BioControl **49:** 21–32, 2004.

The effects of thirteen species of aphids on some life history parameters of the ladybird *Coccinella septempunctata*

Plamen KALUSHKOV[1]* and Ivo HODEK[2]
[1] *Institute of Zoology, Bulgarian Academy of Sciences, 1 Tzar Osvoboditel Blvd., 1000 Sofia, Bulgaria;* [2] *Institute of Entomology, Academy of Sciences, Branisovska 31, 370 05 Ceske Budejovice, Czech Republic*
Author for correspondence; e-mail: p_k_kalushkov@yahoo.com

Received 25 May 2002; accepted in revised form 14 July 2003

Abstract. The prediction of impact of coccinellids in an aphid infested crop depends on the food specificity of the predator. The response towards thirteen species of aphids (Sternorrhyncha: Aphididae) was therefore tested in the most abundant aphidophagous coccinellid *Coccinella septempunctata* L. (Coleoptera: Coccinellidae). All aphid species studied (*Eucalipterus tiliae* (L.), *Tuberculatus annulatus* (L.), *Euceraphis betulae* (L.), *Cavariella konoi* Takahashi, *Liosomaphis berberidis* (Kaltenbach), *Acyrthosiphon ignotum* Mordvilko, *Aphis spiraephaga* Müller, *Aphis fabae* Scopoli, *Macrosiphoniella artemisiae* Boyer de Fonscolombe, *Capitophorus hippophaeus* (Walk.), *Acyrthosiphon pisum* (Harris), *Aphis craccivora* Koch, *Sitobion avenae* (Fabricius) were suitable food according to the rate of larval development, larval mortality and adult fresh weight. Females of *C. septempunctata* fed with *A. pisum* and *S. avenae* laid twice as many eggs as those fed with *A. fabae* and *A. craccivora*. These data are needed for effective mass rearing of the studied coccinellid species.

Key words: adult fresh weight, essential food, fecundity, larval development, longevity, mortality

Introduction

Coccinella septempunctata L. is abundant in a wide range of Eurasian, African and now also North American agroecosystems, preying upon several economically important aphid species. European populations of this coccinellid have been intensively studied (Majerus, 1994; Hodek and Honek, 1996; Dixon, 2000). When aphids are rare or missing (in early spring or autumn) the aphidophagous coccinellids eat alternative foods (other arthropod prey, fungal spores, pollen and nectar) to supply energy (Triltsch, 1999). However, they need specific aphid food for egg laying and successful larval development. While Hodek and Honek (1996) quoted records of 23 aphid species as essential prey for *C. septempunctata*, 48 essential prey aphids were recorded for *Adalia bipunctata* L. (Hodek and Honek, 1996; Kalushkov, 1998). We hoped therefore that extensive research could reveal more suitable aphid preys for *C. septempunctata.* This would enhance not only our basic knowledge but also the rational pest management. Such evidence would facilitate the prediction of predatory impact in the critical initiation phase when the populations of aphids and their natural enemies are established in a habitat (Smith, 1966). Aphids feeding on some economically neutral plants may serve as food in mass rearing of *C. septempunctata* for inundative releases.

Majerus (1994) considers as essential only those preys actually eaten in the wild by reproducing adults and developing larvae. According to Hodek and Honek (1996) the essential prey is characterized in the safest way by a combination of both observation and experiment.

The aim of the reported laboratory experiments and field observations was to determine the quality of 13 species of aphids as food for larvae of *C. septempunctata* by recording their development and mortality. Five aphid species (*Acyrthosiphon ignotum, Aphis spiraephaga, Cavariella konoi, Capitophorus hippophaeus* and *Euceraphis betulae*) were not listed among preys for this coccinellid species in Hodek and Honek (1996). Suitability of four aphids was checked also by recording fecundity of this coccinellid. Field observations were carried out to determine which of the aphid species found to be suitable for larval development of *C. septempunctata* in laboratory experiments, are also natural prey for this species.

Materials and methods

Larval development and mortality

Ten species of aphids, used in experiments on suitability for larval development were collected in the field near Ceské Budejovice, Czech Republic: *Eucalipterus tiliae* (L.) from *Tilia cordata* Mill., *Tuberculatus annulatus* (L.) from *Quercus robur* L., *Euceraphis betulae* (L.) from *Betula pendula* Roth, *Cavariella konoi* Takahashi from *Salix purpurea* L., *Liosomaphis berberidis* (Kaltenbach) from *Berberus vulgaris* L., *Acyrthosiphon ignotum* Mordvilko and *Aphis spiraephaga* Muller from *Spiraea vanhoutei* Zabel, *Aphis fabae* Scopoli from *Philadelphus coronarius* L. and *Atriplex sagittata*, *Macrosiphoniella artemisiae* Boyer de Fonscolombe from *Artemisia vulgaris* L. and *Capitophorus hippophaeus* (Walk.) from *Hippophae rhamnoides* L.

Three aphids were cultured in the laboratory in Sofia, Bulgaria – *Acyrthosiphon pisum* (Harris) and *Aphis craccivora* Koch on the broad been *Vicia faba* L. and *Sitobion avenae* (Fabricius) on wheat *Triticum vulgare* Vill.

grown in soft-wood sawdust inside nylon cages. The aphids were reared at a temperature of 25 ± 2 °C, relative humidity 63–85%, and 16L:8D photoperiod.

Nearly 30 adults of the ladybird *Coccinella septempunctata* were collected from alfalfa fields in April–May 1999 and 2000 near Sofia, and in May–June 1997 and 1998 near Ceské Budejovice. Coccinellids were fed in the laboratory with *Acyrthosiphon pisum* (in Czechia) and with mixture of *A. fabae* and *A. craccivora* (in Bulgaria). They laid eggs, and newly hatched larvae were randomly divided and reared individually in 7 cm Petri dishes on the studied aphid species. Thirty larvae were tested on each diet. Developmental time, survival and fresh weight of adults were recorded. Coccinellid larvae in each treatment were provided daily with excess of a fresh mixture of aphid instars on plant sections (next day some live aphids remained).

The experiments with *M. artemisiae, E. tiliae, E. betulae, A. fabae* and *A. spiraephaga* were done in May–June 1997, and with *C. hippophaeus, T. annulatus, L. berberidis, C. konoi*, and *A. ignotum* in May–June 1998 in Ceske Budejovice when tested aphids were present on plants in a high number. Coccinellid larvae were reared at a constant temperature 25 ± 1 °C, relative humidity 55–75%, and 18L:6D photoperiod.

The experiments with *A. pisum* were done in May 1999, and with *A. craccivora* and *S. avenae* in May–June 2000 in Sofia at a temperature 25 ± 2 °C, relative humidity 63–85%, and 16L:8D photoperiod.

Fecundity and longevity

In the experiments on fecundity and longevity 30 adults of *C. septempunctata* were collected from alfalfa fields in April–May 1999 and 2000 near Sofia and reared in the laboratory on a mixture of *A. fabae* and *A. craccivora.* They laid eggs, and newly hatched larvae were reared individually in 7 cm Petri dishes on appropriate species of aphids. The aphids *A. fabae, A. craccivora* and *A. pisum* were cultured in the laboratory on broad bean and *S. avenae* on wheat grown in soft-wood sawdust inside nylon cages. Emerging adults from one day (n $\sim$ 30) were first kept together in 1000 ml glass jars for copulation and were fed on either *A. fabae, A. craccivora, A. pisum* or *S. avenae.* Copulated pairs were then separated in 500 ml glass jars covered with nylon and reared on the same species of aphids. Once a day the laid eggs were counted and removed from jars, and fresh food was added in excess. The test was continued until all females and males died. When a male died, the pair was completed with another male from a jar where the female had died.

The experiments were carried out with aphids *A. fabae* and *A. pisum* in 1999 and with *A. craccivora* and *S. avenae* in 2000. Coccinellids and aphids

Table 1. The effect of thirteen species of aphids on *Coccinella septempunctata* under laboratory conditions. Figures in the same columns, followed by the same letter are not significantly different from one another (LSD test)

Aphid species	Host plants	Mean larval development			Adult fresh weight (mg) ± SD	
		n	Duration (days) ± SD (min.–max.)	Mortality (%)	Male [1]	Female [1]
Acyrthosiphon pisum[4]	*Medicago sativa*	30	8.9 ± 0.6 (8–10) a	7	33.6 ± 3.0 a	38.8 ± 3.8 a
Macrosiphoniella artemisiae[2]	*Artemisia vulgaris*	30	8.6 ± 0.6 (8–10) a	3	32.3 ± 2.6 b	38.5 ± 3.4 a
Capitophorus hippophaeus[3]	*Hippophae rhamnoides*	30	9.1 ± 1.0 (8–11) a	7	31.8 ± 3.5 b	37.8 ± 4.1 a
Sitobion avenae[4]	*Triticum vulgare*	30	8.8 ± 0.6 (8–10) a	3	32.9 ± 2.4 a	38.3 ± 3.2 a
Eucalipterus tiliae[2]	*Tilia europea*	30	9.2 ± 1.0 (8–11) a	7	32.9 ± 2.4 a	35.6 ± 3.3 b
Euceraphis betulae[2]	*Betula pendula*	30	9.1 ± 1.0 (8–11) a	3	31.7 ± 3.4 b	36.2 ± 3.0 b
Tuberculatus annulatus[3]	*Quercus robur*	30	9.3 ± 1.0 (8–11) a	7	29.8 ± 2.4 c	34.4 ± 3.4 b
Liosomaphis berberidis[3]	*Berberus vulgaris*	30	9.2 ± 1.0 (8–10) a	7	31.0 ± 3.6 c	36.0 ± 2.8 b
Aphis spiraephaga[2]	*Spiraea vanhoutei*	30	8.9 ± 0.6 (8–10) a	3	29.9 ± 3.9 c	35.3 ± 3.1 b
Aphis fabae[2]	*Philadelphus coronarius*	30	9.2 ± 0.6 (8–10) a	7	28.2 ± 3.2 c	34.0 ± 3.0 c
Aphis fabae[2]	*Atriplex sagittata*	30	9.1 ± 1.0 (8–11) a	7	28.0 ± 2.8 c	33.6 ± 2.8 c
Aphis craccivora[4]	*Vicia faba*	30	9.2 ± 0.6 (8–10) a	7	27.4 ± 3.4 d	33.8 ± 2.8 c
Acyrthosiphon ignotum[3]	*Spiraea vanhoutei*	30	8.8 ± 0.6 (8–10) a	3	29.4 ± 2.8 c	34.0 ± 3.0 c
Cavariella konoi[3]	*Salix purpurea*	30	9.3 ± 1.0 (8–11) a	10	26.5 ± 3.3 d	32.7 ± 3.5 d

[1] mean weight from 10 individuals.
[2] experiments carried out in 1997 in the Czech Republic.
[3] experiments carried out in 1998 in the Czech Republic.
[4] experiments carried out in 1999 in Bulgaria.

were reared and the experiments were done at a temperature of 25 ± 2 °C, relative humidity 63–85%, and 16L:8D photoperiod.

To determine if development time (in days) and adult weight varied with the diet, data were analysed by the LSD test (least significant difference test, $\alpha = 0.05$).

Field observations

The same plants from which aphids were collected for laboratory experiments, were observed for a field check of food specificity. Twenty plants of *Artemisia vulgaris* and *Atriplex sagittata*, ten trees of *Salix purpurea, Tilia europea, Betula pendula* and *Quercus robur* (up to 2 m height), 100 shoots of *Spiraea vanhoutei*, 20 shoots of *Philadelphus coronarius, Hippophae rhamnoides* and *Berberus vulgaris* and 5 × 50 sweeps from alfalfa and wheat were used to sample weekly from the beginning of May until the middle of July. *S. purpurea* plants observed were shrubs (young, small trees up to 2 m high, near the rivers Vltava in C. Budejovice and Iskar in Sofia). Field observations were carried out in different years according to infestation with aphids of plants: alfalfa (*Medicago sativa* L.), wheat (*Triticum vulgare*), *A. vulgaris, T. europea, B. pendula, A. sagittata, P. coronarius*, and *S. vanhoutei* infested with *A. spiraephaga* were observed during the year 1997 and *H. rhamnoides, Q. robur, B. vulgaris, S. purpurea* and *S. vanhoutei* infested with *A. ignotum* were observed during the year 1998 near Ceske Budejovice. The plants *Medicago sativa* (alfalfa), *Triticum vulgare* (wheat), *A. sagittata, S. purpurea, A. vulgaris, T. europea, H. rhamnoides* and *B. pendula* infested with a high number of aphids were monitored near Sofia, Bulgaria during the year 1999 too (see Table 3).

Results

Mean developmental time, percent mortality and adult fresh weight of *Coccinella septempunctata* fed with the thirteen aphid species are listed in Table 1. There was no significant difference in rate of larval development between individuals fed with different aphid species ($F = 0.48$, $df = 1$, $P = 0.63$). Data on larval mortality indicate that all thirteen aphid species were suitable prey (mortality less than 10%).

The weight of newly emerged adults differed among individuals fed with different prey ($F = 37$, $df = 3$, $P = 0.0001$). Four groups of species were distinguished by the LSD-test (Table 1a, b, c, d). *A. pisum, A. ignotum, M. artemisiae* and *S. avenae* appeared to be the best food for coccinellid larvae.

Table 2. Longevity and fecundity of *Coccinella septempunctata* reared on four aphid diets. Means in the column "Fecundity", and within rows "Females" and "Males", followed by the same letter are not significantly different from one another (LSD test)

Food	Type of numer. data	Fecundity	Longevity (days)	
			Females	Males
Acyrthosiphon pisum	mean ± SD	1428 ± 585 a	78 ± 32 a	63 ± 21 b
	range	268–2386	22–136	18–98
	n	30	30	30
Sitobion avenae	mean ± SD	1286 ± 532 a	76 ± 29 a	52 ± 26 b
	range	218–2291	24–148	12–114
	n	30	30	30
Aphis fabae	mean ± SD	626 ± 417 b	78 ± 40 a	68 ± 20 a
	range	98–1528	18–162	36–126
	n	20	20	20
Aphis craccivora	mean ± SD	683 ± 446 b	68 ± 33 a	64 ± 21 a
	range	134–1839	16–145	22–121
	n	30	30	30

The mean weight of adult females in this group was about 6 mg greater than that of the individuals of the last group fed with *C. konoi*. The difference in weight between the sexes was significant ($F = 49$, $df = 3$, $P = 0.0001$).

Females of *C. septempunctata* fed with *A. pisum* and *S. avenae* laid twice as many eggs as those ladybirds fed with *A. fabae* and *A. craccivora* (Table 2). The egg masses contained an average number of 27 eggs (range 9–56). During the first 45 days 79–83% of eggs were fertile while near the end of the reproductive period only 46–51% of the eggs were fertile. The average number of eggs per mass and percentage of hatchability did not vary significantly between the four diets.

The longevity of females (68–78 days) and males (52–68 days) was not affected by the species of aphid provided as food. There was significant difference only between males and females fed either with *A. pisum* or *S. avenae* (the longevity of males was shorter than that of females) (Table 2).

In the field (Table 3), all developmental stages of *C. septempunctata* were most often associated with *A. pisum, A. spiraephaga, A. ignotum, S. avenae* and *A. fabae* on *Philadelphus coronarius.* Less commonly visited preys were *M. artemisiae, C. hippophaeus, C. konoi, E. tiliae, L. berberidis* and *E. betulae*. No eggs, larvae or adults of *C. septempunctata* were observed in the field on *Quercus robur* with *T. annulatus.*

Table 3. Observation of *Coccinella septempunctata* in the field

Aphid species	Host-plant	Total number during one season							
		In Czech Republic				In Bulgaria			
		eggs	larvae	pupae	adult	eggs	larvae	pupae	adult
A. pisum	*Medicago sativa*[1,2]	—*	144	—*	118	—*	224	—*	102
S. avenae	*Triticum vulgare*[1,2]	—*	143	—*	98	—*	260	—âst	151
A. ignotum	*Spiraea vanhoutei*[3]	96	85	51	52				
A. spiraephaga	*Spiraea vanhoutei*[2]	221	109	60	54				
A. fabae	*Philadelphus coronaries*[2]	98	61	44	47				
A. fabae	*Atriplex sagittata*[1,2]	21	8	1	1	—	2	—	—
C. konoi	*Salix purpurea*[1,3]	16	4	1	2	22	3	2	2
C. hippophaeus	*Hippophae rhamnoides*[1,3]	18	12	4	2	—	6	4	4
M. artemisiae	*Artemisia vulgaris*[1,2]	18	1	1	—	—	1	—	1
L. berberidis	*Berberus vulgaris*[3]	20	4	4	2				
E. tiliae	*Tilia europea*[1,2]	—	—	—	2	—	—	—	3
E. betule	*Betula pendula*[1,2]	—	4	—	—	—	1	—	—
T. annulatus	*Quercus robur*[3]	—	—	—	—				

[1]Observations in Bulgaria during 1999.
[2]Observations in the Czech Republic during 1997.
[3]Observations in the Czech Republic during 1998.
*When we observed the whole plants many eggs and pupae were present on alfalfa and wheat but they did not fall into the entomological net.

Discussion

The original assumption that all aphids are suitable for all species of aphidophagous coccinellids (e.g., Balduf, 1935) was rejected by Hodek (1956, 1960) and Blackman (1967). Since then, it has been generally accepted that not all eaten preys are suitable food for coccinellids. It should be discriminated between the food enabling development and oviposition ("essential" sensu Hodek, 1960) and the food that is good only for survival ("alternative"). However, there may be different levels of suitability of individual essential preys (Hodek and Honek, 1996). Laboratory experiments indicated that all thirteen investigated aphid species are essential food for *Coccinella septempunctata* according to the above definition.

Hodek (1956, 1960) tested the suitability of four aphid species and found *Aphis sambuci* to be unsuitable prey. When rearing *C. septempunctata* on seven aphid species, Blackman (1967) found *A. pisum* to be highly suitable, based upon mean larval developmental time, larval survival and adult weight at eclosion. *A. pisum* was also a highly suitable prey for Czech and North American populations of *C. septempunctata* (Ruzicka et al., 1981; Obrycki and Orr, 1990). Hauge et al. (1998) tested the influence of three cereal aphids (*Sitobion avenae, Rhopalosiphum padi* L., *Metopolophium dirhodum* (Walker)) and mixed aphid diet on survival, development and adult weight of *C. septempunctata* and found that those given a mixed diet did not perform "better" than those on single-species diets.

Until now there were records of 24 aphid species suitable as food for *C. septempunctata*: *Acyrthosiphon pisum* (Blackman, 1965, 1967; Schanderl et al., 1988; Obrycki and Orr, 1990); *Aphis citricola* Van der Goot (Lucas et al., 1997); *Aphis craccivora* (Hodek, 1960; Iperti, 1965); *Aphis fabae* (Hodek, 1956; Blackman, 1965, 1967; Iperti, 1965; Brun and Iperti, 1978; Mills, 1981); *Aphis gossypii* Glover (Iperti, 1965; Agarwala et al., 1987; Zhang, 1992); *Aphis jacobaeae* Schrank (Mills, 1981); *Aphis urticae* Scopoli (Iperti, 1965), *Brevicoryne brassicae* (L.) (Mills, 1981; Blackman, 1965); *Diuraphis noxia* (Kurdj.) (Michels and Flanders, 1992; Formuson and Wilde, 1993); *Hyalopterus pruni* (Geoffray) (Hodek, 1960); *Hyperomyzus lactucae* (L.) (Mills, 1981); *Lipaphis erysimi* (Kaltenbach) (Atwal and Sethi, 1963; Sethi and Atwal, 1964; Agarwala et al., 1987); *Longiunguis donacis* (Passerini) (Iperti, 1965); *Macrosiphoniella artemisiae* (Boyer de Fonscolombe) (Iperti, 1965); *Megoura viciae* (Buckton) (Blackman, 1965); *Metopolophium dirhodum* (Walker) (Mills, 1981; Hauge et al., 1998); *Microlophium carnosum* (Buckton) (Mills, 1981); *Myzus persicae* (Sulzer) (Blackman, 1965, 1967; Brun and Iperti, 1978; Kariluoto, 1980; Mills, 1981; Satpathi, 2000); *Rhopalosiphum maidis* (Fitch) (Obrycki and Orr, 1990); *Rhopalosiphum. padi* (L.) (Hauge et al., 1998); *Schizaphis graminum*

(Rondani) (Fye, 1981; Michels and Behle, 1991; Formusoh and Wilde, 1993); *Sitobion avenae* (Mills, 1981; Ghanim et al., 1984; Hauge et al., 1998); *Uroleucon cirsii* (L.) (Mills, 1981); *Uromelan aeneus* (Hille Ris Lambers) (Hodek, 1960).

Two aphid species were unsuitable – *Aphis sambuci* L. on *Sambucus nigra* L. (Hodek, 1960, 1965) and *Macrosiphum albifrons* Essig on *Lupinus mutabilis* Sweet (Gruppe and Roemer, 1988). *Aphis nerii* Boyer de Fonscolombe was unsuitable on *Nerium oleander* L. (Iperti, 1966), but when feeding on *Calotropis procera* L. it was a suitable food for *C. septempunctata* (Agarwala et al., 1987).

Based upon larval development time, larval mortality and the weight of newly emerged adults we rate *S. avenae, M. artemisiae* and *C. hippophaeus* highly suitable, similar to *A. pisum*. According to larval development and larval mortality all tested aphids were equally suitable. However, there were differences between the weight of resulting adults: they had the lowest weight when fed on *C. konoi. A. pisum* enabled highest weight for both females and males. Other authors also found effects of different aphid food on coccinellid larvae. Atwal and Sethi (1963) found that *Lipaphis erysimi* was a better larval prey for *C. septempunctata* than *Aphis gossypii*: it increased both larval and pupal weight.

Fecundity of *C. septempunctata* indicated that *A. pisum* and *S. avenae* were a similarly suitable food source, and both were more suitable than *A. fabae* and *A. craccivora.* The ascertained fecundity of *C. septempunctata* fed with *A. pisum* was lower in this study than for a Czech population fed on the same aphid (Ruzicka et al., 1981). Only the maximum fecundity in this study equalled mean values of the Czech population. When *A. fabae* and *A. craccivora* were used as prey, the fecundity of *C. septempunctata* was similar to that of the Finnish population fed with *Myzus persicae* (Hämäläinen et al., 1975). *C. septempunctata* fed with *Aphis spiraephila* and *Sitobion avenae* deposited more eggs than when fed with *Schizaphis graminum, Aphis pomi* De geer, *A. gossypii* and *Rhopalosiphum padi* (Kuznetsov, 1975; Hodek and Honek, 1996).

Field crops are typical habitats for *C. septempunctata* in Europe (Hodek and Honek, 1996; Nedved, 1999). Our results indicate absence of this coccinellid species on *Q. robur*, a low number on *B. pendula* and *T. europea*, and a high number on alfalfa and wheat. Numerous *C. septempunctata* developed on shrubs of *S. vanhoutei. C. septempunctata* arrived on these shrubs in early June and during one month thousands of them developed in Ceske Budejovice on *A. spiraephaga* and *A. ignotum.* Both aphids occur on shoots of *S. vanhoutei* in street hedges that are regularly cut. Stary (1995) found a maximum of 8 specimens per week of this coccinellid on 100 shrubs.

It seems that this shrub is an important reservoir of *C. septempunctata* and it is recommended to do cutting after mid July. Nedved (1999) studied host complexes of predaceous coccinellids in Central Bohemia and found *C. septempunctata* on shrubs of *H. rhamnoides* and *P. coronarius*. He did not find this species on *A. vulgaris*. In our observations the number of *C. septempunctata* on this weed was low although the aphid *M. artemisiae* appeared to be essential prey in laboratory experiments. This prey is probably very difficult to catch in the field as it has long legs and falls easily from the plant but, it is good for mass rearing.

Various essential aphid foods affected adult weight at eclosion and fecundity of *C. septempunctata.* The different results of individual aphid preys might be affected by previous adaptation of the concerned population or by the specific nutritional quality of the tested aphid species, influenced in addition by the chemical composition of the plant.

Coccinellids have not proven effective in classical biological control programmes against aphids (Dixon et al., 1997). According to our view this is due to insufficient knowledge of their food ecology and ethology. In this paper we found five new essential prey aphids for *C. septempunctata.* Aphids *A. spiraephaga* and *A. ignotum* on *S. vanhoutei* may have practical importance. This shrub is common in central Europe and we recorded it as a reservoir for this coccinellid species. In places where the shrubs *H. rhamnoides* and *P. coronarius* are common they may have a similar important role as reservoirs.

Acknowledgements

We are most thankful to Drs J. Holman and J. Havelka, Institute of Entomology, Czech Academy of Sciences, for the determination of aphids and their host-plants. The study was undertaken in the framework of co-operation between the Institute of Zoology, Bulgarian Academy of Sciences and the Institute of Entomology, Czech Academy of Sciences. The work was supported from the Entomology Institute project S5007102 (Acad.Sci.CR).

References

Agarwala, B.K., S. Das and A.K. Bhaumik, 1987. Natural food range and feeding habits of aphidophagous insects in north east India. *Journal of Aphidology* 1: 18–20.

Atwal, A.S. and S.L. Sethi, 1963. Biochemical basis for the food preference of a predator beetle. *Current Science* 32: 511–512.

Balduf, W.V., 1935. *The Bionomics of Entomophagous Coleoptera*. J.S. Swift, Chicago, New York. 220 pp.

Blackman, R.L., 1965. Studies on specificity in Coccinellidae. *Annals of Applied Biology* 56: 336–338.

Blackman, R.L., 1967. The effects of different aphid foods on *Adalia bipunctata* L. and *Coccinella septempunctata* L. *Annals of Applied Biology* 59: 331–338.

Brun, J. and G. Iperti, 1978. Influence de l'alimentation sur la fecondité des coccinellides aphidophages. *Annales de Zoologie – Ecologie Animale* 10: 449–452.

Dixon, A.F.G., J-L. Hemptinne and P. Kindelmann, 1997. Effectiveness of ladybirds as biological control agents: patterns and processes. *Entomophaga* 42: 71–83.

Dixon, A.F.G., 2000. *Insect Predatory – Prey Dynamics. Ladybird Beetles & Biological Control.* Cambridge University Press, 248 pp.

Formusoh, E.S. and G.E. Wilde, 1993. Preference and development of two species of predatory Coccinellids on the Russian wheat aphid and greenbug biotype E (Homoptera: Aphididae). *Journal of Agricultural Entomology* 10: 65–70.

Fye, R.E., 1981. Rearing and release of coccinellids for potential control of pear psylla. Agricultural Research Service, *Advances in Agricultural Technology*, Western Series 20: 9 pp.

Ghanim, A.E.B., B. Freier and T. Wetzel, 1984. Zur Nahrungsaufnahme und Eiablage von *Coccinella septempunctata* L. bei unterschiedlichem Angebot von Aphiden der Arten *Macrosiphum avenae* (Fabr.) und *Rhopalosiphum padi* (L.). *Archiv für Phytopathologie und Pflanzenschutz* 20: 117–125.

Gruppe, A. and P. Roemer, 1988. The lupin aphid (*Macrosiphum albifrons* Essing, 1911) (Hom. Aphididae) in West Germany: its occurrence, host plants and natural enemies. *Zeitschrift für Angewandte Entomologie* 106: 135–143.

Hämäläinen, M., M. Markkula and T. Raij, 1975. Fecundity and larval voracity of four ladybeetle species (Col., Coccinellidae). *Annales Entomologici Fennici* 41: 124–127.

Hauge, M.S., F.H. Nielsen and S. Toft, 1998. The influence of three cereal aphid species and mixed diet on larwal survival, development and adult weight of *Coccinella septempunctata. Entomologia Experimentalis et Applicata* 89: 319–322.

Hodek, I., 1956. The influence of *Aphis sambuci* L. as prey of the ladybird beetle *Coccinella septempunctata* L. *Acta Societatis Zoologicae Bohemoslovacae* 20: 62–74. (In Czech, English abstract).

Hodek, I., 1960. The influence of various aphid species as food for two lady-birds *Coccinella 7-punctata* L. and *Adalia bipunctata* L. In: *The Ontogeny of Insects*. Academia Prague. pp. 314–316.

Hodek, I. and A. Honek, 1996. *Ecology of Coccinellidae.* Kluwer Academic Publishers, Dordrecht. 464 pp.

Iperti, G., 1965. Contribution a l'étude de la specificité chez les principales coccinelles aphidiphages des Alpes-Maritimes et des Basses-Alpes. *Entomophaga* 10: 159–178.

Iperti, G., 1966. Comportement naturel des Coccinelles aphidiphages du Sud-Est de la France. Leur type de specificité, leur action predatrice sur *Aphis fabae* L. *Entomophaga* 11: 203–210.

Kariluoto, K.T., 1980. Developing artificial diets for *Adalia bipunctata* (L.) and *Coccinella septempunctata* L. *Bulletin SROP/WPRS* 3: 99–100.

Kalushkov, P.K., 1998. Ten aphid species (Homoptera: Aphididae) as a prey for *Adalia bipunctata* (Coleoptera: Coccinellidae). *European Journal of Entomology* 95: 343–349.

Lucas, E., D. Coderre and Ch. Vincent, 1997. Voracity and feeding preferences of two aphidophagous coccinellids on *Aphis citricola* and *Tetranychus urtice*. *Entomologia Experimentalis et Applicata* 85: 151–159.

Majerus, M.E.N., 1994. *Ladybirds.* Harper Collins Publisher. 367 pp.

Michels, G.J. and R.W. Behle, 1991. A comparison of *Coccinella septempunctata* and *Hippodamia convergens* larval development on greenbugs at constant temperatures. *Southwestern Entomologist* 16: 73–80.

Michels, G.J. and R.V. Flanders, 1992. Larval development, aphid consumption and oviposition for five imported coccinellids at constant temperature on Russian wheat aphids and greenbugs. *Southwestern Entomologist* 17: 233–243.

Mills, N.J., 1981. Essential and alternative foods for some British Coccinellidae (Coleoptera). *Entomologist's Gazette* 32: 197–202.

Nedved, O., 1999. Host complexes of predaceous ladybeetle (Col., Coccinellidae). *Journal of Applied Entomology* 123: 73–76.

Obrycki, J.J. and C.J. Orr, 1990. Suitability of three prey species for Nearctic populations of *Coccinella septempunctata*, *Hippodamia variegata*, and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). *Journal of Economic Entomology* 83: 1292–1297.

Ruzicka, Z., G. Iperti and I. Hodek, 1981. Reproductive rate and longevity in *Semiadalia undecimnotata* and *Coccinella septempunctata* (Col.: Coccinellidae). *Vestnik Ceskoslovenske Spolecnosti Zoologicke* 54: 115–128.

Satpathi, C.R., 2000. Consumption and utilisation of food by the larvae of ladybird beetle *Coccinella septempunctata* L. *Journal of Aphidology* 14: 109–112.

Schanderl, H., A. Ferran and V. Garcia, 1988. L'élevage de deux coccinelles *Harmonia axyridis* et *Semiadalia undecimnotata* a l'aide d'oeufs d' *Anagasta kuehniella* tués aux rayons ultraviolets. *Entomologia Experimentalis et Applicata* 49: 235–244.

Sethi, S.L. and A.S. Atwal, 1964. Influence of temperature and humidity on the development of different stages of *Coccinella septempunctata* (Coleoptera, Coccinellidae). *Indian Journal of Agricultural Sciences* 34: 166–171.

Stary, P., 1995. Natural enemy spectrum of *Aphis spiraephaga* (Hom.: Aphididae), an exotic immigrant aphid in Central Europe. *Entomophaga* 40: 29–34.

Smith, R.F., 1966. Summing-up of section V. In: I. Hodek (ed), *Ecology of Aphidophagous Insects*. Junk, The Haag. pp. 285–287.

Triltsch, H., 1999. Food remains in the guts of *Coccinella septempunctata* (Coleoptera, Coccinellidae) adults and larvae. *European Journal of Entomology* 96: 355–364.

Zhang, Z.Q., 1992. The natural enemies of *Aphis gossypii* Glover (Hom., Aphididae) in China. *Journal of Applied Entomology* 114: 251–252.