseiidae) in subsequent generations

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ABSTRACT
Diet is an important component of mass-production system of bio-control agents. Thus, using a non-prey diet (such as plant pollen) instead of natural prey could be more cost-effective in mass-production of phytoseiid predatory mites. Therefore, the present study aimed to examine the multigenerational effect of maize, *Zea mays* L. (Poaceae), pollen diet on life table parameters of *Amblyseius swirskii* Athias-Henriot and *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) reared for one, five and 11 consecutive generations. The predatory mites *A. swirskii* and *C. negevi* successfully completed their development on maize pollen for up to 11 generations. In G1, oviposition days, adult longevity, and fecundity showed significantly higher values in the case of *C. negevi* as compared to *A. swirskii*. Despite statistically similar oviposition days in the G11, *A. swirskii* females (44.43 eggs/♀) deposited significantly more eggs than those of *C. negevi* (40.60 eggs/♀). There were no significant differences in finite rate of increase (λ), intrinsic rate of increase (r), net (R_0) and gross (*GRR*) reproductive rates between the two predatory mites in G1 and G5 ($P \geq 0.05$). In G11, individuals of *C. negevi* had significantly higher values of r (0.181 day^{-1}) and λ (1.198 day^{-1}) compared to those of *A. swirskii* (r = 0.159 day^{-1}, λ = 1.173 day^{-1}). However, there were no significant differences in R_0 and *GRR* values between *A. swirskii* (R_0 =34.18 offspring, *GRR* = 39.75 offspring) and *C. negevi* (R_0 = 31.23 offspring, *GRR* = 35.44 offspring) in G11. In conclusion, maize pollen has a great potential as a suitable and cost-effective diet for developing the mass-production system of *A. swirskii* and *C. negevi* on non-prey diets, where the performance of these predators remained to some extent constant across generations.

KEYWORDS: Bio-control agents, life table parameters, mass-rearing programs, performance across generations, pollen grains, predatory mites.

PAPER INFO.: Received: 26 June 2023, Accepted by *A. Farazmand*: 27 November 2023, Published: 15 January 2024

INTRODUCTION

Biological control is an important alternative system for pest control, particularly among organic farmers who are concerned about human health (Dalir *et al*. 2021). This method forms the principal element of integrated pest management (IPM) (Fathipour and Maleknia 2016). Phytoseiid predatory mites are increasingly utilized in IPM tactics due to their great capability to feed on various food sources, such as mites, insects, pollen, nematodes, and fungi (McMurtry *et al*. 2013; Alipour *et al*.

How to cite: Lamlom, M., Fahim, S.F. & Momen, F.M. (2024) The effects of maize pollen on development and population growth potential of *Amblyseius swirskii* and *Cydnoseius negevi* (Acari: Phytoseiidae) in subsequent generations. *Persian Journal of Acarology*, 13(1): 115–130.

2019; Khanamani *et al*. 2021). Actually, the predatory mites presented the second largest group of biological control agents just after the hymenopterans (van Lenteren 2012; Soltaniyan *et al*. 2020).

In the Middle East and Egypt, *Amblyseius swirskii* Athias-Henriot and *Cydnoseius negevi* (Swirski and Amitai) (Acari: Phytoseiidae) are indigenous species and could be well adapted to native habitat than many other exotic phytoseiid species. Both mite species, as generalist (type III) phytoseiids, are able to feed on many food items (McMurtry *et al*. 2013). *Amblyseius swirskii* can develop and reproduce on spider mites (El-Laithy and Fouly 1992; Riahi *et al*. 2017; Fahim and El-Saiedy 2021), eriophyid, tenuipalpid and tarsonemid mites (Momen and Abdel-Khalek 2008; Pena *et al*. 2009; Park *et al*. 2010; Abou-Awad *et al*. 2014), small insects (Nomikou *et al.* 2001; Messelink *et al*. 2006; Medd and Greatrex 2014), and plant pollen (Nemati *et al*. 2019). This predator is used as a bio-control agent in greenhouses in more than 50 countries (Knapp *et al*. 2018). *Cydnoseius negevi* can feed on a wide array of food sources, including small insects, spider and eriophyid mites, in addition to plant pollen (Momen *et al*. 2009; Metwally *et al*. 2015; Hussein *et al*. 2016; Fahim and Momen 2022).

Release of the predatory mites in IPM programs involves a sufficient number of these phytoseiid species, so it appears necessary to choose suitable procedures for their mass production (Naqshbandi *et al*. 2023). In this regard, mass-rearing method depending on using natural prey requires the keeping of three trophic levels: the predator species, their prey, and host plant of the prey (Nemati and Riahi 2020). Since each of these elements needs enormous resources, considerable savings can be achieved if prey and their host plants are not required (Nemati and Riahi 2020). In order to decrease rearing costs, the storage mites are utilized for mass rearing of *A. swirskii* (San *et al*. 2020). However, in addition to requiring time and space, handling these storage mites may lead to health problems for the workers (Elshazly 2022). Therefore, using a non-prey diet (such as, plant pollen) instead of natural prey could be more cost-effective in the mass-production of phytoseiid mites (Rahmani Piyani *et al.* 2021). Generalist predatory mites can feed and reproduce on pollen of different plant species (Nomikou *et al*. 2003; Delisle *et al*. 2015; Riahi *et al*. 2017; Nemati *et al.* 2019; Yazdanpanah *et al*. 2021). Under field and greenhouse conditions, plant pollen grains may be used as supplementary or alternative food for many predaceous mites (Vangansbeke *et al*. 2016; Palevsky 2017; Lee and Zhang 2018).

Plant pollen grains have different sizes, shapes, and surfaces (Bujang *et al.* 2021). The main nutrients in plant pollen grains are proteins, carbohydrates, vitamins, lipids flavonoids, minerals, and free amino acids (Goleva and Zebitz 2013). The high protein contents make pollen serve as food of high nutritional quality for predatory mite species (Cook *et al*. 2003; Riahi *et al*. 2016). In fact, pollens from various plants might vary in their nutritive value to phytoseiid mites (Khanamani *et al*. 2017b), which is reflected in predators' performance (Eini *et al*. 2022). The effect of diet on mite performance does not necessarily appear in one generation and can become obvious over many generations, thus influencing the quality of mass-production of predatory mites in the long-term (Nguyen *et al*. 2014). The effect of different factors on predatory mites (e.g., diet) are widely evaluated using life table parameters (Nemati and Riahi 2020). Any possible nutrient imbalances can be explored, which possibly can result in a decline in parameters of life table over several generations (De Clercq *et al*. 2005). Maize, *Zea mays* L. (Poaceae), is a common plant species and is widely cultivated in Egypt. Therefore, in order to clarify whether *A. swirskii* and *C. negevi* perform well on maize pollen as a diet across generations, the present study aimed to examine the multigenerational effect of this pollen on life table parameters of the two predatory mites reared for one, five and 11 consecutive generations.

MATERIALS AND METHODS

Pollen collection

Zea mays pollen used in the experiments was collected through the flowering season and dried for two days at room temperature then stored at −20 °C for long-term storage.

Colonies of predatory mites

Individuals of *A. swirskii* and *C. negevi*, originally collected from cucumber plant at Giza Governorate, Egypt, were used to initiate a stock colony of each predatory mites. The individuals of *A. swirskii* and *C. negevi* in the stock colony were reared using rearing units and providing with maize pollen grains as food source. The predatory mites' colonies were kept separately in an incubator at 26 ± 2 °C, 65 ± 5% RH and 16L: 8D photoperiod. The rearing units consisted of bean leaves put on water saturated cotton layers placed in Petri dishes. Water was added regularly to maintain the cotton humid.

Multi-generation rearing

In order to study the life table parameters in the first (G1), fifth (G5), and eleventh (G11) generations for each predatory mite, females of *A. swirskii* or *C. negevi* were transferred to new leaf units and left to lay eggs for 12 h. For each predatory mite, the newly laid eggs (G1) were transferred separately to the experimental units and inspected daily which continued in each of the replicates for up to eleven generations. The experimental units were similar to the rearing units but with a smaller size. Maize pollen was provided as food every other day for mite individuals of each predator during the whole experiments. Care was taken that the food source was never depleted. In addition to studying the life table parameters of each predatory mite in the G1, the eggs from the females of the fourth and tenth generation were also used to determine the life table parameters of each predator in the G5 and G11 generations.

Life table experiments

The population growth parameters of *A. swirskii* and *C. negevi* were determined at first, fifth and eleventh generations rearing on *Z. mays* pollen grains. For each predator, eggs of the first, fifth and eleventh generations were transferred separately to the experimental units. Larvae and subsequent stages of each predator were provided with maize pollen as a food source every other day. Care was taken that the food source was never depleted. Each experimental unit was observed daily, and the development time of immature stages was recorded. After reaching the adulthood, predatory female was mated with a male and provided with maize pollen diet. To gather data on adult longevity and fecundity, inspections were made daily until the death of the tested individuals in each experiment. All experiments were conducted in an incubator at 26 ± 2 °C, 65 ± 5% RH and 16L: 8D photoperiod. The sample size subjected to the statistical analysis was 35 replicates for each predatory mite in the G1, G5, and G11 generations.

Statistical analysis

The life history data of *A. swirskii* and *C. negevi* were analyzed according to the age-stage, two-sex life table method (Chi and Liu 1985; Chi 1988; Chi *et al*. 2022 using the TWOSEX-MSChart of Chi 2023). All parameters including age-stage-specific survival rate (s_{xj}) (where x = age and j = stage), age-stage-specific fecundity (f_{xj}) of females, age-specific survival rate (l_x), age-specific fecundity (m_x), the age-stage specific reproductive value (v_{xj}), as well as population growth parameters [intrinsic rate of increase (r), finite rate of increase (λ), gross reproductive rate (*GRR*), net reproductive rate (R_0), and mean generation time (T)] were estimated using TWOSEX-MSChart program (Chi 2023). The means and standard errors of developmental stages durations, total pre-oviposition period (TPOP), adult pre-oviposition period (APOP), fecundity, oviposition days, and adult longevity along with the population parameters (r, λ, R_0, T, and *GRR*) were estimated by the Bootstrap method with 100000 re-sampling using the TWOSEX-MSChart program (Chi 2023); the means were compared by the Paired Bootstrap test based on the confidence interval of difference ($P < 0.05$) (Huang and Chi 2013; Wei *et al*. 2020).

RESULTS

Development and fecundity of predatory mites

The predatory mites *A. swirskii* and *C. negevi* successfully completed their development on *Z. mays* pollen for up to eleven generations (Table 1). For all tested generations, the pre-adult period (egg-adult) of *C. negevi* female (G1: 8.20 day, G5: 8.40 day, G11: 8.27 day) was significantly shorter than that of *A. swirskii* (G1: 9.43 day, G5: 9.63 day, G11: 10.03 day). The same trend was noticed for both predators in the case of TPOP (Table 1). No statistical differences in APOP were found between *C. negevi* and *A. swirskii* when reared on maize pollen in G1 and G5 ($P \geq 0.05$); this period was significantly longer for *A. swirskii* than for *C. negevi* in G11 (Table 1).

In G1, oviposition days, adult longevity, and fecundity showed significantly higher values in the case of *C. negevi* as compared to *A. swirskii* ($P < 0.05$) (Table 1). In comparison to G1 and G5, the highest number of oviposition days of *A. swirskii* was recorded in G11 (23.77 day). The oviposition days of *C. negevi* females ranged from 24.13 to 34.97 day, where the lowest value was in G5 and the highest in G1. Females of the two predators raised on *Z. mays* pollen had statistically similar longevity and fecundity in G5 (Table 1). Despite statistically similar oviposition days in the G11, *A. swirskii* females (44.43 eggs/♀) deposited significantly more eggs than those of *C. negevi* (40.60 eggs/♀) ($P < 0.05$). On the other hand, total egg production per *C. negevi* female was higher in G1 (43.87 eggs) than in G5 (41.67 eggs) and G11 (40.60 eggs). The sex ratio ranged from 60.11 in G1 to 68.12% in G11 for *A. swirskii*. However, the highest sex ratio for *C. negevi* was recorded in G1 (65.71%) (Table 1).

Table 1. Biological parameters and fecundity (mean ± SE) of *Amblyseius swirskii* and *Cydnoseius negevi* females fed on pollen grains of maize for 11 generations.

Biological parameters	**G1**		**G5**		**G11**	
	A. swirskii	***C. negevi***	***A. swirskii***	***C. negevi***	***A. swirskii***	***C. negevi***
Egg-adult (day)	9.43 ± 0.09a	8.20 ± 0.09b	9.63 ± 0.15a	8.40 ± 0.11b	10.03 ± 0.03a	8.27 ± 0.14b
TPOP (day)	11.90 ± 0.18a	10.43 ± 0.16b	12.10 ± 0.19a	10.63 ± 0.16b	13.03 ± 0.03a	10.50 ± 0.17b
APOP (day)	2.47 ±0.13a	2.23 ± 0.11a	2.47 ± 0.13a	2.23 ± 0.08a	3.00 ± 0.00a	2.23 ± 0.09b
Oviposition days	22.63 ± 0.27b	34.97 ± 0.18a	22.90 ± 0.25b	24.13 ± 0.19a	23.77 ± 0.25a	24.67 ± 0.4a
Female longevity (day)	37.33 ±0.35b	47.87 ± 0.26a	37.67 ± 0.38a	36.43 ± 0.25a	38.90 ± 0.33b	39.43 ± 0.38a
Fecundity (eggs/♀)	42.07 ± 2.02b	43.87 ± 0.41a	42.07 ± 0.37a	41.67 ± 0.25a	44.43 ± 0.44a	40.60 ± 0.20b
Sex ratio (♀%)	60.11	65.71	60.37	60.37	68.12	60.37

Means within the same row for each generation followed with different letters are significantly different ($P < 0.05$; Paired Bootstrap test with 100000 re-sampling).

Population growth parameters

Data displayed in table 2 showed no significant differences in finite rate of increase (λ), intrinsic rate of increase (r), net (R_0) and gross (GRR) reproductive rates between the two predatory mites in G1 and G5 ($P \geq 0.05$). The generation time (T) of *A. swirskii* reared on *Z. mays* pollen in G5 (20.78 day) was statistically longer than that in *C. negevi* (19.13 day). For *A. swirskii*, the lowest values of r and λ were recorded in G11 (r = 0.159 day^{-1}, λ = 1.173 day^{-1}), compared to the other tested generations. The values of R_0, GRR, and T of *A. swirskii* increased gradually across generations from G1 to G11, where G11 showed the highest values of these parameters (Table 2).

Table 2. Life table parameters (mean ± SE) of *Amblyseius swirskii* and *Cydnoseius negevi* fed on pollen grains of maize for 11 generations.

Biological parameters	**G1**		**G5**		**G11**	
	A. swirskii	***C. negevi***	***A. swirskii***	***C. negevi***	***A. swirskii***	***C. negevi***
Intrinsic rate of increase (r)	0.168 ± 0.005a	0.171 ± 0.005a	0.169 ± 0.005a	0.181 ± 0.006a	0.159 ± 0.005b	0.181 ± 0.006a
Finite rate of increase (λ)	1.183 ± 0.006a	1.186 ± 0.006a	1.184 ± 0.006a	1.199 ± 0.007a	1.173 ± 0.005b	1.198 ± 0.007a
Net reproductive rate (R_0)	31.550 ± 2.877a	35.570 ± 2.260a	33.210 ± 2.781a	32.050 ± 2.797a	34.180 ± 3.001a	31.230 ± 2.731a
Generation time (T)	20.560 ± 0.219a	20.920 ± 0.210a	20.780 ± 0.242a	19.130 ± 0.186b	22.182 ± 0.095a	19.038 ± 0.242b
Gross reproductive rate (GRR)	37.500 ± 2.104a	39.990 ± 1.690a	37.560 ± 2.120a	36.790 ± 2.140a	39.750 ± 2.125a	35.440 ± 2.279a

Means within the same row for each generation followed with different letters are significantly different ($P < 0.05$; Paired Bootstrap test with 100000 re-sampling).

In G11, individuals of *C. negevi* had significantly higher values of r (0.181 day^{-1}) and λ (1.198 day^{-1}) compared to those of *A. swirskii* (r = 0.159 day^{-1}, λ = 1.173 day^{-1}) ($P < 0.05$). However, there were no significant differences in R_0 and GRR values between *A. swirskii* (R_0 = 34.18 offspring, GRR = 39.75 offspring) and *C. negevi* (R_0 = 31.23 offspring, GRR = 35.44 offspring) in G11 ($P \geq 0.05$). The lower values of r and λ of *C. negevi* were observed in G1 (r = 0.171 day^{-1}, λ = 1.186 day^{-1}) compared to the other tested generations (Table 2). For *C. negevi*, the values of R_0, GRR, and T decreased gradually across generations from G1 to G11, where G11 showed the lowest values of these parameters.

Age-stage, two-sex life table

Age-stage specific survival rate (s_{xj}) of *A. swirskii* and *C. negevi* fed on *Z. mays* pollen in the first, fifth and eleventh generations are shown in Figure 1. The s_{xj} of predatory mite displays the probability that a newborn will survive to age x and develop to stage j. The curves of s_{xj} also exhibited the overlap between predator stages during the developmental duration. The probability that a newborn egg of *A. swirskii* survived to the adult stage was 0.75, 0.79, and 0.77 for females and 0.13, 0.13, and 0.13 for males in G1, G5, and G11 on maize pollen, respectively. These values were recorded in the case of *C. negevi* for females as 0.81, 0.77, and 0.77 and for males as 0.14, 0.13, and 0.13 in the above tested generations, respectively.

The age-specific survivorship (l_x), age-specific fecundity (m_x), and the age-stage-specific fecundity (f_{xj}) of *A. swirskii* and *C. negevi* reared on maize pollen in G1, G5, and G11 are presented in Figure 2. The f_{xj} represented the number of progenies produced by predator individuals at age x and stage j per day. The maximum values of f_{xj} were 2.03, 2.00, and 2.17 eggs/female/day for *A. swirskii* in G1, G5, and G11, respectively. For *C. negevi*, the highest f_{xj} values were 1.8, 2.00, and 2.00 eggs/female/day in G1, G5, and G11, respectively.

Age-stage specific reproductive value (v_{xj}) of *A. swirskii* and *C. negevi* reared on *Z. mays* pollen in G1, G5, and G11 is displayed in Figure 3. The v_{xj} of *A. swirskii* and *C. negevi* revealed the contribution of predator individuals of age x and stage j to the future population. The peaks of v_{xj} for *A. swirskii* were 12.19, 11.99, and 13.03 in G1, G5, and G11, respectively. In the case of *C. negevi*, the maximum values of v_{xj} when maize pollen was offered as food were 9.71, 11.28, and 10.72 for G1, G5, and G11, respectively.

DISCUSSION

The ability of natural enemies to be reared on pollen and increase their populations (Riahi *et al*. 2017) would also be very important in the mass rearing of predators for release purposes (Kadkhodazadeh *et al*. 2021). Thus, the occurrence of plants producing suitable pollen grains around and in orchards might lead to sustaining predator populations and reducing prey populations (Hashemi *et al*. 2021). In addition, pollen may sustain phytoseiid population even under prey scarcity circumstances (McMurtry and Croft 1997). Alternative foods (e.g., pollen) can improve the performance of predators, and subsequently improve their success in IPM (Cloutier and Johnson 1993). Using pollen can reduce costs of predator mass production which could reduce the market price of phytoseiid species and increase the number of farmers utilizing biological control tactics for pest control (Khanamani *et al*. 2017a).

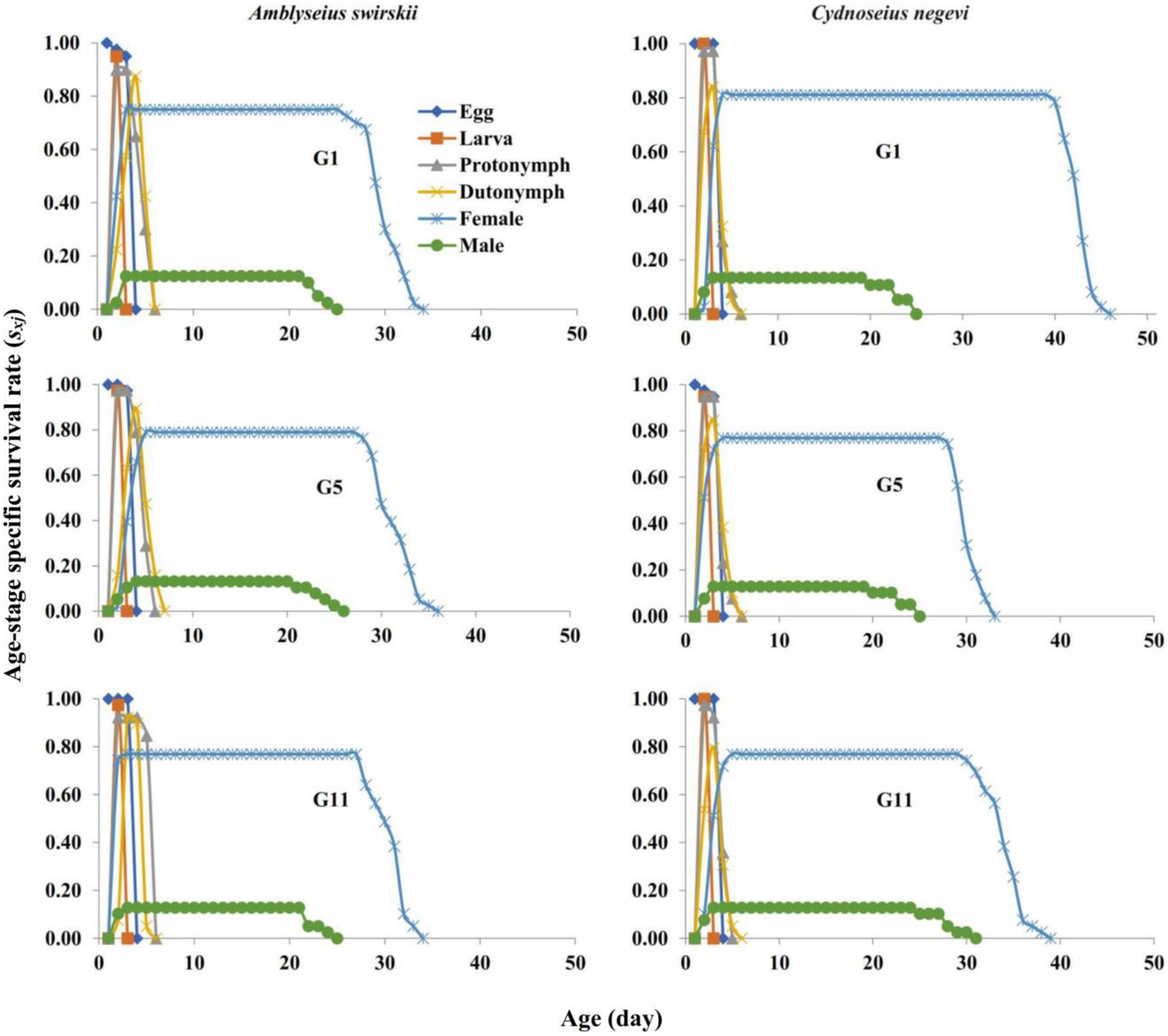

Figure 1. Age-stage specific survival rate (s_{xj}) of *Amblyseius swirskii* and *Cydnoseius negevi* reared on pollen grains of maize for 11 generations.

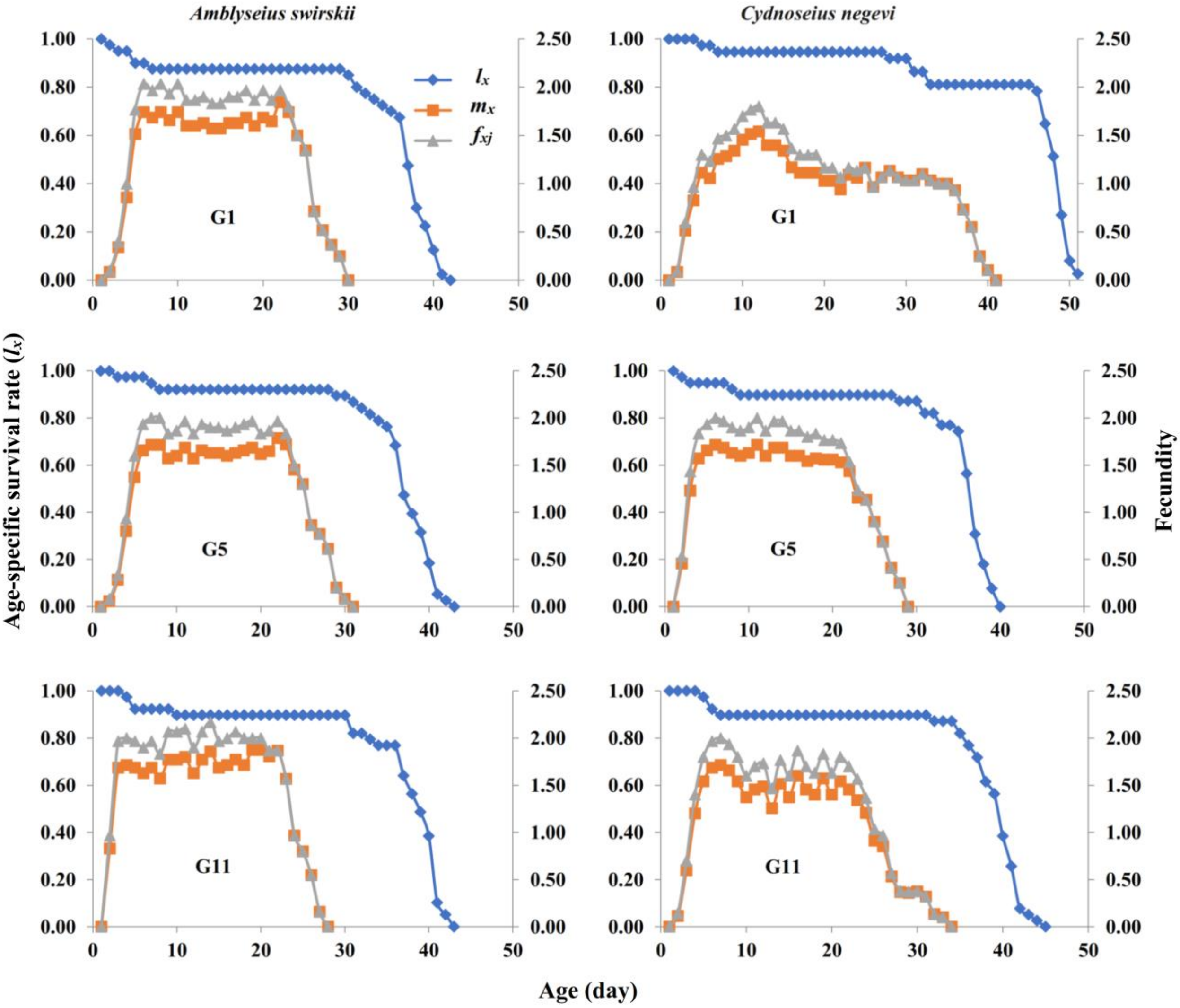

Figure 2. Age-specific survival rate (l_x), age-stage specific fecundity of female (f_{xj}) and age-specific fecundity rate (m_x) of *Amblyseius swirskii* and *Cydnoseius negevi* reared on pollen grains of maize for 11 generations.

Many studies have indicated that pollen grains were excellent as supplementary diet and appropriate food for mass rearing of phytoseiid species (Li *et al*. 2006; Khanamani *et al*. 2017c; Yazdanpanah *et al*. 2021; Eini *et al*. 2022; Gravandian *et al*. 2022). However, the long-term impacts of rearing on plant pollen on the performance of phytoseiid mites must be assessed if such food is to be used for mass production (Sørensen *et al*. 2012). Both *A. swirskii* and *C. negevi* are generalist predators preying on different mite pests. In the current study, the potential of *Z. mays* pollen as a diet for *A. swirskii* and *C. negevi* over eleven generations of rearing were investigated. Our results displayed that these predatory mites could feed, develop, and reproduce well on *Z. mays* pollens over 11 generations. These findings are substantial since the quality of the organisms reared in laboratory over time is very important for the mass rearing of biocontrol agents (Nemati and Riahi 2020). Similar to our results, *A. swirskii* have been reared on almond, *Prunus dulcis* (Mill.) (Rosaceae), pollen over six generations (Nemati and Riahi 2020). Efficacious long-term rearing on plant pollen for other predatory mites was also reported; for instance, *Neoseiulus californicus* (McGregor) (Acari:

Phytoseiidae) have been reared on almond pollen beyond 20 generations (Khanamani *et al*. 2017c). Also, *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae) found to develop and reproduce for 50 generations on almond pollen (Yazdanpanah *et al*. 2021) and for 25 generations on cattail, *Typha latifolia* L. (Typhaceae), pollen (Gravandian *et al*. 2022).

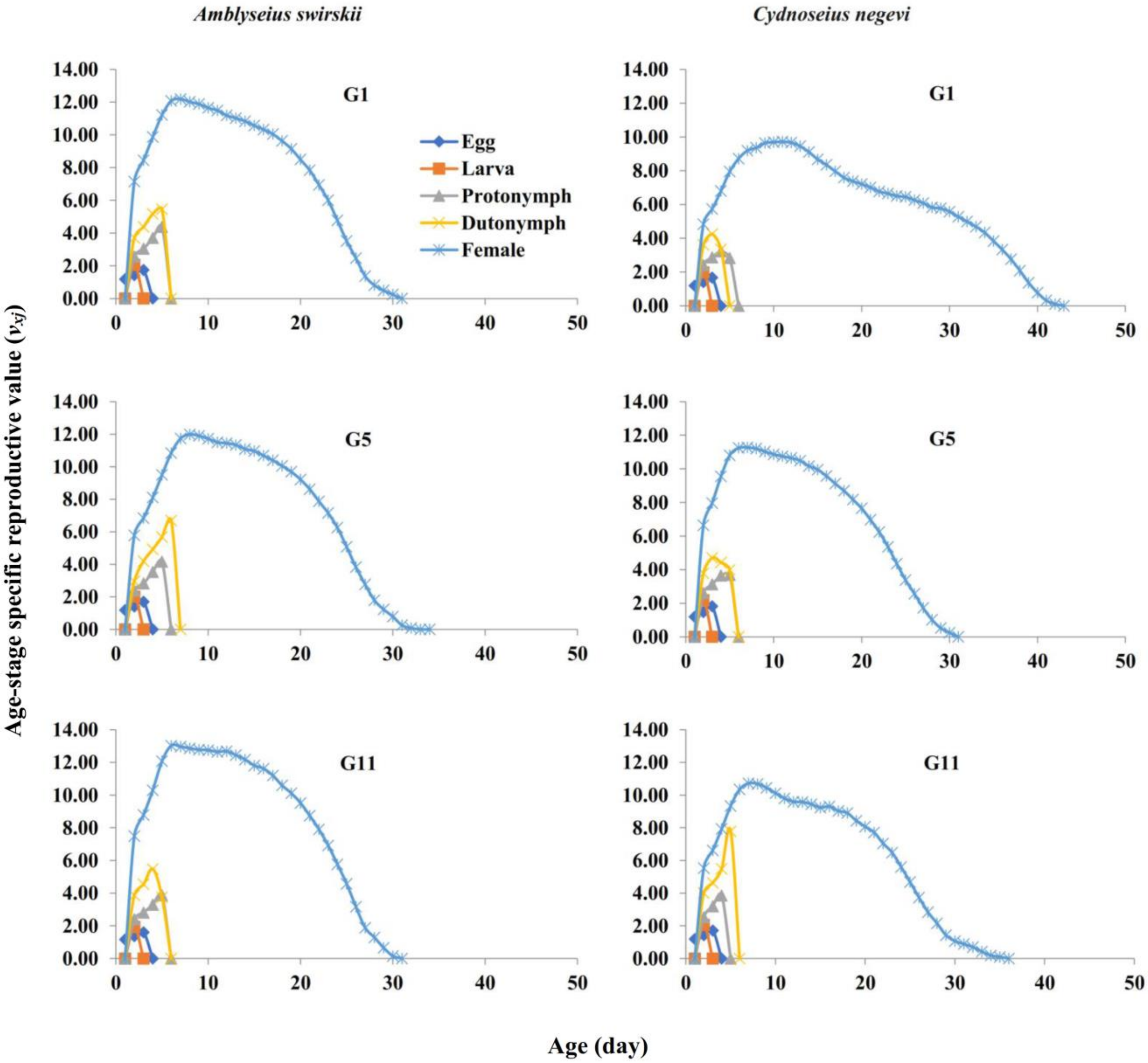

Figure 3. Age-stage specific reproductive value (v_{xj}) of *Amblyseius swirskii* and *Cydnoseius negevi* reared on pollen grains of maize for 11 generations.

Our results showed that the pre-adult period of *A. swirskii* was longer than that reported for this predator when reared on maize pollen (Nemati and Riahi 2020) and date palm, *Phoenix dactylifera* L., pollen (Abou-Elella *et al*. 2013; Rahmani Piyani *et al*. 2021). On the other hand, shorter pre-adult period was achieved for *C. negevi* reared on castor bean, *Ricinus communis* L., pollen (Momen *et al*. 2009) and *Tetranychus urticae* Koch (Acari: Tetranychidae) (Fouly *et al*. 2021) compared to the same predator when fed on date palm pollen (Fouly *et al*. 2021) and *Z. mays* pollen (present study). In this regard, the nutritional value of pollen differs among plant species and consequently the performance of predatory mites on various pollens may also be different (Yue and Tsai 1996). Herein, individuals of both tested predators showed longer pre-adult duration compared to other phytoseiid mites when fed on maize pollen [e.g., *Euseius aizawai* (Ehara and Bhandhufalck) (Li *et al*. 2006), *N. californicus* (Khanamani *et al*. 2017b; Eini *et al*. 2022), and *Amblyseius herbicolus* (Chant) (Hou *et al*. 2022)].

When *A. swirskii* fed on date palm pollen (Abou-Elella *et al*. 2013; Riahi *et al*. 2017) or maize pollen (Nemati and Riahi 2020), the fecundity was lower in comparison to the present results for this mite. In addition, longevity and fecundity of *C. negevi* were reported to be shorter and lower, respectively, when this predator was reared on date palm pollen or *T. urticae* (Fouly *et al*. 2021) in comparison to our study. Female longevity of *A. swirskii* fed cattail pollen (23.00 day) (Park *et al*. 2011) was shorter than the current results on *Z. mays* pollen. Total fecundity attained when *A. swirskii* and *C. negevi* were reared on *Z. mays* pollen in our study was higher than that recorded for *A. swirskii* on cattail pollen (Park *et al*. 2011) and other predators when fed on maize pollen [e.g., *E. aizawai* (Li *et al*. 2006), *N. californicus* (Khanamani *et al*. 2017b), *Typhlodromus bagdasarjani* Wainstein & Arutunjan (Riahi *et al.* 2016), and *A. herbicolus* (Hou *et al*. 2022)]. In this regard, the ability of phytoseiids to feed on pollen are different (Khanamani *et al*. 2017b), and consequently their performance response can differ. Al-Shammery (2011) revealed that the feeding preference of the generalist predatory mite species may be related to two factors, pollen type and predator species.

The estimated values of r and λ for *A. swirskii* when fed on date palm pollen (Abou-Elella *et al*. 2013; Rahmani Piyani *et al*. 2021) were higher than those reported for the same predator on the same pollen (Riahi *et al*. 2017) or on *Z. mays* (current study). Presently, the r value of *A. swirskii* was higher than that recorded for this predator reared on cattail pollen (0.158 day^{-1}), a recommended diet to keep colonies of *A. swirskii* in laboratory (Lee and Gillespie 2011). Moreover, the r values of G1 and G5 for *A. swirskii* in our results were higher than that estimated for *A. swirskii* reared on two natural prey, *T. urticae* (0.167 day^{-1}) (El-Laithy and Fouly 1992) and *Thrips tabaci* Lindeman (Thripidae) (0.024 day^{-1}) (Wimmer *et al*. 2008). Similarly, the higher reproductive potential of *T. bagdasarjani* and *N. californicus* raised on plant pollen compared to their natural prey has been reported (Riahi *et al*. 2016; Khanamani *et al*. 2017b).

The r value of *A. swirskii* in the current study was higher than those observed by Fadaei *et al*. (2018) (0.050 day^{-1}) and Nemati *et al.* (2019) (0.031 day^{-1}) for this predator raised on date palm pollen. In addition, the R_0 value of *A. swirskii* in our study was higher than previous studies when this predator was reared on cattail pollen (17.93 offspring) (Park *et al*. 2011), date palm pollen (24.17 offspring) (Abou-Elella *et al*. 2013), (6.058 offspring) (Riahi *et al*. 2017), (20.04 offspring) (Rahmani Piyani *et al*. 2021) and *T. urticae* (19.776–26.396 offspring) (Fahim and El-Saiedy 2021). These differences in results may be due to variations in the quality of pollens of different plants, which lead to variations in the food supply required by mites (Khanamani *et al*. 2017b). Variations in pollen surface morphology, grain hardness and/or secondary metabolites may be also sources of these differences (Khanamani *et al*. 2017b). As compared to the current study, lower values of r and R_0 were reported when *C. negevi* was reared on date palm pollen (r = 0.132 day^{-1}, R_0 = 16.26 offspring) and *T. urticae* (r = 0.146 day^{-1}, R_0 = 16.90 offspring) (Fouly *et al*. 2021). In contrast, a higher r value was reported for the same predator on castor bean pollen (0.27 day^{-1}) (Momen *et al*. 2009). Feeding of *C. negevi* on date palm pollen or *T. urticae* (Fouly *et al.* 2021) resulted in a lower λ value as compared to the present results for this predator. However, a higher value of this parameter was reported in the case of feeding of *C. negevi* on castor bean pollen (1.31 day^{-1}) (Momen *et al*. 2009). The values of r, λ, and R_0 of the two predatory mites in the current study were superior to those for other predatory mites when fed on maize pollen [e.g., *E. aizawai* (Li *et al*. 2006), *T. bagdasarjani* (Riahi *et al*. 2016), *N. californicus* (Eini *et al*. 2022), and *A. herbicolus* (Hou *et al*. 2022)].

The present study supports similar results with *A. swirskii*, *N. baraka*, and *N. californicus*, where maize pollen is also recommended as an appropriate diet (Wimmer *et al*. 2008; Zannou and Hanna 2011; Goleva and Zebitz 2013; Khanamani *et al*. 2017b). In this study, the good performance of both tested predators reared on the tested pollen grains could be due to the nutritive quality of *Z. mays* pollen. In this regard, maize pollen is found to contain proteins, carbohydrates, and many minerals (Bujang *et al*. 2021). Based on a study done by Khanamani *et al.* (2017b) on seven types of pollen grains, the levels (%) of protein content were the highest in almond pollen followed by maize. The protein content is vital for growth and reproduction (Roulston and Cane 2000). In addition, carbohydrates could be the next indicator of the nutritional value of pollen for consumers (Khanamani *et al*. 2017b). Rearing on pollen grains not only results in less cannibalism in predatory mites (Hoogerbrugge *et al*. 2008), but also provides the phytoseiid with a great amount of nutrients (Khanamani *et al.* 2016). Additionally, pollen grains are known as a possible main factor in the success of biological management of spider mites (Kennett *et al*. 1979; Barret and Kreiter 1995) and of thrips (van Rijn and Tanigoshi 1999).

In contrast, the r and λ values estimated for *A. swirskii* in our study were lower than that reported previously for the same predator fed on maize pollen (Goleva and Zebitz 2013; Nemati and Riahi 2020). The difference between these results could be because of the variations in experimental conditions, variations in predatory mite strains, and differences in the freshness of maize pollen. In addition, differences in plant varieties, climatic conditions, and soil type are factors causing variations in nutritional value of plants and thus leading to differences in mite performance (Ranabhat *et al*. 2014). Values of R_0 and GRR of *A. swirskii* in the current study were higher than those calculated by Nemati and Riahi (2020) for *A. swirskii* on maize pollen.

In our study, both oviposition days and female longevity of *C. negevi* were shorter in the later generations (G5 and G11) than that in G1. Similarly, the first generations of *A. swirskii* reared on almond pollen had longer female longevity and oviposition days than that in G5 and G10 (Ansari *et al*. 2022). Here, total number of eggs/*A. swirskii* female in G11 was higher than that of those in G1. In the same way, female fecundity in G1 (33.27 eggs/♀) of *A. swirskii* fed on almond pollen was lower than that in the G10 (34.25 eggs/♀) (Ansari *et al*. 2022). In our results, oviposition days, female longevity, and fecundity of *A. swirskii* were higher in the case of the individuals in G11 as compared to those in G1. In contrast, for the same predator, feeding on cattail pollen resulted in reductions in female longevity, oviposition days, and fecundity of individuals in G10 compared to those in G1 (Hadadi *et al*. 2022). These variations in results may be due to the differences in the pollen type. Recently, Pourbahram *et al.* (2022) observed an increase in the fecundity, female longevity, and oviposition days of *A. swirskii* reared on saffron pollen in the case of G10 versus G1, which are in agreement with our results for the same predator.

Herein, the values of R_0 and GRR of *A. swirskii* in addition to the values of r and λ of *C. negevi* were higher in G11 than in G1. In a previous study, the population growth rate of *A. swirskii* increased over six generations when reared on almond pollen (Nemati and Riahi 2020). Also, feeding on almond pollen and cattail pollen improved the values of r, λ, R_0, and GRR of *A. swirskii* during the tenth generation compared to those in the first one (Ansari *et al*. 2022; Hadadi *et al*. 2022). Likewise, lower values of r and λ were reported by Pourbahram *et al.* (2022) in G1 of *A. swirskii* reared on saffron pollen compared to G10.

CONCLUSION

On the basis of the present results, we can conclude that *Z. mays* pollen supported the development and reproduction of *A. swirskii* and *C. negevi* for 11 generations. Therefore, maize pollen has great potential as a suitable and cost-effective diet for developing the mass-production system of *A. swirskii* and *C. negevi* on non-prey diets, where the performance of these predators remained to some extent constant across generations. Further research is also needed to investigate if long-term rearing on *Z. mays* pollen decreases the ability of tested predators to locate, and consume natural prey (for instance, *T. urticae*) under greenhouses or field conditions.

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اثرهای گردهٔ ذرت بر رشد و پتانسیل رشد جمعیت *Amblyseius swirskii* و *Cydnoseius negevi* (Acari: Phytoseiidae) در نسل‌های بعدی

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چکیده

رژیم غذایی جزء مهمی از سامانهٔ تولید انبوه عوامل مهار زیستی است. بنابراین، استفاده از رژیم غذایی غیر شکاری (مانند گردهٔ گیاهان) به جای طعمه طبیعی می‌تواند در تولید انبوه کنه‌های شکارگر فیتوزئید مقرون به صرفه‌تر باشد. بنابراین، مطالعهٔ حاضر با هدف بررسی اثر چند نسلی ذرت، *Zea mays* L. (Poaceae)، رژیم غذایی گرده بر آماره‌های جدول زندگی *Amblyseius swirskii* Athias-Henriot و *Cydnoseius negevi* (Swirski & Amitai) (Acari: Phytoseiidae) برای یک، پنج و ۱۱ نسل پیاپی پرورش یافته انجام شد. کنه‌های شکارگر *A. swirskii* و *C. negevi* با موفقیت رشد خود را با تغذیه از گردهٔ ذرت تا ۱۱ نسل به پایان رساندند. در نسل یکم، روزهای تخمگذاری، طول عمر کنهٔ کامل و باروری به طور معنی‌داری بالاترین مقادیر را در مورد *C. negevi* در مقایسه با *A. swirskii* نشان دادند. برخلاف روزهای تخمگذاری مشابه از نظر آماری در نسل یازدهم، ماده‌های *A. swirskii* (۴٤/٤۳ تخم در ♀) تخم‌های بسیار بیشتری نسبت به *C. negevi* (٤۰/٦۰ تخم در ♀) گذاشتند. در حال حاضر، تفاوت معنی‌داری در نرخ متناهی افزایش (λ)، نرخ ذاتی افزایش (r)، نرخ خالص (R_0) و نرخ تولیدمثل ناخالص (GRR) بین دو کنه شکارگر در نسل یکم و پنجم ($P \geq 0.05$) وجود نداشت. در نسل ۱۱، افراد *C. negevi* مقادیر بیشتر معنی‌داری از r (۰/۱۸۱ در روز) و λ (۱/۱۹۸ در روز) در مقایسه با *A. swirskii* ($r = 0.159$ در روز، $\lambda = 1.173$ در روز) داشتند. با این حال، تفاوت معنی‌داری در مقادیر R_0 و GRR بین *A. swirskii* ($R_0 = 34.18$ فرزند، $GRR = 39.75$ فرزند) و *C. negevi* ($R_0 = 31.23$ فرزند، $GRR = 35.44$ فرزند) در نسل ۱۱ وجود نداشت. در نتیجه، گردهٔ ذرت دارای پتانسیل زیادی به عنوان یک رژیم غذایی مناسب و مقرون به صرفه برای توسعه سیستم تولید انبوه *A. swirskii* و *C. negevi* در جیره‌های بدون طعمه است، که در آن عملکرد این شکارگرها در طی نسل‌ها تا حدی ثابت باقی مانده است.

واژگان کلیدی: عوامل مهار زیستی، آماره‌های جدول زندگی، برنامه‌های پرورش انبوه، عملکرد در طی نسل‌ها، دانه‌های گرده، کنه‌های شکارگر.

اطلاعات مقاله: تاریخ دریافت: ۱٤۰۲/٤/۵، تاریخ پذیرش توسط *آ. فرازمند*: ۱٤۰۲/۹/٦، تاریخ چاپ: ۱٤۰۲/۱۰/۲۵