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Development and Reproduction of Three *Euseius* (Acari: Phytoseiidae) Species in the Presence and Absence of Supplementary Foods

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ABSTRACT

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Development duration, mortality and oviposition rate of *Euseius tularensis* (Congdon), *E. stipulatus* (Athias-Henriot) and *E. hibisci* (Chant) were determined on three basic foods (pollen of iceplant, Pacific spider mite and citrus red mite) in the presence and absence of supplementary foods (honeydew from aphids and whiteflies). The studies were conducted in the laboratory at a constant temperature of 25 °C. The mean duration of each development stage and total development time did not differ significantly between treatments with and without supplementary food, regardless of species and basic foods. The mortality of the immature stages of the three *Euseius* species was generally higher in the absence of supplementary foods than in the presence of these foods, but differences were not significant ($P=0.05$). Oviposition rates generally were significantly higher in the presence of supplementary foods. The basic food was the most important factor affecting development, survival and oviposition rate; the most favorable food was pollen and the least favorable was citrus red mite. The development and oviposition rates differed somewhat among the three *Euseius* species on the same food or food combination.

INTRODUCTION

The phytoseiid mites *Euseius hibisci* (Chant), *E. tularensis* (Congdon) and *E. stipulatus* (Athias-Henriot) are important natural enemies on citrus and avocado in southern California. In groves where there is minimal pesticide interference, these acarine predators generally can be important mortality factors in biological control of the citrus red mite, *Panonychus citri* (McGregor) on citrus, *Oligonychus punicae* (Hirst) and *Eotetranychus sexmaculatus* (Riley)

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on avocado (McMurtry, 1982), and the citrus thrips, *Scirtothrips citri* (Moulton), on citrus (Tanigoshi et al., 1985). Recent evidence obtained by morphological and hybridization studies (Congdon and McMurtry, 1985) demonstrated that the mite referred to as *E. hibisci* in earlier papers involves two sibling species. The first species, *E. hibisci*, tends to be limited to coastal areas of southern California and occurs on both citrus and avocado. The second species, *E. tularensis*, is found on citrus, especially in the inland areas of southern California and the San Joaquin Valley, and rarely is found on avocado. *Euseius stipulatus* was introduced from the Mediterranean region and is established on citrus in coastal areas of southern California (McMurtry, 1977) where it has displaced *E. hibisci* on citrus in many orchards in San Diego, Ventura and Santa Barbara counties (McMurtry, 1982).

These three species of phytoseiid mites feed not only on tetranychid mites and thrips, but also on pollen and honeydew (McMurtry and Scriven, 1964; McMurtry, 1977; Tanigoshi et al., 1981; Ferragut et al., 1987). Some species of *Euseius* can complete their life-cycle and reproduce more rapidly on pollen than on tetranychid mites (McMurtry and Scriven, 1964; Swirski et al., 1967; De Moraes and McMurtry, 1981). McMurtry and Scriven (1962) also observed that *E. hibisci* from coastal southern California laid more eggs when feeding on tetranychid mites in combination with an agar-base medium containing yeast hydrolysate than when feeding on mite prey alone. McMurtry and Scriven (1964) found that female *E. hibisci* fed a combination of spider mites and honeydew during development had a shorter mean time to oviposition compared with those fed mites alone, and that the phytoseiids could survive for more than one month on honeydew alone. This indicated that supplementary foods such as honeydew and yeast probably play an important role in the diet of these predaceous mites.

It was felt that further studies of feeding habits of the three *Euseius* species might provide a better understanding of some of the factors affecting their abundance in the field. The objective of this study was to evaluate and compare the development, mortality and reproduction of these species on different basic foods in the presence and absence of supplementary foods.

MATERIALS AND METHODS

The test arenas consisted of excised 'Valencia' orange leaves placed upper-surface-down on 12-mm-thick, foam mats (17×17 cm) in stainless-steel pans (20×20 cm) with water. Each leaf arena (4×4 cm) was surrounded by a 1.5.-cm-wide strip of Cellucotton®. Each steel pan contained 9 such leaf arenas. The Cellucotton strips, saturated with water, served as a barrier to prevent the predaceous mites from escaping from the arenas and to keep the leaves moist. Whenever a leaf began to deteriorate, it was replaced with another fresh leaf.

All experiments were conducted in small, modified refrigerators (Platner et al., 1973) at 25±0.5°C, 40–70% relative humidity (r.h.), and a 12:12-h photoperiod. None of the species is known to have a diapause.

The basic foods tested for the three *Euseius* species included pollen of the iceplant *Malephora crocea* (Jacq.), eggs of the Pacific mite *Tetranychus pacificus* McGregor, extracted from glasshouse-grown lima bean plants by the method described by Scriven and McMurtry (1971) (the eggs began to hatch about one day after being placed into test arenas), and eggs of the citrus red mite *Panonychus citri* (McGregor). Three days before the test began, approximately 10 adult females of citrus red mite were transferred from field-collected citrus leaves to each test arena. Consequently, when the predaceous mites were introduced to test arenas, numerous eggs and a few larvae of citrus red mite were available as food. Five additional adult females were transferred daily to each test arena during the experiment.

The supplementary foods tested were honeydew from the bean aphid *Aphis fabae* Scopoli, and from the woolly whitefly *Aleurothrixus floccosus* (Maskell). The aphid honeydew was obtained by placing 15×15-mm cover glasses for 24 h under broad-bean plants heavily infested with aphids in the greenhouse. The honeydew of whiteflies was obtained by collecting a large number of orange leaves infested with woolly whiteflies. The honeydew was transferred from the whitefly colonies drop by drop with a pin onto cover glasses. At least 10 drops of honeydew were placed on each cover glass. One of these cover glasses then was placed on each test arena. When honeydew became extensively covered by growth of microorganisms (ca. 7–10 days), it was replaced with another coverslip with fresh honeydew.

Nine experimental treatments were set up for each of the three *Euseius* species: (1) iceplant pollen alone (P); (2) pollen plus aphid honeydew (P+AH); (3) pollen plus whitefly honeydew (P+WH); (4) Pacific spider mite (PM) only; (5) PM+AH; (6) PM+WH; (7) citrus red mite (RM) alone; (8) RM+AH; and (9) RM+WH. Six replicates, each containing 5 eggs of the phytoseiid species on a test arena, were employed for each experiment treatment.

The phytoseiids were obtained from insectary cultures. Samples of 20–30 adult females from each culture were mounted and identified in order to confirm that cultures were not contaminated with other phytoseiid species. For development studies, eggs were obtained by placing clumps of cotton on tiles of rearing units of the stock culture. After 24 h, the clumps were examined and eggs of the predaceous mites that had been oviposited thereon were collected and placed in test arenas. Each species was studied separately. To determine the duration of development stages, observations were made every 12 h until all individuals reached the adult stage.

To determine oviposition rates, newly mature females and males were taken from the development experiment and introduced onto new test arenas, each containing two females and two males as a replicate. Each treatment was replicated three times. Eggs laid by these females were counted and removed daily for 11–12 days. The mean number of eggs laid per female per day was compared by Duncan's multiple-range test (Steel and Torrie, 1960) at the end of the experiment. To determine the approximate duration of F_1 eggs, 10 eggs oviposited on the same day were taken from each treatment and placed in a new test arena. These eggs were observed every 12 h until all eggs hatched.

RESULTS AND DISCUSSION

All three *Euseius* species fed and developed to maturity on all foods or food combinations, but their development rates varied with species and foods, especially basic foods. The development of the three species on three different basic foods in the presence and absence of supplementary foods is shown in Table 1. The differences in the development duration of each mite species on different basic foods (averages of the three treatments for each basic food) are shown in Fig. 1.

The mean duration of each development stage and total time for immature development were not significantly affected by the presence of supplementary foods, regardless of *Euseius* species and basic food (Table 1). Basic food was an important factor affecting the rate of development of these mites. The fastest rate occurred when the mites were fed on pollen. These results are consistent with those of McMurtry and Scriven (1964) and Ferragut et al. (1987). Our results, however, do not agree entirely with some previous reports. McMurtry and Scriven (1964) and Ferragut et al. (1987) reported that the development duration of *E. hibisci* and *E. stipulatus*, respectively, when fed on *Tetranychus* species, was longer than when fed on citrus red mite. Our data show that all three *Euseius* species developed more rapidly when fed *Tetranychus pacificus* than when fed citrus red mite. With Pacific spider mite as the basic food, the duration of immature development for *E. tularensis, E. stipulatus*, and *E. hibisci* was 11.4, 17.2 and 16.0 h shorter, respectively, than with citrus red mite as the basic food (Fig. 1). The reason probably was that Pacific spider mite used in these tests was primarily in the egg stage. As these eggs were washed from glasshouse-grown lima-bean plants (Scriven and McMurtry, 1971), there was little webbing to impede the movement of the phytoseiid mites. Moreover, some eggs hatched soon after they were placed into test arenas, resulting in prey eggs and larvae, both of which were favored foods for the phytoseiids. On the other hand, the citrus red mite used in the tests was mainly in the egg stage, with few larvae. Previous observations indicated that, with citrus red mite as prey, *E. hibisci* females captured and consumed mainly larvae and small nymphs, with very little feeding on eggs (McMurtry and Scriven, 1964).

Mortality of the three *Euseius* species on different foods is shown in Table 2. With pollen as the basic food, the mortality was low for all species and sup-

TABLE 1

Development duration (h) of three *Euseius* species on different foods and food combinations at 25°C

Food provided[1]	Egg		Larva		Nymph (proto- + deuto-)		Immature (all stages)
	Mean	SD[2]	Mean	SD	Mean	SD	Mean
Euseius tularensis							
P	61.2	8.4	26.7	7.4	50.1	15.2	137.6 abc[3]
P+AH	57.6	8.1	25.5	7.8	45.3	11.1	131.4 ab
P+WH	57.6	8.1	24.8	9.1	42.2	12.2	128.5 a
PM	61.2	8.4	30.4	7.6	57.3	8.4	148.6 cd
PM+AH	64.8	8.9	26.9	7.2	56.6	6.1	144.6 bc
PM+WH	64.8	8.9	23.9	5.8	58.9	7.1	144.8 bc
RM	59.3	8.7	27.3	10.2	71.8	11.4	160.3 d
RM+AH	61.2	10.1	27.5	8.5	73.2	9.9	158.7 d
RM+WH	57.6	5.8	26.2	8.2	65.4	11.2	153.2 cd
Euseius stipulatus							
P	50.4	8.1	20.8	7.7	45.6	7.7	114.8 a
P+AH	50.4	9.9	19.3	6.0	48.0	10.5	118.7 a
P+WH	49.2	8.4	19.6	7.6	46.4	9.1	118.0 a
PM	57.6	11.4	30.0	5.7	54.1	12.6	140.7 b
PM+AH	56.4	7.6	26.4	5.9	55.6	11.8	138.0 bc
PM+WH	56.4	7.6	29.2	6.6	55.1	11.7	137.1 bcd
RM	52.8	6.8	30.8	4.8	78.8	11.6	158.0 cd
RM+AH	54.0	8.0	26.8	4.7	77.9	9.2	155.1 d
RM+WH	56.4	9.5	26.4	5.5	78.2	11.2	154.2 d
Euseius hibisci							
P	46.8	6.2	18.4	8.5	55.2	6.9	120.0 a
P+AH	48.0	6.3	20.7	12.8	51.7	10.4	118.6 a
P+WH	48.0	6.3	19.9	7.4	55.8	8.8	120.0 a
PM	46.8	10.1	33.0	13.7	63.9	13.5	141.8 bcd
PM+AH	44.4	9.5	29.6	11.9	58.0	13.6	132.0 ab
PM+WH	43.2	10.5	25.6	9.2	60.7	15.1	133.7 abc
RM	49.2	8.4	29.2	9.3	78.1	12.7	154.9 d
RM+AH	48.0	8.5	29.9	4.5	72.9	11.3	150.0 cd
RM+WH	51.6	11.0	28.4	5.5	75.8	13.9	150.6 cd

[1]P, pollen; PM, Pacific mite; RM, citrus red mite; AH, aphid honeydew; WH, whitefly honeydew.
[2]Standard deviation of mean.
[3]Data for each *Euseius* species followed by the same letter are not significantly different ($P=0.05$; Duncan's Test).

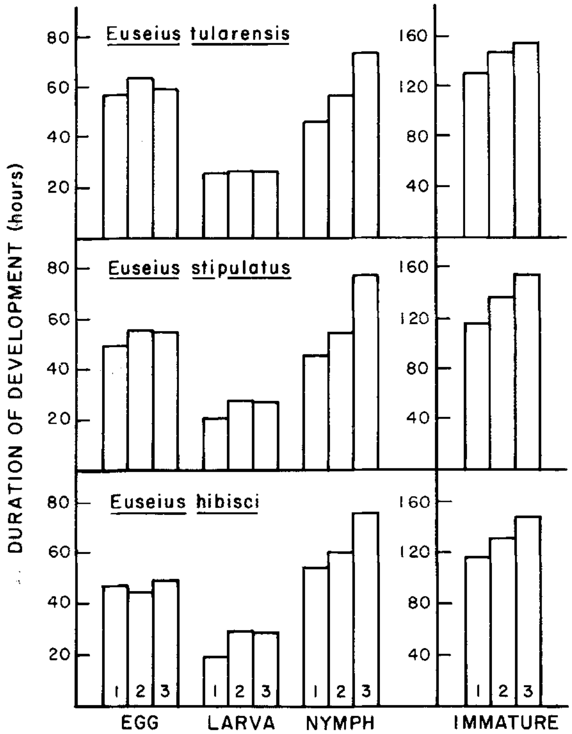

Fig. 1. Duration of development (h) of three *Euseius* species when fed on different basic foods: (1) with pollen as basic food; (2) with Pacific mite as basic food; and (3) with citrus red mite as basic food. Values represent means of the three treatments (two kinds of honeydew and without honeydew) for each basic food.

plementary foods, while with citrus red mite as food, the mortality was 53.3 and 40.0% for *E. tularensis* and *E. stipulatus*, respectively. Mortality of *E. tularensis* on Pacific mite was higher than that of the other two species on the same prey.

Immature mortality of *E. tularensis* and *E. stipulatus* in the presence of supplementary foods was generally lower than in the absence of supplementary foods, although there were no significant differences ($P=0.05$) between the presence and absence of supplementary foods.

The mortality of the three *Euseius* species mainly occurred in the nymph stages. In the course of the experiments, some of the larvae which did not feed (evidenced by lack of coloration in the gut) molted to the nymphal stage. These nymphs, however, died shortly after molting. Some individuals of certain phytoseiid mite species may molt to the protonymphal stage without feeding, but none reached the deutonymphal stage (Burnett, 1971; Amano and Chant, 1977; Sabelis, 1981). Our observations confirmed their results. They also explained why the mortality of the nymphal stage was higher than that of the larval stage.

TABLE 2

Mortality of three *Euseius* species on different foods and food combinations at 25 °C

Food provided[1]	Larva		Nymph		Immature
	N	Mortality[2] (%)	*N*	Mortality (%)	Mortality (%)
Euseius tularensis					
P	30	0	30	3.3	3.3 a[3]
P+AH	31	0	31	0	0
P+WH	30	0	30	3.3	3.3 a
PM	28	0	28	39.3	39.3 bc
PM+AH	29	0	29	24.1	24.1 b
PM+WH	30	3.3	29	20.1	23.3 b
RM	30	20.0	24	41.7	53.3 c
RM+AH	30	20.0	24	25.0	40.0 bc
RM+WH	30	30.0	21	9.5	36.7 bc
Euseius stipulatus					
P	31	3.2	30	0	3.2 a
P+AH	30	6.7	28	0	6.7 a
P+WH	30	0	30	0	0
PM	30	0	30	10.0	10.0 a
PM+AH	30	0	30	13.3	13.3 a
PM+WH	30	0	30	6.7	6.7 a
RM	30	0	30	40.0	40.0 b
RM+AH	30	3.3	29	34.5	36.7 b
RM+WH	30	0	30	33.3	33.3 b
Euseius hibisci					
P	31	3.2	30	0	3.2 a
P+AH	29	0	29	0	0
P+WH	30	3.3	29	0	3.3 a
PM	30	0	30	6.7	6.7 a
PM+AH	30	0	30	0	0
PM+WH	30	0	30	6.7	6.7 a
RM	30	3.3	29	24.1	26.7 b
RM+AH	30	6.7	28	32.1	36.7 b
RM+WH	30	0	30	30.1	30.0 b

[1]P, pollen; PM, Pacific mite; RM, citrus red mite; AH, aphid honeydew; WH, whitefly honeydew.
[2]Number of individuals in the tests.
[3]Data for each *Euseius* species followed by the same letter are not significantly different ($P = 0.05$; χ^2 contingency test for % survival).

Oviposition rates (the number of eggs laid per female per day) of all three *Euseius* species in the presence of supplementary foods were higher than in the absence of such foods. Most of the differences were statistically significant between the presence and absence of supplementary foods (Table 3). However, no significant differences occurred between the two types of supplementary foods (honeydew of aphids and whiteflies). McMurtry and Scriven (1964) found that the combination of honeydew and either abundant mite prey or pollen stimulated a higher oviposition rate of *E. hibisci* than mite prey or pollen alone. Our results were similar, although there were some differences in the oviposition rates because of the different experimental conditions. Ragusa and Swirski (1977) showed that the addition of honeydew increased the oviposition rate of *Amblyseius swirskii* Athias-Henriot on *Tetranychus cinnabarinus* Boisd.

The oviposition rates of the three *Euseius* species did not differ significantly between pollen and Pacific mite as basic food, but significant differences did occur between citrus red mite and the other two basic foods. The oviposition rates of all three species, with citrus red mite as the basic food, were lower than pollen or Pacific mite as the basic food. The reason for this probably was because the citrus red mite in the tests was mostly in the egg stage, eggs being unfavorable for these phytoseiids. Tanigoshi et al. (1981) found that *E. hibisci* did not lay eggs when fed exclusively on citrus red mite. Our observations showed that adult females of the three *Euseius* species, confined on leaves with

TABLE 3

Oviposition rate of three *Euseius* species on different foods and food combinations at 25°C[1]

Food provided[2]	*Euseius tularensis*		Euseius stipulatus		*Euseius hibisci*	
	Mean	SD	Mean	SD	Mean	SD
P	1.22 ab[3]	0.23	1.25 ae	0.29	1.80 a	0.31
P+AH	1.47 ac	0.25	2.13 d	0.17	2.73 b	0.37
P+WH	1.68 c	0.23	1.90 dc	0.21	2.86 b	8.36
PM	1.05 b	0.24	1.48 ab	0.10	1.83 a	0.14
PM+AH	1.52 ac	0.07	1.73 bc	0.03	2.53 b	0.32
PM+WH	1.47 ac	0.11	1.68 bc	0.09	2.78 b	0.20
RM	0.61 d	0.13	0.78 f	0.13	0.64 c	0.05
RM+AH	0.97 b	0.13	1.11 ef	0.17	0.89 c	0.17
RM+WH	1.03 b	0.25	1.17 ae	0.22	0.97 c	0.21

[1]With pollen and Pacific mite as the basic foods, the oviposition rate is the number of eggs laid per female per day for a 10-day period; with citrus red mite as the basic food, for a 6-day period.
[2]P, pollen; PM, Pacific mite; RM, citrus red mite; AH, aphid honey dew; WH, whitefly honeydew.
[3]Data in each column followed by the same letter are not significantly different ($P=0.05$; Duncan's test).

few larvae and many eggs of citrus red mite, oviposited but ceased reproduction after 5–6 days.

Oviposition rates showed some differences between species on the same food or food combination. The oviposition rate of *E. tularensis* generally was lower than that of the other two *Euseius* species. When pollen served as the basic food, the oviposition rates of *E. tularensis, E. stipulatus* and *E. hibisci* were 1.50, 1.76 and 2.46 eggs $female^{-1}$ day^{-1} for a 10-day period, respectively; when Pacific mite served as the basic food, oviposition rates were 1.40, 1.63 and 2.38 eggs respectively; when citrus red mite served as the basic food, oviposition rates were respectively 0.87, 1.02 and 0.82 eggs $female^{-1}$ day^{-1} for a 6-day period.

Honeydew is a commonly available supplemental food in southern California citrus orchards. Sources of this honeydew are primarily aphids, mainly in the spring and early summer, and whiteflies, essentially throughout the year. Other Homoptera, such as lecaniine (soft) scale insects and mealybugs, are probably of minor importance on citrus in most areas, although mealybugs generally are the most common honeydew-producing insects on avocado. Honeydew may play a significant role in the dynamics of *Euseius* populations on citrus, by promoting a higher rate of increase of these predators when spider mites are the main basic food present. Moreover, utilization of these supplemental foods may prolong survival and thus prevent severe declines in the phytoseiid populations during shortages of primary foods.

The results of this study also suggest that laboratory tests to determine reproductive rates of 'generalist' phytoseiids confined with one kind of food (e.g., spider mites) may underestimate their reproductive potential in the presence of that food in the field, as these predators probably supplement a diet of spider mites or thrips with carbohydrate-rich foods that elevate the reproductive rate on the basic foods. Thus, it may be profitable for a phytoseiid to capture and consume a moderately or marginally favorable prey (in terms of reproduction on that food alone) if supplemental foods are available.

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