Effect of Different Pollens on Development, Survivorship and Reproduction of *Euseius finlandicus* (Acari: Phytoseiidae)

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ABSTRACT Development, imaginal survivorship, adult longevity and fecundity of the predatory phytoseiid mite *Euseius (Amblyseius) finlandicus* Oudemans reared on seven different plant pollens were determined in the laboratory. The rationale behind these experiments was to assess the nutritional value and the possible effect on development and population dynamics of the mite. Mites were kept individually on bean (*Phaseolus vulgaris* L.) leaf disks at 20 ± 1°C and a photoperiod of 16:8 (L:D) h, with a sufficient quantity of pollen of apple (*Malus silvestris* M.), pear (*Pyrus communis* L.), cherry (*Prunus avium* L.), peach (*Prunus persica* L.), apricot (*Prunus armeniaca* L.), walnut (*Juglans regia* L.), or poppy (*Papaver rhoeas* L.). Developmental time from neonate larva to adult emergence varied between the different pollens from 6.03 to 6.62 d for females and from 5.46 to 6.14 d for males. Survivorship during immature development varied from 67.2 to 95.9% with the lowest value recorded on peach pollen. The average life span of adult females reared on the different pollens varied from 18.2 to 56.2 d, whereas the respective total fecundity ranged from 2.5 to 46.5 eggs per female. The estimated values of the intrinsic rate of increase (r_m) varied from 0.012 to 0.150. The analysis of these results show that cherry, peach, apricot, walnut, and poppy pollens are of higher nutritional value for *E. finlandicus* than apple and pear pollens and thus may play an important role in the field for sustaining and increasing the predator's population.

KEY WORDS Phytoseiidae, *Euseius finlandicus,* pollen, life table

THE PREDATORY PHYTOSEIID mite *Euseius (Amblyseius) finlandicus* Oudemans is widespread on deciduous trees and one of the few *Euseius* species found in temperate climates (Kropczyncka and Petanovic 1987, Kropzynska and Tuovinen 1988, Duso and Sbrissa 1990, McMurtry and Croft 1997). In Greece, it is found on forest, peach, and cherry trees (Ragusa Di Chiara 1995; unpublished data). Mites of the genus *Euseius* are characterized as specialized pollen feeders and generalist predators (Abou-Setta and Childers 1989, Grout and Richards 1992, Grafton-Cardwell and Ouyang 1995, Oliver et al. 1996, McMurtry and Croft 1997). *E. finlandicus* can feed and develop on a number of different plant pollens (Schausberger 1992, Kostiainen and Hoy 1994), scale insects (Schausberger 1998), and the herbivorous mites *Panonychus ulmi* Koch and *Aculus schlechtendali* (Nalepa) (Van de Vrie 1975, McMurtry 1981, Dicke et al. 1988, Duso 1992). Knowledge of the nutritional value of different plant pollens for *E. finlandicus* could be of importance not only for mass rearing of the mite, but also for a better understanding of its population dynamics in the field. The reproductive potential of some phytoseiid species is highest on pollen, whereas in some cases spider mites alone are unsuitable for development unless supplementary foods are present (Overmeer 1985, Abou-Setta and Childers 1987, Ferragut et al. 1987, Abou-Setta and Childers 1989, Zhao and McMurtry 1990). Population dynamics of *Euseius* species, which are mostly found in arboreal habitats, are often related to pollens found on the foliage rather than to the presence of any prey species (Kennett et al. 1979, Grout and Richards 1992, McMurtry and Croft 1997). For example, in citrus orchards the population of *E. addonensis addonensis* (McMurtry), which is an important predator of citrus thrips *Scirtothrips aurantii* Faure and tetranychid mites, increased on trees adjacent to windbreaks of certain anemophilous species that produce large amounts of pollen grains (Grout and Richards 1990). If plants in and around orchards produce suitable pollen early in spring this might sustain populations of predacious phytoseiids which may reduce prey populations later in the season. This hypothesis might be valid for *E. finlandicus.* It is difficult, however, to test such a hypothesis in the field because our knowledge concerning the nutritional value of different pollens for this mite is limited. Schausberger (1991, 1992) found that *E. finlandicus* can develop from larva through the adult and reproduce both on *Panonychus ulmi* Koch and *Tetranychus urticae* Koch individuals, although developmental rate and egg production on the later prey was lower than on cherry, apple, and birch pollens. Kostiainen and Hoy (1994) managed to rear massively *E. finlandicus* on a number of different pollens. However, in both studies a small number of pollens were used and the reproductive potential of the mite was assessed as the number of eggs laid over a short period and not through the entire adult life.

In commercial orchards of northern Greece, common pollen sources in early spring are, among others, the flowers of cultivated orchard trees, such as stonefruit and pomaceous trees, flowers of solitary walnut trees, found occasionally around the orchards and the widespread weed *Papaver rhoeas* L. (poppy). Studying the suitability of these pollens for the development and reproduction of *E. finlandicus* in the laboratory is important to evaluate their possible role in population increase of the mite in the field. In our study, developmental rate, immature survivorship, adult longevity, and fecundity of *E. finlandicus* were determined on seven different pollens and used as an index for their nutritional value.

Materials and Methods

Mite Colony. Our laboratory stock colony of *E. finlandicus* was established with individuals collected from commercial cherry orchards in northern Greece in summer of 1997. The stock colony mites were then maintained on detached bean leaves (*Phaseolus vulgaris* L.) at 25°C and a photoperiod of 16:8 (L: D) h for ≈7 wk before used in the experiments. Pollen of *Typha* sp. was offered on the bean leaf surface as food for the mites in a manner similar to that described by Kostiainen and Hoy (1994).

Voucher specimens of the mite were deposited in the collection of Natural History Museum, London.

Pollen. Pollen from apple (*Malus silvestris* M.), pear (*Pyrus communis* L.), peach (*Prunus persica* L.), cherry (*Prunus avium* L.), apricot (*Prunus armeniaca* L.), and walnut (*Juglans regia* L.) trees, and from the common wild poppy (*P. rhoeas* L.), were collected during the flowering season. Mature flower buds were collected just before opening from the experimental unsprayed orchard of the Institution of Deciduous Trees in Naousa, northern Greece. Anthers were cut from the flower buds and placed on a tray in an incubator at 30°C. After ≈24 h, most of the anthers had burst open and pollen grains were released on the tray. Subsequently, pollen was sieved through a 200-μm mesh and stored in glass vials at –10°C or at 0°C during the experiments.

Rearing Units. Mites were reared individually on bean leaf discs (2 cm diameter) maintained on wet cotton wool inside cylindrical cells of polystyrene multiwell tissue culture plates (Corning, Corning, NY), each having 12 cells (22.1 mm in diameter). A sufficient quantity of pollen grains and a few threads of cotton serving as an oviposition site were placed on each leaf disk.

Development and Survival of Immature Stages. Approximately 60 adult females from the stock colony were placed on an excised bean leaf maintained on wet cotton wool in plastic cups. *Typha* sp. pollen and cotton threads were placed on the leaf surface. The leaves with the mites were maintained at 25°C and a photoperiod of 16:8 (L:D) h, and eggs laid within 12 h on the cotton threads were transferred to another bean leaf and maintained at 20 ± 1°C and 16:8 (L:D) h. Newly hatched larvae within a 6-h period were collected and transferred individually to the leaf disks in the rearing units with the help of a fine camel's-hair brush (N_0 000). The mites developed from larva to adult in a climatic incubator at 20 ± 1°C and 16:8 (L:D) h. The relative humidity at the level of the mites was 70–80% and the intensity of the light ≈1,500 lux.

Every other day a sufficient quantity (0.2–0.3 mg) of pollen grains was added to each leaf disk, and old pollen grains were removed with the help of a fine camel's-hair brush to prevent the development of fungus or any other contaminants. The developmental stage of each individual was recorded every 12 h. The presence of an exuvium on the leaf disk was used as criterion for a successful molting of each mite. Analysis of variance (ANOVA) was used to compare the influence of food on the developmental time. Log transformation of larval and nymphal development time was used to minimize variances and means were compared using Student–Newman–Keuls sequential test (SPSS 1998). The chi-square test was used to compare immature survivorship on the different pollens.

Sex Ratio. Six groups of ≈60 females were reared from larva through adult on each pollen diet at 20°C and 16:8 (L:D) h. The eggs (≈80 per group) laid by each group of females on the sixth day of adult age were collected and placed on a bean leaf disk (4 cm diameter) maintained in contact with wet cotton wool in a 9-cm plastic petri dish at 20°C and 16:8 (L:D) h. The same pollen was used as food for both the parental and offspring generations. The sex ratio of the progeny, i.e., the percentage (%) of females in the population, was determined after ≈10 d. Data were arcsine square-root transformed and Student–Newman–Keuls test was used to compare the sex ratios of the mites on the different pollens (SPSS 1998). The number of eggs laid by females reared on pear and apple pollen was very low and the sex ratio was estimated for the total number of progeny. Therefore, the sex ratios on these two pollens were not compared statistically with those on the other pollens.

Adult Longevity and Reproduction. Newly molted females reared on a specific pollen were transferred individually on a leaf disk in the rearing unit together with a young male and fed the same pollen as that used during immature development. Egg laying and survivorship were recorded daily. Eggs were removed with the help of a fine camel's-hair brush. Fresh pollen was added on each leaf disk every other day. Males that escaped from the leaf disk or died were replaced with new ones. Females that drowned in the wet cotton wool or died because of improper handling were excluded from the data analysis. Leaf disks were renewed once a week.

Differences in longevity and total fecundity among different plant pollens were compared by ANOVA with the procedure of SPSS (1998). Log transformation of survival time and $\log(x + 1)$ of total fecundity were used to minimize variances and means were compared using Student–Newman–Keuls sequential test (SPSS 1998).

Table 1. Mean developmental time (days) (±SEM) of immature stages of *E. finlandicus* reared on seven plant pollens at 20 ± 1°C

Plant pollen	*n*	Larva	Protonymph	Deutonymph	Total immature development
Females					
Cherry	72	2.06 ± 0.05a	1.91 ± 0.05a	2.24 ± 0.04a	6.09 ± 0.07a
Peach	76	1.91 ± 0.04b	2.32 ± 0.08d	2.26 ± 0.05b	6.38 ± 0.09b
Apricot	85	1.90 ± 0.03b	2.08 ± 0.04abc	2.10 ± 0.04a	6.08 ± 0.06a
Walnut	34	2.16 ± 0.06a	2.22 ± 0.09cd	2.25 ± 0.07a	6.63 ± 0.11c
Poppy	45	1.95 ± 0.05b	1.95 ± 0.06ab	2.05 ± 0.04a	6.03 ± 0.09a
Pear	67	2.10 ± 0.03a	2.15 ± 0.05cd	2.32 ± 0.04a	6.62 ± 0.08c
Apple	64	1.92 ± 0.04b	2.12 ± 0.05bc	2.39 ± 0.08ab	6.42 ± 0.10c
F		6.09	2.26	6.55	7.85
df		6,436	6,436	6,436	6,436
P		<0.001	<0.001	<0.001	<0.001
Males					
Cherry	28	2.12 ± 0.08a	1.91 ± 0.09a	1.91 ± 0.07ab	5.78 ± 0.09ab
Peach	30	1.78 ± 0.05c	1.90 ± 0.06ab	2.13 ± 0.06c	5.85 ± 0.12ab
Apricot	31	1.79 ± 0.05c	1.82 ± 0.06ab	1.82 ± 0.05a	5.46 ± 0.08a
Walnut	27	1.98 ± 0.04ab	2.09 ± 0.09b	2.04 ± 0.06bc	6.11 ± 0.12b
Poppy	39	2.03 ± 0.04ab	1.81 ± 0.06ab	1.95 ± 0.04abc	5.64 ± 0.13a
Pear	38	2.02 ± 0.02ab	2.03 ± 0.06ab	2.11 ± 0.04c	6.14 ± 0.09b
Apple	45	1.86 ± 0.03bc	1.84 ± 0.05ab	2.10 ± 0.05bc	5.78 ± 0.08ab
F		6.15	2.40	4.52	4.60
df		6,231	6,231	6,231	6,231
P		<0.001	<0.05	<0.001	<0.001

Within the same column means followed by the same letter are not significantly different at $P > 0.05$ using Student–Newman–Keuls test.

Jackknife estimates of intrinsic rates of increase (r_m) and their variance were calculated as described by Meyer et al. (1986). For the comparison of the different r_m, Student–Newman–Keuls sequential test was used (Sokal and Rohlf 1969).

According to the procedure described by Tsai (1998), for calculation of life-table statistics, first different r_m values were arrayed in order of magnitude, the difference between two r_m from the sequence is considered significant at the alpha level if it is equal or greater than a least significant range (LSR) estimated by the following formula:

$$LRS = Q_{(K,V)}\sqrt{S_{av}^2}\sqrt{\frac{n_1+n_j}{2n_in_j}},$$

where K is the number of r_m in the set whose range is tested, V is the degree of freedom, n_i and n_j are the sample sizes of the two r_m, $Q_{a(K,\,V)}$ is a value from the table of the studentized ranges. S_{av}^2 is the weighted average variance of r_m calculated as follows:

$$S_{av}^2 = \frac{\sum^a (n_1-1)S_i^2}{\sum^a (n_i-1)},$$

where a is the number of r_m values to be tested and n_i the sample size of *ith* r_m, S_i^2 is jackknife estimate of the variance for *ith* r_m.

Results

Immature Development and Survivorship. Development time of immature stages of both females and males differed significantly among the different pollens (females $F = 7.85$; df = 6, 436; $P < 0.001$; males $F = 4.6$; df = 6, 231; $P < 0.001$) (Table 1). In females reared on cherry, apricot, and poppy pollens the mean total development time was significantly shorter than in

Table 2. Sex ratio (±SEM) in offspring of females of *E. finlandicus* reared on five different plant pollens

Plant pollen	Sex ratio, %
Cherry	66.04 ± 1.83
Peach	64.79 ± 1.84
Apricot	70.58 ± 3.40
Walnut	70.51 ± 2.13
Poppy	61.99 ± 3.40
F	2.609
df	4,25
P	= 0.06

Table 3. Longevity (days) and fecundity (total number of eggs) of *E. finlandicus* females reared on seven plant pollens at 20 ± 1°C

Plant pollen	*n*	Longevity (mean ± SEM)	Fecundity (mean ± SEM)
Cherry	38	53.7 ± 3.3a	46.5 ± 2.9a
Peach	17	46.3 ± 2.8a	39.3 ± 4.0a
Apricot	57	49.4 ± 3.1a	41.5 ± 2.7ab
Walnut	38	56.2 ± 3.6a	42.1 ± 2.5ab
Poppy	26	31.6 ± 3.3b	27.8 ± 3.3b
Pear	39	18.2 ± 0.9c	7.3 ± 0.9c
Apple	42	20.6 ± 0.9c	2.5 ± 0.6c
F		29.85	68.28
df		6,250	6,250
P		<0.001	<0.001

Within the same column means followed by the same letter are not significantly different at $P > 0.05$ using Student–Newman–Keuls test.

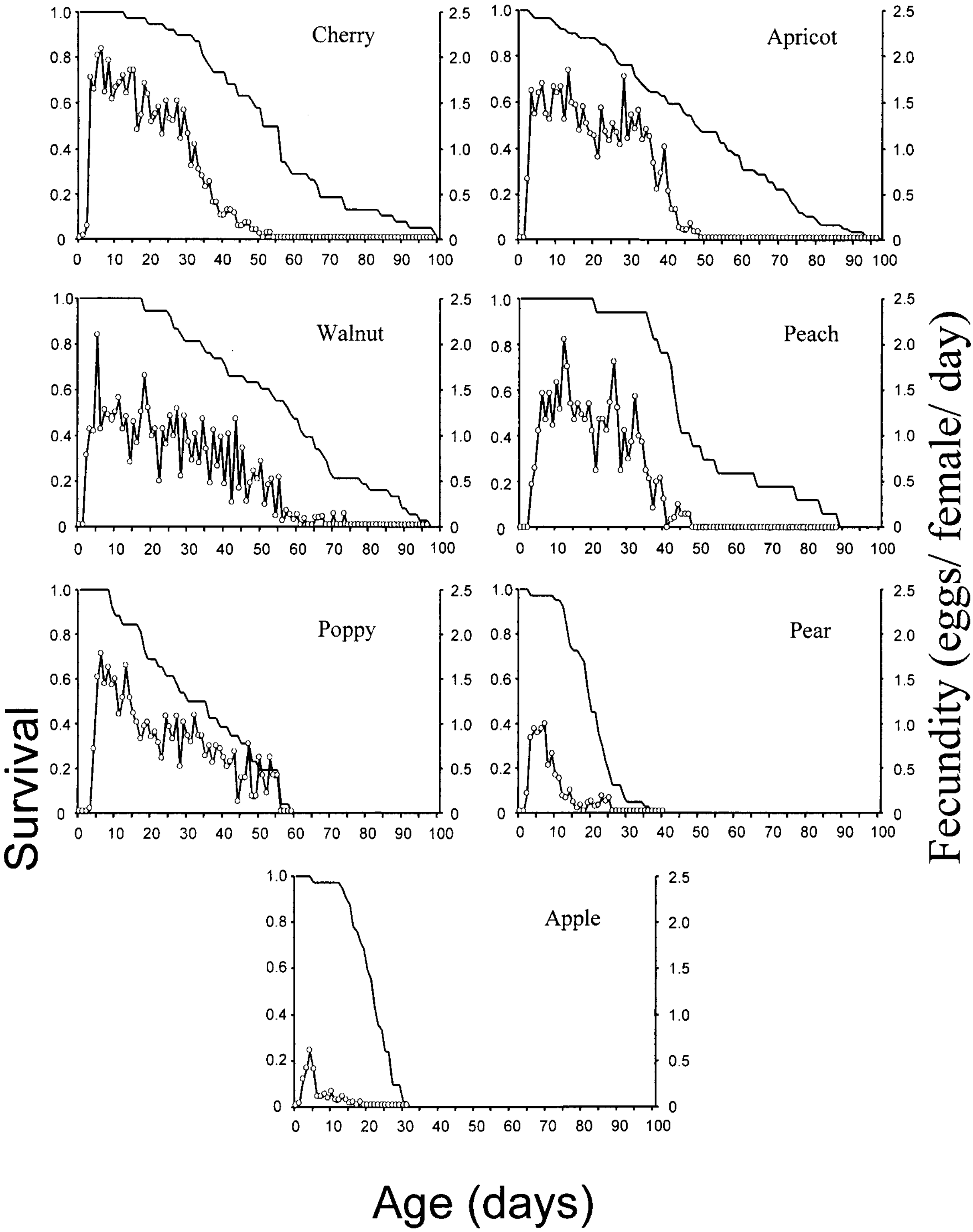

Fig. 1. Age-specific survival (solid line) and fecundity (open cycles) of *E. finlandicus* reared on seven different pollens.

those reared on peach, apple, walnut, and pear pollen (Table 1). The total development time also differed significantly ($P < 0.001$) between males reared on the different plant pollens. Development time was shorter on stone fruit, poppy, and apple pollens than on pear and walnut pollens.

Survivorship during immature development varied among mites reared on the seven different pollens. On

Table 4. Comparison of life table parameters of *E. finlandicus* on seven pollens

Plant pollen	Parameters					
	n	r_m	95% CI	R_0	T	DT
Cherry	38	0.145a	0.149 0.142	29.96 ± 0.04	27.6	4.78
Peach	17	0.150a	0.151 0.149	26.37 ± 0.17	27.3	4.62
Apricot	59	0.147a	0.151 0.143	27.08 ± 0.09	28.3	4.71
Walnut	38	0.143a	0.145 0.140	28.45 ± 0.04	32.1	4.87
Poppy	26	0.120b	0.125 0.115	14.94 ± 0.07	27.3	5.77
Pear	40	0.082c	0.091 0.072	3.74 ± 0.01	16.3	8.45
Apple	42	0.012d	0.023 0.001	1.34 ± 0.01	14.7	57.76

Within the same column means followed by the same letter are not significantly different ($P > 0.05$), Student–Newman–Keuls test. n, number of females used; r_m, jacknife estimate of intrinsic rate of increase; CI, interval estimate for r_m; R_0, net reproductive rate (female progeny per female); T, mean generation time (days); DT, doubling time of population (days).

peach pollen, survivorship was 67.2% and significantly lower than on cherry (94.2%) ($\chi^2 = 21.8$, $P < 0.001$), apricot (95.9%) ($\chi^2 = 29.4$, $P < 0.001$), walnut (95.2%) ($\chi^2 = 16.4$, $P < 0.001$), poppy (88.2%) ($\chi^2 = 10.5$, $P < 0.001$), apple (91.6%) ($\chi^2 = 17.9$, $P < 0.001$), and pear (93.3%) ($\chi^2 = 21.6$, $P < 0.001$) pollens. No significant differences were found in survivorship among mites reared on cherry, apricot, walnut, poppy, apple, and pear pollens ($\chi^2 = 21.8$, df = 5, $P = 0.08$).

Sex Ratio. As shown in Table 2, percentages of female progeny were not affected significantly by the kind of pollen on which the parental mites were reared. On apple and pear pollens the estimated sex ratios (not shown in Table 2) were 65% (80 adult progeny were examined) and 68% (20 adult progeny were examined), respectively, and therefore within the range found in the other pollens.

Longevity, Fecundity, and Life Table Parameters. Females reared from larva through the adult on cherry, peach, apricot, and walnut pollens lived significantly longer than those reared on poppy, pear, and apple pollens (Table 3). The age-specific survival curves shown in Fig. 1 indicate that during the first 20 d of adult life mortality was low in all the seven tested pollens. After the 20th day of adult life, percentages of survival declined sharply in females reared on pear and apple pollens and reached zero soon after the 30th day. On cherry, apricot, walnut, and peach pollens, survival declined gradually and reached zero between the 90th and 100th day of adult life and a considerable proportion of females survived after the end of the oviposition period (Fig. 1).

Females reared on cherry, peach, apricot, and walnut pollens had a significantly higher fecundity than those reared on poppy, pear, and apple pollens (Table 3). The first eggs were laid on the third day of adult life irrespective of the kind of pollen the females were reared on. Females reared on cherry, apricot, and peach pollens (Fig. 1) continued to lay eggs until the 50th day of adult life, whereas on poppy and walnut pollens they continued to lay until the 55th and 60th day, respectively. By contrast, females reared on pear and apple pollens laid considerably fewer eggs.

Life table statistics of *E. finlandicus* on the seven different pollens are shown in Table 4. Mites reared on cherry, peach, apricot, walnut, and poppy pollens had a significantly higher intrinsic rate of increase than those fed on pear and apple pollens. The net reproductive rate (R_0) for mites reared on cherry, apricot, and walnut pollens was considerably higher than for those reared on peach or poppy pollens. On pear and apple pollens, R_0 had the lowest values (Table 4). The mean generation time ranged from 27.3 to 32.1 d in all except apple and pear pollens on which it was much shorter. Similarly, the doubling time varied from ≈ 4.6 to 8.4 d in all the pollens tested except apple, on which it was much longer (57.76 d) (Table 4).

Discussion

Euseius finlandicus is a widespread polyphagous predatory mite found feeding in orchard trees on various eriophyoid species and the red spider mite, *Panonychus ulmi* (Koch) (Van de Vrie 1975, McMurtry 1981, Kropczyncka and Petanovic 1987, Dicke et al. 1988, Kropzynska and Tuovinen 1988, Duso and Sbrissa 1990, Duso 1992, McMurtry and Croft 1997). In early spring, population densities of the prey species are low and the presence of alternative food such as pollen could favor an early growth of the predator's population. Population increase of *Euseius* species is often correlated with pollen fallout onto the foliage rather than with the presence of prey species (Grout and Richards 1992, McMurtry and Croft 1997). Various *Euseius* species, such as *E. tularensis* Congdon, *E. hibisci* Chant, *E. fustis* (Pritchard & Baker), *E. finlandicus*, and *E. membrasicus* (Dean), when reared on certain pollens showed a lower immature mortality and a higher reproductive capacity than when reared on their prey species, which indicates that pollens are of high nutritional value for these mites (Tanigoshi et al. 1983, Abou-Setta and Childers 1989, Zhao and McMurtry 1990, Schausberger 1992, Kostiainen and Hoy 1994, Bruce-Oliver et al. 1996).

In our study we found that cherry, apricot, peach, and walnut pollens were of high nutritional value for the mite because immature mortality was low (with the exception of peach pollen) and r_m, net reproductive rate, and mean adult longevity were high. Kostiainen and Hoy (1994) developed a mass-rearing technique for *E. finlandicus*, and proposed cattail pollen as the best option for laboratory rearing. Although they used a large number of pollen types, only the effect of cattail pollen on development and reproduction was reported. Schausberger (1992) found that apple pollen was an adequate alternative food source for development and reproduction of the mite. By contrast, our results showed that fecundity was very low when the mites were reared on apple pollen. On cherry pollen, however, fecundity was found to be close to Schausberger's (1992) findings. The difference in the effect of apple pollen on the fecundity of *E. finlandicus* between ours and Schausberger's experiments might be attributed to either genetic differences in food demands between the Greek and Austrian strains of the mite or to differences in pollen quality used in the bioassays. Qualitative and quantitative chemical analysis of the pollens or development of the two mite strains on the same pollen may help to clarify this point.

Euseius finlandicus has been considered as an important natural enemy of *P. ulmi* in apple and peach orchards in Italy and The Netherlands (Van de Vrie 1975, McMurtry 1981, Duso 1992). In northern Greece, both species are found in apple, peach, cherry, and apricot orchards (unpublished data). We have found that overwintering diapause females of *E. finlandicus* leave their hibernation sites, which are mainly bark crevices, after the first week of March (unpublished data). However, the overwintering eggs of *P. ulmi* do not hatch until the first half of April (Broufas and Koveos 2000). Therefore, before hatching the most available food for the mite could be pollen. Our results show that the nutritional value of cherry, peach, apricot, walnut, and poppy pollens for *E. finlandicus* is higher than that of apple and pear. From an ecological point of view these quality differences among pollens may indicate that in early spring a more rapid population increase of the predator could be expected in cherry, peach, and apricot orchards than in apple orchards. Our results also suggest that walnut pollen, falling naturally from trees found occasionally around orchards, or poppy pollen from the ground floor vegetation cover, could increase pollen availability in an orchard and may have a direct effect on population dynamics of the arboreal predatory mite. Furthermore, because walnut is an anemophilous species that produces large amounts of pollen, we can easily collect large quantities of this pollen and dust orchard trees to increase food availability for the predator. Studying the nutritional ecology of phytoseiid predators is of fundamental importance to conserve and augment them as natural enemies of fruit pests. However, further field experiments, are needed to substantiate our laboratory results and fully evaluate these pollens for increasing and sustaining the predator's population.

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