Effect of cannibalism and predation on the larval performance of two ladybird beetles

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Abstract

The relative impact of cannibalism and predation on the development and survival of fourth instar larvae was assessed in two species of aphidophagous ladybird beetles, Coccinella septempunctata and Harmonia axyridis. The effect of eating aphids, conspecific larvae or heterospecific larvae on larval performance differed in the two species: aphids were the best food for C. septempunctata and survival of C. septempunctata larvae was significantly lower when offered heterospecific larvae rather than conspecific larvae or aphids as food, indicating that H. axyridis larvae were not suitable food for C. septempunctata. However, as the different foods did not affect the larval performance of H. axyridis, this species appears to be more polyphagous. Both intraguild predation by the aggressive larvae of H. axyridis and the polyphagous food habit of this species may account for its dominance in ladybird assemblages and its displacing other ladybird beetles in several places in the world.

Introduction

In biological communities complex trophic interactions and more recently cannibalism and intraguild predation (IGP) are seen as important determinants of population dynamics and community structure (Polis et al., 1989; Polis & Holt, 1992). For example, in the wolf spider, Schizocosa ocreata, cannibalism acts as a strong density dependent mortality factor which seems to regulate the population density of the spider (Wagner & Wise, 1996). In addition, in larval odonate communities, cannibalism and IGP are often observed and sometimes are important factors structuring these communities (Spence & Carcamo, 1991; Johansson, 1993; Fincke, 1994; Wissinger et al., 1996). Therefore, in order to understand how arthropod predatory guilds are structured it is necessary to determine the effect of these factors on predators.

Predatory ladybird beetles can mainly be categorized as either aphidophagous or coccidophagous depending on the nature of their prey. The developmental times of these two groups of ladybirds are related to their prey species (Dixon et al., 1997). In the case of aphidophagous ladybirds, larval performance is influenced by the quality of aphids (Blackman, 1967; Hukushima & Kamei, 1970; Hamalainen & Markkula, 1972; Pastels, 1978; Hodek & Honek, 1996). In addition to this, a number of researchers have revealed the effects of egg cannibalism and egg predation by larvae of several ladybird beetle species on their survival and/or development (Koide, 1962; Warren & Tadic, 1967; Kawai, 1978; Hodek & Honek, 1996). Furthermore, the ladybirds contain species-specific toxins which are differentially toxic to animals (Pastels et al., 1973; Marples et al., 1989; Agarwala & Bhattacharya, 1995). It is known that cannibalism and IGP occur in aphidophagous ladybird beetles and varies in intensity between species (Takahashi, 1989; Agarwala & Dixon, 1992; Yasuda & Shinya, 1997). Therefore, cannibalism and predation in ladybird beetles may affect their development and survival differently. However, there are few studies on the effects of conspecific and/or heterospecific interactions between ladybird larvae on their performance.
Table 1. Mortality of the fourth instar larvae of two species of ladybird beetles fed one of three different kinds of prey

<table>
<thead>
<tr>
<th>Predator</th>
<th>Prey</th>
<th>No. of individuals that died</th>
<th>Mortality due to Starvation</th>
<th>Survival rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unknown (%)</td>
<td></td>
</tr>
<tr>
<td>H. axyridis (Ha)</td>
<td>Aphid</td>
<td>1</td>
<td>0</td>
<td>92.9a</td>
</tr>
<tr>
<td>Ha</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>87.5a</td>
</tr>
<tr>
<td>Ca</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>93.3a</td>
</tr>
<tr>
<td>C. septempunctata (Cs)</td>
<td>Aphid</td>
<td>1</td>
<td>0</td>
<td>93.3a</td>
</tr>
<tr>
<td>Ha</td>
<td>13</td>
<td>13</td>
<td>0</td>
<td>18.8b</td>
</tr>
<tr>
<td>Cs</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>84.6a</td>
</tr>
</tbody>
</table>

Numbers with same letter are not significantly different in the survival rate between prey species (χ²-test, P > 0.05).

In the farm at Yamagata University, in northern Japan, five species of aphidophagous ladybird beetles coexist on Hibiscus syrihis, which is the primary host of the cotton aphid, Aphis gossypii. Of the ladybird beetles, Coccinella septempunctata and Harmonia axyridis, are the most abundant species. Although it is known that cannibalism and IGP occur between these two species when prey is scarce, and that IGP is asymmetrical (Yasuda & Shinya, 1997), little is known about the effects of these interactions on larval survival and development. In this study, we assess the relative impacts of cannibalism and predation on the performance of the larvae of two ladybird species, especially during the fourth instar, which is the most voracious stage.

Materials and methods

Eggs of the two ladybird species were collected from trees of H. syridis in Tsuruoka (38°43′ N, 139°49′ E) and were kept in 9 cm Petri dishes. The larvae that hatched from these eggs were reared on cotton aphids.

A less than 12 h old fourth instar larva of C. septempunctata or H. axyridis was placed in a Petri dish with a conspecific or heterospecific fourth instar larva as food. As preliminary experiments showed that intact H. axyridis larvae offered as prey attacked and killed C. septempunctata larvae, the legs of larvae supplied as food were removed.

Observations were made at 08:00 and 19:00 each day until the larvae died or developed into adults and the incidence of predation and/or pupation were recorded. The cause of mortality was recorded as starvation or unknown. The presence of a shrunken carcass indicated starvation and a more normal sized carcass was considered as death due to an unknown factor. In order to compare the larval performance when fed aphids or larvae, fourth instar larvae of C. septempunctata and H. axyridis were reared individually with either 50 adult cotton aphids on a leaf of H. syridis or a ladybird larva in Petri dishes. The aphids were replaced every 24 h and the ladybird larva every 12 h. The weight of the ladybirds was measured to the nearest 0.01 mg at the beginning of the experiment and on the day following pupation. Weight gain during the fourth instar was calculated as follows: Weight gain = Weight of pupa − Weight of fourth instar larva at the beginning of the experiment.

All experiments, including rearing of larvae, were done in an incubator at a constant temperature of 22 ± 1.0 °C and a photoperiod of L16:D8. Data were analysed using ANOVA and mean differences separated using Tukey’s HSD multiple comparison test. The survival rate was tested by χ².

Table 2. Number (x ± SE) of conspecific and heterospecific larvae eaten by the two species of ladybird beetles

<table>
<thead>
<tr>
<th>Predator</th>
<th>Prey</th>
<th>Number eaten</th>
<th>n³</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. axyridis: developed¹ (Ha)</td>
<td>Ha</td>
<td>5.92 ± 0.71</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>5.28 ± 0.38</td>
<td>14</td>
</tr>
<tr>
<td>H. axyridis: starved²</td>
<td>Ha</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>C. septempunctata: developed (Cs)</td>
<td>Ha</td>
<td>6.33 ± 0.88</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>5.00 ± 0.42</td>
<td>11</td>
</tr>
<tr>
<td>C. septempunctata: starved</td>
<td>Ha</td>
<td>1.25 ± 0.30</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Cs</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

¹‘Developed’ indicates that the fourth instar larvae pupated.
²‘Starved’ indicates that the fourth instar larvae died of starvation.
³Deaths due to unknown causes were not included.
Survival. Survival of *C. septempunctata* larvae was significantly lower when given heterospecific larvae as food than when given conspecific larvae or aphids (*P* < 0.05; Table 1). The larvae offered heterospecific larvae mostly starved to death as 81.3% of the larvae did not eat the legless *H. axyridis* larvae. In contrast, there was no significant difference in the mortality of *H. axyridis* larvae fed the three prey (*P* > 0.05) and most larvae pupated. When *H. axyridis* larvae were offered conspecific larvae as food, 12.5% of them died of starvation. All pupae of *H. axyridis* developed into adults, irrespective of the nature of the prey eaten. However, in *C. septempunctata* only three pupae out of 16 larvae developed when they were fed *H. axyridis* larvae and eleven out of 13 larvae developed when fed *C. septempunctata* larvae. Of these, one reared on conspecific larvae and one on heterospecific larvae failed to emerge.

Food consumption. The larvae of both ladybird beetle species, which pupated, ate five to six conspecific or heterospecific larvae during the fourth instar (Table 2) and the number of individuals eaten by each species did not differ significantly (Kruskal–Wallis test; *P* > 0.05). However, in both species the larvae that died each ate less than two larvae.

Weight gain. Weight gained by both species during the fourth instar when fed one of the three prey types is shown in Figure 1. Weight gain in *C. septempunctata* was higher when fed aphids than coccinellid larvae (*P* > 0.05), indicating that in terms of weight gain aphids were a very suitable food for *C. septempunctata*. The weight gain of *H. axyridis* larvae was independent of prey type (*P* > 0.05).

Developmental time. The fourth instar larvae of both species took approximately a week to pupate (Figure 2) and this was not affected by the nature of the prey supplied (*P* > 0.05).

Discussion

The effects of the different prey on larval performance differed between the two species: aphids were the best food for *C. septempunctata* and *H. axyridis* larvae the worst. As for *H. axyridis*, the different prey appeared equally suitable.
C. septempunctata indicates that weight gain in than those of C. septempunctata shown that & Honek, 1988) and Lucas et al. (1997) have also H. axyridis 1997). The cannibalism is known to be beneficial when aphid density is low (Agarwala, 1991; Osawa, 1992a) and eggs are better food than aphids for young larvae in terms of larval growth and survival (Kawai, 1978; Agarwala & Dixon, 1992). Egg predation by larval ladybirds sometimes can affect their survival and the effect differs between species: C. septempunctata larvae tended to die after eating a few eggs of A. bipunctata, however, this was less likely when A. bipunctata larvae ate eggs of C. septempunctata. (Agarwala & Dixon, 1992). These findings indicate that the quality of prey is important for aphidophagous ladybirds, and predation might result in death. In the present study, when H. axyridis larvae were supplied as food to C. septempunctata larvae, 80% of them died. But, this was due to starvation and not the consequence of eating H. axyridis larvae. In the case of H. axyridis larvae, most pupated after eating both conspecific and heterospecific larvae. These results indicate that the toxin in the larvae of the two species does not appear to determine larval mortality in these species. However, eating conspecific larvae or heterospecific larvae may influence adult longevity and reproduction.

Aphidophagous ladybird beetles will eat conspecific and/or heterospecific eggs, larvae, and pupae depending on the availability of aphid prey (Kawai, 1978; Mills, 1982; Osawa, 1989, 1992b; Takahashi, 1989; Agarwala & Dixon, 1992; Yasuda & Shinya, 1997) and the incidence of cannibalism and predation differs between species (Takahashi, 1987; Agarwala & Dixon, 1992; Yasuda & Shinya, 1997); Coccinella larvae ate more conspecific than heterospecific larvae, but Adalia larvae ate more heterospecific than conspecific larvae (Agarwala & Dixon, 1992). In terms of predation H. axyridis larvae often ate C. septempunctata larvae, but the reverse is rare (Yasuda & Shinya, 1997). H. axyridis is a polyphagous species (Hodek & Honek, 1988) and Lucas et al. (1997) have also shown that H. axyridis larvae are more polyphagous than those of C. septempunctata. The present study indicates that weight gain in C. septempunctata larvae was highest when fed aphids, but that food type had no affect on the larval performance of H. axyridis. Therefore, it seems that C. septempunctata is a more aphid-specific predator than H. axyridis.

The legs of the ‘prey individuals’ were cut off in order to prevent the ‘prey’ eating the ‘predator’ in this study. In preliminary experiments all the C. septempunctata larvae were killed by intact H. axyridis larvae, but no larvae of H. axyridis were eaten by C. septempunctata larvae. So, not only are H. axyridis larvae polyphagous they are also very voracious, whereas those of C. septempunctata are oligophagous and less aggressive.

The effect of an invading species on a native ladybird assemblage was studied on apple trees in eastern West Virginia for 8 years (Brown & Miller, 1998). After the invasion by C. septempunctata in 1983, the assemblage was dominated by C. septempunctata, and subsequent invasion of H. axyridis in 1994 resulted in this species replacing C. septempunctata as the dominant species. This replacement of C. septempunctata by H. axyridis has also been reported in agricultural and natural ecosystems in midwestern USA (Horn, 1996). However, the mechanism of the replacement has not been known. Our findings on the aggressive behaviour of H. axyridis provide one of the possible explanations. The relationship between C. septempunctata and H. axyridis in northern Japan was studied using life table analysis (Yasuda & Shinya, 1997). H. axyridis was the dominant species in 2 years and the mechanism was IGP by H. axyridis larvae on those of C. septempunctata after the aphid became scarce. Both IGP and the polyphagous habit of H. axyridis negatively affect the larval performance of C. septempunctata and contribute to the replacement of this species by H. axyridis.

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References


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