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Comparison of life tables of *Coccinella septempunctata* L. and *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) reared on *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) Biotype B prey

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Abstract
Bemisia tabaci is a major pest of many agricultural crops worldwide. *Coccinella septempunctata* and *Harmonia axyridis* are two important polyphagous predators of *B. tabaci* on different agricultural crops. In the present study, life tables of the two predators were compared with feeding on *B. tabaci* biotype B prey on tomato host plant leaves as arena of observations under laboratory conditions. The results showed that both *C. septempunctata* and *H. axyridis* were able to complete embryonic and immature development and reached to adult stage when fed on *B. tabaci* prey. Mean total duration from egg to adult stage was 26.5 and 24.8 days for *C. septempunctata* and 20.6 and 19.9 days for *H. axyridis* females and males, respectively. Mean adult longevity of *C. septempunctata* was 74.8 and 61.8 days and of *H. axyridis* 62.6 and 47.3 days for females and males, respectively. *C. septempunctata* laid a mean total number of 710.5 eggs/female, while *H. axyridis* 542.0 eggs/female. Total mortality during different immature stages of *C. septempunctata* was 35.8% and of *H. axyridis* it was 37.2%. Female to male sex ratio was 51:49 for *C. septempunctata* and 52:48 for *H. axyridis*.

Keywords: *B. tabaci, C. septempunctata, H. axyridis,* Life table, Tomato

1. Introduction
Bemisia tabaci (Gennadius) (Homoptera: Aleyrodidae) is a highly polyphagous pest of more than 500 host plant species [1] belonging to more than 60 plant families [2]. *B. tabaci* biotype B is a key pest of many field, horticultural and greenhouse crops world-wide [2, 3]. The pest is difficult to control with conventional insecticides because of its high reproductive rate and preferred habitat on the undersurface of leaves [4].
Direct damages by *B. tabaci* to its hosts are due to the piercing and sucking cell contents by its nymphs and adults and excreting high quantities of honeydew that promotes sooty mould fungal development and reducing photosynthetic efficiency and thus yield. Indirect damages are caused by the transmission of more than 50 geminiviruses including the tomato yellow leaf curl virus (TYLCV) [5] tomato mottle virus (TMoV), and bean golden mosaic virus (BGMV) [6]. *B. tabaci* pose high threat to the production of food and fiber crops, which provides an impetus to use biological control for its control. Being an ecological phenomenon, biological control can provide environmentally harmonious and economical pest management [7]. Estimation of life-history parameters under diverse biotic and abiotic conditions helps in understanding changes in the status of pest species [8].
In northern China, *B. tabaci* has become an important pest of greenhouse- and field-grown vegetables and cotton crop since 1990s [9]. Therefore, biological control of the pest has to be practiced both under greenhouse and field cropping systems. Cotton agro-ecosystem has many polyphagous predators including *Propylaea japonica* (Thunberg), *Harmonia axyridis* (Pallas), *Coccinella septempunctata* L. (Coleoptera: Coccinellidae), *Chrysopa pallens* (Rambur), *Chrysopa sinica* Tjeder, *Chrysopa formosa* Brauer (Neuroptera: Chrysopidae), *Orius sauteri* (Poppius) (Heteroptera: Anthocoridae), and spiders. The densities of these natural enemies often peaks between June and October [10] and have been observed preying on *B. tabaci* [11]. While two native oligophagous predators mentioned above cannot survive in northern China's cold climate [12] and because *B. tabaci* B biotype is not native to China [13] therefore, understanding the role of native natural enemies in controlling the pest is very important.

An important initial step in this process is to determine biological parameters of the natural enemies with feeding on the pest species.

The ladybird beetle (*Coccinella septempunctata* L.) (Coleoptera: Coccinellidae) is an important polyphagous coccinellid species throughout the world. It has been successfully established in glasshouse crops such as tomato, sweet peppers and cucumbers. It feeds on diverse pest species including aphids, thrips, whiteflies, mites and lepidopteron eggs [14]. The multicolored Asian ladybeetle (*Harmonia axyridis* Pallas) (Coleoptera: Coccinellidae) is a well-known non-specific predator of many insect pests species [15]. It has high searching ability and consumption rate, and easy mass rearing and release in pest hot spot infestations in open fields and greenhouses [16]. Although the predator originated in Japan, Korea, Formosa, China and other parts of Asia [17] but due to high efficiency, it has been imported to many other countries of the world (i.e. France, USA, Greece, Egypt and Syria) [18, 19, 20].

Before launching a biological control program, it is important to investigate predator's biology and prey consumption, preference for a particular stage of a pest or pest species to be controlled as well as its interaction with other natural enemies present in the agro-ecosystem [21]. In addition, determination of oviposition and egg-laying behaviour strategies of the natural enemy greatly helps in better understanding its biological and ecological characteristics, which determines its offspring's efficiency and population growth rate [22].

This information may greatly help in using it in a biological control program against pest species. In the present research work, the embryonic and immature development, longevity, mortality, fecundity and sex ratio as life table parameters of *C. septempunctata* and *H. axyridis* were determined in the laboratory with feeding on *B. tabaci* biotype B prey on tomato host plant.

2. Materials and Methods

2.1 Insect pest and plant stock culture

The experiments were conducted at the Chinese Academy of Agricultural Sciences (CAAS) Beijing, China during 2006-07. A stock culture of *B. tabaci* biotype B was developed on tomato plants, variety Zhong Za No. 9, with individuals obtained from a previously maintained colony on cotton plants, variety Shi Yuan 321, in a glasshouse of the Institute of Plant Protection (IPP), South Campus, Chinese Academy of Agricultural Sciences (CAAS) Beijing, China. *B. tabaci* rearing was carried out in medium sized rectangular aluminum cages (80×50×60 cm) meshed with muslin cloth from all sides for aeration. The cages were maintained in a climatically controlled chamber at the IPP (South Campus), at 25±2°C temperature, 60±5% relative humidity and 16:8 h (L:D) photoperiod with 4000 lux artificial light intensity. Tomato plants were grown in small pots (10-cm diameter and 8-cm height) in a glasshouse. The plants were exposed to adult *B. tabaci* infestation in the stock culture. The adults were removed the next day and the plants were incubated as per above climatic conditions and daily observed until the individuals reached the desired stage, i.e. eggs, nymphs or puparia, for the different experiments. The newly grown plants were infested by the old ones.

2.2 Insect predator's stock culture

Stock cultures of *C. septempunctata* and *H. axyridis* were initiated with few individuals obtained from the cultures maintained for other laboratory experiments at the IPP. The rearing took place in cages, which were stored in climatic chambers at conditions as per *B. tabaci*. *Aphis craccivora* infested bean plants were used as substrate plants and prey for rearing the predators. For continuous prey supply, bean plants were grown every week, which were infested by the old ones.

For the different experiments, the desired stages of eggs, larvae and pupae as well as adult females and males of *C. septempunctata* and *H. axyridis*, were obtained from the rearing cages. The desired stages of the predators were separately transferred to fresh uniform sized leaves of the host plant and confined using the clip cages, with a mesh-covered hole in the bottom for aeration.

For the experiments on embryonic development, newly emerged adult pairs of *C. septempunctata* and *H. axyridis* were separately transferred to 2-3 week old tomato plants infested with abundant different instars of the prey and allowed to lay eggs for 24-48 hours. The adults were removed afterwards and 25 of the laid eggs by each species were confined in plastic clip-cages and observed daily for development. The plants were stored in the climatic chamber. The embryonic developmental duration was determined after all the eggs hatched.

2.3 Immature developmental periods of the insect predators

For the experiments on immature development of *C. septempunctata* and *H. axyridis*, 25 fresh individuals of each larval stage (1st, 2nd, 3rd and 4th larval stage) as well as pupal stage were selected from batches of similar aged-groups and confined on fresh uniform sized leaves of the host plant using clip-cages. The predators were daily supplied with abundant eggs, nymphs and pupal stages of the prey. The plants were stored in the climatic chamber. The leaves were daily observed for predators entering in to the next stage. The date of entering each larval as well as pupal stage into the next stage was recorded.

2.4 Embryonic and immature mortality of the insect predators

Embryonic as well as immature mortality of *C. septempunctata* and *H. axyridis* was determined in another experiment. For this, 250 freshly laid eggs as well as 125 newly emerged individuals of each of 1-4 larval instars as well as pupae were located and confined in clip-cages on fresh host plant leaves, with daily excess supply of different *B. tabaci* stages. The plants were stored in the climatic chamber. The mortality of eggs was determined by counting the number of hatching nymphs. For determining mortality during the larval stages and pupal stage, the test individuals were daily observed for development and mortality recorded by counting the number of individuals entering in the subsequent stage.

2.5 Longevity of the insect predators

For investigating adult longevity, newly emerged pairs (one female and one male) of *C. septempunctata* and *H. axyridis* were released/clip-cage and attached to a fresh uniform sized tomato leaf. The adult couples were daily supplied with excess number of different stages of *B. tabaci*. The observations on longevity of both sexes were daily made until the last adult died. The adults were transferred to fresh leaves when the old leaves showed signs of deterioration. Twenty five replicates were set up in this experiment.

2.6 Fecundity of the insect predators

For determination of fecundity of *C. septempunctata* and *H. axyridis*, newly emerged adult couples (one female and one male adult) were aspirated into clip-cages on the fresh host

plant leaves and supplied daily with excess number of different prey stages. The adults were transferred to fresh leaves when the previous leaves showed signs of deterioration. The number of laid eggs/female during its lifetime, until the last female died, was counted. The experiment was replicated 13 times.

To determine the pre-oviposition, oviposition and post-oviposition periods of *C. septempunctata* and *H. axyridis,* the first and last egg-laying days of the adult mated females were recorded during the longevity's experiment. For establishing fecundity of *C. septempunctata* and *H. axyridis* females during their oviposition period, the number of laid eggs was recorded daily and removed directly from the cages during the experiment on longevity. Daily and total fecundities were determined. There were 13 replications for each species.

2.6 Sex ratio of the insect predators

To establish the sex ratios of *C. septempunctata* and *H. axyridis,* one hundred adults were randomly selected from the stock cultures of each predator species and sexed under a binocular microscope. The female to male sex ratio was determined for each species.

In all the experiments, uniform sized fresh leaves and 2-3 weeks old tomato plants were used. All the experiments were conducted at 25±2ºC temperature, 60±5% RH, 16:8h photoperiod and a light intensity of 4000 lux.

2.7 Statistical analysis

The data obtained from the different experiments were subjected to T-test and significance levels were determined at $p \leq 5\%$. The means were compared using Statistic 8.1 software program.

3. Results and Discussion

3.1 Embryonic and immature developmental periods of the insect predators

In the present study, life tables of *Coccinella septempunctata* and *Harmonia axyridis* with *Bemisia tabaci* biotype B prey on tomato host plant was determined. The results showed that both *C. septempunctata* and *H. axyridis* were able to develop and reach the adult stage when fed on *B. tabaci* prey on tomato host plant. The immature development of *C. septempunctata* and *H. axyridis* consisted of an egg stage, four larval instars and a pupal stage. Mean developmental duration of *C. septempunctata* and *H. axyridis* egg, L_1, L_2, L_3, L_4 and pupal stage was 3.6, 3.4, 3.8, 3.9, 4.1, 7.7 and 3.2, 2.1, 3.3, 3.5, 3.8, 4.8 days for females (Fig 1) and 3.3, 3.2, 3.5, 3.7, 3.9, 7.2 and 3.1, 2.1, 3.2, 3.4, 3.6, 4.6 days for males (Fig 2), respectively. Mean total duration from egg to adult was 26.5, 20.6 days for females and 24.8, 19.9 days for males of *C. septempunctata* and *H. axyridis,* respectively.

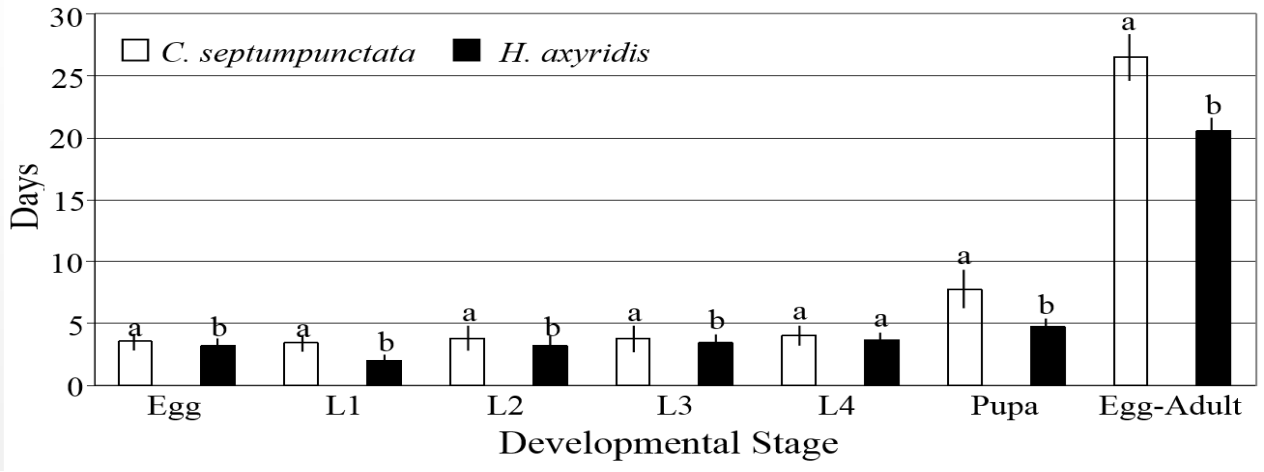

Fig 1: Mean duration of different developmental stages (days) of *Coccinella septumpunctata* and *Harmonia axyridis* females fed on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod. Bar heads with different letters are significantly different at $p \leq 5\%$ (t-test). Vertical lines at bar heads indicate Standard Error.

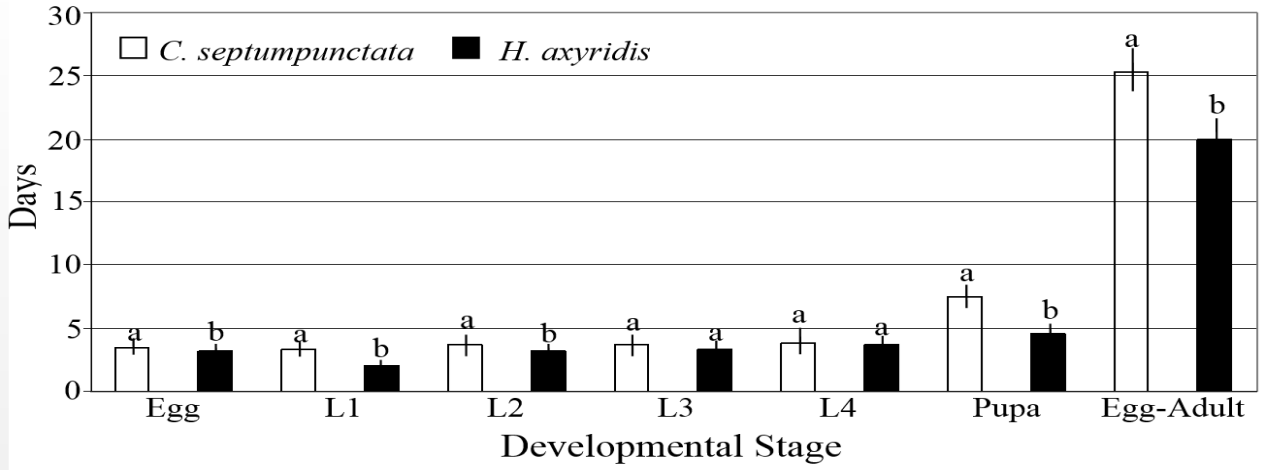

Fig 2: Mean duration of different developmental stages (days) of *Coccinella septumpunctata* and *Harmonia axyridis* males fed on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod. Bar heads with different letters are significantly different at $p \leq 5\%$ (t-test). Vertical lines at bar heads indicate Standard Error.

In the present study, total developmental time of *H. axyridis* immature stages in the current study was higher than reported by some previous researchers, e.g., 18.9 days, when fed on *Sitotroga cerealella* eggs [23] 18.6 days, fed on *M. persicae* [24] 18.0 days, fed on *E. kuehniella* [25] 18.07 days, fed on *A. gossypii* [26], 14.6 days from L_1 to adult eclosion on *A. pisum* [27].

3.2 Longevity of the insect predators

Duration of longevity was different for the two sexes of both species, where the females of both species lived longer than their males. Mean longevity was 74.8 days for females and 61.8 days for males of *C. septempunctata* and 62.6 days for females and 47.3 days for males of *H. axyridis* (Fig 3). Pre-oviposition, oviposition and post-oviposition periods for females were 7.8, 59.7 and 7.3 days for *C. septempunctata* and 8.3, 49.0 and 5.2 days for *H. axyridis*, respectively.

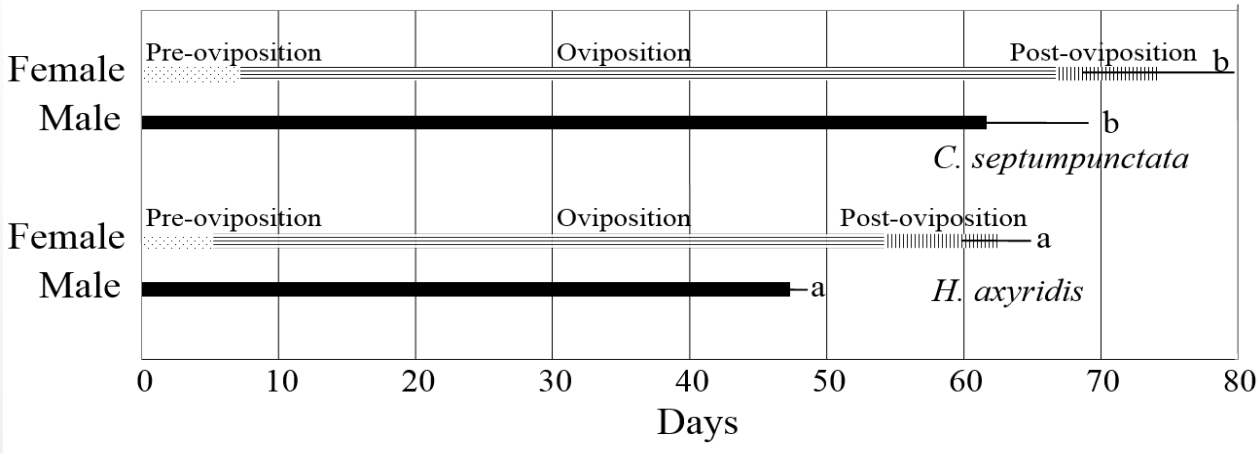

Fig 3: Mean duration of longevity (days) of *Coccinella septumpunctata* and *Harmonia axyridis* adults fed on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod. Bar heads with different letters are significantly different at p ≤ 5% (t-test). Horizontal lines at bar heads indicate Standard Error.

Duration of *C. septempunctata* pre-oviposition, oviposition and post-oviposition periods and total longevity in the present and earlier studies were found different, e.g., 31.4 days longevity on *A. gossypii* [28], 13-30 days pre-oviposition period when fed on *A. gossypii* [26], 27.5 days longevity, 7.4 days pre-oviposition, 13.7 days oviposition and 3.6 inter-oviposition period when fed on *M. persicae* [29].

3.3 Fecundity of the insect predators

Fecundity of *C. septempunctata* was a mean total number of 710.5 eggs/female, ranging from 649-760 eggs and of *H. axyridis* 542.0 eggs/female, ranging from 475-630 eggs (Fig 4). Great variation has been observed between *C. septempunctata* fecundity determined in the present and earlier studies, e.g., 312.83 eggs/female [29], 1764.10 eggs/female [30]. While some previous authors have reported *H. axyridis* fecundity almost similar to ours, e.g., 560.5 eggs/female (18.3 eggs/f/day) fed on *M. persicae* [28] but others have reported much lesser, e.g., 314.0 eggs/female fed on *M. persicae* and 342.2 eggs/female fed on *A. fabae* [31] or higher fecundities, e.g., 718.7 eggs/female fed on *A. gossypii* [27], 751 eggs/female fed on *A. gossypii* [25].

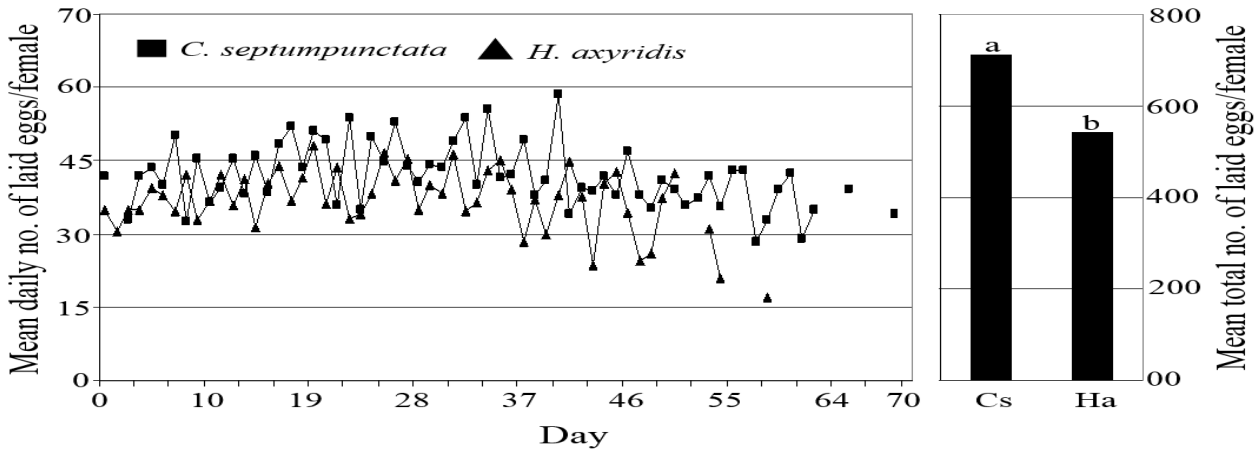

Fig 4: Mean daily and total fecundity (no. of eggs/female) of *Coccinella septumpunctata* (Cs) and *Harmonia axyridis* (Ha) with feeding on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod. Bar heads with different letters are significantly different at p ≤ 5% (t-test). Standard Error for Cs = 8.16 and for Ha = 14.01.

3.4 Mortality of the insect predators

Mortality recorded during embryonic, L_1, L_2, L_3, L_4 and pupal stage was 9.4, 6.4, 4.8, 4.8, 4.8, 4.8, 5.6% for *C. septempunctata* and 9.2, 6.4, 5.6, 4.0, 5.6, 6.4% for *H. axyridis*, respectively (Table 1). Total mortality from egg to adult stage was 35.8% for *C. septempunctata* and 37.2% for *H. axyridis*.

Table 1: Mortality (%) during embryonic, immature and adult stages of *Coccinella septumpunctata* and *Harmonia axyridis* fed on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod.

Species	n	Mortality (%) during egg stage	Mortality (%) during immature stages Total Mortality (%)				Pupa	Total Mortality (%)
			L_1	L_2	L_3	L_4		
C. septempunctata	100	9.4	6.4	4.8	4.8	4.8	5.6	35.8
H. axyridis	100	9.2	6.4	5.6	4.0	5.6	6.4	37.2

Earlier researchers have reported different mortalities of *C. septempunctata*, e.g., 9.33% mortality of 4th instar larvae fed on aphid [31], 8.34% mortality [29], 12.12% mortality [30]. Similarly, great variation was found in *H. axyridis* mortalities recorded during present and earlier studies, e.g., 14.1% fed on *A. gossypii* [27], Pre-imaginal mortality of 3.3% fed on *A. gossypii* [32], 36.8% embryonic mortality fed on *M. persicae* and 36.1% mortality fed on *A. fabae* [31]. The first instar of *C. septempunctata* and *H. axyridis* was the most sensitive developing stage to food quality and vulnerable to mortality factors [33].

3.5 Sex ratio of the insect predators

The sex ratio experiment revealed 51:49 and 52:48 female to male ratio for *C. septumpunctata* and *H. axyridis*, respectively (Table 2). *H. axyridis* showed 39% female ratio fed on *M. persicae* [28].

Table 2: Sex ratio of *Coccinella septempunctata* and *Harmonia axyridis* adults fed on *Bemisia tabaci* biotype B prey on tomato leaves as arena of observation at 25±2ºC, 70±5% RH and 16:8h photoperiod.

Species	n	Female (%)	Male (%)	Sex ratio (Female: Male)
C. septempunctata	100	51	49	51:49
H. axyridis	100	52	48	52:48

Comparison between the results of the present and earlier studies has clearly demonstrated that life-history parameters, i.e., immature and mature development, fecundity and survival, are highly influenced by food quality, prey stage and prey species.

Comparison of life tables of the two polyphagous predators of *B. tabaci* might help better understand and predict its population dynamics under field conditions. The present information of natural enemies can be used in devising new or improving the already existing integrated pest management programs for suppression of the pest in the different agricultural cropping systems both under glasshouse and filed conditions.

4. Acknowledgment

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