

Voracity and conversion efficiency by larvae of *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) on *Aphis fabae* Scop. (Homoptera: Aphididae) reared on two faba bean cultivars with different levels of resistance

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Abstract

This study was conducted under laboratory conditions to determine the consumption rate and food utilization of predator *Coccinella septempunctata* larvae. Predator larvae were fed on black bean aphids, *Aphis fabae*, maintained separately either on partially resistant, 79S4, or on the aphid-susceptible, *Vicia faba major*, cultivars. There were no significant differences in the consumption rate of each instar of the predators between the two cultivar treatments, except for the first instar. When predator larvae were supplied with aphids being kept on partially resistant 79S4 plants as a source of food, 14.49 aphids were consumed per day by each larva during larval development, which was significantly greater than the consumption by predator larvae fed the diet of aphids from susceptible plants (on average 13.72 aphids/d). Also, total consumption by predator larvae was higher when the consumed aphids were obtained from partially resistant host plants, where approximately 648.9 aphids were needed during development. In contrast, only 569 aphids from susceptible faba bean plants were devoured by each predator larva during larval growth. The predator larvae using aphids from susceptible faba bean plants as a source of food were considerably more efficient in converting food to body mass.

Key words: Consumption rate; conversion efficiency; predator; aphid; plant resistant

INTRODUCTION

The black bean aphid, *Aphis fabae* Scop., is almost worldwide in distribution. It is an extremely polyphagous species colonizing more than 200 recognized plant species in various families (Blackman, 1974). Parthenogenetic and sexual reproductions are combined by *A. fabae*, but in Southern Europe and in subtropical and tropical regions where the winter is mild, this aphid reproduces parthenogenetically all year (Avidov and Harpaz, 1969). *Aphis fabae* is able to multiply at an immense rate on host plants under favorable environmental conditions and exploits the host plant rapidly (Way and Banks, 1967), causing massive losses to cultivated *Vicia faba* in temperate and Mediterranean regions, and often overwhelming the most numerous aphids on this crop (Blackman, 1974).

A major tactic for the control of *A. fabae* has been the use of insecticides. This approach could be fairly efficient, but today the increasing economic and environmental concerns over the extensive use of pesticides have led to awareness of the usefulness of integrated pest management schemes in which plant resistance and biological control must have a central role. High levels of resistance toward *A. fabae* have been identified in some faba land races (Holt and Birch, 1984) and in the crop's close wild relatives from the taxonomic section Faba of the genus *Vicia* (Birch and Wratten, 1984), whereas partial resistance was recognized among some existing *V. faba* cultivars (Bond and Lowe, 1975; Morvan, 1987). The nature of resistant plants has been reported to alter the development and or reproduction of aphids (Dixon and Dharma, 1980; De Ponti, 1983). Partially resistant faba bean, 79S4 cultivar, was found to postpone devel-

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opment and reduce the adult weight and reproductive potential, along with detrimental effects on longevity of *A. fabae* in comparison with the *V. faba major* cultivar (Shannag and Obeidat, 2006). Because partially resistant varieties need few insecticide applications, they are compatible with natural enemies (Pathak, 1977) that attack *A. fabae* and other faba bean pests. The role of natural enemies in the control of this aphid is of extreme importance. In addition to various pathogens, a great variety of parasitoids and predators have been identified worldwide (Hagen and Bosch, 1968; Long, 1994). The ladybird beetle, *Coccinella septempunctata* L., is one of the dominant predaceous coccinellids of different aphid species on various crops all over the world (Frazer, 1988). As with other aphidophagous predators, the efficacy of *C. septempunctata* as a natural enemy is a function of its voracity, as well as of the number, timing and duration of generation in relation to the seasonal occurrence of aphid populations (Shands and Simpson, 1972). In addition to phytophagous insects, plants may influence the effectiveness of the predators due to altering prey suitability or host-finding success (Obrycki and King, 1998).

It has also been reported that the amount of food consumed is strongly determined by predator size (Hodek, 1996), and size and density of the prey (Hagen, 1962). The consumption per unit weight and the proportion of food assimilated fluctuates little between the predator instars and within an instar (Ferran and Larroque, 1977; Isikber and Copland, 2001). Conversion efficiency can also vary with the feeding behavior of the predator (Cohen, 1989) and prey quantity (Zheng et al., 1993).

Since certain aphids serving as prey for different coccinellids are uneven in terms of food suitability and the nutritional value of the same species differs from one host plant to another (Smith, 1978), we hypothesize that *A. fabae* raised on faba bean plants with different levels of resistance may impact the food consumption and utilization by the larvae of *C. septempunctata*. A thorough knowledge of the ways in which insects interact with their food sources is basic to an understanding of their behavior, biology and ecology, as well as to the development of sound pest management strategies (Isikber and Copland, 2001).

The objective of this paper was to compare consumption rate and conversion efficiency of food to

body mass for larvae of the predators, which fed on aphids from susceptible and partially resistant cultivars of faba beans.

MATERIALS AND METHODS

Rearing and maintenance of black bean aphids. Black bean aphids, *A. fabae*, were collected from an infested field of faba beans in the vicinity of Irbid, Jordan. Faba bean, cultivar, *V. faba minor*, was grown in pots (20 cm diameter) at a rate of three plants per pot under greenhouse conditions. These plants were then used as hosts for the rearing of black bean aphids. Infested plants were kept in organdy-screened cages (80 cm×60 cm×60 cm) at $27\pm 3^{\circ}\text{C}$. To supply aphids continuously with optimal food, new faba bean plants were introduced into the cages when old plants deteriorated due to aphid feeding.

For the tests, two other stock cultures of *A. fabae* were established separately either on 79S4 cultivar, partially resistant to *A. fabae*, or on aphid-susceptible *V. faba major*, using the procedures described above. To initiate all experimental tests with aphids of similar age, synchronized colonies of *A. fabae* were established by transferring five adult aphids onto the leaf of a 2 wk-old plant using a fine, moist camel-hair brush. Adult aphids were confined to the leaf undersurface of each plant with a clip-on cage made of a plastic petri dish (5 cm diameter). Each cage possessed two openings in the sides, which were covered with screen cloth for air circulation. A ring-shaped sponge was positioned on the cage edge to avoid injury to the leaf. Each cage was attached to the leaf undersurface where released aphids could feed and reproduce. A lid of the petri dish was installed on the opposite upper surface of the infested leaflet after its edge was removed, and fixed to the cage by a modified hair clamp.

Aphids were left on the leaf for 4–5 h to produce progeny. Thereafter, adults were removed and the quantity of offspring was reduced to 20–30 nymphs per leaf to avoid an aggregation effect, which might have inhibited similar aphid growth. Aphids reaching the third instar stage were used in the tests as prey.

Rearing and maintenance of ladybird beetles. Ladybird beetles were reared from *C. septempunctata* adults collected near Irbid, Jordan, at the be-

ginning of March 2003. The predators were maintained in a laboratory at $27 \pm 3^\circ\text{C}$, about 70% relative humidity, and 1,000 lx for a 10 h photoperiod regime. Such environmental conditions prevent *C. septempunctata* from advancing into diapause. *C. septempunctata* was reared according to the procedures described by Pinsdorf (1977). Adult *C. septempunctata* were placed in white plastic containers (18 cm \times 13 cm \times 8 cm) covered with transparent nylon sheets and supplied with adequate amounts of black bean aphids on faba bean shoots. Small pieces of a black-colored plastic sheet were added to each container for egg-laying. Oviposition sheets with eggs were relocated into a new container at 24 h intervals to avoid cannibalism by the parents. Subsequent to egg hatching, emerged larvae were kept in the same containers and provided with abundant aphids on plant shoots every 2–3 d. When predator larvae reached the fourth instar stage, roof-like paper pieces were added to the rearing container as suitable sites for pupation. Pupae were removed from the container afterward and kept in a plastic petri dish (9 cm dia.) until reaching adulthood.

For the tests, two other stock cultures of ladybird beetles were maintained. In the first one, predators were nourished with *A. fabae* kept on aphid-susceptible *V. faba major*, while the second culture was established on aphids fed partially resistant plants.

Food consumption and utilization by larvae of *C. septempunctata*. The consumption rate and conversion efficiency of ingested food by the instars of the ladybird beetles that were fed aphids from faba bean plants having different levels of resistance were assessed in growth chambers kept at $27 \pm 1^\circ\text{C}$, $60 \pm 5\%$ relative humidity and a 16 : 8 (L : D) photoperiod regime, and compared to several other studies. Prior to the commencement of each test, the initial weights of individual newly hatched larvae of *C. septempunctata* were estimated by weighing 20 predator larvae, which were obtained from the cultures of the ladybird beetles being fed *A. fabae* from susceptible plants. The individual weights of an additional 20 larvae whose parents were supplied with aphids from partially resistant plants were measured by means of a microbalance (with accuracy of ± 0.0001 mg). Individual larvae from both treatments were then transferred into individual plastic petri dishes (9 cm dia.) containing

100, 200, 300 or about 400 third nymphal instars of aphids on excised faba bean leaves, for the first, second, third, and fourth larval instars of the predator, respectively. Each petri dish represented an experimental unit, with 20 replications conducted. After release, predator larvae were checked twice a day to record molting. At each observation, the quantity of molted skins was recorded and removed. This protocol was continued for the duration of the larval development of the predators, and the number of aphids was replenished with aphids from the same plant cultivar.

The number and weight of aphids consumed by *C. septempunctata* instars, in addition to the weight of predator larvae, were determined at each observation to assess the feeding rate and conversion efficiency for each instar. The increase in fresh body weight (weight gain) for each larval stage of the predator was calculated as the final weight of the instar minus the initial weight of the instar. Moreover, the number of aphids eaten by each larval stage at 24 h intervals (consumption rate) was computed by dividing the number of aphids consumed by the total development period of the respective larval instar of the predator. To quantify the fresh and dry mass of aphids eaten by predator larvae, 50 specimens of third-instar aphids maintained on susceptible plants, or on partially resistant plants, were individually weighed by means of the microbalance. These aphids were then oven dried to a constant weight (at 60°C for 24 h) and weighed afterwards to determine the dry weight.

The same procedures were used to determine the fresh and dry weights of 25 specimens each for the first, second, third, and fourth larval instars of *C. septempunctata* fed either with aphids from partially resistant or susceptible faba bean cultivars. Linear equations, which were attained from the regression analysis of dry and fresh weights, were used to convert the fresh weight of predator larvae to dry weight. The dry weight of aphids eaten by the predator larvae, and the increase in dry weight for each predator instar, were used to avoid variability associated with weight losses of aphid prey by dehydration during molting. A calculation based on the equation described by Isikber and Copland (2001) was used to assess the conversion efficiency of ingested food by each instar of the predator;

Conversion efficiency %
 =dry weight gain in each predatory instar/dry weight of aphids consumed×100

Data were subject to analysis of variance (ANOVA). Collected data were analyzed using MSTATC software (Michigan State University, 1988). Means were separated by LSD at the 5% level.

RESULTS

Consumption rates (number of aphids consumed per day) of the larval instars of predators, as well as the total number of aphids eaten throughout the development period (from egg hatch to pupation) of *C. septempunctata*, that fed on the black bean aphid from both faba bean cultivars, are illustrated in Table 1. Results indicate that the consumption rate of each larval stage is not influenced significantly by the source of aphids served as food for the predators, with the exception of the first instar. First larval instars of the predators reared on aphids from partially resistant cultivars devoured more aphids, about 12, than those fed aphids from susceptible cultivars. The voracity showed a tendency to rise with successive larval instars of the predator in both treatments. Nevertheless, the average sum of aphids consumed at 24 h intervals during the course of this study was significantly greater by the beetle larvae furnished with prey from partially resistant plants, 79S4 cultivar. The consumption rate averaged 14.49 and 13.72 aphids per larva per day for predators fed on aphids from partially resistant and susceptible plants, respectively (Table 1).

When predator larvae were maintained on aphids obtained from the partially resistant cultivar, each instar consumed on average considerably more aphids than from susceptible faba bean during its development. Furthermore, the number of aphids eaten throughout the entire larval development of the predators was significantly different between the two treatments, and was estimated to be 569.0 and 648.9 aphids per predator larva for aphids grown on susceptible and partially resistant plants, respectively (Table 1). It is also evident that the third nymphal instars of the aphid, which served as a food source for the predator larvae during this investigation, showed a significant decrease in mean fresh weight when they were kept on par-

Table 1. Consumption rate per hour and mean number of aphids eaten by larval instars and throughout the development of *Coccinella septempunctata* fed on *Aphis fabae* from susceptible and partially resistant cultivars of the faba bean

Cultivars	1st instar		2nd instar		3rd instar		4th instar		Overall development	
	Consumption rate	Total aphids consumed	Consumption rate	Total aphids consumed	Consumption rate	Total aphids consumed	Consumption rate	Total aphids consumed	Consumption rate	Aphids consumed
<i>Vicia faba major</i> (susceptible)	1.963 a	59.3 a	3.680 a	114.8 a	3.943 a	134.6 a	4.138 a	260.3 a	13.720 a	569.0 a
79S4 (partially resistant)	2.232 b	71.9 b	3.826 a	120.3 a	3.876 a	151.9 b	4.559 a	304.9 b	14.490 b	648.9 b
LSD value	0.2476	7.8	0.2855	8.9	0.3819	7.0	0.7135	25.7	0.6605	26.6

Means within each column followed by the same letter(s) are not significantly different at $p \leq 0.05$.

Table 2. Conversion efficiencies of larval instars of *Coccinella septempunctata* fed on *Aphis fabae* from susceptible and partially resistant cultivars of faba bean, and average weight of third nymphal instar aphids served as a source of food to predators

Cultivars	1st instar	2nd instar	3rd instar	4th instar	Average	Aphid weight (mg)
<i>Vicia faba major</i> (susceptible)	8.942 a	20.45 a	26.85 a	21.12 a	19.37 a	0.415 a
79S4 (partially resistant)	6.626 b	14.55 b	16.86 b	16.17 b	13.55 b	0.347 b
LSD value	2.187	5.794	9.295	4.936	2.969	0.051

Means within each column followed by the same letter(s) are not significantly different at $p \leq 0.05$.

tially resistant 79S4 cultivar. The average weights attained by individual third-instar aphids were 0.415 and 0.347 g on *V. faba major* and 79S4 cultivars, respectively (Table 2).

Results presented in Table 2 show the efficiencies of conversion of ingested food to body substances by larval instars of *C. septempunctata*. All larval instars of the predator sustained on prey from susceptible plants displayed significantly higher conversion efficiencies than specimens fed aphids from partially resistant host plants. The conversion efficiencies of four individual predator instars fed on *A. fabae* from susceptible faba bean plants ranged from 8.94% to 26.85% and were significantly higher than those supplied with aphids from partially resistant cultivars, which varied between 6.62% and 16.86%. However, for the first three instars of *C. septempunctata*, the conversion efficiencies increased while progressing through the instar sequence in both treatments. Food utilization by the fourth larval instar of the predators was much lower than that of the third instars when predator larvae were maintained on aphids from susceptible cultivars, while conversion efficiencies for the third and fourth instars fed on aphids from partially resistant plants were almost equal (Table 2). During total development of *C. septempunctata* larva, the average proportion of food converted to body tissues for predators nourished on aphids from susceptible plants was estimated to be 19.37%, and was significantly greater than that of predators feeding on aphids from partially resistant plants, which reached 13.55% (Table 2).

DISCUSSION

In this study, the consumption rate of larval instars of *C. septempunctata* obviously increased for

predators fed aphids from the partially resistant cultivar, in comparison with predator larva provided with the same prey species from a susceptible faba bean cultivar. During total development, predator larvae were more voracious, on average eliminating a significant amount of additional aphids on the partially resistant 79S4 cultivar (14%) when compared with those maintained on prey from susceptible plants. Conforming with the findings of Clausen (1940), an increase in the consumption rate and total number of aphids eaten by predator larvae on aphids from partially resistant cultivar could be due to the undersized aphids recorded in this cultivar, in addition to the expanded larval development of ladybird beetle on 79S4 plants, as observed in our preliminary investigation (unpublished). The low nutritional value of aphids cultured on partially resistant faba beans could be a further explanation for the difference in voracity of the predator in both treatments. Smith (1978) also pointed out that the nutritional value of the same aphid species might vary from one host plant to another.

Predaceous coccinellids have been reported to decimate double the amount of *Heliothis zea* larvae on a resistant cotton variety compared to specimens on a susceptible one (Lincoln et al., 1971). Predation by the spider, *Lycosa pseudoannulata*, to the brown planthopper, *Nilaparvata lugens*, was highest on a varietal resistant rice variety, presumably due to the increased movement of plant assailants in search of a proper feeding site, which in turn inspires predators to attack moving prey (Kartohardjono and Heinrichs, 1984).

With the aphids from both host plants used in this study, all larval instars of *C. septempunctata* were fairly efficient in converting food to body mass. There was a slight decrease in food utiliza-

tion at the fourth-instar stage. This result is somewhat in accordance with data obtained for two coccinellid predators, *Sycymnus levaillanti* and *Cycloneda sanguinea*, fed on the cotton plant aphid, *Aphis gossypii* (Isikber and Copland, 2001), attributing the reason to the greater metabolic costs at the fourth-instar stage, which may be connected with preparing for the process of pupation. Predator larvae provided with aphids from susceptible plants were more efficient in utilizing food than those fed on aphids from partially resistant bean plants, presumably due to the poor nutritional status of aphids kept on partially resistant host plants.

The conversion efficiencies of larval instars of *C. septempunctata* recorded from this study are much lower than those of *Adalia bipunctata* (Mills, 1981), of *Semiadalia undecimnotata* (Ferran and Larroque, 1977), and of *Cycloneda sanguinea* and *Scymnus levaillanti* (Isikber and Copland, 2001), nourished with different aphid species, which in turn, varied widely among each other. This could be attributed not only to dissimilarities in species and experimental conditions, but also in different methods of measuring and calculating data (Isikber and Copland, 2001).

In conclusion, larval instars of *C. septempunctata* kept on prey from susceptible plants are more competent in converting food to body mass, while larvae of the same predator species supplied with aphids from partially resistant plants are less efficient, even though they are more voracious than predators on aphids from susceptible plants. Therefore, it seems that host plants can have a great indirect impact on the food consumption and efficiency of the predator's conversion of food to body mass.

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