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Studies to identify an alternative aphid host for culturing the predatory syrphid, *Ischiodon scutellaris* (Fabricius) (Diptera: Syrphidae)

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Abstract

Background Aphidophagous syrphid, *Ischiodon scutellaris* (Fabricius) (Diptera: Syrphidae) is an effective predator of aphids that infest many agricultural and horticultural crops. Cowpea aphid, *Aphis craccivora* Koch (Hemiptera: Aphididae), is the natural host for culturing syrphid predator, *I. scutellaris*. The present study was conducted to evaluate the feeding and development of *I. scutellaris* on seven species of aphid hosts viz., *A. craccivora*, *Aphis fabae* Scopoli, *Aphis gossypii* Glover (from cotton), *Schoutedenia emblica* (Patel & Kulkarni), *Brevicoryne brassicae* (L.), *Aphis gossypii* (from okra) and *Hyperomyzus carduellinus* (Theobald) and to identify an alternative aphid host to maintain the culture of *I. scutellaris* during the situation of non-availability/loss of the culture of *A. craccivora*.

Results *Aphis fabae* was not accepted for feeding by the larvae of *I. scutellaris*. The larvae of *I. scutellaris* did not survive on *S. emblica*. The descending order of feeding potential of aphids by *I. scutellaris* was *A. craccivora* > *H. carduellinus* > *B.brassicae* > *A. gossypii* (from cotton) > *A. gossypii* (from okra) > *S. emblica*. The larva of *I. suctellaris* completed its development in combination of the aphid prey (*A. craccivora* + *H. carduellinus*). The net reproductive rates (R_0) of *I. scutellaris* when fed on *A. craccivora* and *H. carduellinus* were 308.28 and 302.33, respectively. The intrinsic rate of increase (*r*) of *I. scutellaris* was significantly higher when reared on *H. carduellinus* (0.155 ± 0.003) than on *A. craccivora* (0.143 ± 0.004).

Conclusion The results confirmed that *H. carduellinus* reared on *Lactuca virosa* could serve as an alternate host for the mass production of *I. scutellaris*.

Keywords *Ischiodon scutellaris*, *Aphis craccivora*, Alternate host, *Hyperomyzus carduellinus*, Mass-rearing

Background

Aphids are a major group of sucking pests that cause economic damage by sucking sap from different plant parts like stems, leaves, flower buds, and fruits in several agricultural and horticultural crops (Shylesha et al. 2006; Thakur et al. 2009; Bashir et al. 2013). Syrphids are very important predators of many species of economically important aphids (Chambers et al. 1983). *Ischiodon scutellaris* (Fabricius) (Syrphidae: Diptera) is an efficient predator of different species of aphids like *Aphis craccivora* Koch (Joshi et al. 1999), *Brevicoryne brassicae* (L.) (Sharma and Bhalla 1988), *Lipaphis pseudobrassicae* (Davis) (Devjani and Singh 2006), *Rhopalosiphum maidis* (Fitch) (Singh and Mishra 1988) and *Toxoptera aurantii* (Boyer de Fonscolombe) (Radhakrishnan and Muraleedharan 1993). Hitherto aphid, *Aphis craccivora* was the only natural host used for the rearing of the larvae of *I. scutellaris* (Joshi et al. 1998).

To maintain the culture of *I. scutellaris*, there is a need for year-round maintenance of *A. craccivora* cultured on cowpea plants. The unavailability of aphid culture to feed

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the developing syrphid larvae leads to starvation and loss of culture. In the event of the non-availability of *A. craccivora*, there is a need to identify alternate aphid hosts for maintaining the culture of *I. scutellaris*. There is a single greater reliance on the cowpea or other pulse crops cultivated in the fields which are infested by *A. craccivora* to initiate the culture. Many a time it is difficult to ensure the availability of the culture of *A. craccivora* during the monsoon season. The rainy days negatively impact the population establishment of sucking pests like aphids, whiteflies, and mealybugs (Villanueva 2019). The natural parasitization by parasitoids under field conditions is an additional factor that directly causes the loss of an active culture of *A. craccivora* (Amin et al. 2009).

Hence, there is a need to identify another suitable aphid host for rearing and maintaining the culture of *I. scutellaris* rather than depending solely on *A. craccivora* as a natural host. The present study was conducted to identify another suitable aphid host that could be effectively multiplied on a host plant to serve as a supplement to maintain the culture of *I. scutellaris* during the non-availability of the natural host, *A. craccivora*. Although the predatory potential of *I. scutellaris* on different species of aphids has been well investigated across the globe, there has been no published literature on the identification of any alternate host in addition to *A. craccivora* for long-term maintenance of the live culture. In the present study, the development of *I. scutellaris* on different species of aphid hosts was compared and evaluated. The development of larva and adult and population growth parameters of *I. scutellaris* on *A. craccivora* were compared with those on other species of aphids so as to identify an alternative host for maintaining and mass rearing of *I. scutellaris*.

Methods

Study site

The study was carried out at the experimental farm of the National Bureau of Agricultural Insect Resources (NBAIR) of ICAR in Bengaluru, Yelahanka Campus (13.096932N, 77.56759E) which is located in the heart of the rapidly growing capital city of the south Indian state of Karnataka.

Maintenance of stock culture of *A. craccivora*

Cowpea seeds were sown in earthen pots (20 × 20 cm) at the rate of four seeds per pot and maintained in the greenhouse. The plants after germination were watered regularly. The live culture of *A. craccivora* was collected from the field-infested cowpea plants. Three to four leaves of cowpea infested with *A. craccivora* were hand collected and placed gently over the healthy cowpea plants raised in the earthen pots. The settlement and colonization of the aphids was monitored on a daily basis. This served as the stock culture of *A. craccivora* for the entire set of experiments.

Maintenance of plants for oviposition studies

Another set of cowpea seeds was sown in small-sized plastic pots (10 × 10 cm) at a rate of two seeds per pot to serve as plants for oviposition by the adult flies. The germinated plants after attaining the five-leaf stage were inoculated with aphids. These plants have been monitored for the colonization of inoculated aphids on daily basis. This set of plants has been used in experiments on the oviposition of adult flies.

Culture of the syrphid, *Ischiodon scutellaris*

Cabbage crop was raised at the experimental farm of the ICAR-NBAIR Yelahanka campus. The crop was regularly monitored for syrphids' predators. The larvae of *I. scutellaris* were collected from the aphid-infested leaves using a fine hair brush in a circular plastic rearing container (9 × 4 cm) with fine mesh fitted at the lid for aeration. The collected larvae were brought to the laboratory and supplied with *A. craccivora* ad libitum till pupation. The pupae were collected separately and kept for the emergence of adult flies.

Rearing of adult syrphid flies

After the emergence of the adult flies, they were released inside a wooden cage (30 × 30 × 30 cm). Honey solution (50%) swabbed on cotton was placed in a Petri plate as a carbohydrate source for the adults. Pollen grains collected from the flowers of castor plants were placed in a dish inside the cage. In addition to the pollen and honey, cowpea plants infested with *A. craccivora* were placed inside the cage for oviposition by adult flies. Cowpea plants with aphids were checked on a daily basis for the presence of eggs laid by *I. scutellaris*. Plants were replaced every alternate day for oviposition. The plants taken out of the cage were placed inside a plastic container with a lid fitted with mesh for proper aeration. The hatchlings were monitored regularly. First instar larvae upon hatching were collected using a camel hair brush and released into the circular plastic rearing container (9 × 4 cm) with a fine mesh fitted at the lid for aeration and provided with cowpea leaves infested with *A. craccivora* on a daily basis for its feeding and development. This served as a stock culture of syrphid predator, *I. scutellaris*.

Aphid host suitability studies for the rearing of *I. scutellaris* larvae

Host suitability of seven different aphid species viz., *Aphis craccivora* from cowpea, *A. gossypii* (from cotton), *A. fabae* from *S. nigrum*, *S. emblica* from *Phyllanthus* sp, *A. gossypii* (from okra) and *H. carduellinus* from *Lactuca virosa* (wild lettuce) for the rearing of *I. scutellaris* was evaluated. From the stock culture of *I. scutellaris*, the freshly hatched first instar larva was collected gently using a fine camel hair brush and released inside the circular rearing dish (9 × 4 cm) fitted with mesh at the top for aeration. Ten replicates each with one larva per replicate was maintained. The number of aphids consumed (only emptied exoskeleton) was counted on a daily basis in each treatment. A fresh supply of host aphids (100 mixed stages of aphids/day) in each treatment was also supplied on a daily basis. The duration of larva, pupa and pupal weight of *I. scutellaris* when reared on five aphid host species viz., *A. craccivora*, *A. gossypii* from cotton, *H. carduellinus*, *A. gossypii* from okra and *B. brassicae* were recorded. Since the larvae of *I. scutellaris* failed to accept *A. fabae* for feeding and did not survive on *S. emblica*, the development of *I. scutellaris* was recorded only from the other five aphid prey, which was accepted by the syrphid larvae. The survival percentage of the feeding stage i.e., larvae of *I. scutellaris* was also recorded in each treatment.

Development of *I. scutellaris* reared on a combination of aphid species

Out of the five aphid prey species evaluated, the most preferred aphid in terms of the number of aphids consumed per day was *H. carduellinus.* It was used for further studies. The experiment was conducted with the aim to meet the situations of nonavailability or sudden loss of standard natural host, *A. craccivora* during the rearing of *I. scutellaris*. In this experiment, the larvae of *I. scutellaris* were reared on a combination of aphid preys viz., *A. craccivora* and *H. carduellinus*. Five replicates were maintained and the experiment was repeated twice. Newly hatched first instar larvae of *I. scutellaris* at the rate of one larva per replicate were collected from the stock culture and supplied with *A. craccivora* for 1–3 days and *H. carduellinus* for 4–6 days. The number of aphids consumed per day and the duration of the larval and pupal stages were recorded. The survival percentage of the larvae was also recorded when reared on two different aphid preys.

Fecundity of *I. scutellaris* reared on *A. craccivora* and *H. carduellinus*

A mated pair of the newly emerged adult flies of *I. scutellaris* was released inside a wooden rearing cage (30 × 30 × 30 cm) and supplied with cotton swabbed with a honey solution for feeding. Honey bee pollen (approximately 1 g) was given in a small bowl inside the cage. Two treatments viz., cowpea plant grown in tiny pots at 4–5 leaf stage infested with *A. craccivora* and *Lactuca virosa* plant grown in tiny pots at 4–5 leaf stage infested with *H. carduellinus* were maintained. A uniform density of both aphid species (100 nymphs of each aphid host) was maintained inside the cages. Ten replicates were maintained for this study. Freshly aphid-infested plants were supplied for the adults for oviposition on alternate days. The plants with aphids that were exposed to the flies for oviposition were taken out from the cage and separately maintained outside the cage and observed on daily basis for the hatching of the eggs. The pre-oviposition, the number of ovipositional days and total fecundity were recorded. The rate of hatching of the eggs laid by *I. scutellaris* was calculated by taking the ratio of the number of hatched eggs with the total number of eggs laid in both treatments. The population growth parameters (net reproductive rate R_0, intrinsic rate of increase r, finite rate of increase λ and mean generation time T_G) (Birch 1948) were worked out using the following formulae:

1. Net reproductive rate, $R_0 = \Sigma \text{lxmx}$

   where lx indicates the number of individuals surviving to age x and mx indicates the number of female offspring per female of age x.
2. Mean generation time, $T_G = \Sigma \text{xlxmx}/\Sigma \text{lxmx}$
3. Intrinsic rate of increase, $r = \log R_0/T_G$, where R_0 indicates net reproductive rate and T_G indicates mean generation time.
4. Finite rate of increase, $\lambda = e^r$

Data analysis

Analysis of variance (GLM in SAS 9.3; SAS Institute, Cary, NC) was used to compare the feeding preference and development of larvae and adults of *I. scutellaris* in different species of aphids. Where significant difference was detected, treatment means were separated using Tukey's HSD Test (0.05%).

Results

Aphid host suitability studies for rearing the larvae of *I. scutellaris*

The influence of seven different species of aphids on the development of larvae of syrphid, *I. scutellaris* was studied (Fig. 1). The larva of *I. scutellaris* did not prefer to be fed on *A. fabae*. A significant difference in the number of aphids consumed by the larva of *I. scutellaris* per day was recorded across the six different species of aphids (F value = 9.21; df = 5.45; $P < 0.0001$). Amongst the remaining six different aphids, the mean number of *A. craccivora* (50.05 aphids/day) consumed by *I. scutellaris* was the highest, which was statistically on par with the consumption of *H. carduellinus* (50.20 aphids/day), *B.*

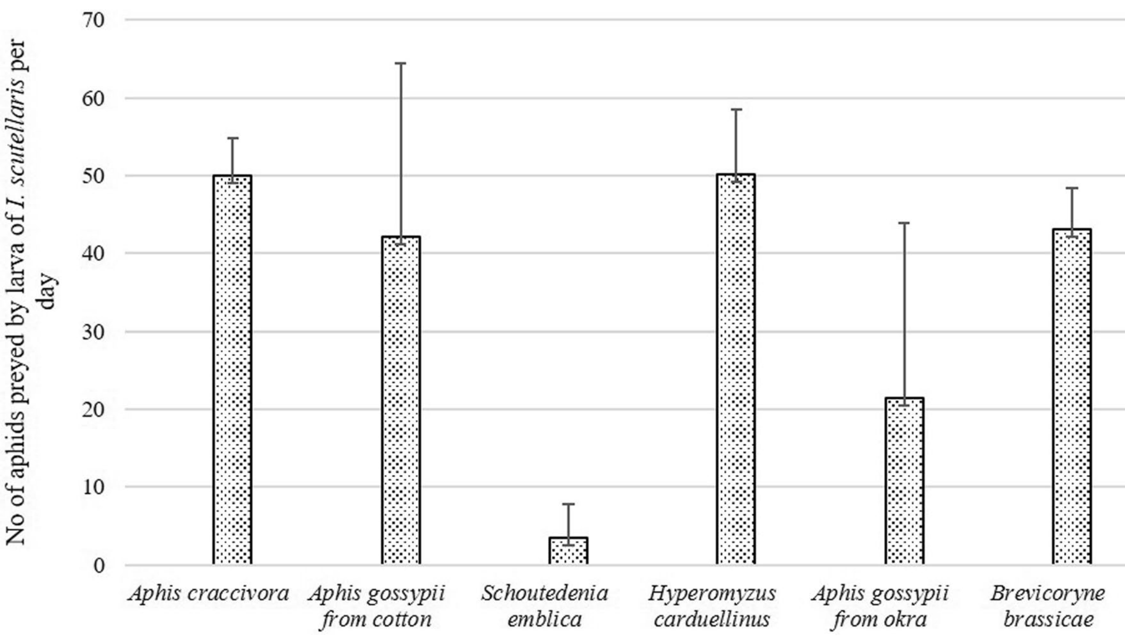

Fig. 1 Feeding potential of the larva of *Ischiodon scutellaris* on different aphid hosts. Note: Among all the species of aphids studied, *Aphis fabae* was not accepted by the syrphid, *I. scutellaris* hence not included for statistical analysis

brassicae (43.08 aphids/day), *A. gossypii* (42.10 aphids/day) and *A. gossypii* from okra (21.45 aphids/day). The lowest rate of consumption by the larva of *I. scutellaris* was recorded on *S. emblica* (3.55 aphids/day).

There was a significant difference in the larval duration of *I. scutellaris* reared on different species of aphids (F value = 4.04; df = 5.45; $P < 0.0001$) (Table 1). The duration of the larval stage of *I. scutellaris* was the lowest on *A. craccivora* (4.40 ± 2.50 days), which was statistically on par with that of *H. carduellinus* (5.60 ± 0.55 days). The larval duration of *I. scutellaris* fed with *A. gossypii* was (6.20 ± 0.44 days) which was on par with *A. gossypii* from okra (7.20 ± 0.84 days) and *B. brassicae* (7.00 ± 0.71 days). There was a non-significant difference in the duration of the pupal stage of *I. scutellaris* reared on different species of aphids. The pupal period of *I. scutellaris* ranged between 4.80 ± 0.81 to 7.00 ± 0.71 days across the different aphid hosts.

There was a significant difference in the pupal weight of *I. scutellaris* reared on different species of aphids (F value = 3.53; df = 5.45; $P < 0.0001$). The highest weight of pupae of *I. scutellaris* was recorded when the larvae were reared on *B. brassicae* (27 mg), which was statistically on par with that on *H. carduellinus* (23 mg), *A. craccivora* (19 mg) and *A. gossypii* (19 mg). The lowest weight of pupae of *I. scutellaris* (9 mg) was when reared on *A. gossypii* from okra.

Table 1 Development of *Ischiodon scutellaris* on different aphid hosts

Aphid species	Development of *Ischiodon scutellaris*			
	Larval duration (days)	Pupal duration (days)	Pupal weight (mg)	Survival (%)
Aphis gossypii from cotton	6.20 ± 0.44[a]	5.20 ± 0.84	19.0 ± 3.00[a]	100.00[a]
Aphis craccivora	4.40 ± 2.50[b]	4.80 ± 0.81	19.0 ± 10.00[a]	100.00[a]
Hyperomyzus carducellinus	5.60 ± 0.55[ab]	5.60 ± 0.89	23.0 ± 3.00[a]	100.00[a]
Aphis gossypii from okra	7.20 ± 0.84[a]	7.00 ± 0.71	9.0 ± 12[b]	56.40[b]
Brevicoryne brassicae	7.00 ± 0.71[a]	6.60 ± 0.55	27.0 ± 2[a]	100.00[a]
F value	4.04	–	3.53	3.51
P value	$p < 0.0001$	NS	$p < 0.0001$	$p < 0.0001$

Means followed by same letter do not differ significantly from each other

Among all the aphid species studied, the larvae of *I. scutellaris* didn't survive on *Schoutedenia emblica, hence* not included for statistical analysis

The larval survival rate of *I. scutellaris* differed significantly when reared on the different aphid hosts (F value = 3.51; df = 5.45; $P < 0.0001$). The larvae of *I. scutellaris* reared on *A. craccivora*, *A. gossypii*, *H. carduellinus* and *B. brassicae* recorded a 100% rate of survival. A significantly lower rate of survival of *I. scutellaris* was observed when fed on *A. gossypii* from okra (56.40%).

Development of *I. scutellaris* reared on a combination of aphid species

In the combination of the aphid species feeding experiment, the mean larval and pupal duration of *I. scutellaris* was 6.80 ± 0.84 and 5.60 ± 0.55 days (Table 2). The average pupal weight was 27.60 ± 0.55 mg. There was 100% survival of the larvae of *I. scutellaris* when reared on a combination of the two aphid species viz., *A. craccivora* from cowpea and *H. carduellinus*.

Fecundity of *I. scutellaris* reared on *A. craccivora* and *H. carduellinus*

Adult fecundity and population growth studies were recorded in cowpea plants infested with *A. craccivora* and *L. virosa* infested with *H. carduellinus* (Table 3). There was a non-significant difference in the pre-ovipositional period and the number of ovipositional days of adult flies of *I. scutellaris* when fed on both the aphid hosts. The mean pre-ovipositional period of *I. scutellaris* in *A. craccivora* and *H. carduellinus* were 4.40 ± 0.55 and 4.20 ± 0.84 days, respectively. The ovipositional period of *I. scutellaris* was recorded for a time span of 23.80 ± 2.38 and 26.41 ± 1.81 days in *A. craccivora* and *H. carduellinus* hosts, respectively. Fecundity of *I. scutellaris* differed significantly (F value = 17.91; df = 2.18; $P < 0.0001$) with respect to the two aphid hosts viz., *A. craccivora* (353.40 ± 8.56 eggs/female) and *H. carduellinus* (323.81 ± 13.08 eggs/female). There was a non-significant difference in the hatching rate of eggs laid by adults of *I. scutellaris* in the colonies of *A. craccivora* (80.20 ± 3.49%) and *H. carduellinus* (82.80 ± 4.21%).

Population growth parameters of *I. scutellaris* reared on *A. craccivora* and *H. carduellinus*

Based on the adult ovipositional studies, the population growth parameters viz., net reproductive rate, intrinsic rate of increase, mean generation time and finite rate of increase of *I. scutellaris* worked out on two aphid hosts; *A. craccivora* and *H. carduellinus* (Table 3). There was a non-significant difference in the net reproduction rate (R_0) between *A. craccivora* (308.28) and *H. carduellinus* (302.33). The mean generation time (T_G) of *I. scutellaris* differed significantly (F value = 20.79; df = 2.18; $P < 0.001$) between the two aphid hosts; *A. craccivora* (16.74 ± 0.35 days) and *H. carduellinus* (16.02 ± 0.04 days). The values of the intrinsic rate of increase (r) of *I. scutellaris* differed significantly (F value = 22.10; df = 2.18; $P < 0.001$) between the two aphid hosts *A. craccivora* (0.143 ± 0.004) and *H. carduellinus* (0.155 ± 0.003). The finite rate of increase (λ) of *I. scutellaris* varied significantly (F value = 48.69; df = 2.18; $P < 0.001$) between the two aphid hosts *H. carduellinus* (2.02 ± 0.03) and *A. craccivora* (1.97 ± 0.03).

Table 3 Comparison of reproductive parameters of *Ischiodon scutellaris* on the two different aphid hosts

Parameters	*A. craccivora*	*H. carduellinus*
Pre-oviposition period	4.40 ± 0.55	4.20 ± 0.84
Number of ovipositional days	23.80 ± 2.38	26.41 ± 1.81
Fecundity (no. of eggs per female)	353.40 ± 8.56[a]	323.81 ± 13.08[b]
Rate of egg hatching (%)	80.20 ± 3.49	82.80 ± 4.21
Net reproductive rate, R_0	308.28	302.33
Intrinsic rate of increase, r	0.143 ± 0.004[b]	0.155 ± 0.003[a]
Mean generation time, T_G	16.74 ± 0.35[a]	16.02 ± 0.04[b]
Finite rate of increase, λ	1.97 ± 0.03[b]	2.02 ± 0.03[a]

Means followed by same letter do not differ significantly from each other

Discussion

Among the seven different species of aphids evaluated in descending order of preference of hosts for feeding by *I. scutellaris* were *A. craccivora* > *H. carduellinus* > *B. brassicae* > *A. gossypii* (from cotton) > *A. gossypii* (from okra) > *S. emblica*. Some species of aphids viz., *A. fabae* were not preferred by *I. scutellaris* for feeding. *A. fabae* was seen colonizing the unripe green berries of *Solanum nigrum* in greater numbers with few nymphs in leaves. The green berries of *S. nigrum* were reported to contain Solanine, a glycoalkaloid (Kanteh and Norman 2015). Aphids have been reported to sequester host plant

Table 2 Development of *Ischiodon scutellaris* on combination of aphid hosts

Aphid species	Development of *I. scutellaris*			
	Larval duration (days)	Pupal duration (days)	Pupal weight (mg)	Survival (%)
Aphis craccivora (cow pea) (fed for 1–3 days) + *H. carduellinus* (fed for 4–6 days)	6.80 ± 0.84	5.60 ± 0.55	27.60 ± 0.54	100

alkaloids/allelochemicals for their own defence against their natural enemies (Desneux et al. 2009). *A. fabae* may have sequestered the alkaloids during the process of feeding on *S. nigrum,* which later may have resulted in *I. scutellaris* rejecting *A. fabae* as a host. The larvae of *I. scutellaris* consumed a significantly lower number of *S. emblica* per day. Similarly, most plants belonging to the genus *Phyllanthus* were reported to contain alkaloids, flavonoids, terpenes and lignans (Seeff et al. 2013). The larvae of *I. scutellaris* reared on *S. emblica* were observed to die on the third day after feeding. The dead larvae appeared shrunken and turned pale yellowish brown. The authors also observed the natural oviposition of syrphid predators in the colonies of all studied species of aphids, except in *A. fabae* and *S. emblica*. They also attribute the reason for non-preference/underdevelopment of the larvae of *I. scutellaris* on *A. fabae* and *S. emblica* might be due to the sequestration of chemical constituents in the host plants by the respective aphid species.

The developmental duration of larvae and pupae was not significantly influenced by the aphids' species on which they were fed. However, the larvae of *I. scutellaris* reared on *A. gossypii* from okra recorded the least pupal weight. This could be directly correlated with larval feeding activity. Compared to other aphid hosts evaluated, the number of *A. gossypii* from okra consumed per day by the larvae of *I. scutellaris* was relatively lower resulting in the decreased pupal weight of *I. scutellaris* than other species of aphids. The critical weight of the life stage of a fly is directly dependent on the quality and quantity of the larval diet (Davidowitz and Nijhout 2004). The observations on the mean pupal weight of *I. scutellaris* reared on *A. craccivora* in the present study (19.0 mg) is in conformity with that recorded by Joshi et al. (1999) when reared on *A. craccivora*. The survival percentage of *I. scutellaris* fed on *A. gossypii* from cotton was observed to be better than that of *A. gossypii* from okra. The effect of the host plant may be one of the possible reasons for the increased survival rate and pupal weight of *I. scutellaris* when fed on *A. gossypii* from cotton compared to *A. gossypii* from okra. Similar observations were recorded by one of the co-authors where a relatively higher mortality rate of larvae of *I. scutellaris* was observed when reared on *A. craccivora* from *Glyricidia maculata* than *A. craccivora* from cowpea (Joshi et al., Personal communication).

The results of the combination of aphids feeding experiment concluded that the growth and development of *I. scutellaris* were not affected by the change in host aphid species during its course of development. This is very crucial in the rearing of *I. scutellaris* as there could be a sudden loss of the natural host, *A. craccivora* due to coccinellid predation. Also, sudden loss of colonies of *A. craccivora* due to the parasitization by *Aphidius colemani* Viereck. a major parasitoid of *A. craccivora* as reported by Rakhshani et al. (2005). The results indicated that during the situations of non-availability of *A. craccivora*, to avoid the disruption in the rearing of *I. scutellaris,* the larvae could be fed alternately when fed on *H. carduellinus.*

The egg-hatching rate of *I. scutellaris* was slightly higher on *H. carduellinus* in *L. virosa* than *A. craccivora* in cowpea. The reason could be that the cowpea plant tends to lose its turgor pressure at a faster rate than *L. virosa* which might have resulted in a slightly higher egg-hatching rate of the eggs laid in the colonies of *H. carduellinus* in *L. virosa*. Cowpea plants at the five-leaf stage showed a tendency to droop even when maintained with a proper supply of moisture in the root zone, unlike *L. virosa*. The maintenance of the lengthy and sturdy nature of *L. virosa* plant compared to cowpea might be also a reason for the increased number of ovipositional days. Life table parameters are viable measures to estimate population development, survival and reproduction (Price 1997). The net reproductive rate (R_0) is a factor that indicates the stability of the population (Ning et al. 2017). The non-significant difference in R_0 values in the present study, when *I. scutellaris* was reared on *A. craccivora* and *H. carduellinus* indicated that the syrphid culture could be maintained on both the aphid species. The value of the intrinsic rate of increase (r) indicates the population growth of the organism under study. Insects with shorter pre-ovipositional periods were reported to have a high r-value (Lewontin 1965). In the present study, the r-value of *I. scutellaris* was significantly higher on *H. carduellinus*. The pre-ovipositional period of *I. scutellaris* on both the aphid hosts viz. *A. craccivora* and *H. carduellinus* was statistically on par with each other. The mean generation time (T_G) of *I. scutellaris* was significantly shorter on *H. carduellinus* than *A. craccivora*. Lower generation time recorded on *H. carduellinus* indicated that it is a suitable host for the rearing of *I. scutellaris.* The authors infer that the host plant turgidity could be one of the probable reasons for higher T_G values in *A. craccivora*. The leaf branches of cowpea were less sturdy than *L. virosa*. T_G values are the indicator of the survival rate and fecundity, host plant stature might also be a factor of concern that resulted in lower values of T_G in *I. scutellaris* reared on *H. carduellinus* in *L. virosa* plants. The finite rate of increase and intrinsic rate of increase was higher on *H. carduellinus* though generation time was lower on *H. carduellinus.* The reproductive rate of *I. scutellaris* was comparable on both *A. craccivora* and *H. carduellinus.* This showed that *I. scutellaris* could be a more effective predator while preying on *H. carduellinus* compared to *A. craccivora*. However, the finite rate of increase values differed marginally between the two aphid hosts (2.02 in

H. carduellinus and 1.97 in *A. craccivora*), which implies that the predatory syrphid, *I. scutellaris* could be multiplied on both the aphid hosts.

Conclusions

Active colonization of aphid, *H. carduellinus* was recorded throughout the year on *Lactuca virosa*. Natural oviposition by *I. scutellaris* in the colonies of *H. carduellinus* was observed in the study area. The host plant propagation through seeds of *L. virosa* so as to ensure host plant availability for multiplication of *H. carduellinus* throughout the year was studied.

Considering the various biological parameters like a greater number of aphids consumed per day, shorter larval/pupal duration and higher r- value in *H. carduellinus*, it was concluded that it is another potential alternative natural aphid host apart from *A. craccivora* for successful culturing and maintenance of the predatory syrphid, *I. scutellaris*.

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Author contributions
CKGR conducted the experiments and collected the data. AU analysed the data and drafted the manuscript. SJ guided the experiments on mass culturing of the syrphids. TMS reviewed the draft. All the authors read and approved the manuscript.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
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The authors declare that they have no competing interests.

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