Performance of a predatory ladybird beetle, *Anegleis cardoni* (Coleoptera: Coccinellidae) on three aphid species

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Key words. Coccinellidae, *Anegleis cardoni*, prey, *Aphis gossypii*, *Aphis craccivora*, *Lipaphis erysimi*, reproduction, life table, fitness

Abstract. Qualitative and quantitative differences in prey are known to affect the life histories of predators. A laboratory study was used to evaluate the suitability of three aphid prey, *Aphis gossypii*, *Aphis craccivora* and *Lipaphis erysimi*, for the ladybird beetle, *Anegleis cardoni* (Weise). Development was fastest on *A. gossypii* followed by *A. craccivora* and *L. erysimi*. Percentage pupation, immature survival, adult weight and the growth index were all highest when reared on *A. gossypii* and lowest on *L. erysimi*. Similarly, oviposition period, lifetime fecundity and egg viability were all highest on a diet of *A. gossypii*, lowest on *L. erysimi* and intermediate on *A. craccivora*. Age-specific fecundity functions were parabolic. Adult longevity, reproductive rate and intrinsic rate of increase were all highest on *A. gossypii* and lowest on *L. erysimi*. Life table parameters reflected the good performance on *A. gossypii* and poor performance on *L. erysimi*. Estimates of individual fitness values for the adults reared on *A. gossypii* and *A. craccivora* were similar and higher than that of adults reared on *L. erysimi*. Thus, the three species of aphid can all be considered essential prey for *A. cardoni*.

INTRODUCTION

Food quality can influence many aspects of the development, survival and reproduction of predators. In order to understand the behaviour, biology and ecology of insects and develop pest management strategies it is important to have a good knowledge of the ways insects interact with their food sources. Ladybird beetles are predators of aphids, mealybugs, scale insects, whiteflies, thrips, mites and a number of other pest species (Hodek, 1996; Dixon, 2000). However, some ladybirds are generalists and others specialists (Hodek, 1996). Studies on prey suitability can increase our understanding of the feeding preferences and prey specificity of ladybirds.

Although the suitability of prey for ladybird beetles is well studied (reviewed in Hodek, 1996) the importance of the subject remains undiminished (Michaud, 2000, 2005; Kalaskar & Evans, 2001; Nielsen et al., 2002). Both larvae and adults of the majority of the species of coccinellid are predators. Most coccinellid predators survive on a “mixed diet” composed of “essential” and “alternative” prey (Hauge et al., 1998; Evans et al., 1999; Nielsen et al., 2002). Essential prey supports development and reproduction, whereas alternative prey enables adults to survive when essential prey is scarce (Hodek, 1962; Mills, 1981; Evans et al., 1999). Dixon (2000) distinguished “nursery” prey as the prey selected by ovipositing females for their immature stages. The range of nursery prey is more limited than that of adults. Malcolm (1992) proposed “included”, “peripheral” and “excluded” as alternatives to essential, alternative and rejected prey, respectively. Based on larval performance Michaud (2005) categorized prey suitability as either “optimal”, “adequate” or “marginal”. In general, the growth, survival and reproduction of the predator are best when it is reared on essential prey. Rana et al. (2002) suggested that the performance of a ladybird can be improved by selection, even if the prey is initially less suitable.

Apart from nutritional quality, numerous factors, viz. prey defense mechanisms (Dixon, 1958, 2000; Arakaki, 1989), plant architecture (Carter et al., 1984; Rott & Ponsoby, 1992; Vohland, 1996; Clark & Messina, 1998), etc. can further influence prey suitability. Though laboratory studies rarely include all these aspects, they can provide an indication of prey preference and nutritional quality.

The suitability of a species of prey can be assessed by evaluating the effect feeding on it has on the life history attributes of the predator, namely development, survival, adult weight and reproduction. Kalushkov & Hodek (2001) suggest that quantitative data on a predator’s rate of development, survival and reproduction indicate the adequacy of the prey. The influence of food quality on growth, development and reproductive success is well studied (Gilbert & Owen, 1990; Francis et al., 2000; Bilde & Toft, 2001; Stamp & Meyerhoefer, 2004; Ishiguri & Toyoshima, 2006). Reproduction requires high-energy resources that are supplied by food, which is a major regulatory factor of reproductive success (Houck, 1991).

Owing to their economic and biological importance, prey-dependent responses have been evaluated for a number of ladybird beetles, viz. *Propylea quatuordecimpunctata* L. (Baumgartner et al., 1987), *Adalia bipunctata* (Kalushkov, 1998), *Coccinella septempunctata* Linnaeus.
Immature development and survival were removed.

ing, fed on the same species of aphid and the eggs they laid they pupated. The freshly emerged adults were paired for mat-

eggs that hatched were recorded. Larvae were reared on the 

camel hair brush and placed into Petri dishes. The numbers of 

monitored twice daily and eggs removed with the help of a fine 

aphid supply was replenished every 24 h. Oviposition was 

erysimi (Kaltenbach), Propylaea dissecta (Mulsant) (Omkar & 

Mishra, 2005), Scymnus frontalis Fabricius (Gibson et al., 

1992), Coelophora bipilagata (Swartz) (Omkar et al., 

many more.

Angeles cardoni (Weise) (Tribe: Coccinellini) is an 

attractively patterned, medium-sized ladybird beetle, which occurs in southern and northern parts of India (Put-

tarudriah & Channabasavanna, 1953; Ghorpade, 1979).

Kapur (1972) and Omkar & Bind (1993) reported A. car-

doni from Goa and Lucknow, respectively. Angeles car-

doni is reported to be a voracious feeder on whiteflies (Sternorrhyncha: Aleyrodidae) (Ramani et al., 2002) and 

scale insect pests (Sternorrhyncha: Coccidae) of sandal-

wood (Sundararaj, 2008). Both larvae and adults of A. cardoni feed on various aphid species, viz. Aphis gossypii 

Glover on Solanum melongena Linnaeus, Brevicoryne 

brassicae Linnaeus on Brassica oleraceae Linnaeus, 

Macroisum miscanthi (Takahashi) on Triticum aer-

tivum Linnaeus and M. pisi Kaltstenbach on Pisum sativum 

Linnaeus (Afroze, 2000). It is also a predator of Aphis 

craccivora Koch, Lipaphis erysimi (Kaltstenbach), Uro-

lecon compositae Theobald, Myzus persicae Sulzer, 

Acythosiphon pisum (Harris) and many other species of 

aphids (Aphids of Karnataka; http://www.aphidweb. 

com). The objective of the present study was to determine 

the larval performance of A. cardoni on three common 

species of aphid in order to assess their suitability as prey 

for this ladybird.

MATERIAL AND METHODS

Laboratory maintenance

To establish a stock culture, adults and different life stages (eggs, larvae and pupae) of A. cardoni were collected from 

Ashoka (Polyalthia longifolia) trees, located within the campus 

of the University of Lucknow, India (26°50´N, 80°54´E). 

Mating pairs and different life stages were kept in Petri dishes 

of the University of Lucknow, India (26°50´N, 80°54´E).

Ten pairs of newly emerged adults (n = 10) were isolated in 

Petri dishes (as above) and provided with either fresh A. crac-

civora on D. lablab leaves, A. gossypii on L. vulgaris or L. ery-

simi on B. campestris. Aphids and leaves were replaced every 

24 h. Oviposition and egg viability were recorded daily for 

each female over her entire reproductive life. In addition to 

the longevity of males and females, the pre-oviposition period (time from emergence until first oviposition), oviposition period (time from first to last day of oviposition), post-oviposition period (time from the last oviposition until death) reproductive rate 

(fecundity/oviposition period) and day of peak oviposition were recorded. Age-specific fecundity graphs for the ladybirds fed on each of the aphid species are presented.

Data analysis

The results were subjected to a one-way ANOVA and means were compared using Tukey’s HSD test with α = 0.05 

(MINITAB 2003). Pearson’s correlation coefficient was used to test for correlations between female weight and longevity, fecundity, pre-oviposition, oviposition and post oviposition periods, and between male weight and egg fertility. If significant the 

results were subjected to a regression analysis in order to obtain the best relationship.

Life table parameters

Life table parameters for this ladybird when reared on each of the three prey species were calculated following Birch (1948):

Net reproductive rate (Ro) = Σ lxMx. 

Mean generation time (Tc) = Σ lxMx/Ro (where, x = pivotal age).

lx = number of females surviving in a given population (n = 10). 

Mx = net fecundity of emerging female. 

Intrinsic rate of increase (rm) = ln Ro/Tc 

The finite rate of increase (λm) = antilog e^rm. (where e = 2.718228).

Generation time (GT) = ln Ro/rm. 

Doubling time (DT) = ln 2/rm. 

Individual female fitness

The performance of an insect reared under standard conditions is perhaps best described by an overall measure of individual fitness. McGraw & Caswell (1996) use the following equation to estimate individual fitness (R) from life history data: 

\[ R = \frac{|n| (mV)}{D}, \text{ where } m = \text{ survival (1 or 0 )}, \] 

\[ V = \text{ potential fecundity}, \] 

\[ D = \text{ total development time}. \]
Individual fitness measures were calculated for females reared on all three species of aphids and then subjected to a one-way ANOVA followed by Tukey’s HSD test with $\alpha = 0.05$.

**RESULTS**

**Immature development and survival**

The duration of the various life stages of *A. cardoni* reared on each of the three aphid diets varied significantly (Table 1). Incubation time and total developmental period of *A. cardoni* were shortest when fed on *A. gossypii* and longest on *L. erysimi*. Total larval development was significantly shorter on *A. gossypii* than on *L. erysimi* and the total developmental period on each of the three species of aphid differed significantly. Mean weights of both males and females were lower when reared on *L. erysimi* compared to the other two aphid species (Table 2). The growth index and survival from egg hatch to adult emergence were highest on *A. gossypii* and lowest on *L. erysimi*. There were no significant differences in sex ratio of *A. cardoni* reared on three aphid species.

**Reproduction**

There were no significant differences between the treatments in either the pre-oviposition or post-oviposition periods of *A. cardoni* females, but the oviposition period was significantly longer and the reproductive rate higher on *A. gossypii* and *A. craccivora* than on *L. erysimi* (Table 3). Lifetime fecundity was highest on *A. gossypii*, lowest on *L. erysimi* and intermediate on *A. craccivora*. Percentage egg viability was lower on *L. erysimi* than on either *A. gossypii* or *A. craccivora*.

In all three treatments the age-specific fecundity function was parabolic. The oviposition rate increased with reproductive age up to a peak followed by a gradual decline (Fig. 1). Female age at peak oviposition also differed among treatments, occurring earlier on *A. craccivora* than on either *A. gossypii* or *L. erysimi* (Table 3).

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**Table 1.** Mean (± S.E.) duration (days) of each stage in the development of *A. cardoni* recorded when reared on one of three aphid species (df = 2, 42). Means within rows with the same letter were not significantly different (\( \alpha > 0.05 \)).

<table>
<thead>
<tr>
<th>Stage</th>
<th><em>A. gossypii</em></th>
<th><em>A. craccivora</em></th>
<th><em>L. erysimi</em></th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incubation period</td>
<td>4.07 ± 0.12a</td>
<td>4.27 ± 0.12a</td>
<td>4.40 ± 0.13a</td>
<td>1.87</td>
<td>0.166</td>
</tr>
<tr>
<td>First instar</td>
<td>2.75 ± 0.08a</td>
<td>3.20 ± 0.08a</td>
<td>3.87 ± 0.05b</td>
<td>62.28</td>
<td>0.000</td>
</tr>
<tr>
<td>Second instar</td>
<td>3.32 ± 0.13a</td>
<td>4.03 ± 0.08b</td>
<td>3.92 ± 0.05b</td>
<td>17.67</td>
<td>0.000</td>
</tr>
<tr>
<td>Third instar</td>
<td>3.82 ± 0.17a</td>
<td>4.60 ± 0.12b</td>
<td>4.67 ± 0.12b</td>
<td>11.66</td>
<td>0.000</td>
</tr>
<tr>
<td>Fourth instar</td>
<td>4.71 ± 0.13a</td>
<td>5.34 ± 0.13ab</td>
<td>5.85 ± 0.14b</td>
<td>18.26</td>
<td>0.000</td>
</tr>
<tr>
<td>Pre-pupa</td>
<td>1.84 ± 0.05a</td>
<td>1.91 ± 0.03a</td>
<td>2.04 ± 0.03b</td>
<td>7.93</td>
<td>0.001</td>
</tr>
<tr>
<td>Pupa</td>
<td>5.21 ± 0.12a</td>
<td>5.40 ± 0.11ab</td>
<td>5.90 ± 0.11b</td>
<td>7.74</td>
<td>0.001</td>
</tr>
<tr>
<td>Total development</td>
<td>25.71 ± 0.25a</td>
<td>28.75 ± 0.27b</td>
<td>30.56 ± 0.21c</td>
<td>101.65</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Table 2.** Mean developmental parameters of *A. cardoni* when reared on one of three aphid species (df = 2, 42). Means within rows with the same letter were not significantly different (\( \alpha > 0.05 \)).

<table>
<thead>
<tr>
<th>Aphid species</th>
<th><em>A. gossypii</em></th>
<th><em>A. craccivora</em></th>
<th><em>L. erysimi</em></th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immature survival (%)</td>
<td>88.46 ± 2.46a</td>
<td>84.00 ± 3.49a</td>
<td>75.00 ± 4.45a</td>
<td>3.93</td>
<td>0.027</td>
</tr>
<tr>
<td>Pupation (%)</td>
<td>89.78 ± 2.49a</td>
<td>86.67 ± 3.74a</td>
<td>79.67 ± 3.17a</td>
<td>2.75</td>
<td>0.075</td>
</tr>
<tr>
<td>Growth index</td>
<td>4.59 ± 0.25b</td>
<td>3.49 ± 0.21ab</td>
<td>2.48 ± 0.19a</td>
<td>23.02</td>
<td>0.000</td>
</tr>
<tr>
<td>Male wt (mg)</td>
<td>6.81 ± 0.13b</td>
<td>6.13 ± 0.13c</td>
<td>5.04 ± 0.14a</td>
<td>44.56</td>
<td>0.000</td>
</tr>
<tr>
<td>Female wt (mg)</td>
<td>7.91 ± 0.17b</td>
<td>7.16 ± 0.20c</td>
<td>5.85 ± 0.19a</td>
<td>31.20</td>
<td>0.000</td>
</tr>
<tr>
<td>Sex ratio</td>
<td>0.55 ± 0.03a</td>
<td>0.55 ± 0.06a</td>
<td>0.47 ± 0.06a</td>
<td>0.96</td>
<td>0.392</td>
</tr>
</tbody>
</table>

**Table 3.** Mean (± SE) reproductive data for *A. cardoni* females (n = 10 per treatment) when fed on one of three aphid species (df = 2, 27). Means within rows with the same letter were not significantly different (\( \alpha > 0.05 \)).

<table>
<thead>
<tr>
<th>Life history parameters</th>
<th><em>A. gossypii</em></th>
<th><em>A. craccivora</em></th>
<th><em>L. erysimi</em></th>
<th>F value</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-oviposition period (days)</td>
<td>2.00 ± 0.39a</td>
<td>2.6 ± 0.40a</td>
<td>2.90 ± 0.23a</td>
<td>1.70</td>
<td>0.201</td>
</tr>
<tr>
<td>Oviposition period (days)</td>
<td>58.30 ± 1.67b</td>
<td>52.1 ± 1.59b</td>
<td>27.00 ± 1.76a</td>
<td>97.97</td>
<td>0.000</td>
</tr>
<tr>
<td>Post-oviposition period (days)</td>
<td>5.80 ± 0.49a</td>
<td>6.60 ± 0.56a</td>
<td>3.70 ± 1.27a</td>
<td>3.09</td>
<td>0.062</td>
</tr>
<tr>
<td>Lifetime fecundity (eggs)</td>
<td>397.00 ± 10.84c</td>
<td>327.70 ± 14.81b</td>
<td>136.60 ± 10.13a</td>
<td>124.19</td>
<td>0.000</td>
</tr>
<tr>
<td>Egg viability (%)</td>
<td>78.00 ± 1.60b</td>
<td>73.85 ± 0.73b</td>
<td>61.86 ± 1.22a</td>
<td>45.98</td>
<td>0.000</td>
</tr>
<tr>
<td>Female age at peak oviposition (days)</td>
<td>29.30 ± 0.78c</td>
<td>23.90 ± 1.06b</td>
<td>18.3 ± 1.10a</td>
<td>31.05</td>
<td>0.005</td>
</tr>
<tr>
<td>Peak oviposition rate (eggs/day)</td>
<td>22.70 ± 0.40b</td>
<td>21.5 ± 0.40b</td>
<td>17.3 ± 0.52a</td>
<td>41.19</td>
<td>0.000</td>
</tr>
<tr>
<td>Adult longevity (days)</td>
<td>75.70 ± 1.55c</td>
<td>68.60 ± 1.55b</td>
<td>43.95 ± 1.47a</td>
<td>124.44</td>
<td>0.000</td>
</tr>
<tr>
<td>Mean reproductive rate (eggs/day)</td>
<td>6.81 ± 0.06b</td>
<td>6.28 ± 0.16b</td>
<td>5.07 ± 0.20a</td>
<td>33.97</td>
<td>0.000</td>
</tr>
<tr>
<td>Individual fitness</td>
<td>0.23 ± 0.002c</td>
<td>0.23 ± 0.002b</td>
<td>0.15 ± 0.003a</td>
<td>201.03</td>
<td>0.000</td>
</tr>
</tbody>
</table>

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Individual comparison of means revealed that the peak oviposition rate of *A. cardoni* fed on *L. erysimi* differed significantly from that when fed *A. gossypii* or *A. craccivora*, and was highest on *A. gossypii* and *L. erysimi*. Age-specific fertility showed trends similar to those for fecundity except *A. gossypii* where it was bimodal (Fig. 2). The longevity of males of *A. cardoni* was not significantly different from that of the females (F...
DISCUSSION

The present study reveals a significant influence of aphid prey on the life attributes of A. cardoni, with overall best performance on A. gossypii. The shorter developmental period on A. gossypii than on A. craccivora and L. erysimi indicates that A. gossypii was the most suitable prey for larval development, probably due to the presence of the nutrients essential for growth and development. The higher immature survival and adult emergence on A. gossypii and A. craccivora compared to L. erysimi indicates the lower suitability of the latter prey species.

The suitability of A. gossypii and A. craccivora for A. cardoni suggests that these aphids do not sequester toxic chemicals from their host plants, L. vulgaris and D. lablab. Many studies have reported A. craccivora as an essential prey for ladybird beetles, viz. C. septempunctata (Hodek, 1960), P. dissecta (Omkar & Mishra, 2005) and C. sexmaculata (Omkar & Bind, 2004), but A. craccivora fed on Robinia pseudoacacia L. (Fabales: Fabaceae) was found to be toxic to Harmonia axyridis, due to the presence of the amines, canavanine and ethanolanine sequestered from the host plant (Obatake & Suzuki, 1985). So what constitutes suitable prey varies among ladybird species, e.g. A. gossypii is suitable for C. sexmaculata (George, 1999) but less so for C. septempunctata (Zalavadia & Kapadia, 2000). Myzus persicae is suitable for C. undecimpunctata (Karaman et al., 1998) but less so for C. septempunctata (Lakhanpal & Raj, 1998).

Differential consumption can play a role in influencing reproductive attributes and may have been partly responsible for the reduced reproductive performance of A. cardoni on L. erysimi. Since adults were fed the same prey as larvae the observed reproductive performance reflects the sum effect of prey species on both immature development and subsequent adult reproduction. The shorter longevity of A. cardoni reared on L. erysimi relative to other diets, suggests the possible presence of chemicals or alkaloids (Hodek, 1956; Okamoto, 1966) that make this prey unsuitable for this ladybeetle. Lipaphis erysimi has a pungent smell, presumably the result of compounds sequestered from its host plant, and it is possible that allyl isothiocyanates sequestered from its host plant are, to some degree, responsible for its reduced suitability as prey, as previously reported for other Coleoptera (Williams et al., 1993; Noble et al., 2002). C. septempunctata also develops more slowly when reared on L. erysimi (Singh et al., 1994; Kumar & Verma, 1996; Joshi et al., 1999). On the other hand C. septempunctata (Ali & Rizvi, 1999).
and low fecundity recorded when fed on this aphid. Low
fitness in Gargaphia solani (Hemiptera: Tingidae) is also
associated with a low fecundity and a delay in egg pro-
duction to later in a female’s life (Tallamy & Denno,
1982).

This study reveals that all the species of aphids tested
serve as essential prey for the predator A. cardoni and
Aphis gossypii was the most suitable. The performance of
A. cardoni was prey-dependent and the order of suit-
ability of the prey tested was A. gossypii > A. craccivora
> L. erysimi.

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