Influence of diet on development and oviposition of *Forficula auricularia* (Dermaptera: Forficulidae)

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In North America, the life cycle of the European earwig (*Forficula auricularia* L.) can be divided into a nesting phase (hypogean phase) and a free-foraging phase (epigean phase) (Crumb *et al.* 1941; Behura 1956; Lamb and Wellington 1975). Adults spend the nesting phase in the soil; females burrow into the ground at the onset of the cold weather, lay eggs, and then care for the eggs. Hatching occurs in spring; first- or second-instar nymphs move to the soil surface for the free-foraging period. The earwig, a nocturnal insect, spends the entire daylight period of hiding under trash or in dark crevices. Where two broods occur, females reenter the ground a second time (Lamb and Wellington 1975). Stomach content analyses (Crumb *et al.* 1941; Sunderland and Vickerman 1980) and food preference tests (McLeod and Chant 1952; Buxton and Madge 1976) revealed that the European earwig is omnivorous. Under laboratory conditions, nymphs fed freshly frozen aphids, *Rhopalosiphum padi* (L.) (Hemiptera: Aphididae), survive better than those fed green algae or carrots, develop faster, and produce heavier females (Phillips 1981; Carrillo 1985).

In previous laboratory studies, we have kept earwigs exclusively on a vegetarian diet of carrots and pollen (*ad libitum*), as did Lamb and Wellington (1974), to facilitate rearing. Fed this diet, the fecundity of females collected in the field as adults was satisfactory, but with females collected in the field as nymphs or hatched in the laboratory this diet resulted in fewer females ovipositing and lower fecundity.

The main purpose of our study was to evaluate the impact of four diets, some containing animal matter, on nymphal development and egg-laying and oviposition behaviour. Based on the results of Crumb *et al.* (1941) and Behura (1956), diets containing animal matter should result in faster nymphal development, higher survival rates, a greater proportion of females laying eggs, and higher fecundity.

Adults were collected on 26 August 1996, at Deux-Montagnes, about 20 km northwest of Montréal (45°N, 74°W, altitude 82 m), and kept under natural outdoor conditions in Mason™ jars, in groups of 20 females and 20 males; they were fed *ad libitum* carrots and commercially available bee-collected pollen. On 3 September, 100 mating pairs were isolated in 10-cm Petri dishes containing a thin layer of moist sand, transferred to an incubator at 13 ± 2°C, and kept in constant darkness until egg hatch. Adults had unlimited access to carrots and pollen until oviposition but were not fed during the incubation period.

The effect of the diet on nymphal and adult weights, duration of development, first preoviposition time, and fecundity were tested using ANOVA. A Tukey's procedure was performed for comparisons of means ($\alpha = 0.05$), whereas the number of surviving nymphs and number of females that laid eggs were compared using an overall and two by two χ^2 tests. All statistical tests were done with Statistix™ Analytical Software.

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TABLE 1. Influence of diet on mean weight, survival, and duration of larval development of *Forficula auricularia* (13 ± 2°C).

	Larval development						
	Weight of instar 1		Weight of instar 4		Survival		
Diet*	*n*	Mean ± SD (mg)	*n*	Mean ± SD (mg)	*n*	%	Duration (mean ± SD; d)
A	120	1.5±0.3*a*	53	12.8±2.9*a*	44	36.7*a*	182.7±14.6*a*
B	104	1.4±0.2*bc*	60	14.4±2.7*b*	54	51.9*b*	175.2±12.0*b*
C	139	1.5±0.2*ab*	131	23.1±3.2*c*	131	93.5*c*	148.6±10.6*c*
D	138	1.3±0.2*c*	134	23.5±3.0*c*	128	92.8*c*	144.5±9.7*d*
	$F = 13.1, P < 0.001$		$F = 273.2, P < 0.001$		$\chi^2 = 156.1, P < 0.001$		$F = 202.8, P < 0.001$

NOTE: Means in a column followed by the same letter do not differ ($P > 0.05$).
* A, carrots; B, carrots and pollen; C, carrots and eggs of *Ephestia kuhniella*; D, carrots, eggs of *E. kuhniella*, and pollen.

Nymphal development

Newly hatched nymphs (72 ± 24 h) were weighed individually and isolated in Petri dishes containing a damp swab of cotton wool. Between 23 December 1996 and 6 January 1997, four groups of 150 nymphs were isolated and kept at 13 ± 2°C in complete darkness and fed weekly in excess one of the following diets: A, carrots; B, carrots and pollen; C, carrots and frozen eggs of *Ephestia kuhniella* Zell. (Lepidoptera: Pyralidae); or D, carrots, frozen eggs of *E. kuhniella*, and pollen. Old food was removed before new food was added. Dishes were examined daily to determine molts, mortality, and nymph weights after each ecdysis. Nymphs killed were removed from the study.

The nymphal weights, survival rates, and durations of development differed between groups in all instars (Table 1). Diet influenced mean duration of development in the sequence A > B > C > D, and survival rates and mean weights in a similar fashion in the sequence A < B < C = D. Our results are consistent with those of Phillips (1981) and Carrillo (1985). In our study, mortality rate among nymphs kept on diet B (carrots and pollen) was higher (48%) than that reported by Lamb and Wellington (1974) (10%), where nymphs were fed aphids occasionally and were kept in groups, which may have led to cannibalism, hence animal food.

Adult development and oviposition

On 1 June (diets C and D) and 30 June (diets A and B), teneral females (A, 25 ♀; B, 26 ♀; C, 43 ♀; D, 44 ♀) were paired with males, from the same diet group, fed their respective diet, and reared at 23 ± 2°C, with the photoperiod adjusted weekly to match natural conditions. Females from diet group A were observed eating males, thus all males were removed on 15 July. Three months after adult emergence, females were transferred to darkness (*i.e.*, until 1 April 1998) to simulate the hypogean phase and reared at 6 ± 2°C for 3 weeks and 13 ± 2°C for the remainder of the experiment. Female weight was recorded at ages 0, 14, 30, and 60 d. Every third day, numbers of ovipositions and numbers of eggs were recorded. Females were not fed after oviposition.

Mean weights of females differed between diets at all time intervals (Table 2). Weights at emergence and 14 d later differed in the sequence A < B < C = D, and little weight gain was observed afterwards. The first preoviposition period differed among diets: A > D > C > B (Table 2). Fecundity during first oviposition also varied with diet in the sequence A < B < C = D, and the proportion of females that oviposited the first time varied with diet in the sequence A < B = C = D. None of the females fed diet A

TABLE 2. Influence of diet on mean weight, percentage of females ovipositing, preovipositing period, and fecundity of *Forficula auricularia* (13 ± 2°C).

	Adult development and oviposition							
	At emergence		At 14 days		First reproductive cycle			
Diet*	*n*	Weight (mean ± SD; mg)	*n*	Weight (mean ± SD; mg)	*n*	Percentage of females that oviposited	Preovipositing period (mean ± SD; d)	Fecundity (mean ± SD)
A	25	30.5±4.0*a*	25	45.8±8.1*a*	5	20.0*a*	193.4±17.4*a*	5.6±0.9*a*
B	26	35.2±5.5*b*	26	62.4±12.0*b*	19	73.1*b*	155.8±11.9*b*	38.2±16.8*b*
C	43	54.7±5.6*c*	43	99.8±11.8*c*	28	65.1*b*	165.0±6.7*c*	58.0±23.1*c*
D	44	53.7±4.1*c*	44	98.9±9.9*c*	35	79.5*b*	170.0±7.1*d*	54.1±21.3*c*
		$F = 209.2, P \leq 0.001$		$F = 201.2, P \leq 0.001$		$\chi^2 = 26.2, P < 0.001$	$F = 26.1, P < 0.001$	$F = 11.7, P < 0.001$

NOTE: Means in a column followed by the same letter do not differ ($P > 0.05$).

* A, carrots; B, carrots and pollen; C, carrots and eggs of *Ephestia kuhniella*; D, carrots, eggs of *E. kuhniella*, and pollen.

oviposited twice, and the proportion of females that produced a second clutch did not differ among the other three diets ($\chi^2 = 2.2$, $P > 0.05$). Fecundity of females kept on diets C and D was similar to that obtained by Tourneur and Gingras (1992) for females caught in the field and reared in laboratory conditions (*i.e.*, first oviposition 51.6–61.7 eggs). Our proportion of females that oviposited twice was lower, probably because under field conditions females had consumed plant material that was more nourishing than carrots, and perhaps also some animal food.

Our results indicate that the reproductive performance of nymphs and females of *F. auricularia* reared on carrots alone or with proteins, in the form of pollen, was negatively affected compared to that observed for nymphs and females reared on diets with animal matter. Thus, reproductive benefits derived by females of *F. auricularia* from a diversified and partly carnivorous diet indicate that animal food is more important than was previously thought. Indeed, no proliferation of the species seems possible without the availability of animal matter in the environment.

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