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Food consumption and utilisation by larvae of two coccinellid predators, *Scymnus levaillanti* and *Cycloneda sanguinea*, on cotton aphid, *Aphis gossypii*

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Abstract. This study was carried out under laboratory conditions at various temperatures to compare food consumption and efficiency of conversion of food to body mass for larvae of two coccinellid predators, *Scymnus levaillanti* Mulsant (Coleoptera: Coccinellidae) and *Cycloneda sanguinea* (L.) (Coleoptera: Coccinellidae), which differ in body size and feeding method. The consumption rate of each larval stage of both species increased with increasing temperature. The consumption rate for total development (from egg hatch to pupation) of *S. levaillanti* was found to be 22.9 aphids per day at 30 °C. It was much higher for *C. sanguinea* (975.1 aphids per day at 25 °C and 1066 aphids per day at 30 °C). The larger species, *C. sanguinea* was more voracious at each temperature than the smaller species, *S. levaillanti*. The larvae of *S. levaillanti*, employing pre-oral digestion, were more efficient in converting food to body mass than larvae of *C. sanguinea*, which used chewing and sucking. The fourth instars of both species were less efficient in converting food to body mass than were their first three instars. It was concluded that body size and feeding method of coccinellid predators play an important role in food consumption and efficiency of conversion of food to body mass.

Key words: consumption rate, conversion efficiency, voracity, pre-oral digestion, Aphididae, Coccinellidae, Homoptera

Introduction

A thorough knowledge of the ways in which insects interact with their food sources is basic to an understanding of their behaviour, biology, and ecology as well as to the development of sound pest management strategies. Growth and development vary in relation to prey quality. The availability of food strongly affects the growth and survival of juvenile arthropod predators (Wise, 1975; Hagen, 1987). Whilst temperature will affect growth and development rates of predators directly, it can also exert an influence by changing the prey consumption rate (Pickup and Thompson, 1990). The rate at which

food passes through the gut will be positively temperature-dependent, and this will affect consumption rate by affecting hunger (Johnson et al., 1975).

The amount of food consumed is strongly determined by predator size. Naturally, the smaller predators usually take less food than the larger ones. For instance, the larvae of a larger species, *Semiadalia undecimnotata* (Schneider) (Coleoptera: Coccinellidae) consumed 98 mg of *Myzus persicae* (Sulzer) (Heteroptera: Aphididae) during the total larval development, whereas the larvae of a smaller species, *Adalia bipunctata* (L.) (Coleoptera: Coccinellidae) consumed only 55 mg (Hodek, 1996). Furthermore, Ferran and Larroque (1977) reported that the quantity of *M. persicae* consumed by *S. undecimnotata* depends on the increase in larval size. As a consequence, the consumption per unit weight and proportion of food assimilated (converted to body tissues) varied little between the instars.

Conversion efficiency can vary with consumption rate within an instar. Third instar larvae of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) provided with low prey densities have a reduced consumption rate compared with third instar larvae given high prey densities, but they have a higher conversion efficiency (Zheng et al., 1993). A similar difference in conversion efficiency is shown by the early instars of the bug, *Blepharidopterus angulatus* (Fall.) (Heteroptera: Miridae) (Glen, 1973). According to Cohen (1989), predaceous insects with piercing, suctorial mouthparts (e.g., Heteroptera), because they obtain a larger proportion of highly digestible materials from their prey (a process assisted by pre-oral digestion), ought to have higher efficiency of conversion of food into body substance (higher ECI values) than predators with chewing mouthparts. So far as we know, no broad comparative studies have been carried out to test this hypothesis.

Scymnus levaillanti Mulsant (Coleoptera: Coccinellidae) is an aphidophagous coccinellid species and among the dominant coccinellid predators of *Aphis gossypii* Glover (Homoptera: Aphididae) on cotton in Turkey (Kişmir, 1983). *Cycloneda sanguinea* (L.) (Coleoptera: Coccinellidae) is primarily an aphidophagous coccinellid species and mostly found in temperate areas of Central and South America (Vandenberg and Gordon, 1988). The objective of this paper was to compare (at various temperatures) food consumption, and efficiency of conversion of food to body mass, for larvae of these coccinellid predators, which differ in body size and feeding method.

Materials and methods

Cultures of aphids and coccinellids were established in controlled temperature rooms. The cotton aphid, *A. gossypii*, and the coccinellid, *S. levaillanti* were collected from ‘Haciali Cotton Research Centre’ near Adana in Turkey

while the coccinellid, *C. sanguinea*, was collected by Mike Copland from the fields near Merida in Mexico. Cotton (*Gossypium hirsutum* L.) and okra (*Hibiscus esculentus* L.) plants, grown in the glasshouse, were used as host plants for production of the cotton aphids. Aphid and predator cultures were maintained at 25 ± 1 °C, 55 ± 10% RH, and a photoperiod of 16:8 (L:D).

In order to determine the growth and consumption of *S. levaillanti* and *C. sanguinea*, 20 newly-hatched larvae were weighed using a microbalance (accurate to 0.001 mg) to record their initial weights. They were then transferred into individual Petri-dishes (15 × 60 mm) containing either 100, 200, 300 or 400 medium-size cotton aphids (third to fourth instar) for first, second, third and fourth instar larvae respectively, on excised cotton leaves placed on an agar medium. The studies were conducted at three constant temperatures, namely 20, 25 and 30 ± 1 °C with a photoperiod of 16:8 (L:D), in incubator cabinets with 60 ± 5% RH maintained by using a saturated salt solution of magnesium nitrate ($MgNO_3$). The Petri-dishes were placed in large transparent boxes (270 mm × 160 mm × 100 mm) to maintain the humidity. The predators were observed twice a day to record moulting. Before and after each observation, the weights of aphids offered and remaining, and the weights of the predator larvae were recorded using the microbalance. Thus, numbers and fresh weights of aphids consumed and increase in fresh weights of the larvae were recorded for each observation. During larval development, the numbers of moulted skins were also recorded and removed at each observation. Aphids were replenished at each observation.

The following parameters were measured for each larval instar at each temperature:

- *Weight gain* (fresh body weight increase during each instar; mg) calculated as the final weight of the instar less initial weight of the instar;
- *Consumption rate* (the number of aphids eaten per day) calculated as the number of aphids eaten divided by duration of the instar.

The fresh weights of first, second, third and fourth instars of *S. levaillanti* and *C. sanguinea* maintained at 25 ± 1 °C were determined by weighing 25 individuals of each stage. Their dry weights were then determined by placing them in an oven at 60 °C for 24 h. The fresh weights and dry weights of medium-size cotton aphids (third to fourth instar) maintained at 25 ± 1 °C were determined using the same procedures. The fresh weights and dry weights of medium-size cotton aphids were determined as 0.043 ± 0.0014 mg and 0.014 ± 0.0005 mg (n = 50), respectively. Thus, these values were used to determine the fresh and dry weights of the aphids consumed by these predators.

The dry weights of first, second, third and fourth larval instars of *S. levaillanti* and *C. sanguinea* were plotted against their fresh weights and regression

analysis applied (SAS Institute, 1985). From these analyses, linear equations were used to convert the fresh weight gain of larval instars of *S. levaillanti* and *C. sanguinea* to dry weight gain. The dry weights of the aphids consumed and dry weight gain in each instar were used to avoid error due to weight losses of aphid prey by dehydration and weight losses due to water loss during moulting. The efficiency of conversion of ingested food into body substance by each larval instar of *S. levaillanti* and *C. sanguinea* was estimated as follows:

$$\text{Conversion efficiency}(\%) = \frac{\text{Dry weight gain in each insar}}{\text{Dry weight of aphids consumed}} \times 100$$

The consumption rate, fresh weight of aphids consumed and fresh weight gain by the larvae of *S. levaillanti* and *C. sanguinea* were analysed using one-way ANOVA and the means were separated by LSD at 1% level (SAS Institute, 1985).

Results

The fresh weight increases of larval instars of *S. levaillanti* and *C. sanguinea* during their development at various temperatures are shown in Figures 1 and 2, respectively. The fresh weight of both coccinellids increased steadily throughout each instar. At the time of the moult, the fresh weight fell slightly due to the loss of the exuvium and loss of some water which is not immediately replaced because the larvae stop feeding. The fastest development of larvae of *S. levaillanti* was found at 30 °C, followed by that at 25 and 20 °C, respectively (Figure 1), presumably due to their higher rate of metabolism and their faster food consumption at higher temperatures. However, the larvae of *C. sanguinea* showed similar development at 25 and 30 °C, which was faster than at 20 °C (Figure 2).

Consumption rate (numbers of aphid consumed/day) of the larval instars, as well as total development (from egg hatch to pupation) of *S. levaillanti* and *C. sanguinea* at various temperatures are presented in Table 1. The consumption rate of each larval stage of both species increased with increasing temperatures. However, the increase in consumption rate for total development of *C. sanguinea* was not significantly different at 25 °C from that at 30 °C, but there was a significant difference in the consumption rate of *S. levaillanti* at each temperature. *C. sanguinea* was more voracious than *S. levaillanti* at all temperatures.

Fresh and dry weight of larval instars of *S. levaillanti* and *C. sanguinea* are presented in Table 2. The fresh and dry weight increased with successive

Table 1. Consumption rate (mean numbers of aphid eaten/day ± SE) by larval instars and for total development (from egg hatch to pupation) of *Scymnus levaillanti* and *Cycloneda sanguinea* at various temperatures

Temperature	1st instar		2nd instar		3rd instar		4th instar		Total development	
	C. sanguinea	*S. levaillanti*	*C. sanguinea*	*S. levaillanti*	*C. sanguinea*	*S. levaillanti*	*C. sanguinea*	*S. levaillanti*	*C. sanguinea*	*S. levaillanti*
20 °C	7.7±0.3 b (20)	1.9±0.1 c (23)	38.1±2.5 c (20)	3.1±0.2 c (22)	104.6±5.9 c (20)	7.9±0.5 b (21)	522.8±37.3 b (20)	28.1±1.3 b (21)	673.3±42.1 b (20)	41.0±0.23 c (21)
25 °C	24.3±1.5 a (21)	2.8±0.2 b (20)	67.7±3.3 b (21)	4.7±0.2 b (20)	143.6±9.8 b (20)	9.2±0.5 b (20)	738.6±22.9 a (19)	32.9±2.2 b (18)	975.1±27.4 a (19)	49.6±0.5 b (18)
30 °C	25.2±1.8 a (19)	6.3±0.3 a (18)	115.6±11.1 a (19)	9.8±0.7 a (14)	178.8±14.1 a (16)	16.7±0.8 a (14)	761.8±59.1 a (15)	43.1±2.7 a (13)	1066±69.5 a (15)	75.9±1.2 a (13)
F and *p* value	F= 53.5 d.f. = 2, 57 $p < 0.01$	F= 130 d.f. = 2, 58 $p < 0.01$	F= 34.3 d.f. = 2, 57 $p < 0.01$	F = 109 d.f. = 2, 53 $p < 0.01$	F = 13.4 d.f. = 2, 53 < 0.01	F = 61.7 d.f. = 2, 52 $p < 0.01$	F = 11.5 d.f. = 2, 51 $p < 0.01$	F = 13 d.f. = 2, 49 $p < 0.01$	F = 20.2 d.f. = 2, 51 $p < 0.01$	F = 154 d.f. = 2, 49 $p < 0.01$
LSD value	3.8004	0.5773	18.656	0.8973	28.365	1.618	113.38	5.7832	131.78	1.8063

Means within a column with the same letter are not significantly different (LSD test at 1% level). One-way ANOVA was applied for data Figures in brackets show the number of individuals as replicates.

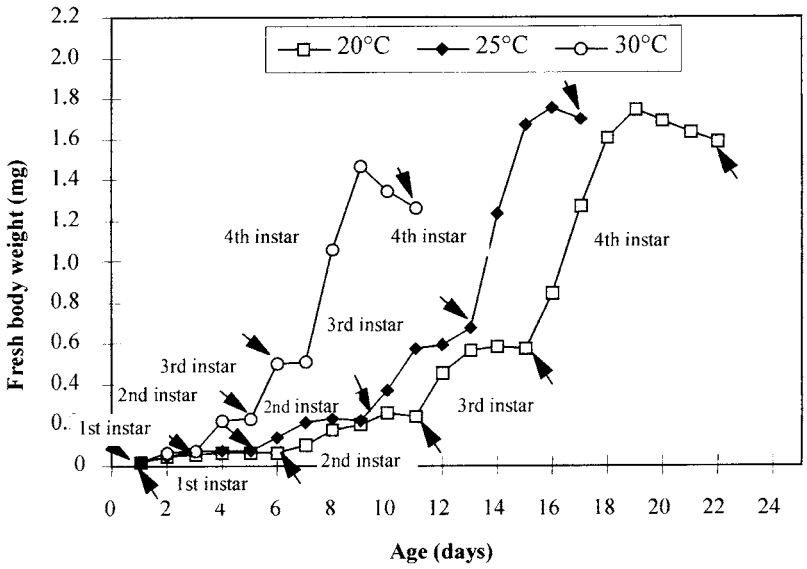

Figure 1. Fresh weight increases of larval instars of *Scymnus levaillanti* during their development at various temperatures (arrows indicate the start and the end of each instar).

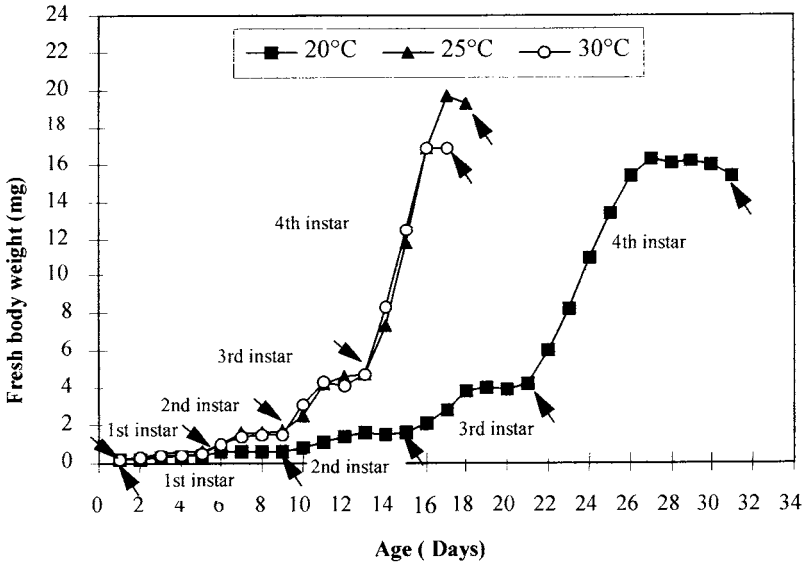

Figure 2. Fresh weight increases of larval instars of *Cycloneda sanguinea* during their development at various temperatures (arrows indicate the start and the end of instar stages).

Table 2. Fresh and dry weight (mean ± SE) of larval instars of *Scymnus levaillanti* and *Cycloneda sanguinea*; data are based on twenty replicate individuals per instar per species

Stage	*S. levaillanti*		*C. sanguinea*	
	Fresh weight (mg)	Dry weight (mg)	Fresh weight (mg)	Dry weight (mg)
1st instar	0.036±0.0075	0.009±0.002	0.200±0.021	0.049±0.007
2nd instar	0.120±0.012	0.030±0.0028	0.590±0.036	0.150±0.0078
3rd instar	0.350±0.029	0.077±0.007	2.080±0.13	0.420±0.03
4th instar	0.860±0.075	0.210±0.021	6.280±0.44	1.340±0.12

larval instars of both coccinellid species. According to the results of regression analyses, plotting dry weights of larval instars of both coccinellid species versus their fresh weights produced the best fit linear curve ($F = 1301$, d.f. = 1, 2, $p < 0.01$ for *S. levaillanti* and $F = 3072$, d.f. = 1, 2, $p < 0.01$ for *C. sanguinea*). From these regression analyses, the linear equations were used to convert the fresh weight gain by both coccinellid species to their dry weights ($y = 0.2406x - 0.0013$, $r^2 = 0.9985$ for *S. levaillanti* and $y = 0.2106x - 0.0078$, $r^2 = 0.9993$ for *C. sanguinea*).

Fresh weight of aphids consumed and fresh weight gain by larval instars and during total development (from egg hatch to pupation) of *S. levaillanti* and *C. sanguinea* at various temperatures are presented in Tables 3 and 4, respectively. The fresh weights of aphids consumed during total development of both coccinellid species were significantly higher at 20 and 25 °C than at 30 °C, whilst they were not significantly different at 20 °C from 25 °C. The highest fresh weight of aphids consumed by all larval instars, except first instars, and during total development of *S. levaillanti* were found to be at 20 °C (Table 3). Although given a constant food level, the fresh weight of aphids consumed by the larval instars of *C. sanguinea* varied with temperature (Table 4). The highest fresh weight of aphids consumed by first, second, third and fourth larval instars and during total development of *C. sanguinea* was found to be at 25, 30, 25, 25 and 25 °C, respectively. The fresh weight of aphids consumed by larval instars of *C. sanguinea* was much higher than that of *S. levaillanti* at any temperature.

Figures 3 and 4 give the efficiencies of conversion of ingested food to body substance by larval instars and during total development of *S. levaillanti* and *C. sanguinea*, respectively. The first three instars of *S. levaillanti* had almost the same conversion efficiencies at all temperatures (except the first

Table 3. Fresh weight of aphids consumed and fresh weight gain per instar by larval instars, and during total development of *Scymnus levaillanti* at various temperatures (means ± SE)

Temperature	1st instar		2nd instar		3rd instar		4th instar		Total development	
	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)
20 °C	0.07±0.002 a (23)	0.04±0.001 c (23)	0.24±0.008 a (22)	0.09±0.004 c (22)	0.49±0.02 a (21)	0.34±0.01 a (21)	2.26±0.082 a (19)	1.25±0.03 a (19)	3.13±0.08 a (19)	1.79±0.03 a (19)
25 °C	0.07±0.002 a (20)	0.06±0.002 a (20)	0.21±0.004 b (20)	0.13±0.007 b (20)	0.48±0.017 a (20)	0.36±0.02 a (20)	2.16±0.074 a (18)	1.14±0.04 a (18)	2.94±0.075 a (18)	1.69±0.04 a (18)
30 °C	0.07±0.003 a (18)	0.05±0.002 b (18)	0.23±0.006 a (14)	0.29±0.023 a (14)	0.36±0.017 b (14)	0.27±0.02 b (14)	1.86±0.094 b (13)	1.02±0.05 b (13)	2.55±0.099 b (13)	1.49±0.05 b (13)
F and *p* value	F = 0.81 d.f. = 2, 58 $p = 0.448$	F = 16.8 d.f. = 2, 58 $p < 0.01$	F = 4.4 d.f. = 2, 53 $p < 0.05$	F = 80.4 d.f. = 2, 53 $p < 0.01$	F = 13.9 d.f. = 2, 52 $p < 0.01$	F = 7.39 d.f. = 2, 52 $p < 0.01$	F = 5.7 d.f = 2, 47 $p < 0.01$	F = 8.4 d.f = 2, 47 $p < 0.01$	F = 11.4 d.f. = 2, 47 $p < 0.01$	F = 11.9 d.f. = 2, 47 $p < 0.01$
LSD value	–	0.005	0.0186	0.0317	0.0534	0.0461	0.2379	0.112	0.2385	0.118

Means within a column with the same letter are not significantly different (LSD test at 1% level). One-way ANOVA was applied
Figures in brackets show the number of individuals as replicates.

Table 4. Fresh weight of aphids consumed and fresh weight gain per instar by larval instars, and during overall development of *Cycloneda sanguinea* at various temperatures (means ± SE)

Temperature	1st instar		2nd instar		3rd instar		4th instar		Total development	
	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)	Fresh weight of aphid consumed (mg)	Fresh weight gain of predator (mg)
20 °C	0.77±0.033 c (20)	0.38±0.012 a (20)	2.79±0.1 c (20)	1.04±0.039 a (20)	7.89±0.17 b (20)	2.70±0.06 b (20)	62.1±2.33 ab (20)	12.80±0.49 b (20)	72.80±2.49 a (20)	16.80±0.55 b (20)
25 °C	1.28±0.052 a (21)	0.39±0.015 a (21)	3.17±0.09 b (21)	1.04±0.032 a (21)	9.28±0.33 a (20)	3.10±0.11 a (20)	68.60±2.15 a (19)	15.30±0.49 a (19)	72.90±2.02 a (19)	19.90±0.57 a (19)
30 °C	1.12±0.068 b (19)	0.28±0.014 b (19)	3.82±0.15 a (19)	0.91±0.035 b (19)	9.08±0.35 a (16)	2.90±0.11 ab (16)	57.50±3.61 b (15)	12.80±0.80 b (15)	62.72±3.35 b (15)	16.90±0.83 b (15)
F and *p* value	F = 25.1 d.f = 2, 57 $p < 0.01$	F = 19 d.f = 2, 57 $p < 0.01$	F = 20.5 d.f. = 2, 57 $p < 0.01$	F = 4.2 d.f. = 2, 57 $p < 0.05$	F = 7.04 d.f. = 2, 53 $p < 0.01$	F = 5.4 d.f. = 2, 53 $p < 0.01$	F = 4.3 d.f. = 2, 51 $p < 0.05$	F = 6.5 d.f. = 2, 51 $p < 0.01$	F = 4.7 d.f. = 2, 51 $p < 0.05$	F = 7.4 d.f. = 2, 51 $p < 0.01$
LSD value	0.149	0.0394	0.3221	0.0998	0.8287	0.2737	7.5402	1.6656	7.3794	1.8302

Means within a column with the same letter are not significantly different (LSD test at 1% level). One-way ANOVA was applied
Figures in brackets show the number of individuals as replicates.

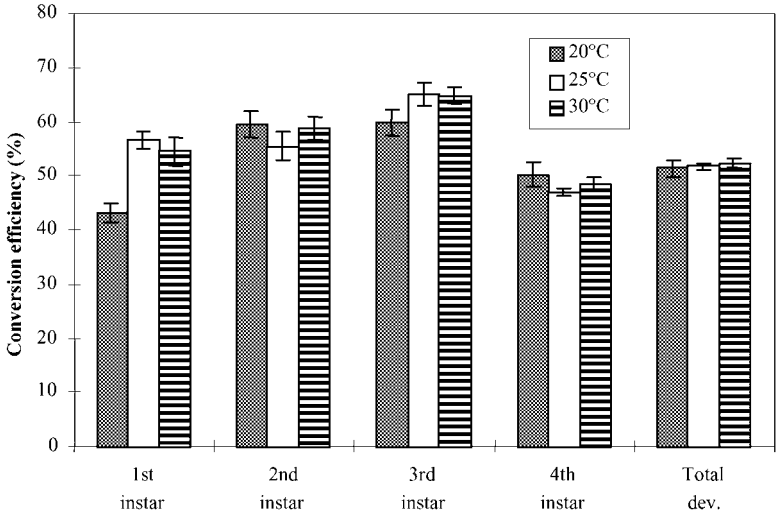

Figure 3. Conversion efficiencies of larval instars and during total development of *Scymnus levaillanti*. Bar = Standard error of mean conversion efficiency (%). Thirteen to twenty-three individuals were used as replicates.

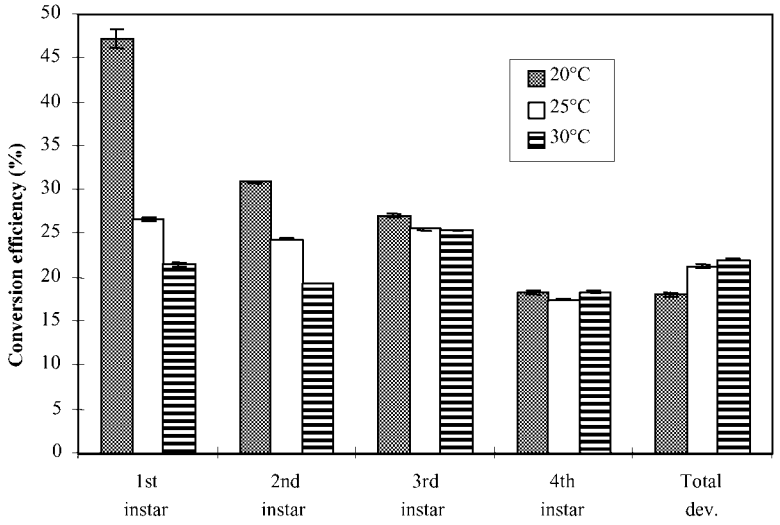

Figure 4. Conversion efficiencies of larval instars and during total development of *Cycloneda sanguinea*. Bar = Standard error of mean conversion efficiency (%). Fifteen to twenty-one individuals were used as replicates.

larval instar at 20 °C), varying between 56% and 65% whilst for the first three instars of *C. sanguinea* the conversion efficiencies decreased with progressing through the instar sequence at any one temperature (except third instar larvae at 25 and 30 °C). The conversion efficiencies of fourth instars of both species were much lower than those of the first three instars at any temperature. The conversion efficiencies for larval instars of *S. levaillanti* ranged from 43% to 65% at different temperatures and were higher than those of *C. sanguinea* which ranged from 17% to 47%.

Discussion

The voracity and the effectiveness of coccinellids varies greatly in relation to species and developmental stage of coccinellid and the species of aphid provided as food (Hodek, 1967). In this study, the consumption rate of each larval instar of both species increased with increasing temperature. The maximum consumption rate of the larvae of *S. levaillanti* was found to be at 30 °C, but it was between 25 and 30 °C for *C. sanguinea*. The larger species, *C. sanguinea*, was more voracious at all temperatures than was the smaller species, *S. levaillanti*. Gurney and Hussey (1970) also reported that *C. sanguinea* was more voracious than *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) and *A. bipunctata*, but relatively less voracious than *Coelomegilla maculata* (DeGeer) (Coleoptera: Coccinellidae).

The literature contains a great amount of information on the numbers of prey insects consumed by the larvae of different coccinellid species. There is little point in comparing the numerical data, because the results were obtained by different methods, and because different species of prey are concerned. Even if the same prey is used under similar conditions, the results may be totally different, depending on the developmental stage of the prey and its abundance. For instance, *C. sanguinea* larvae have been reported to consume an average of 276 cotton aphids at 21 °C (Gurney and Hussey, 1970), but in this study it was 1824 at 20 °C.

The first three instars of both species were more efficient in converting the food to body mass than the fourth instars. The reason could be the greater metabolic costs of the fourth instars which may be connected with the preparation for the process of pupation. The conversion efficiencies of larval instars of *Adalia bipunctata* reported by Mills (1981) are similar to those of *C. sanguinea* estimated from this study, but much lower than those of *S. levaillanti*. However, the conversion efficiencies of larval instars of *C. sanguinea* recorded from this study are much lower than those of *Semiadalia undecimnotata* reported by Ferran and Larroque (1977), which were, in turn, slightly lower than those of *S. levaillanti*. This could be due not only to diffe-

rences in species and experimental conditions, but also to different methods of measuring and calculating the data.

The conversion efficiencies for larval instars of *S. levaillanti* ranged from 43% to 65% at different temperatures and were higher than those of *C. sanguinea* which ranged from 17% to 47%. Therefore, the larval instars of *S. levaillanti* were more efficient in converting food to body mass than those of *C. sanguinea*. This could be because the larval instars of *S. levaillanti* are able to obtain a larger proportion of highly digestible materials from the aphids compared with those of *C. sanguinea*. *S. levaillanti* show pre-oral digestion, in which they periodically regurgitate fluid from the gut into the chewed aphids, suck back the pre-digested aphid material and reject the exoskeleton with appendages. The larval instars of *C. sanguinea* consume the aphids completely by sucking and chewing (Işıkber, 1999). Neuropteran (Zheng et al., 1993) and hemipteran (Cohen, 1984) predaceous insects with piercing-sucking mouth-parts usually have higher conversion efficiencies than most chewing predaceous insects due to their ability to obtain a larger proportion of highly digestible materials from their prey by a process aided by pre-oral digestion of their food (Cohen, 1984).

In conclusion, the smaller species, *S. levaillanti*, is more efficient in converting food to body mass, whilst the bigger species, *C. sanguinea*, is less efficient, even though it is more voracious than *S. levaillanti*. Therefore, it seems that body size and feeding method of predators can have a great impact on their food consumption and efficiency of conversion of food to body mass.

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