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Article

A life table analysis to evaluate biological control of banks grass mite using the predatory mite, *Galendromus flumenis* (Acari: Phytoseiidae)

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Abstract

The predatory mite, *Galendromus flumenis* (Chant) (Acari: Phytoseiidae), has shown promising traits for biological control of Banks grass mite, the major pest of date palms in California. In the present study, reproduction and population growth parameters of *G. flumenis* on Banks grass mite eggs were studied at 34ºC, 50±10% RH and a photoperiod of 16: 8 (L: D) hours. 100 percent of eggs hatched and 63.5 percent of the emerged larvae survived to adulthood. The total immature developmental time was 5.7 and 5.5 days for females and males, respectively. The sex ratio of *G. flumenis* was 0.70 (females/ females+ males). Mated females laid on average 1.6 eggs per day and 19.9 eggs during their mean ovipositional period of 12.5 days. The net reproductive rate (R_0) was 11.5 females/ female/ generation, the intrinsic rate of increase (r_m) was 0.200 females/ female/ day, the finite rate of increase (λ) was 1.222 population multiplication/ day, the mean generation time (T) was 12.2 days, and the doubling time (DT) was 3.5 days. The lower r_m value of *G. flumenis* than that of its prey (0.24–0.48) explains why Banks grass mite escapes control by *G. flumenis* in field. These results suggest that augmentative release of this predator would offset the lower r_m of the predator, thereby contributing to the control of Banks grass mite. Combined with the benefit of early releases determined in companion studies, future field studies with *G. flumenis* are being planned.

Keywords: *Oligonychus pratensis*, population growth, demography, biology

Introduction

California leads the nation in date production, with 99% of the production (US Department of Agriculture 2015). In 2014, 16,238 tons of dates valued at $35,800,000 were harvested from 3,142 hectares of date gardens in the Coachella Valley (Riverside County) in California. The Banks grass mite, *Oligonychus pratensis* (Banks) (Acari: Tetranychidae) has been a problematic pest of California dates since the early 1900s (Banks 1914). The mites' feeding damage leaves scarred and cracked fruits that are unmarketable (Elmer 1965, Carpenter and Elmer 1978). Chemical control of Banks grass mite is limited to Savey® (Hexythiazox), a growth regulator which is recommended to be sprayed on mite eggs or early developmental stages. However, growers' concerns about the development of resistance to Savey® and reliance on a single management strategy has resulted in support of research to find additional management tools. Among these efforts has been the use of biological control agents.

Mites in the family Phytoseiidae are considered as important predators of several phytophagous mites and small insects on various crops (Helle and Sabelis 1985, McMurtry & Croft 1997, McMurtry *et al*. 2013). Surveys for predatory mites in date gardens of the Coachella Valley revealed that *Galendromus flumenis* (Chant) was the only phytoseiid species in association with *O. pratensis*

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on date bunches (Ganjisaffar & Perring 2015a). Therefore, a series of laboratory experiments were initiated to elucidate the biological properties of *G. flumenis* in an effort to predict the performance of the predator in the field. Previous research on the prey stage preference of *G. flumenis* indicated that *G. flumenis* feeds on all life stages of *O. pratensis*, but it prefers eggs over the other stages, and displays a type II functional response on all *O. pratensis* immature stages (Ganjisaffar & Perring, 2015a).

Temperature-dependent studies showed that *G. flumenis* develops successfully from egg to adult under a wide range of temperatures from 18°C to 42°C, and the optimal temperature for development was calculated to be 37.6°C (Ganjisaffar & Perring 2015b). Not only is this a high optimal temperature among phytoseiids, but also the thermal requirements of *G. flumenis* are very close to the Banks grass mite (Perring *et al*. 1984a). This suggests that the prey and predator should be active at the same time in date garden, with overwintering adults of both species emerging and reproducing at the same time. However, field observations do not agree with this prediction, and dates are heavily damaged by Banks grass mites early in the season (Gispert *et al*. 2001). Therefore, additional population parameters of *G. flumenis* were studied to complete a life table analysis. For this purpose, survivorship, reproduction and population growth of *G. flumenis* at its optimal temperature were studied. Our aim was to further understand why *G. flumenis* fails to keep up with Banks grass mite densities in field. In addition, information gained from life table studies can help understand release timing, release numbers, and geographic regions in which the predator can be used, thereby enhancing the use of *G. flumenis* in the management of Banks grass mite.

Materials and methods

Mite Culture Maintenance

Colonies of *G. flumenis* and *O. pratensis* were collected from date gardens in the Coachella Valley (Riverside County), California in 2012, and have been maintained in growth chambers at 30±1°C, 50±10% RH, and 16L: 8D photoperiod since then. Every year, the colonies were supplemented with field collected mites to insure genetic variability. *O. pratensis* were reared on field corn plants, *Zea mays* variety 31G71, with 7–8 fully developed leaves. *G. flumenis* were reared on black ceramic tiles (10×10 cm) as described by McMurtry and Scriven (1965). The tile was resting on a water-saturated foam in a stainless steel pan (20×20 cm) filled with water. To prevent mites from escaping, strips of tissue paper were placed around the edge of the tile which were immersed in water in the pan. A microscope cover slip with a few cotton threads underneath was placed in the center of the tile to provide ovipositional site and shelter for *G. flumenis*. Using a mite brushing machine (Bioquip Products, Rancho Dominguez, CA), *O. pratensis* infested corn leaves were brushed three times a week to provide mixed stages of prey for *G. flumenis* culture.

Experimental Procedure

Studies to determine survival, reproduction and population growth parameters of *G. flumenis* were initiated at the optimal temperature of 37.6°C (≈ 38°C) with 50±10% RH, and 16L: 8D photoperiod. The newly emerged females at this temperature did not lay eggs; therefore, the study was conducted at 34°C which was the temperature with the next shortest developmental time (Ganjisaffar & Perring 2015b).

G. flumenis was reared for one generation on *O. pratensis* eggs at 34°C. Then, 63 deposited eggs of newly emerged females were transferred individually to the experimental arenas which consisted of two Petri dishes. A 3 cm Petri dish with a 5 mm hole in the bottom was placed in a 5 cm Petri dish containing water. A cotton layer was placed in the small Petri dish on top of which a corn leaf cut to

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fit the 3 cm dish was placed abaxial side up. The leaf margin was covered with a water-saturated cotton strip to prevent mites from escaping and to maintain freshness in the leaf. A 1-cm hole was made in the lid of the large Petri dish, and this hole was covered with fine mesh for ventilation. Eggs of *O. pratensis* were supplied as food since previous study indicated that *G. flumenis* prefers eggs over the other stages of *O. pratensis* (Ganjisaffar & Perring 2015a). Development from egg to adult was recorded every 24 h. Second generation newly emerged females were paired with a male obtained in the experiment or taken from the colony. The pair was kept together until the end of the study and males that escaped or died were replaced by new ones. Approximately 250 *O. pratensis* eggs were supplied as food daily to each predator mite pair. To obtain these eggs, 50 *O. pratensis* females were transferred to a new experimental arena, and allowed to oviposit for 24 h. After this time, the females were removed and the eggs were counted and adjusted so that 250 eggs were available in each arena. The predators were moved to these new arenas containing the eggs each day until the female died. Daily observations were conducted under a stereomicroscope (10X) to determine female reproduction and survivorship.

Statistical Analysis

Life and fertility tables were constructed using the survival and reproduction data according to Carey (1993). Then, according to the method described by Meyer *et al*. (1986), the Jackknife procedure was used to calculate the following population growth parameters and their mean and standard errors (SAS Institute 2013):

Net reproductive rate (R_0) $\sum l_x m_x$

Intrinsic rate of population increase (r_m) $\sum_{x=0}^{n} e^{-rx} l_x m_x = 1$

Mean generation time (T) $\ln {}^{R_0}/_{r_m}$

Doubling time (DT) $\ln {}^{2}/_{r_m}$

Finite rate for increase (λ) e^{r_m}

Briefly, the Jackknife procedure is based on recombining the original data, calculating pseudo-values for each recombination, and estimating the mean and standard error of the parameters from the resulting frequency distribution of pseudo-values. The steps for the application of this method are as follow:

Step 1) true calculation of r_m, R_0, λ, T and DT is done considering the survival and reproduction data for all the n females. The estimates obtained are denoted as $r_{m(\text{all})}$, $R_{0(\text{all})}$, $\lambda_{(\text{all})}$, $T_{(\text{all})}$ and $DT_{(\text{all}).}$

Step 2) the procedure described is repeated n times, each time excluding one of the n females. Therefore, the remaining n-1 females are used to re-compute parameters, now named $r_{m(i)}$, $R_{0(i)}$, $\lambda_{(i)}$, $T_{(i)}$ and $DT_{(i).}$

Step 3) pseudo-values are calculated for each parameter, subtracting the estimate in step 1 from the estimate in step 2, for example, the pseudo-values of r_m ($r_{m(j)}$) were calculated for n samples using the following equation:

$$r_{m(j)} = n \times r_{m(all)} - (n-1) \times r_{m(i)}$$

Step 4) after calculating all the n pseudo-values for r_m, the mean ($r_{m(\text{mean})}$), variance ($VAR\, r_{m(\text{mean})}$) and standard error ($SE\, r_{m(\text{mean})}$) was calculated by the following equations:

$$r_{m(mean)} = \frac{\sum_{1}^{n} r_{m(j)}}{n}$$

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$$VARr_{m(mean)} = \frac{\sum_{1}^{n}\left(r_{m(j)} - r_{m(all)}\right)^2}{n-1}$$

$$SEr_{m(mean)} = \sqrt{\frac{VARr_{m(mean)}}{n}}$$

Results

100 percent of the eggs hatched and all of the newly emerged larvae developed to the protonymph stage. A sharp decline in the survival curve occurred during the protonymph stage (days 3–5) (Fig. 1). Forty individuals of the original 63 eggs survived to adult (63.49% immature survival). The age specific survival rate (l_x) of *G. flumenis* was recorded as 0.83 at the time of first adult emergence (day 5) (Fig. 1). The egg to adult developmental time was 5.6 (in table 1) and 5.5 days for females and males, respectively (Table 1). The pre-oviposition period was on average 2.7 days (Table 1), and the first oviposition occurred on day 6 (Fig. 1). Females laid an average of 19.9 eggs during their mean oviposition period of 12.5 days, and the number of eggs laid daily by a female ranged from 0–3 eggs with the average being 1.6 eggs per day. The mean duration of the post-oviposition period was 2.5 days. The sex ratio of *G. flumenis* was biased towards females with a proportion of 0.70. The population growth parameters were calculated as: net reproductive rate (R_0)= 11.5 females/ female/ generation, intrinsic rate of increase (r_m)= 0.200 female/ female/ day, the finite rate of increase (λ)= 1.222 population multiplication/ day, the mean generation time (T)= 12.2 days, and the doubling time (DT)= 3.5 days (Table 2).

TABLE 1. Mean (±SE) duration of different life stages and reproduction parameters of *Galendromus flumenis* on Banks grass mite eggs.

Parameters	Female (n=28)	Male (n=12)	Combined sexes (n=40)
Egg to adult development	5.6 ± 0.2	5.5 ± 0.1	5.6 ± 0.1
Adult longevity	17.7 ± 0.6	16.8 ± 1.8	17.4 ± 0.7
Life span	23.3 ± 0.6	22.3 ± 1.8	23.0 ± 0.7
Pre-oviposition period	2.7 ± 0.1		
Oviposition period	12.5 ± 0.7		
Post-oviposition period	2.5 ± 0.1		
Total fecundity (eggs/female)	19.9 ± 1.1		
Fecundity rate (eggs/female/day)	1.6 ± 0.0		
Sex ratio (females: males)	0.70 (2.33: 1)		

n is the number of replicates.

Discussion

Egg to adult developmental time for *G. flumenis* in the present study at 34°C was 5.6 days. However, in another study in which *G. flumenis* eggs had been collected from the stock colony at 30°C and reared at 34°C, the immature developmental time was 7.0 days (Ganjisaffar & Perring 2015b). This difference could be due to the shorter incubation period of eggs collected at 34°C compared to 30°C.

The fecundity rate of *G. flumenis* was 1.6 eggs/ day which is similar to other species in the genus *Galendromus* which are classified as phytoseiids with medium reproductive capacities (McMurtry

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& Croft 1997). In addition, McMurtry & Croft (1997) stated that Type II phytoseiids (selective predators of tetranychid mites, most frequently associated with dense-web-producing species) have r_m values of up to 0.4, however, they note that the r_m values for Type III species (generalist predators) are sometimes under 0.1, but can be as high as 0.25 when fed on spider mites or pollen. Based on this life-style classification, *G. flumenis* with a r_m= 0.20 would be placed on the specialist side of a type III predator approaching type II which also is in agreement with classification made by Blackwood *et al*. (2004) based on the prey type.

TABLE 2. Population growth parameters of *Galendromus flumenis* on Banks grass mite eggs**.**

Parameter	Mean ± SE
Net reproductive rate (R_0)	11.5 ± 1.3
Intrinsic rate of increase (r_m)	0.20 ± 0.01
Finite rate of increase (λ)	1.22 ± 0.01
Mean generation time (T)	12.2 ± 0.5
Doubling time (DT)	3.5 ± 0.2

TABLE 3. A comparison between population growth parameters of *Galendromus flumenis* and its prey, *Oligonychus pratensis***.**

Parameter	*O. pratensis*[*] 33–39°C	134°C
Egg to adult development	4.9–5.3	5.6
Oviposition period	7–16	12.5
Net reproductive rate	6.45–33.36	11.5
Intrinsic rate of increase	0.24–0.48	0.20
Finite rate of increase	1.27–1.62	1.22
Mean generation time	5.93–8.99	12.2
Doubling time	1.6–2.9	3.5

[*] Population growth parameters of *O. pratensis* were obtained from Perring *et al*. (1984b).

Most of the *G. flumenis* females that had been reared at 38°C (optimum temperature for their development) died without laying eggs. It has been shown that high temperatures can result in mortality or reduced mobility of sperm thereby resulting in a failure in egg fertilization of phytoseiids (Ferragut *et al*. 1987, Broufas & Koveos 2001). According to the meteorological data from the California Irrigation Management Information System (CIMIS) station in the Coachella Valley (OASIS.A (#136)), the daily maximum temperatures exceed 38°C (up to 45°C) for a few hours during the summer months of June through September, which may adversely affect the population dynamics of *G. flumenis* and consequently, biological control of Banks grass mites. This finding is of great importance since it helps explain our field observations of Banks grass mites not being controlled by *G. flumenis* at warm desert temperatures. In addition, a comparison among life table parameters of *O. pratensis* (reported by Perring et al. (1984b) and *G. flumenis* shows distinct differences between the prey and the predator. For example, at comparable temperatures the net reproductive rate of *O. pratensis* can reach 3 times the maximum potential of *G. flumenis* (Table 3). This contributes to an intrinsic rate of increase of the prey mite that is more than double that of the predator mite, and much longer mean generation times and doubling times for the predator (Table 3). Taken together, these data explain why this predator is barely able to keep up with Banks grass

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mite densities, especially when densities of *G. flumenis* are low in the early season at the time (Gispert *et al*. 2001) when Banks grass mite populations begin to increase. However, while *G. flumenis* has inferior population growth parameters to its prey, it has other traits that can be exploited in a biological control strategy. Ganjisaffar & Perring (2015a) found that *G. flumenis* prey on an average of 147.6 eggs, 63.8 larvae, 19.9 protonomyphs, or 16.3 deutonymphs of *O. pratensis* per day and they have a high searching efficiency. These traits may help compensate for the lower population growth parameters of *G. flumenis*.

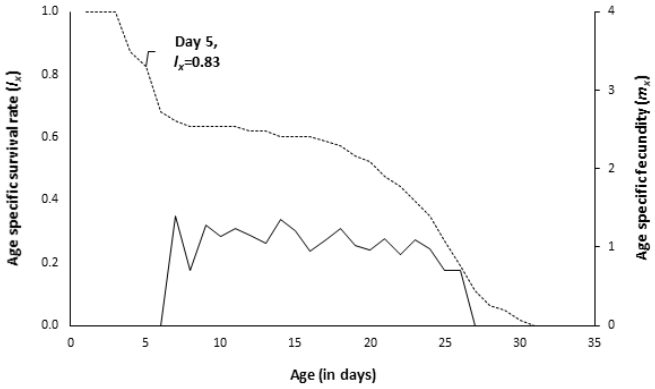


FIGURE 1. Age specific survival rate (dotted line) and fecundity (solid line) of *Galendromus flumenis* on Banks grass mite eggs.

Increasing the numbers of *G. flumenis* through augmentative releases should improve the management of Banks grass mite if releases are made early in the season when there is a higher proportion of prey eggs which are preferred life stage by the predator (Ganjisaffar & Perring 2015a). Based on the negative impact of high temperatures determined in this study, we also recommend that releases be made during the cool morning hours of day and in the inner canopy of the trees or inside the date bunches with minimum exposure to the sun and heat. Future field studies will be conducted to evaluate these release strategies.

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