

# Biological traits and life table of the exotic *Harmonia axyridis* compared with *Hippodamia variegata*, and *Adalia bipunctata* (Col., Coccinellidae)

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**Abstract:** As part of an environmental risk assessment study of exotic natural enemies used in inundative biological control, life-history characteristics of *Harmonia axyridis* (Pallas), *Hippodamia variegata* (Goeze) and *Adalia bipunctata* (L.) (Col., Coccinellidae) were quantified under laboratory conditions at 25°C on *Myzus persicae* (Sulzer) as prey. Comparative studies showed significant differences among pre-adult development times: *H. axyridis* developed slower ( $\bar{X}$  = 19.8 days) than *H. variegata* ( $\bar{X}$  = 18.1 days) and *A. bipunctata* ( $\bar{X}$  = 18.4 days). Differences were also evident in the duration of egg, larval and pupal stages. No measurable differences among the three species were found for fecundity, oviposition rate and adult longevity. *Harmonia axyridis* exhibited the longest pre-oviposition ( $\bar{X}$  = 7.4 days) and interoviposition ( $\bar{X}$  = 3.6 days) periods and the shortest oviposition period ( $\bar{X}$  = 13.7 days). The Bieri model was used to describe age-specific fecundity for the three species of coccinellids. The intrinsic rate of increase ( $r_m$ ), net reproductive rate ( $R_0$ ) and mean generation time ( $T$ ) were higher for *H. variegata* ( $r_m$  = 0.114,  $R_0$  = 52.75,  $T$  = 41.88 days) than for *H. axyridis* ( $r_m$  = 0.089,  $R_0$  = 26.27,  $T$  = 38.81 days) or *A. bipunctata* ( $r_m$  = 0.081,  $R_0$  = 18.49,  $T$  = 40.06 days). Our findings show that the biological traits of *H. axyridis* do not seem to be factors that may contribute to the invasiveness of this coccinellid.

**Key words:** *Adalia bipunctata*, *Harmonia axyridis*, *Hippodamia variegata*, development time, environmental risk, fecundity, life table parameters

## 1 Introduction

The Asian multicoloured ladybeetle *Harmonia axyridis* (Pallas) is a Palearctic polyphagous species originating from the Far East. This arboreal ladybird occurs in orchard and forest habitats and preys mostly on various aphid species, but it also accepts scales and two species of chrysomelids (TEDDERS and SCHAEFER, 1994). Because of its good searching capacity and predation activity, *H. axyridis* is an effective biological control agent against aphid pests. It has been introduced in France by I.N.R.A. in 1982 (FERRAN et al., 1996); it has also been introduced and established in the United States (LAMANA and MILLER, 1996; BROWN and MILLER, 1998; COLUNGA-GARCIA and GAGE, 1998; BROWN, 1999), in Canada (CODERRE et al., 1995) and released in Italy.

It is well known that the introduction of generalist entomophagous insects could cause environmental risks. In particular these problems could regard intra-guild competition, with negative effects on native species (SIMBERLOFF and STILING, 1996; THOMAS and WILLIS, 1998).

At present, no data about negative effects of the introduction of *H. axyridis* in Europe are available. Regarding the USA, field surveys by BROWN and MILLER (1998) in West Virginia, revealed that by 1995 *H. axyridis* had become dominant in the Coccinellinae tribe, continuing to dominate the Coccinellinae guild on apple. According to these authors the exotic species *Coccinella septempunctata* (L.), that had been present in the region since 1983, had been displaced by *H. axyridis*. This species was found by COLUNGA-GARCIA and GAGE (1998) to have become a dominant coccinellid in the agricultural landscape of southwestern Michigan. Adults were reported for all the habitats sampled, including early secondary succession, poplar plantation, alfalfa, soybean, corn and winter wheat crops.

A methodology for risk assessment has been developed as a basis for regulation of import and release of exotic natural enemies (VAN LENTEREN et al., 2003). In this contest biological traits are essential for assessing the potential rate of population increase of a species, thus providing, together with other parameters, a

theoretical evaluation of the potential of an exotic natural enemy to compete with native species.

Laboratory experiments were carried out to study the life history of the exotic species *H. axyridis* and, as a comparison, of the native species *Adalia bipunctata* (L.) and *Hippodamia variegata* (Goeze). These two indigenous species were chosen because they are common in hedgerows and orchard trees (HODEK and HONĚK, 1996) and abundant in the agroecosystems of northern Italy (BORIANI et al., 1998; FERRARI et al., 1998; BURGIO et al., 1999). *Myzus persicae* (Sulzer) was chosen as prey because its widespread occurrence and harmfulness make it a relevant target for inundative release of coccinellids. The biological traits of the three coccinellids species, including development time, fecundity, adult longevity and life-table, were compared.

## 2 Materials and Methods

### 2.1 Insect rearing

Aphids and coccinellids were reared in the entomological laboratories of DiSTA (Dipartimento di Scienze e Tecnologie Agroambientali), University of Bologna. Cultures of *A. bipunctata* and *H. variegata* were derived from field-collected specimens; *H. axyridis* was supplied by Koppert (The Netherlands). Larvae of the three coccinellid species were fed with frozen eggs of *Ephestia kuehniella* Zeller. Adults were fed with *M. persicae* that had been reared on 'Primizia' green pea (*Pisum sativum* L.) sprouts. Adult coccinellids were maintained in Plexiglas cages (40 × 30 × 45 cm) and larvae in plastic cylinders (Kartell®, Milan, Italy) (Ø = 18 cm, h = 18 cm). Both adults and larvae were kept at 20–25°C with a relative humidity of 60–80%, L : D = 16 : 8.

### 2.2 Experiments for determining biological traits

Egg masses from each of the three coccinellid species were placed separately in cylindrical containers (Ø = 9 cm, h = 28.5 cm, thickness = 4 mm) that were then kept in an environmental chamber (25 ± 1°C, UR = 60–80%, L : D = 16:8). The new-hatched larvae were reared on *M. persicae* until adult eclosion. The sex of the adults was determined. Ten pairs (male and female) of *A. bipunctata* and *H. variegata* and eight of *H. axyridis* were selected. Adults were taken from different containers to avoid the inbreeding of siblings. Each pair was put in a Plexiglas cylindrical cage (Ø = 9 cm, h = 28.5 cm, thickness = 4 mm) that was covered with a screened lid. Each cage was lined on the inside with an air bubble plastic film to act as oviposition substrate. The adults were daily fed *ad libitum* with *M. persicae* infesting fresh sprouts. Dead aphids and old sprouts were removed daily. The number of eggs laid by each female, including the cannibalized ones, was recorded daily until the female's death. Any deceased males during the experimental period were replaced. The pre-oviposition period was calculated as the number of days between emergence and the first oviposition, while the interoviposition one as the number of days between two subsequent ovipositions. Finally, the oviposition period was made up of the interoviposition period plus the number of days during which oviposition occurred.

In order to determine pre-imaginal development times, pre-imaginal survival, and sex ratio of the three species, 10 eggs were collected from different females of each species, starting on the fifth day after the first oviposition. The

operation was repeated every 10 days throughout female lifespan until 50 eggs were collected for each species. The eggs were incubated at 25 ± 1°C, UR = 60–80%, L : D = 16:8 and placed individually in cylindrical containers (Ø = 4 cm, h = 4 cm, thickness = 2 mm) to avoid larval cannibalism. Eggs were checked daily for hatch. Larvae were fed *ad libitum* with *M. persicae* and examined every day for ecdysis. Only the individuals reaching adulthood were taken into consideration for determining development times of each instar. After emergence adults were sexed. The experiment was replicated twice for a total of 20 pairs (15 for *H. axyridis*), development times being determined on the basis of 85 eggs for *H. axyridis* 108 eggs for *H. variegata* and 100 eggs for *A. bipunctata*.

The intrinsic rate of increase ( $r_m$ ) was calculated by the BIRCH (1948) method, that is based on the equation of Lotka;  $r_m$  can be determined by iteratively solving the equation:

$$\int_0^n \exp(-rt) l_x m_x = 1,$$

where  $m_x$  is the age-specific fecundity and  $l_x$  is the survival (DENT, 1997). Net reproductive rate ( $R_0$ ), and mean generation time ( $T$ ) were calculated by the following formulas:

$$R_0 = \sum l_x m_x,$$

$$T = \sum x l_x m_x / \sum l_x m_x.$$

The parameters of the life-table were estimated on the basis of the sex ratio noticed in our experiments.

Voucher specimens of *A. bipunctata*, *H. variegata* and *H. axyridis* have been deposited into the Dipartimento di Scienze e Tecnologie Agroambientali insect collection, Alma Mater Studiorum-Università di Bologna.

### 2.3 Statistical analysis

Data on development times and on reproduction patterns were studied by analysis of variance (ANOVA), and means were separated using Tukey's honestly significant differences (HSD) procedure ( $P < 0.05$ ). Differences in pre-imaginal survival were analysed using  $\chi^2$  contingency tables (ZAR, 1984). The relationship between female age and oviposition rate (number of eggs laid/female/day) was fitted by the Bieri model (BIERI et al., 1983):

$$y = [P_1(x - P_2)] / \{\exp[\ln(P_3)(x - P_2)]\},$$

where  $x$  = age of female (days), and  $P_1$ ,  $P_2$  and  $P_3$  are coefficients.

The STATISTICA software for Windows STATSOFT™ (1994) was used for statistical analysis.

## 3 Results and Discussion

There were significant differences in pre-adult development times ( $F = 13.79$ ; d.f. = 2, 115;  $P < 0.0001$ ) (table 1). In particular, *H. axyridis* took about 1.5 more days to complete its development than *H. variegata* and *A. bipunctata*. Overall, the larval stage was significantly longer in *H. axyridis* than in the other two species ( $F = 8.19$ ; d.f. = 2, 115;  $P = 0.0005$ ), and some significant differences were found among the three species in the first ( $F = 5.90$ ; d.f. = 2, 115;  $P = 0.0036$ ), second ( $F = 6.48$ ; d.f. = 2, 115;  $P = 0.0022$ ) and fourth ( $F = 55.09$ ; d.f. = 2, 115;  $P < 0.0001$ ) instar larvae, but not in the third

**Table 1.** Pre-imaginal development times and survival of three species of coccinellid reared on *Myzus persicae* at 25°C

Species	n	X ± SE Developmental time (days)										Pre-imaginal survival X (%)
		Larva										
		Egg	First	Second	Third	Fourth	Total	Pupa	Total			
<i>H. axyridis</i>	42	2.8 ± 0.1 a	2.3 ± 0.1 a	1.5 ± 0.1 a	2.0 ± 0.1 a	4.7 ± 0.1 a	10.4 ± 0.2 a	6.6 ± 0.1 a	19.8 ± 0.2 a	49.4		
<i>H. variegata</i>	53	2.6 ± 0.1 a	2.6 ± 0.1 b	1.9 ± 0.1 b	2.0 ± 0.1 a	2.9 ± 0.1 b	9.4 ± 0.2 b	6.1 ± 0.1 b	18.1 ± 0.3 b	49.1		
<i>A. bipunctata</i>	25	2.3 ± 0.1 b	2.8 ± 0.1 b	1.6 ± 0.1 ab	1.8 ± 0.1 a	3.4 ± 0.2 b	9.6 ± 0.2 b	6.5 ± 0.1 a	18.4 ± 0.2 b	25.0		

Mean values within a column followed by the same letter are not significantly different, P < 0.05, Tukey's (HSD) test.

( $F = 1.07$ ; d.f. = 2, 115;  $P = 0.3466$ ) (table 1). In particular the fourth instar larval development time of *H. axyridis* was 1.6 and 1.4 times longer than that of *H. variegata* and *A. bipunctata*, respectively. As fourth instar is characterized by a strong predatory activity and *H. axyridis* shows a strong intraguild predation (HIRONORI and KATSUHIRO, 1997; YASUDA and OHNUMA, 1999; YASUDA et al., 2001) this factor may represent an advantage for the exotic. Moreover, the quicker development of first and second instar larvae, that are more prone to IGP attack (G. BURGIO, unpublished data), may give *H. axyridis* a further advantage respect to native species. Pupal development time was shorter in *H. variegata* than in *H. axyridis* and *A. bipunctata* ( $F = 6.58$ ; d.f. = 2, 115;  $P = 0.002$ ). *Adalia bipunctata* showed the shortest embryonic development time ( $F = 6.13$ ; d.f. = 2, 115;  $P = 0.0029$ ).

The pre-imaginal development times of *H. axyridis* were found to be fairly much in line with those reported by other authors (KIM and CHOI, 1985; SCHANDERL et al., 1985; NIJIMA et al., 1986; McCLURE, 1987; LAMANA and MILLER, 1998; ABDEL-SALAM and ABDEL-BAKY, 2001). In others studies *H. axyridis* took less time to complete its development (BALDACCI, 1998; PHOFOLO and OBRYCKI, 1998; MICHAUD, 2000). The development times reported by MICHAUD (2000) on *Aphis spiraeicola* Patch were, instead, longer than that found in our experiment (table 2).

The pre-adult development times reported by OBRYCKI and ORR (1990) for *H. variegata* are quite close to ours, while those reported by ELHAG and ZAITOON (1996) are slightly longer. According to EL HABI et al. (2000) development from the first instar larvae to adult emergence took less time. The development times reported by MICHELS and FLANDERS (1992) for four strains of *H. variegata*, ranged from 23.9 to 30.0 days (table 2).

Our findings essentially agree with those reported by OBRYCKI and TAUBER (1981) for *A. bipunctata*. FRANCIS et al. (2001) found that the time taken by *A. bipunctata* to develop from egg to adult ranged from 21.8 to 23.4 days depending on host plant.

Significant differences were found in the survival percentage of the immature in the three species studied (table 1), the lowest pre-imaginal survival ( $\bar{X} = 25.0\%$ ) being reported for *A. bipunctata*, compared with that of *H. axyridis* ( $\bar{X} = 49.4\%$ ) ( $\chi^2 = 11.85$ ; d.f. = 1;  $P = 0.0006$ ) and that of *H. variegata* ( $\bar{X} = 49.1\%$ ) ( $\chi^2 = 18.12$ ; d.f. = 1;  $P < 0.0001$ ). The low percentage of egg hatching (53% for *H. axyridis*, 73% for *H. variegata* and 55% for *A. bipunctata*) was the most significant factor accounting for the mortality observed by us throughout pre-imaginal development. Overall, the survival percentage findings of our study were lower than those reported by KIM and CHOI (1985), NIJIMA et al. (1986), SCHANDERL et al. (1988), LAMANA and MILLER (1998), PHOFOLO and OBRYCKI (1998), MICHAUD (2000) and ABDEL-SALAM and ABDEL-BAKY (2001) for *H. axyridis*, OBRYCKI and ORR (1990) and ELHAG and ZAITOON (1996) for *H. variegata*, OBRYCKI and TAUBER (1981) and FRANCIS et al. (2001) for *A. bipunctata* (table 2). KALUSHKOV (1994), instead,

**Table 2.** Summary of literature survey of pre-imaginal development times and survival values of three coccinellid species reared on different preys

Coccinellid species	Prey	Host plant	Rearing temperature (°C)	Mean ± SD developmental time (days)	Pre-imaginal survival (%)	References
<i>Harmonia axyridis</i>	Fresh <i>Sitotroga cerealella</i> Oliver eggs	—	27	18.8 ± 0.32*	84	ABDEL-SALAM and ABDEL-BAKY (2001)
	Frozen <i>S. cerealella</i> eggs	—	27	22.5 ± 0.21*	80	
	<i>Aphis gossypii</i> Glover	<i>Cucurbita pepo</i> L.	25	14.9	96.7	BALDACCII (1998)
	Frozen <i>Ephesttia kaehniella</i> Zeller eggs	—	25	15.5	96.6	
	<i>Acyrthosiphon pisum</i> (Harris)	<i>Vicia faba</i> L.	26	17.5 ± 1.1	88.7†	LAMANNA and MILLER (1998)
	<i>A. pisum</i>	<i>V. faba</i>	27	18.6 ± 1.3	—	MCCLAURE (1987)
	<i>Toxoptera citricida</i> (Kirkaldy)	Carrizo citrange‡	23–24	15.3†	95.0	MICHAUD (2000)
	<i>Aphis spiraecola</i> Patch	<i>Viburnum odoratissimum</i> Kerr-Gawl	23–24	27.2†	70.0	
	<i>Lachnus tropicalis</i> (Van der Goot) powder	—	—	20.1 ± 0.3	84.0	NIJIMA et al. (1986)
	<i>A. pisum</i> powder	—	—	20.3 ± 1.1	80.0	
	<i>Anuraphis nume</i> powder	—	—	19.8 ± 0.4	88.0	
	<i>Aphis rumicis</i> (L.) powder	—	—	18.4 ± 2.88	80.0	
<i>Hippodamia variegata</i>	<i>A. pisum</i>	—	26	14.6 ± 0.8†	—	PHOOFOLO and OBRZYCKI (1998)
	<i>Chrysoperla carnea</i> Stephens eggs	—	26	14.0 ± 0.8†	—	
	<i>M. persicae</i>	—	25	18.6	—	SCHANDLER et al. (1985)
	<i>A. gossypii</i> Glover	—	26	19.92	85.9	KIM and CHOI (1985)
	<i>A. gossypii</i>	—	26	10.71 ± 0.69†	—	EL HABI et al. (2000)
	<i>Brevicoryne brassicae</i> (L.) and <i>Rhopalosiphum padi</i> L.	Cabbage and wheat, respectively	25	20.1	61.8	EL HAG and ZAITOON (1996)
	<i>Rhopalosiphum maidis</i> (Fitch)	—	—	—	—	OBRZYCKI and ORR (1990)
	<i>A. pisum</i>	<i>Hordeum vulgare</i> L.	23	19.4 ± 3.3*	95	
	<i>Schizaphis graminum</i> (Rondani)	<i>V. faba</i>	23	19.3 ± 2.8*	88	
	<i>Diuraphis noxia</i> (Mordvilko)	—	20	30.3–24.4–26.1–24.8§	—	MICHELIS and FLANDERS (1992)
	<i>M. persicae</i>	<i>Sinapis alba</i> L.	20	27.7–23.9–28.1–26.8§	—	
	<i>Adalia bipunctata</i>	—	<i>Brassica napus</i> L.	20	21.8 ± 0.8	85.0
—		<i>V. faba</i>	20	22.0 ± 0.7	86.7	
—		—	20	23.4 ± 1.0	87.8	
<i>A. pisum</i>		—	24	17.8 ± 0.5*	70	OBRZYCKI and TAUBER (1981)

\* Mean ± SE.

† First instar larvae to adult emergence.

‡ *Poncirus trifoliata* (L.) Osbeck X *Citrus sinensis* (L.) Rafinesque.

§ Four strains from Canada, Chile, Moldavia and Morocco, respectively.

**Table 3.** Reproduction parameters, longevity and sex ratio of three species of coccinellid reared on *Myzus persicae* at 25°C

Species	<i>n</i>	Fecundity (no. eggs laid/ female)*	Oviposition rate (no. eggs laid/ female/day)*	Adult longevity (days)*	Pre-oviposition period (days)**	Oviposition period (days)**	Interoviposition period (days)*	Sex ratio (% females)
<i>H. axyridis</i>	15	560.5 ± 100.5 a	18.3 ± 2.5 a	27.5 ± 2.6 a	7.4 ± 0.3 a	13.7 ± 2.3 a	3.6 ± 0.8 a	39
<i>H. variegata</i>	20	841.7 ± 115.3 a	21.2 ± 1.9 a	36.9 ± 2.9 a	2.1 ± 0.2 b	32.2 ± 3.2 b	1.5 ± 0.4 b	52
<i>A. bipunctata</i>	20	537.0 ± 76.9 a	16.0 ± 1.9 a	30.7 ± 3.3 a	4.3 ± 0.3 c	24.7 ± 3.0 b	2.2 ± 0.4 ab	56

Mean values within a column followed by the same letter are not significantly different. \*  $P < 0.05$ , \*\*  $P < 0.01$ , Tukey's (HSD) test.

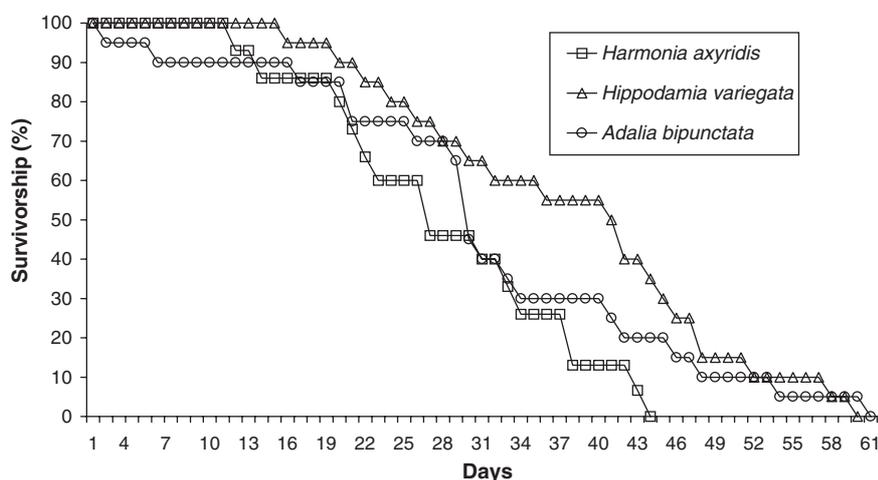
has reported very high mortality rearing *A. bipunctata* on *Aphis fabae* Scopoli (83.3%) and on *A. fabae* plus *Aphis craccivora* Koch (90.0%). The methodology used to separate the eggs from their batches might have damaged some of them and this could explain the high embryonic mortality found in our experiments.

No significant differences in adult female longevity were found among the three coccinellid species ( $F = 2.47$ ; d.f. = 2, 52;  $P = 0.0945$ ) (table 3). A rapid decline in the survival curves was however observed after 30 days for *H. axyridis* and *A. bipunctata* (fig. 1). At 35 days the survivorship of these species was about 30%, whereas for *H. variegata* it was 60%. The highest adult longevity was 44 days for *H. axyridis*, 60 days for *H. variegata* and 61 days for *A. bipunctata* (fig. 1). Appreciably higher mean values of longevity have been reported by HUKUSIMA and KAMEI (1970) for *H. axyridis* on *M. persicae* and *Amphorophora oleracea* and by McCCLURE (1987), BALDACCIO (1998) and ABDEL-SALAM and ABDEL-BAKY (2001). Higher values have also been reported for *H. variegata* by ELHAG and ZAITOON (1996) and by KALUSHKOV (1994) for *A. bipunctata* on *Phorodon humuli* (Schrank). The latter author has however reported female adult longevity values similar to ours by feeding *A. bipunctata* on *A. fabae* and on *A. fabae* added with *A. craccivora* (KALUSHKOV, 1998).

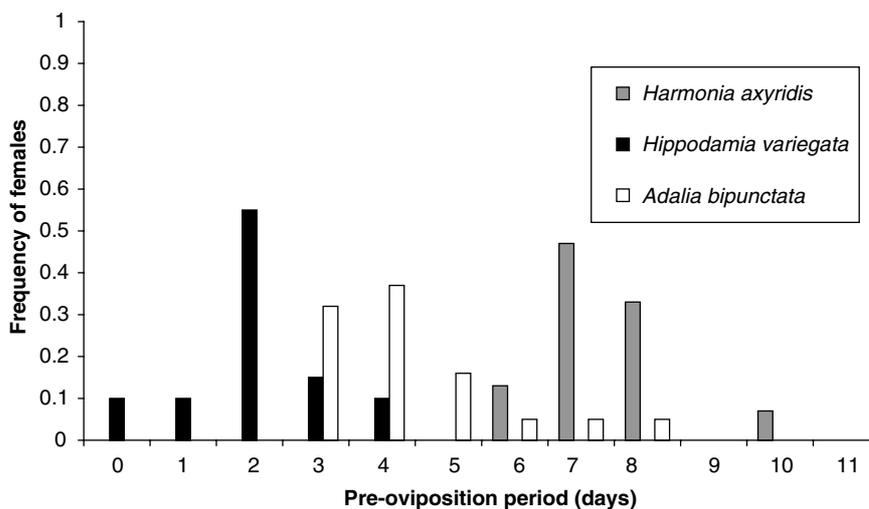
Differences were also observed in the mean pre-oviposition period of the three species examined ( $F = 88.55$ ; d.f. = 2, 51;  $P < 0.0001$ ) (table 3). The longest period was observed for *H. axyridis* (range 6–10 days), followed by *A. bipunctata* (range 3–8 days) and *H. variegata* (range 0–4 days). Frequency

distributions of the pre-oviposition period are shown in fig. 2. Eighty per cent of the females of *H. axyridis* had a pre-oviposition period of 7–8 days, while the pre-oviposition period of 55% of *H. variegata* females and of 69% of *A. bipunctata* females ranged from 2 to 4 days. All females started to oviposit within 10 days of their adult life whereas delayed oviposition over 10 days was not observed for the three species studied. The mean interoviposition period was significantly higher in *H. axyridis* (range 0–10) compared with *H. variegata* (range 0–7) but not compared with *A. bipunctata* (range 0–6) ( $F = 3.73$ ; d.f. = 2, 51;  $P = 0.0309$ ). Frequency distribution showed that in the majority of females of *H. variegata* (90%) and of *A. bipunctata* (78%) the interoviposition periods ranged from 0 to 3 days (fig. 3), while only 53% of *H. axyridis* females had an interoviposition period of up to 3 days and 27% of 6 days.

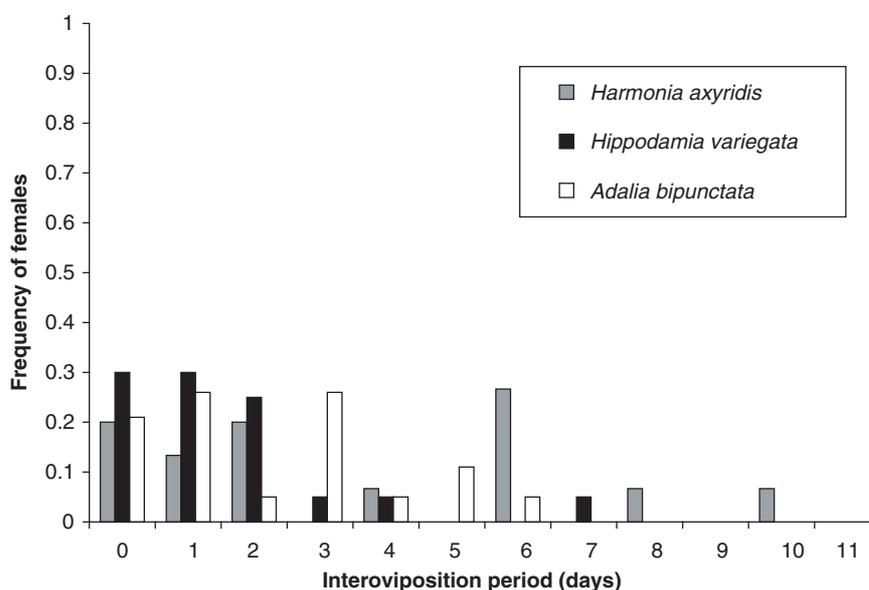
PHOOFOLO and OBRYCKI (1995), studying four populations of *C. septempunctata*, reported that this ladybird exhibits a consistent bimodal pattern in the pre-oviposition and interoviposition periods: one group had short and another group had long (> 15 days) pre-oviposition and interoviposition periods. These authors concluded that the expression of a large range of variation in life-history traits related to fecundity, such as pre-oviposition and interoviposition periods, may be one of the factors responsible for the widespread occurrence of this ladybird in the United States. Our results show that in *H. axyridis*, neither pre-oviposition nor interoviposition frequency distribution exhibited the bimodal pattern reported

**Fig. 1.** Female survival of three coccinellid species reared on *Myzus persicae* at 25°C

**Fig. 2.** Frequency distribution of pre-oviposition period in three coccinellid species reared on *Myzus persicae* at 25°C



**Fig. 3.** Frequency distribution of interoviposition period in three coccinellid species reared on *Myzus persicae* at 25°C



by PHOOFOLO and OBRYCKI (1995) and by HODEK and RUZICKA (1979) for *C. septempunctata*. LEWONTIN (1965), studying the importance of age at first reproduction in the colonizing ability of organisms, underlines the influence of the pre-oviposition period on the variation of the intrinsic rate of increase. He concludes that species with low levels of variance in their age at first reproduction are characterized by having ‘a long history of colonization’. It is because directional selection strongly effects the age at first reproduction during the colonization period. As expected following LEWONTIN’s (1965) conclusions, the native species *H. variegata* and *A. bipunctata* showed a homogeneous pre-oviposition period. On the contrary, *H. axyridis* was expected to have a less homogeneous pre-oviposition period, because of its widespread occurrence in the United States. However, the biofactory strain used in our experiments may have undergone a selection towards a more homogeneous pre-oviposition period, during the rearing process. From these points of view, the biofactory strain of *H. axyridis* used in this study does not seem to have a high invasiveness capacity. The mean

oviposition period of *H. axyridis* was significantly shorter than that of *H. variegata* and of *A. bipunctata* ( $F = 9.26$ ; d.f. = 2, 51;  $P = 0.0004$ ) (table 3). It was remarkably shorter also compared with the findings reported by HUKUSIMA and KAMEI (1970), by McCLURE (1987), and by ABDEL-SALAM and ABDEL-BAKY (2001) for the same species. The egg-laying period for *H. axyridis* ranged from 1 to 28 days, from 6 to 57 for *H. variegata* and from 2 to 50 for *A. bipunctata*.

The three species did not show any significant differences in fecundity or oviposition rates ( $F = 3.06$ ; d.f. = 2, 52;  $P = 0.0554$ ; and  $F = 1.76$ ; d.f. = 2, 52;  $P = 0.1818$ , respectively), although the differences in fecundity were close to the 0.05 significance level (table 3). Despite the evidence that the longevity and oviposition periods found in our experiment are about three times less than those reported by McCLURE (1987) and by ABDEL-SALAM and ABDEL-BAKY (2001), the fecundity findings for *H. axyridis* are substantially in agreement with those observed by these authors. However, BALDACCI (1998), who reported a higher longevity, also found a higher fecundity. The fecundity findings for *H. variegata* in our study are not

in line with those of ELHAG and ZAITOON (1996), according to whom the average female produces 276.3 eggs at the rate of 10.6 eggs/day. Our fecundity findings for *A. bipunctata* were essentially in line with those of HÄMÄLÄINEN et al. (1975). A higher fecundity on *P. humuli* has instead been reported by KALUSHKOV (1994), which was found to be much lower when the ladybeetle was fed on *A. fabae* and on *A. fabae* together with *A. craccivora*.

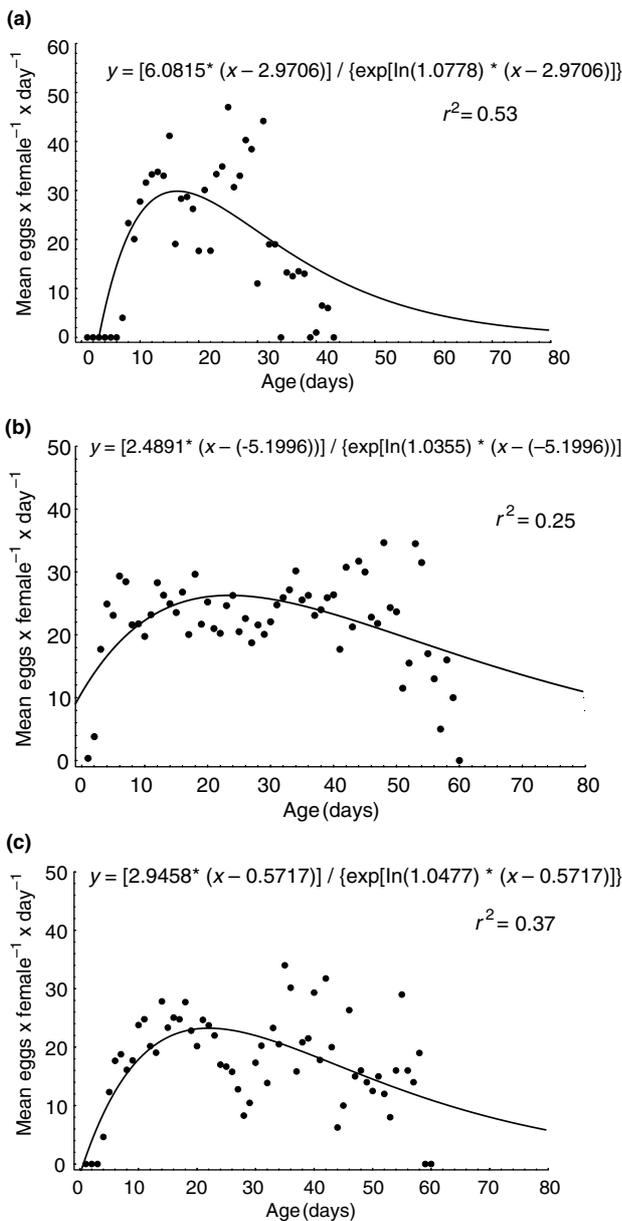
The curves of Bieri model, that fits the age-specific fecundity, for the three species of coccinellids, are shown in fig. 4. The highest daily mean oviposition value was recorded at 16 days for *H. axyridis*, at 24 days for *H. variegata*, and at 22 days for *A. bipunctata*. A similar peak value was found by

KARILUOTO (1980) for *A. bipunctata* reared on *M. persicae*.

A comparison of our findings with those of other studies (e.g. KALUSHKOV, 1994 for *A. bipunctata* and SNYDER et al., 2000 for *H. axyridis*) confirms that factors such as prey species, cannibalistic feeding, and rearing conditions, that may affect development duration, mortality and adult longevity in coccinellids, are of considerable importance. Moreover, as suggested by FRANCIS et al. (2000, 2001) for *A. bipunctata* and GILES et al. (2002) for *C. septempunctata*, it is important that the biological traits of coccinellids be considered in a tritrophic contest. In fact, according to KALUSHKOV (1998), who analysed development time, mortality and adult weight, the suitability of *A. fabae* as food for *A. bipunctata* depends on its host plant. Moreover, survival, developmental time and size of *C. septempunctata* appear to be modulated by the biochemical response of the aphid prey to host plant (GILES et al., 2002). As suggested by FRANCIS et al. (2000, 2001), host plant allelochemical substances may not only affect the herbivores but also the pest predators.

The intrinsic rate of population increase, net reproductive rate and mean generation time are given in table 4. Compared with the other species studied, the highest values for all parameters were recorded for the native *H. variegata*, and the lowest for *A. bipunctata* except for *T* where *H. axyridis* showed the lowest one. In particular, the net reproductive rate of *H. variegata* was 1.5 and 2.9 times higher than that of *H. axyridis* and *A. bipunctata*, respectively. Our findings showed that the potential for population increase of the exotic species *H. axyridis* is slightly greater than that of *A. bipunctata* but lower than that of *H. variegata*. Such a finding is probably ascribable chiefly to the higher development time from egg to adult of *H. axyridis* and to the low pre-imaginal survival of *A. bipunctata*. A comparison between the life table parameters of *H. axyridis* and those of other native ladybirds shows that the potential for population increase is greater also for *Propylea quatuordecimpunctata* L. ( $T = 33.0$  days,  $R_0 = 149.9$ ,  $r_m = 0.15$ ) (OBRYCKI et al., 1993) and *C. septempunctata* ( $T = 34.0$  days,  $R_0 = 567.6$ ,  $r_m = 0.19$ ) (PHOOFOLO and OBRYCKI, 1995).

In conclusion, while *H. axyridis* is indeed an easy-to-rear and good predator for the control of aphid outbreaks, our study shows that under laboratory conditions and using *M. persicae* as prey, it does not exhibit a higher capacity for population increase when compared with that of other native coccinellids. How-



**Fig. 4.** Oviposition rate as a function of age (days) (Bieri model) of *Harmonia axyridis* (a), *Hippodamia variegata* (b) and *Adalia bipunctata* (c) reared on *Myzus persicae* at 25°C

**Table 4.** Estimated laboratory life-table parameters for three species of coccinellid reared on *Myzus persicae* at 25°C

Species	Life table parameters		
	<i>T</i>	<i>R</i> <sub>0</sub>	<i>r</i> <sub>m</sub>
<i>H. axyridis</i>	38.81	26.27	0.089
<i>H. variegata</i>	41.88	52.75	0.114
<i>A. bipunctata</i>	40.06	18.49	0.081

ever, to evaluate the environmental risk of the introduction of exotic natural enemy used in inundative biological control, especially for highly polyphagous predators like *H. axyridis*, life-table data must be integrated by other information such as its capacity to establish, its abilities to disperse, its host range, and direct and indirect effects on non-targets (VAN LENTEREN et al., 2003). Moreover, life history data are of basic importance in an effort to develop a modelistic approach to study interspecific interaction among exotic and native species. Although our present findings show that the biological traits of *H. axyridis* are not factors that may contribute to the invasiveness of this coccinellid, VAN LENTEREN et al. (2003) found the highest risk indexes for generalist predatory insects including *H. axyridis*. Moreover, many authors (see Introduction) have highlighted the impact of the introduction of *H. axyridis* in the United States. This scenario could depend on other reasons, including intra-guild predation (PHOOFULO and OBRYCKI, 1998; BURGIO et al., 2002; SANTI et al., 2003) in particular of the fourth instar larvae (G. BURGIO, unpublished data), overwintering capacity (CARTWRIGHT et al., 1982; BAZZOCCHI et al., 2004) and also different impact of shared coccinellid parasitoids (CARTWRIGHT et al., 1982; OBRYCKI, 1989) and pathogens (CARTWRIGHT et al., 1982).

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### References

- ABDEL-SALAM, A. H.; ABDEL-BAKY, N. F., 2001: Life table and biological studies of *Harmonia axyridis* Pallas (Col., Coccinellidae) reared on the grain moth eggs of *Sitotroga cerealella* Olivier (Lep., Gelechiidae). *J. Appl. Ent.* **125**, 455–462.
- BALDACCI, F., 1998: Influenza del regime alimentare sullo sviluppo del Coccinellide *Harmonia axyridis* Pallas. Degree thesis. Università degli Studi di Bologna, 61 pp.
- BAZZOCCHI, G. G.; LANZONI, A.; ACCINELLI, G.; BURGIO, G., 2004: Overwintering, phenology and fecundity of *Harmonia axyridis* in comparison with native coccinellid species in Italy. *BioControl* **48**(3), 245–260.
- BIERI, M.; BAUMGÄRTNER, J.; BIANCHI, G.; DELUCCHI, V.; VON ARX, R., 1983: Development and fecundity of pea aphid (*Acyrtosiphon pisum* Harris) as affected by constant temperatures and by pea varieties. *Mitt. Schweiz. Ent. Ges.* **56**, 163–171.
- BIRCH, L. C., 1948: The intrinsic rate of natural increase of an insect population. *J. Anim. Ecol.* **17**, 15–26.
- BORIANI, L.; FERRARI, R.; BURGIO, G.; NICOLI, G.; POZZATI, M., 1998: Il ruolo delle siepi nell'ecologia del campo coltivato. II. Ulteriori indagini sui Coccinellidi predatori di afidi. *Inf. Fitopat.* **5**, 51–58.
- BROWN, M. W., 1999: Effect of *Harmonia axyridis* (Coleoptera: coccinellidae) invasion on the aphidophagous coccinellid guild on apple in West Virginia, USA. *IOBC WPRS Bull.* **22**, 7.
- BROWN, M. W.; MILLER, S. S., 1998: Coccinellidae (Coleoptera) in apple orchards of Eastern West Virginia and impact of invasion by *Harmonia axyridis*. *Ent. News* **109**, 143–151.
- BURGIO, G.; VAN LENTEREN, J. C.; FERRARI, R., 1999: Indagine sui parassitoidi e predatori di afidi su colture erbacee dell'Emilia-Romagna. In: 5° Convegno nazionale sulla biodiversità, 9–10 September 1999, Caserta, Italy, 635–642.
- BURGIO, G.; SANTI, F.; MAINI, S., 2002: On intra-guild predation and cannibalism in *Harmonia axyridis* (Pallas) and *Adalia bipunctata* L. (Coleoptera: Coccinellidae). *Biol. Control* **24**, 110–116.
- CARTWRIGHT, B.; EIKENBARY, G. W.; ANGALET, G. W., 1982: Parasitism by *Perilitus coccinellae* (Hym.: Braconidae) of indigenous coccinellid hosts and the introduced *Coccinella septempunctata* (Col.: Coccinellidae) with notes on winter mortality. *Entomophaga* **27**, 237–244.
- CODERRE, D.; LUCAS, E.; GAGNÈ, I., 1995: The occurrence of *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) in Canada. *Can. Entomol.* **127**, 609–611.
- COLUNGA-GARCIA, M.; GAGE, S. H., 1998: Arrival, establishment, and habitat use of the multicolored Asian lady beetle (Coleoptera: Coccinellidae) in a Michigan landscape. *Environ. Entomol.* **27**, 1574–1580.
- DENT, D. R., 1997: Quantifying insect population: estimates and parameters. In: *Methods in Ecological and Agricultural Entomology*. Ed. by DENT, D. R.; WALTON, M. P. Wallingford, Oxon: CABI Publishing, CAB International, 57–109.
- ELHABI, M.; SEKKAT, A.; EL JADD, L.; BOUMEZZOUGH, A., 2000: Biologie d' *Hippodamia variegata* Goeze (Col., Coccinellidae) et possibilités de son utilisation contre *Aphis gossypii* Glov. (Hom., Aphididae) sous serres. *J. Appl. Ent.* **124**, 365–374.
- ELHAG, E. A.; ZAITOON, A. A., 1996: Biological parameters for four coccinellid species in Central Saudi Arabia. *Biol. Control* **7**, 316–319.
- FERRAN, A.; NIKNAM, H.; KABIRI, F.; PICART, J.-L.; DE HERCE, C.; BRUN, J.; IPERTI, G.; LAPCHIN, L., 1996: The use of *Harmonia axyridis* larvae (Coleoptera: Coccinellidae) against *Macrosiphum rosae* (Hemiptera: Sternorrhyncha: Aphididae) on rose bushes. *Eur. J. Entomol.* **93**, 59–67.
- FERRARI, R.; BURGIO, G.; BORIANI, L.; CAVAZZUTI, C.; POZZATI, M., 1998: Siepi ed agroecosistema. In: *Linee guida per l'agricoltura biologica – Fruttiferi e fragola*. Ed. by Centro Ricerche Produzioni Vegetali. Bologna: Edagricole, 13–41.
- FRANCIS, F.; HAUBRUGE, E.; GASPAR, C., 2000: Influence of host plants on specialist/generalist aphids and on the development of *Adalia bipunctata* (Coleoptera: Coccinellidae). *Eur. J. Entomol.* **97**, 481–485.
- FRANCIS, F.; HAUBRUGE, E.; HASTIR, P.; GASPAR, C., 2001: Effect of aphid host plant on development of the third trophic level, the predator *Adalia bipunctata* (Coleoptera: Coccinellidae). *Environ. Entomol.* **30**, 947–952.
- GILES, K. L.; MADDEN, R. D.; STOCKLAND, R.; PAYTON, M. E.; DILLWITH, J. W., 2002: Host plants affect fitness via the nutritional value of herbivore prey: investigation of a plant-aphid-ladybeetle system. *BioControl* **47**, 1–21.
- HÄMÄLÄINEN, M.; MARKKULA, M.; RAUJ, T., 1975: Fecundity and larval voracity of four ladybeetle species (Col., Coccinellidae). *Ann. Ent. Fenn.* **41**, 124–127.
- HIRONORI, Y.; KATSUHIRO, S., 1997: Cannibalism and inter-specific predation in two predatory ladybirds in relation to prey abundance in the field. *Entomophaga* **42**, 153–163.

- HODEK, I.; HONĚK, A., 1996: Ecology of Coccinellidae. Dordrecht: Kluwer Academic Publishers.
- HODEK, I.; RUZICKA, Z., 1979: Photoperiodic response in relation to diapause in *Coccinella septempunctata* (Coleoptera). Acta Entomol. Bohemoslov. **76**, 209–218.
- HUKUSIMA, S.; KAMEI, M., 1970: Effects of various species of aphids as food on development, fecundity and longevity of *Harmonia axyridis* Pallas (Coleoptera, Coccinellidae). Res. Bull. Fac. Agr. Gifu Univ. **29**, 53–66.
- KALUSHKOV, P. K., 1994: Zur lebensdauer, fruchtbarkeit und entwicklung von *Adalia bipunctata* (L.) (Col., Coccinellidae) bei aufzucht mit drei verschiedenen blattlausarten. Anz. Schädlingsk. PflSch. UmwSch. **67**, 6–7.
- KALUSHKOV, P. K., 1998: Ten aphid species (Sternorrhyncha: Aphididae) as prey for *Adalia bipunctata* (Coleoptera: Coccinellidae). Eur. J. Entomol. **95**, 343–349.
- KARILUOTO, K. T., 1980: Survival and fecundity of *Adalia bipunctata* (Coleoptera, Coccinellidae) and some other predatory insect species on an artificial diet and a natural prey. Ann. Ent. Fenn. **46**, 101–106.
- KIM, G. H.; CHOI, S. Y., 1985: Effects of the composition of artificial diets on the growth and ovarian development of an aphidovorous coccinellid beetle, *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae). Korean J. Entomol. **15**, 33–41.
- LAMANNA, M. L.; MILLER, J. C., 1996: Field observation on *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) in Oregon. Biol. Control **6**, 232–237.
- LAMANNA, M. L.; MILLER, J. C., 1998: Temperature-dependent development in an Oregon population of *Harmonia axyridis* (Coleoptera: Coccinellidae). Environ. Entomol. **27**, 1001–1005.
- van LENTEREN, J. C.; BABENDREIER, D.; BIGLER, F.; BURGIO, G.; HOKKANEN, H. M. T.; KUSKE, S.; LOOMANS, A. J. M.; MENZLER-HOKKANEN, I.; van RIJN P. C.; THOMAS M. B.; TOMMASINI, M. G.; ZENG, Q.-Q., 2003: Environmental risk assessment of exotic natural enemies used in inundative biological control. BioControl **48**, 3–38.
- LEWONTIN, R. C., 1965: Selection for colonizing ability. In: The Genetics of Colonizing Species. Ed. by BAKKER, H. G.; STEBBINS, G. L. New York: Academic Press, 77–94.
- MCCLURE, M. S., 1987: Potential of the Asian predator, *Harmonia axyridis* (Coleoptera: Coccinellidae), to control *Matsucoccus resinosae* Bean and Godwin (Homoptera: Margarodidae) in the United States. Environ. Entomol. **16**, 224–230.
- MICHAUD, J. P., 2000: Development and reproduction of ladybeetles (Coleoptera: Coccinellidae) on the citrus aphids *Aphis spiraecola* Patch and *Toxoptera citricida* (Kirkaldy) (Homoptera: Aphididae). Biol. Control **18**, 287–297.
- MICHELS, G. J.; FLANDERS, R. V., 1992: Larval development, aphid consumption and oviposition for five imported coccinellids at constant temperature on Russian wheat aphids and greenbugs. Southwest. Entomol. **17**, 233–243.
- NIJIMA, K.; MATSUKA, M.; OKADA, I., 1986: Artificial diets for an aphidophagous coccinellid, *Harmonia axyridis* and its nutrition. In: Ecology of Aphidophaga. Ed. by HODEK, I. Prague: Academic Press, 37–50.
- OBRYCKI, J. J., 1989: Parasitization of native and exotic Coccinellids by *Dinocampus coccinellae* (Schrank) (Hymenoptera: Braconidae). J. Kansas Entomol. Soc. **62**, 211–218.
- OBRYCKI, J. J.; ORR, C. J., 1990: Suitability of three prey species for nearctic populations of *Coccinella septempunctata*, *Hippodamia variegata*, and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). J. Econ. Entomol. **83**, 1292–1297.
- OBRYCKI, J. J.; TAUBER, M. J., 1981: Phenology of three coccinellid species: thermal requirements for development. Ann. Entomol. Soc. Am. **74**, 31–36.
- OBRYCKI, J. J.; ORR, D. B.; ORR, C. J.; WALLENDORF, M.; FLANDERS, R. V., 1993: Comparative developmental and reproductive biology of three populations of *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). Biol. Control **3**, 27–33.
- PHOOFOLO, M. W.; OBRYCKI, J. J., 1995: Comparative life-history studies of Nearctic and Palearctic populations of *Coccinella septempunctata* (Coleoptera: Coccinellidae). Environ. Entomol. **24**, 581–587.
- PHOOFOLO, M. W.; OBRYCKI, J. J., 1998: Potential for intraguild predation and competition among predatory Coccinellidae and Chrysopidae. Entomol. Exp. Appl. **89**, 47–55.
- SANTI, F.; BURGIO, G.; MAINI, S., 2003: Intra-guild predation and cannibalism of *Harmonia axyridis* and *Adalia bipunctata* in choice conditions. Bull. Insectol. **2**, 207–210.
- SCHANDERL, H.; FERRAN, A.; LARROQUE, M.-M., 1985: Le besoins trophiques et thermiques des larves de la coccinelle *Harmonia axyridis* Pallas. Agronomie **5**, 417–421.
- SCHANDERL, H.; FERRAN, A.; GARCIA, V., 1988: L'élevage de deux coccinelles *Harmonia axyridis* et *Semiadalia undecimnotata* à l'aide d'oeufs d'*Anagasta kuehniella* tués aux rayons ultraviolets. Entomol. Exp. Appl. **49**, 235–244.
- SIMBERLOFF, D.; STILING, P., 1996: How risky is biological control? Ecology **77**, 1965–1974.
- SNYDER, W. E.; JOSEPH, S. B.; PREZIOSI, R. F.; MOORE, A. J., 2000: Nutritional benefits of cannibalism for the lady beetle *Harmonia axyridis* (Coleoptera: Coccinellidae) when prey quality is poor. Environ. Entomol. **29**, 1173–1179.
- StatSoft™, 1994: STATISTICA User's Manual, version 5.0. Tulsa: StatSoft Inc.
- TEDDERS, W. L.; SCHAEFER, P. W., 1994: Release and establishment of *Harmonia axyridis* (Coleoptera: Coccinellidae) in the south-eastern United States. Entomol. News **105**, 228–243.
- THOMAS, M. B.; WILLIS, A. J., 1998: Biocontrol – risky but necessary? Trends Ecol. Evol. **13**, 325–329.
- YASUDA, H.; OHNUMA, N., 1999: Effect of cannibalism and predation on the larval performance of two ladybird beetles. Entomol. Exp. Appl. **93**, 63–67.
- YASUDA, H.; KIKUCHI, T.; KINDLMANN, P.; SATO, S., 2001: Relationships between attack and escape rates, cannibalism, and intraguild predation in larvae of two predatory ladybirds. J. Insect Behav. **14**, 373–384.
- ZAR, J. H., 1984: Biostatistical Analysis, 2nd edn. Englewood Cliffs: Prentice Hall.

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