

Effects of parasitized aphids (Homoptera: Aphididae) as food on larval performance of three predatory ladybirds (Coleoptera: Coccinellidae)

Tadashi Takizawa, Hironori Yasuda* and Basant K. Agarwala¹

Department of Agriculture, Yamagata University, Tsuruoka, Yamagata 997–8555, Japan

¹ Department of Life Sciences, Tripura University, Agartala 799 004, Tripura, India

(Received 24 March 2000; Accepted 24 July 2000)

Abstract

The effects of parasitized aphids as food on development, growth, and survival of fourth stadium larvae were assessed in three species of aphidophagous ladybirds, *Coccinella septempunctata* Linné, *Harmonia axyridis* (Pallas), and *Propylea japonica* (Thunberg) in relation to development of parasitoid larvae. The effects of eating aphids, parasitized aphids or mummies on larval performance were the same in the three species except for survival: parasitized aphids were good food for the three species, while developmental time of fourth stadium larvae of the three species was significantly longer when fed on mummies than when fed on aphids or parasitized aphids, and mummies also produced a negative effect on growth of the three species. Survival of *C. septempunctata* larvae was significantly lower when offered mummies rather than aphids or parasitized aphids as food, though *H. axyridis* and *P. japonica* were not affected by the type of prey supplied in terms of survival, indicating that mummies were not a suitable food for the three species, in particular for *C. septempunctata*.

Key words: Aphids, intraguild predation, ladybirds, parasitoid

INTRODUCTION

Aphidophagous guilds include a number of predatory and/or parasitoid arthropods, and these are capable of reducing aphid abundance. Behaviour and biology of several arthropods are well understood, for example, flower bugs (Russel, 1970), lacewings (Principi and Canard, 1984), ladybirds (Hodek and Honek, 1996), hoverflies (Gilbert, 1986), midges (Nijveldt, 1988), parasitoids (Stáry, 1970), and spiders (Sunderland et al., 1986; Toft, 1995). Recently, there has been an increasing awareness that intraguild predation (IGP) may play an important role in the dynamics of prey-predator interactions (Rosenheim et al., 1993; Ferguson and Stiling, 1996; Cisneros and Rosenheim, 1997; Lucas et al., 1998; Yasuda and Kimura, 2000). In addition, IGP appears to be an important factor which can influence the structure of ladybird guilds (Yasuda and Shinya, 1997).

It is known that aphid predators such as ladybirds, lacewings, and nabid and mirid bugs eat mummies (Wheeler et al., 1968; Wheeler, 1974, 1977; Frazer and Gilbert, 1976), and that predatory ladybirds can influence the behaviour of aphidophagous parasitoids (Taylor et al., 1998). Studies on the interspecific interactions between aphidophagous parasitoids and predators are needed to understand not only the joint effect of parasitoids and predators on aphid reduction but also the mechanisms shaping aphidophagous guild structure (e.g. Pankanin-Franczyk and Ceryngier, 1995). However, we have inadequate information about interactions between these insects, including IGP, and thus the effects of the interaction on larval performance of each arthropod involved in aphidophagous guilds are not well understood.

In aphidophagous ladybirds, larval performance within a species is significantly influenced by the quality of aphids (Blackman, 1967; Hukushima and Kamei, 1970; Hamalainen and Markkula, 1972; Pasteels, 1978; Hodek and Honek, 1996). Furthermore, as the food habits of ladybirds differ among species, for instance, *Harmonia axyridis* (Pallas) is a widely polyphagous species which eats aphids, larval ladybirds, eggs and larvae of lepidopterans, and spiders, while *Coccinella septempunctata* Linné is a more aphid-specific predator (Hodek and Honek, 1988, 1996; Lucas et al., 1997; Sato, 1997; Yasuda and Ohnuma, 1999), the differ-

* To whom correspondence should be addressed at: E-mail: hyasuda@tds1.tr.yamagata-u.ac.jp

ence in food habit between species might result in different larval performances due to the quality of the prey eaten (e.g. Yasuda and Ohnuma, 1999). Although ladybirds eat mummies or parasitized aphids, the effects of these foods on larval performance of ladybirds are not known.

Biological control is considered important in the management of some insect pests in agricultural ecosystems, but several works have cautioned the risk of biological control using introduced species, such as side-effects on non-target native species (Frank, 1998; Thomas and Willis, 1998). This becomes more relevant because recently there is a growing practice of using several species of predators and parasitoids on a commercial scale. To reduce the risks of biocontrol, the effects of introduced species on indigenous arthropods in an agroecosystem should be revealed before their release.

An aphidiid parasitoid, *Aphidius colemani* Viereck, is a commercialized parasitoid and is widely released to reduce aphid abundance (e.g. Grasswitz, 1998). As a number of predatory ladybirds are attracted to aphid colonies and they consume a lot of aphids, ladybirds are likely to prey on parasitized aphids and/or mummies. Larval performance of indigenous predatory ladybirds might be influenced by prey aphids which have already been parasitized by this species. In this study, we assess the effects of parasitized aphids as food on development, growth, and survival of fourth instar larvae of three ladybird species in relation to development of parasitoid larvae.

MATERIALS AND METHODS

The cowpea aphid, *Aphis craccivora* Koch, and adults of the three ladybirds, *H. axyridis*, *C. septempunctata*, and *Propylea japonica* (Thunberg), were collected from several species of plants in the field at Yamagata University. Adult ladybirds were fed cowpea aphids in plastic containers (15 cm in diameter and 9 cm high) and eggs laid by the females were collected daily. Each egg batch was individually put into a 9 cm Petri dish and the larvae reared to the fourth stadium on cowpea aphids. Pupae of the parasitoid, *A. colemani*, were obtained from Koppert B. V., the Netherlands, through Tomen Corporation, Japan.

A less than 24 h old fourth stadium larva of *C. septempunctata*, *H. axyridis*, or *P. japonica* was

placed into a 9 cm Petri dish and provided with 30 ± 1 mg of living mixed-stadia aphids, parasitized aphids, or mummies. The amount of aphids supplied was an excess food since uneaten food remained everyday throughout the experiments. Each prey type was replicated 20 times. In order to produce parasitized aphids and mummies, approximately 100 mixed-stadia aphids and two pieces of 5 cm long apical parts of bean plants, *Vicia faba* Linné, were put into a 9 cm Petri dish with wet cotton at the end of a stem as food for the aphids. Ten previously mated parasitoids at 2 days after emergence were released in the Petri dish and kept with the aphids for 5 days. Preliminary experiments showed that almost all aphids were parasitized by this method. Adult aphids at 7 days after release of parasitoids are referred to as parasitized aphids and these became mummies from 12 to 15 days after the release. The parasitized aphids used in the experiments contained 3-day-old parasitoid larvae and the mummies contained pupae.

Observations were made daily until the larvae of ladybirds died or developed into adults, and the prey was replaced every 24 h. Daily food consumption was estimated as the difference between the weight of the food supplied and the weight of the food not eaten. 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. The difference between the two weights represented the weight gained by a fourth stadium larva in the experiment.

All experiments were done at a constant temperature of $20 \pm 1.0^\circ\text{C}$ and a photoperiod of 16L:8D, but rearing of aphids and ladybirds was done in an incubator at $25 \pm 1.0^\circ\text{C}$ and 16L:8D photoperiod. Data for this investigation were analysed using ANOVA and means were separated using Scheffé's multiple comparison test. If Bartlett's test indicated heterogeneity of variables, we log-transformed data before doing parametric tests. The survival rate was tested by χ^2 .

RESULTS

Survival

The survival rate of *C. septempunctata* larvae developing into pupae that fed on mummies was significantly lower than that of larvae which fed on aphids or parasitized aphids (Fig. 1). In contrast,

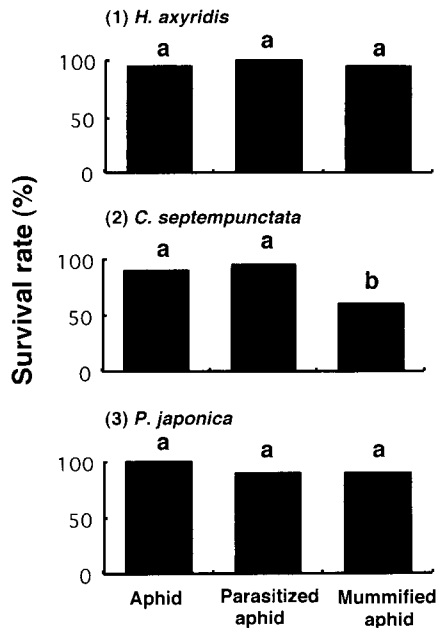


Fig. 1. Survival rate of fourth stadium larvae developing into pupae of three species of ladybirds when fed each type of prey. Bars with different letters are significantly different (χ^2 test, $p < 0.05$).

there was no significant difference in the survival rates of *H. axyridis* and *P. japonica* larvae that fed on the three prey types ($p > 0.05$) and most of these larvae pupated. Most pupae of *H. axyridis* and *P. japonica* developed into adults, irrespective of the type of prey eaten. However, in the case of *C. septempunctata*, 12 out of 20 larvae that fed on mummies developed into pupae and six of these failed to emerge, though a negative effect on adult emergence was not observed in terms of other prey types.

Food consumption

There was a similar tendency to consume prey in the larvae of the three species (Fig. 2). Larvae consumed a significantly smaller amount of mummies in comparison to the other two prey types ($p < 0.01$), and parasitized aphids were intermediate in terms of food consumption.

Weight gain

Gain in live weight of larvae of the three species after feeding on the three prey types is shown in Fig. 3. Weight gain in the three species was higher when larvae were fed aphids or parasitized aphids in comparison to larvae that fed on mummies ($p < 0.01$).

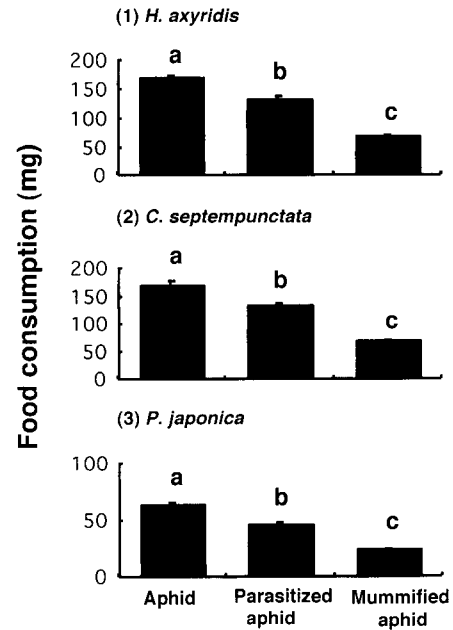


Fig. 2. Food consumption of fourth stadium larvae of three species of ladybirds when fed each type of prey. Bars with different letters are significantly different (Scheffé's test, $p < 0.05$).

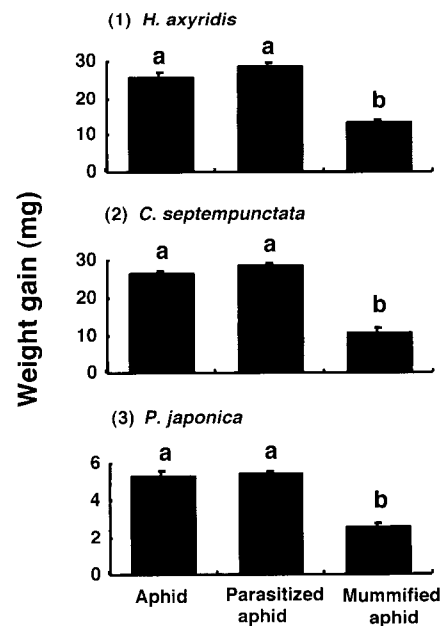


Fig. 3. Weight gain (mg) of fourth stadium larvae of three species of ladybirds when fed each type of prey. Bars with different letters are significantly different (Scheffé's test, $p < 0.05$).

Developmental time

The developmental time of fourth stadium larvae of the three species that fed on mummies was sig-

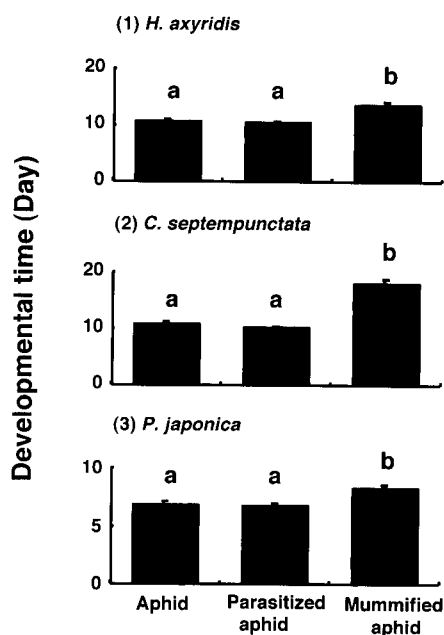


Fig. 4. Developmental time of fourth stadium larvae developing into pupae of three species of ladybirds when fed each type of prey. Bars with different letters are significantly different (Scheffé's test, $p < 0.05$).

nificantly longer than those larvae which fed on aphids ($p < 0.01$; Fig. 4). However, there was no significant difference in developmental time between larvae which fed on aphids and parasitized aphids ($p > 0.05$).

DISCUSSION

This study revealed that larvae of the three ladybird species, *C. septempunctata* in particular, that were offered mummies as food were at a disadvantage in terms of lower survival, eating less food, reduced gain in live weight and longer developmental time in comparison to larvae that were offered aphids or parasitized aphids.

The performance of the larvae of predatory ladybirds is often affected by the species of aphid they eat (Blackman, 1967; Hukushima and Kamei, 1970; Hamalainen and Markkula, 1972; Pasteels, 1978; Takada and Sugimoto, 1994; Sugiura and Takada, 1998). All *H. axyridis* larvae fed *Aphis nerii* Boyer de Fonscolombe died during larval period (Takada and Sugimoto, 1994). In addition, the type of prey eaten influences not only larval performance but also reproductive characteristics of adult ladybirds (Sugiura and Takada, 1998). Egg

predation by larvae of ladybirds can also affect their survival, and the effect differs between species (Agarwala and Dixon, 1992). These findings indicate that the quality of prey is important for survival, development, and reproduction in aphidophagous ladybirds. The results of the present study clearly show the negative impact of mummies as food on the development and survival of fourth stadium larvae of ladybirds; 70% of *C. septempunctata* larvae did not develop to adults, but this was not the case for the other two species. Although we do not know much well about the food habits of *P. japonica*, *H. axyridis* larvae are more polyphagous than those of *C. septempunctata* (Hodek and Honek, 1988; Lucas et al., 1997; Yasuda and Ohnuma, 1999). Therefore, low survival rates in *C. septempunctata* when fed on mummies might be attributable to more aphid-specific food habits.

Egg cannibalism is often observed in a number of ladybird species (Koide, 1962; Warren and Tadic, 1967; Kawai, 1978; Takahashi, 1987; Agarwala, 1991; Agarwala and Dixon, 1992) and eggs are found to be better food than aphids for young larvae in terms of larval growth, and survival (Kawai, 1978; Agarwala and Dixon, 1992). Interestingly, the ladybird larvae of this study, by comparison, ate less parasitized aphids than aphids by weight. However, there were no differences in development and survival of the three species between the two prey treatments. Thus, it may be possible to assume that there is a qualitative difference in the nutrition between aphids and parasitized aphids. The latter food by containing developing larvae of parasitoids may offer additional nutrition.

In aphidophagous insects, IGP between the different predatory species is often observed and sometimes results in an increase in aphid abundance through trophic cascades (Rosenheim et al., 1993; Cisneros and Rosenheim, 1997; Lucas et al., 1998). This phenomenon is also reported between ladybirds and parasitoids, in which the effect of multiple natural enemies on aphid populations were non-additive due to IGP (Ferguson and Stiling, 1996). The present study showed that in the absence of live aphids, predatory ladybirds ate parasitized aphids and even mummies. This suggests that IGP by ladybirds to parasitized aphids might occur in the field. In that event, it is reasonable to

expect that female parasitoids should avoid aphids in a patch where a number of predators already exist. Taylor et al. (1998) revealed that aphidophagous parasitoids spent less time on a patch which contained adult or larval ladybirds, or even if the patch was recently visited by ladybirds. In addition, the parasitoid, *A. colemani*, oviposited less frequently into an aphid patch containing a ladybird larva than in the patch without a ladybird larva (Takizawa et al., unpubl.). Therefore, it appears that a better understanding of the relationships between parasitoids and aphids is necessary in relation to a predator complex.

There is a growing concern that introduced natural enemies might cause side-effects on a population of non-target species (Frank, 1998; Thomas and Willis, 1998). As IGP by the ladybirds to mummies resulted in negative influences in terms of their larval performance, there might be a likelihood from side-effects of using *A. colemani* on these ladybird species. In addition, the efficacy of introduced natural enemies has been given much attention in biological control (Van Driesche and Bellows, 1996). This study suggests that interactions between ladybirds and parasitoids, in particular IGP by ladybirds to parasitized aphids and/or mummies, possibly lead to non-additive effects on reduction of aphid abundance, as shown in Ferguson and Stiling (1996).

Muller and Godfray (1999) pointed out that there are few studies which demonstrate a negative influence of predators on parasitoids through their exploitation of aphid colonies. Thus, studies on interactions between predators and parasitoids such as oviposition behaviour of parasitoids, asymmetrical exploitation competition, and IGP, are needed to understand not only better ways of biological control for aphids but also the mechanisms which shape guilds of aphidophagous insects.

ACKNOWLEDGEMENTS

We are grateful to two anonymous reviewers for their helpful comments which improved this manuscript.

REFERENCES

- Agarwala, B. K. (1991) Why do ladybirds (Coleoptera: Coccinellidae) cannibalize? *J. Biosci.* 16: 103–109.
- Agarwala, B. K. and A. F. G. Dixon (1992) Laboratory study of cannibalism and interspecific predation in ladybirds. *Ecol. Entomol.* 17: 303–309.
- Blackman, B. L. (1967) The effects of different aphid foods on *Adalia bipunctata* L. and *Coccinella 7-punctata* L. *Ann. Appl. Biol.* 59: 207–219.
- Cisneros, J. J. and J. A. Rosenheim (1997) Ontogenetic change of prey preference in the generalist predator *Zelus renardii* and its influence on predator-predator interactions. *Ecol. Entomol.* 22: 399–407.
- Ferguson, K. I. and P. Stiling (1996) Non-additive effects of multiple natural enemies on aphid populations. *Oecologia* 108: 375–379.
- Frank, J. H. (1998) How risky is biological control? *Comment. Ecology* 79: 1829–1834.
- Frazer, B. D. and N. Gilbert (1976) Coccinellids and aphids: a quantitative study of the impact of adult ladybirds (Coleoptera: Coccinellidae) preying on field populations of pea aphids (Homoptera: Aphididae). *J. Entomol. Soc. B.C.* 73: 33–56.
- Gilbert, F. S. (1986) *Hoverflies, Naturalists' Handbooks* 5. Cambridge University Press, Cambridge. 67 pp.
- Grasswitz, T. R. (1998) Effect of adult experience on the host-location behavior of the aphid parasitoid *Aphidius colemani* Viereck (Hymenoptera: Aphidiidae). *Biol. Cont.* 12: 177–181.
- Hamalainen, M. and M. Markkula (1972) Effect of type of food on fecundity in *Coccinella septempunctata* L. (Col., Coccinellidae). *Ann. Entomol. Fenn.* 38: 195–199.
- Hodek, I. and A. Honek (1988) Sampling, rearing and handling of aphid predators. In *Aphids, Their Biology, Natural Enemies and Control, Vol. 2B* (A. K. Minks and P. Harrewijn eds.). Elsevier, Amsterdam, pp. 311–321.
- Hodek, I. and A. Honek (1996) *Ecology of Coccinellidae, Series Entomologica* 54. Kluwer Academic Publishers, Dordrecht. 464 pp.
- Hukushima, S. and M. Kamei (1970) Effects of various species of aphids as food on development, fecundity and longevity of *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). *Res. Bull. Fac. Agric. Gifu Univ.* 29: 53–66.
- Kawai, A. (1978) Sibling cannibalism in the first instar larvae *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). *Kontyu* 46: 14–19.
- Koide, T. (1962) Observations on the feeding habit of the larva of *Coccinella septempunctata bruckii* Mulsant: the feeding behaviour and number of prey fed under different temperatures. *Kontyu* 30: 236–241.
- Lucas, E., D. Coderre and J. Brodeur (1998) Intraguild predation among aphid predators: characterization and influence of extraguild prey density. *Ecology* 79: 1084–1092.
- Lucas, E., D. Coderre and C. Vincent (1997) Voracity and feeding preferences of two aphidophagous coccinellids on *Aphis citricola* and *Tetranychus urticae*. *Entomol. Exp. Appl.* 85: 151–159.
- Muller, C. B. and H. C. J. Godfray (1999) Indirect interactions in aphid-parasitoid communities. *Res. Popul. Ecol.* 41: 93–106.
- Nijveldt, N. (1988) Cecidomyiidae. In *World Crop Pests, Aphids, Vol. 2B* (A. K. Minks, P. Harrewijn and W. Helle eds.). Elsevier Science, New York, pp. 271–277.
- Pankanin-Franczyk, M. and P. Ceryngier (1995) Cereal aphids, their parasitoids and coccinellids on oats in central Poland. *J. Appl. Entomol.* 119: 107–111.

- Pasteels, J. M. (1978) Apterous and brachypterous coccinellids at the end of the food chain, *Cionura erecta* (Asclepiadaceae)–*Aphis nerii*. *Entomol. Exp. Appl.* 24: 379–384.
- Principi, M. M. and M. Canard (1984) Feeding habits. In *Biology of Chrysopidae, Series Entomologica 27* (M. Canard, Y. Semeria and T. T. New eds.). Junk Publishers, The Hague, pp. 76–92.
- Rosenheim, J. A., R. Lawrence, R. Wilhoit and C. A. Armer (1993) Influence of intraguild predation among generalist insect predators on the suppression of an herbivore population. *Oecologia* 96: 439–449.
- Russel, R. J. (1970) The effectiveness of *Anthocoris nemorum* and *A. confusus* (Hemiptera: Anthocoridae) as predators of the sycamore aphid, *Drepanosiphum platanoidis*. *Entomol. Exp. Appl.* 13: 194–207.
- Sato, S. (1997) Effects of cannibalism and intraguild predation on the ladybird assemblage. Master Thesis of Yamagata University, 80 pp.
- Stáry, P. (1970) *Biology of Aphid Parasites, with Respect to Integrated Control, Series Entomologica 6*. Junk Publishers, The Hague. 643 pp.
- Sugiura, K. and H. Takada (1998) Suitability of seven aphid species as prey of *Cheilomenes sexmaculata* (Coleoptera: Coccinellidae). *Jpn. J. Appl. Entomol. Zool.* 42: 7–14 (in Japanese with English summary).
- Sunderland, K. D., A. M. Fraser and A. F. G. Dixon (1986) Field and laboratory studies on money spiders (Linyphiidae) as predators of cereal aphids. *J. Appl. Ecol.* 23: 433–447.
- Takada, H. and N. Sugimoto (1994) Life cycle of *Aphis nerii* (Homoptera: Aphididae) in Kyoto and its natural enemy complex. *Jpn. J. Appl. Entomol. Zool.* 38: 91–99 (in Japanese with English summary).
- Takahashi, K. (1987) Cannibalism by the larvae of *Coccinella septempunctata bruckii* Mulsant (Coleoptera: Coccinellidae). *Jpn. J. Appl. Entomol. Zool.* 31: 201–205 (in Japanese with English summary).
- Taylor, A. J., C. B. Muller and H. C. J. Godfray (1998) Effect of aphid predators on oviposition behavior of aphid parasitoids. *J. Insect. Behav.* 11: 297–302.
- Thomas, M. B. and A. J. Willis (1998) Biocontrol—risky but necessary? *Trends Ecol. Evol.* 13: 325–329.
- Toft, S. (1995) Value of the aphid *Rhopalosiphum padi* as food for cereal spiders. *J. Appl. Ecol.* 32: 552–560.
- Van Driesche, R. G. and T. S. Jr. Bellows (1996) *Biological Control*. Chapman & Hall, New York. 539 pp.
- Warren, L. O. and M. Tadic (1967) Biological observations on *Coleomegilla maculata* and its role as a predator of the fall webworm. *J. Econ. Entomol.* 60: 1492–1496.
- Wheeler, A. G. (1974) Studies on the arthropod fauna of alfalfa. VI. Plant bugs (Miridae). *Can. Entomol.* 106: 1264–1275.
- Wheeler, A. G. (1977) Studies on the arthropod fauna of alfalfa. VII. Predaceous insects. *Can. Entomol.* 109: 423–427.
- Wheeler, A. G., J. T. Hayes and J. L. Stephens (1968) Insect predators of mummified pea aphids. *Can. Entomol.* 100: 221–222.
- Yasuda, H. and T. Kimura (2000) Interspecific interactions in a tri-trophic arthropod system: effects of a spider on the survival of larvae of three predatory ladybirds in relation to aphids. *Entomol. Exp. Appl.* (in press).
- Yasuda, H. and N. Ohnuma (1999) Effect of cannibalism and predation on the larval performance of two ladybird beetles. *Entomol. Exp. Appl.* 93: 63–67.
- Yasuda, H. and K. Shinya (1997) Cannibalism and interspecific predation in two predatory ladybirds in relation to prey abundance in the field. *Entomophaga* 42: 155–165.