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Review Article

Syrphid predators for biological control of aphids

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ABSTRACT: The family Syrphidae is divided into three subfamilies *viz.*, Syrphinae, Milesiinae and Microdontinae. Majority of aphidophagous syrphids belong to the subfamily Syrphinae. Most species are terrestrial, while a few species are aquatic or live in very moist situation. Among the terrestrial forms at least 25 per cent are predacious, chiefly aphidophagous. There are more than 4700 species worldwide with 312 species under 71 genera known from the Indian subcontinent. Many studies have been conducted on the biology, intrinsic rate of increase, feeding behavior and factors affecting their oviposition and techniques for their multiplication. Relatively, less importance has been given to their field evaluation and to the studies dealing with reasons tracing causes for their less effectiveness in the open field. Recently, considerable efforts have been made to enhance their effectiveness by manipulating their habitat. Development of techniques for their effective shipment and release are necessary. Release rates, stage to be released, and stage which can be stored at low temperature need to be identified.

KEY WORDS: Aphids, biology, biological control, syrphids.

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Economic importance of aphids

World over 4000 aphid species have been recorded, out of which 1020 are distributed in the Oriental region. Out of about 800 species described so far in India (Ghosh and Basu, 1995), less than 100 species are pests of economically important crops. *Aphis gossypii* Glover can develop on more than 400 plant species in India (Raychaudhuri, 1983). *Myzus persicae* (Sulzer) alone transmits more than 100 plant viruses (Eastop, 1958). Out of 247 viral diseases of plants, 164 were stated to be transmitted by nearly 200 species of aphids (Kennedy *et al*., 1962).

Why biological control?

At present most of the aphids are managed by application of insecticides alone. Chemical control, though effective is undesirable due to problems of environmental pollution and residual toxicity. Dhingra (1993) recorded rapid change in susceptibility levels of different species to commonly used pesticides. Later, he recorded development of resistance in *Aphis craccivora* Koch, *M. persicae* and *Lipaphis erysimi* (Kaltenbach) (Dhingra, 1994).

Aphids being less mobile are more amenable for biological control. Biological control of pests tends to be long lasting, and often can be implemented at little direct cost to producers and consumers. For these reasons, biological control is considered a cornerstone of many Integrated Pest Management (IPM) programmes. Among insects predacious on aphids, syrphids are important predators which play an important role in the suppression of population of many economically important aphid pests (Tamaki *et al*., 1967; Pollard, 1969; Ghosh, 1974; Chambers *et al*., 1983) on cole crops, legumes, oilseeds, etc.

Aphidophagous syrphids

The superfamily Syrphoidea belongs to the series Aschiza under suborder Cyclorrhapha of order Diptera. The family Syrphidae is divided into three subfamilies *viz*., Syrphinae, Milesiinae and Microdontinae. Majority of aphidophagous syrphids belong to the subfamily Syrphinae.

Habitat

The habitats of the larvae of syrphids vary considerably. Based on their habitat, syrphids can be categorized into aquatic and terrestrial. Both aquatic and terrestrial syrphids can be phytophagous, predatory and scavenger. There are a few commensal species which are associated with social insects like bees, wasp and termites. Phytophagous species mainly belong to subfamily Eumerinae and Macrodontinae. Phytophagous species have been recorded on plants belonging to Liliaceae (onion and hyacinth), Umbelliferae (carrot) and Solanaceae (potato). Scavangers or saprophagous species of *Xylota*, *Syritta* and some species of Eristalinae live in highly polluted aquatic habitat. Some of the members of the genus *Eristalis* are known to cause accidental myiasis in human beings and domestic animals.

Most species are terrestrial, while a few species are aquatic or live in very moist situation. Among the terrestrial forms at least 25 per cent are predacious, chiefly aphidophagous.

There are more than 4700 species worldwide (Chambers, 1988) with 312 species under 71 genera known from the Indian subcontinent (Ghorpade, 1994). In Europe, most of the aphidophagous syrphids are known from two tribes, *viz*., Syrphini and Melastomini of the subfamily Syrphinae. Whereas in India, the tribes Syrphini and Paragini are considered to be important. In Paragini, different species under genus *Paragus* are widely distributed, whereas in Syrphini, *Ischiodon*, *Eupeodes*, *Dideopsis* and *Episyrphus* are important genera. From these genera, *Eupeodes corollae* (Fabricius), *Ischiodon scutellaris* (Fabricius) and *Episyrphus balteatus* (De Geer) are the most extensively researched.

In India, the earlier studies on morphology and biology of syrphids were by Bhatia (1931); Bhatia and Saffi (1932); Ratan Lal and Lal Gupta (1953); Bombosch (1962a and b). These studies are however, not complete and are fragmentary. Other studies by the Indian workers are limited to the new records of syrphids as predators of different species of aphids (Deoras, 1942; Puttarudriah and Channabasavanna, 1957; Patel and Patel, 1969; Rao, 1969; Ghosh, 1974; Raycahudhuri *et al*., 1979; Agarwala *et al*., 1984; Kotwal *et al*., 1984; Sharma and Bhalla, 1988). Intensified work on feeding efficiency and life cycle of different species of syrphid was carried out on different species of aphids only after 1975 (Patnaik, 1976; Roy and Basu, 1977; Makhmoor and Verma, 1987; Makhmoor and Verma, 1989; Sharma and Bhalla, 1991; Radhakrishnan and Muralidharan, 1993; Chitra Devi *et al*., 1996; Bijaya *et al*., 1996; Joshi *et al*., 1999).

Schneider (1969) has published an excellent review on the bionomics and physiology of aphidophagous syrphids and Chambers (1988) reviewed the work done subsequent to the publication by Schneider. In this review, we have tried to provide general information on the biology, feeding potential, rearing techniques and effectiveness of aphidophagous syrphids, with more emphasis on the work done in India.

Biosystematics

Keys for identification of aphidophagous syrphids have been published by Coe (1953), Dixon (1960), Chandeler (1968a) and Goeldlin de Tiefenau (1974). Stubbs and Falk (1983) have published an introductory guide to U.K. fauna. Indian Syrphidae was reviewed by Enrico Brunetii (1923). Knutson *et al*. (1975) provided correct nomenclature of Syrphidae of Oriental region. Ghorpade (1973) conducted faunistic studies on hover flies of south India and listed 542 species of host insects of 47 species of syrphids from India and neighboring countries (Ghorpade, 1981). Thompson and Ghorpade (1992) published a paper on Oriental *Paragus*, wherein notes on Indian Paragini were provided. Later, Ghorpade (1994) provided diagnostic keys to genera and species of Syrphinae from Indian subcontinent. A check list of hover flies occurring in Eastern Himalaya also has been published (Mitra *et al*., 2008). Studies on species occurring in particular zoogeographic area in a state have also been listed (Baskaran *et al.*, 2008). Several faunal studies have been conducted recently from several countries like Turkey (Sarbyk, 2008, Bayrak and Hayat, 2008), East Azerbayjan province and Iran (Ehteshamnia, *et al*., 2010, Khaghanina, 2010). Genera wise and crop wise taxonomic revisions of syrphidae are also available (Sorokina, 2009; Morales and Marinoni, 2009; Rossi *et al*., 2007; Tearmann, 2008).

Development of DNA barcodes

DNA barcoding has become an useful system for linking different biological life stages and for identification of species within known taxonomic framework. Mitochondrial DNA COI barcodes have been developed for hoverfly genus *Merodon* (Stahls *et al*., 2009).

Life stages of syrphids

Egg: The eggs are laid singly inside or near the aphid colony, or in groups side by side on the leaf surface and stem. The eggs are white and elongate oval in shape. They possess a pattern of sculpturing on chorion. The sculpturing is made of parallel small white stripes. These stripes are not continued but are interrupted by depressions that appear to consist of several small white longitudinal patches. The stripes are elevated from the surface. There are numerous such elevations running parallel and completely covering the surface.

Larva: Following are the general characters of syrphid larva, which will be useful in identifying the family Syrphidae.

The head and mouthparts are not conspicuous and in most species they are retractile. Inconspicuous antennae and retractile parallel mouth hooks may occur. In addition to this small, sclerotised laterally projecting mouth spines are also present.

The abdomen is made up of nine wrinkled segments, which are difficult to distinguish, if it were not for the twelve usually conspicuous and definitely located spines or setae. Laterad from the meson the setae are called median, dorsal, dorso-lateral, lateral and two ventro-laterals. Many microspines may cover the entire exoskeleton. Rectal gills are present but are inconspicuous. Two caudal spiracles are contiguous and more or less fused. In addition to the three slits on each spiracle, intra-spiracular nodules, setae and lamellae may be present (Petterson, 1960).

Moulting of larvae: The larval instars have not been differentiated in most of the earlier works. This is probably due to the fact that moulted skins are very thin and transparent and remain adherent to the surface on which they are laid. Moulting of syrphid larva is peculiar. Exuviae are not obtained at the early winter season. Exuviae of trachea and bucco-pharangeal armature are also shed. A small longitudinal slit can be seen at the anterior end of moulted skin through which the larva has emerged. Prior to each moulting the larva passes the faeces and empties the gut contents. The larva remains inactive before moulting. It occasionally feeds at that time and secretes a colourless moulting fluid.

Pupa: Prior to pupation, the larvae secret sticky fluid through the mouth. The larvae migrate to soil and pupate. The puparium is either oval or tear-drop shaped. The dorsal and lateral portions are inflated and the ventral portion is flattened. The posterior spiracles are situated at the caudal end.

In the laboratory, among the different materials like corrugated sheet, tissue paper, cowpea leaf, cotton pad and muslin cloth, *P. serratus* and *I. scutellaris* preferred to pupate on cotton pads, perhaps because the larvae of syrphids need dry surface for pupation and it seeks concealment at the time of pupation. Both these biological needs are fulfilled by cotton pad (PDBC, 1998).

Adult: The syrphid adults are distinguished from other dipterans by the presence of a false or spurious vein in the wing, crossing r-m between R_{4+5} and M_{1+2}. The R_5 cell is closed. Proboscis is short, face is narrow and grooves are not present below antennae (Borror *et al*., 1976).

The adults of syrphids are characterized by hovering behaviour near the pollen and prey source, and hence commonly known as hover lies or flower flies. The adults have bright coloured patches on black abdomen. In many cases they resemble wasps and honeybees. The adults are active during daytime and are found visiting flowers to feed on pollen and nectar.

Larval feeding behaviour

Prey searching: Studies on searching behaviour of syrphid larvae revealed that the larvae *of E. balteatus*, *I. scutellaris* and *E. confrater* wriggled along the leaf midrib in search of prey before diverting their course. The forward movement of the larvae is coupled with sideways swaying movements. The larva fixes its posterior end to the substrate, then raises and stretches the rest of its body and moves sideways in a semi-circular manner. Such movements are continued until the prey is encountered (Kumar *et al*., 1996). Similar kind of observations were made by Joshi *et al.* (1999) in case of *B. fletcheri*, *B. linga*, *D. aegrota*, *P. serratus* and *P. yerburiensis*. They found that the first instar larvae after eclosion remained motionless for 5-10 minutes and later started searching for prey. In the absence of prey it fed on the unhatched eggs.

Cannibalism was highly prevalent in all the larval instars of all the species in absence of prey. The larvae captured the prey only after making physical contact with it. The larvae of *D. aegrota* have the peculiar habit of carrying dead prey on its back. Roy and Basu (1977) stated that the syrphid larvae could survive for several days without food if they are provided with water. Our laboratory observations, however, gave contradictory results.

Kumar *et al*. (1996) found first instar larvae of *M. confrater* to be the most efficient prey hunter (31.7 sec) while the second and third instars of *E. balteatus* took least time in searching their prey (23.3 and 9.5 sec, respectively). Third instar larvae of *E. balteatus*, *I. scutellaris* and *E. confrater* were more efficient prey seekers (9.15-22.2 sec) than the second (23.3-41.5 sec) and first instar (37.4-56.7 sec).

Larvae of *E. balteatus* turn and cast more frequently if they have captured and lost contact with an aphid, and they move forward slowly (Chandler, 1969). Similarly, *Syrphus ribesii* (Linnaeus) and *Eupeodes scalare*, the rate of casting increases after capture of prey and gradually decreases if no further prey are encountered (Rotheray, 1983). He further found that starved and hungry larvae cast more frequently (Rotheray and Martinat, 1984).

Prey handling: On encountering an aphid prey, the syrphid larva exudes a highly sticky secretion from its mouth, to hold the aphid firmly. The first instar larvae of

E. balteatus and *E. confrater* were able to handle with ease only the small sized aphids while second and third instar larvae efficiently lifted the prey irrespective of its size (Kumar *et al*., 1996). Contrary to these observations, Joshi *et al*. (1999) found no marked preference for specific instar of aphid by particular stage of *I. scutellaris* larvae. Even freshly hatched larvae fed on gravid aphid female larger than their own size.

The comparison of three syrphid species, irrespective of their instars and size of prey revealed that, *I. scutellaris* to be the most efficient in handling prey (744.7 sec) followed by *E. confrater* (835.4 sec) and *E. balteatus* (1203.7 sec) (Kumar *et al*., 1996).

Syrphid rebesii was able to catch first instar *M. persicae* with 88% success and consumed in less than 2 minutes, while adult aphids were caught with 98% success and were discarded in 3.5 minutes (Hagver, 1974). Prey was captured more efficiently and handling time was shorter in *S. ribesii* than in *M. scalare* (Rothray and Martinat, 1984). *M. corollae* larvae ingested aphid contents at a decreasing rate over time because the contents of the aphid became increasingly difficult to obtain as the body of the prey was emptied. Starved larvae usually handled prey longer than well-fed larvae. Younger starved larvae fed longer than older larvae. Larvae starved for 24 h ate the most of a prey. Prey handling time and amount of each prey consumed were determined by the size, hunger level of larvae and degree of depletion of prey contents (Barlow and Whittingham, 1986). This study clearly indicated that the syrphid predators usually handle prey items longer and consume more of each prey item when prey are scarce.

Prey consumption: After lifting the prey, the syrphid larvae retract their anterior two segments making a hollow cup for resting the prey in it. The larva then forces oral hooks of bucco-pharyngeal armature into the body of the prey and slowly evacuates the whole of the inner body contents. After sucking the body fluids of the aphid, the larva rejects it when shrunk and dry (Kumar *et al*., 1996; Joshi *et al*., 19996). When three species of syrphids were compared for time taken for consuming prey, it was found that the larvae of *I. scutellaris* spent least time (642.2 sec.), followed by *E. confrater* (702.8 sec.) and *E. balteatus* (1122.1 sec.).

Feeding efficiency and biology: Larvae of *E. corollae* ate mean of 346 *Capitophorus eleagni* (Del Guercio) in 8.6 days of larval period (Taw fik *et al*., 1974), while *E. balteatus* consumed 416 *Aphis pomi* (De Geer) during its development (Wunk, 1977). *Scaeva pyrastri* (Linnaeus) fed on 550 *B. brassicae* (Wunk and Fuchs, 1977). The larvae of *Platycherius clypeatus* (Meigen) and *Melanostoma mellinum* (Linnaeus) (Tribe Melastomini) consume fewer aphids i.e., 135 and 150, respectively (Bankowsa *et al*., 1978). In India several studies have been conducted on the feeding potential and biology of different syrphid species on different aphid prey, which are summarised in Table 1 and 2. Joshi *et al*. (1999) studied the biology and feeding potential of *P. serratus* and *I. scutellaris* on six species of aphids. *P. serratus* exhibited lower larval and pupal mortality and higher adult emergence on all the aphid hosts, indicating its wide host range, but *I. scutellaris* showed higher feeding potential, fecundity and longevity, thereby proving its potential as biocontrol agent. *A. craccivora* was the most preferred host for both the syrphids with higher rate of consumption and fecundity. The two syrphids accepted all the hosts, but *Uroleucon compositae* (Theobald) was the least preferred resulting in lowest fecundity and longevity.

Impact of prey density on feeding potential and development: Developmental period of *I. scutellaris* decreased with increase in *Rhopalosiphum maidis* (Fitch) density. At low prey density only 30% larvae pupated. The larval and pupal mortality decreased with increase in prey density (Singh and Mishra, 1988). When reared on *A. craccivora*, it was found that at low host density of 5 and 15 aphids per day, 24% larvae were able to pupate out of which 33% emerged as adults (PDBC, 1997). Studies on functional response of *I. scutellaris* on *L. erysimi* indicated a positive linear relationship between the prey density and the number of prey. However, a negative relationship was obtained between the density of aphid and percentage consumption (Chitra Devi and Singh, 2000).

Daily kill increases in *E. corollae* as the larva grows, the 3rd instar killing 80-90% of the total food consumed (Benestad, 1970b). 1st, 2nd and 3rd instars of *E. balteatus* ate 3,13, and 84%, respectively, of the total kill. Joshi *et al*. (1999) observed gradual increase in aphid consumption and the last instar larva was the most voracious, consuming 46.99-62.43 per cent of total aphids consumed, in *B. linga*, *B. fletcheri*, *D. aegrota*, *I. scutellaris*, *P. serratus* and *P. yerburiensis* on *A. craccivora*.

Adams (1984) found that the daily kill is influenced only by ambient temperature and relative humidity and is not affected by prey density.

Several workers recorded indirect effect of prey availability on the development. During instances of shortage of food more energy is allocated to body maintenance and hence larval development is longer and pupae are smaller (Ruzicka and Cairo, 1976; Barlow, 1979; Cornelius and Barlow, 1980).

Table 1. Biology of syrphids on different prey species

Syrphid species	Prey species	Egg incubation period	Larval period	Pupal period	Total period	Adult developmental	References longevity
Ischiodon scutellaris	*B. brassicae*	3–4	9–12	13–14		6–9	Sharma and Bhalla, 1988
	L. erysimi						Roy and Basu, 1977
	T. aurantii						Radhakrishnan and Muralidharan, 1993
	A. craccivora						Joshi *et al*., 1999
	R. maidis						Singh and Mishra, 1988
	L. erysimi						Devjani and Singh, 2006
Episyrphus nubilipennis	*T. aurantii*	3–4	9–10	10–11		2–7	Radhakrishnan and Muralidharan, 1993
Betasyrphus serarius	*T. aurantii*	2–3	7–8	8–9		2–6	Radhakrishnan and Muralidharan, 1993
B. fletcheri	*A. craccivora*	–	9–10	9–10		18–19	Joshi *et al*., 1999
B. linga	*A. craccivora*	–	10-11	10–11		13–14	Joshi *et al*., 1999
Dideopsis aegrota	*A. craccivora*	4–5	11–12	10–11		14	Joshi *et al*., 1999
	D. aegrota	4–5	9–10	10–11		1–6	Radhakrishnan and Muralidharan, 1993
Paragus tibialis	*T. aurantii*	3–4	6–7	9–10		1–6	Radhakrishnan and Muralidharan, 1993
P. serratus	*A. craccivora*	2–3	9–10	8–9		14–15	Joshi *et al*., 1999
	A. craccivora	2	9–10	9		–	Patro and Behera, 1992
P. yerburiensis	*A. craccivora*	2–3	8–9	7–8		10–11	Joshi *et al*., 1999
Syrphus pyrastri	*B. brassicae*	3–4	10–13	9–12	22–28	9–15	Sharma and Bhalla, 1988
	B. brassicae	2–3	10–16	10–18		20–22	Makhmoor and Verma, 1987
Eupcodes confrater	*B. brassicae*	3–4	15–17	12–16		5–12	Sharma and Bhalla, 1988
	B. brassicae	2–3	11–16	11–18		11–24	Makhmoor and Verma, 1987
	L. erysimi	4–5	12–13	14		5	Roy and Basu, 1977
	M. rosae	3–4	7–8	8	19–20	15 (male) and 18 (female)	Verma and Sharma, 2006
Macrosyrphus sp.	*B. brassicae*	4–6	11–12	11–13		4–18	Sharma and Bhalla, 1987
Episyrphus balteatus	*B. brassicae*	3–4	8–12	8–9		5–14	Sharma and Bhalla, 1987
	B. brassicae	2–3	11–13	11–16		8–16	Makhmoor and Verma, 1987
	L. erysimi	4	10–11	10		4	Roy and Basu, 1977
	T. aurantii	3–4	9–10	9–10		2–6	Radhakrishnan and Muralidharan, 1993
	M. persicae		6–7				Devjani and Singh, 2006
Eupeodes corollae	*B. brassicae*	3–4	9–10	10–12		9–24	Sharma and Bhalla, 1987
	B. brassicae	2	10	10–11		12–28	Makhmoor and Verma, 1987
Syrphus javana	*A. craccivora*	2	6–7	5	14–15	–	Patro and Behera, 2002

Table 2. Feeding potential and fecundity of syrphids on different prey species

Syrphid species	Prey species	Feeding potential	Fecundity (Eggs/female)	References
Paragus serratus	*A. craccivora*	248.50 ± 12.41	40.4 ± 1.35	Joshi *et al*., 1999
	A. craccivora	258.30 ± 8.1	–	Patro and Behera, 1992
	L. erysimi	163	–	Devjani and Singh, 2006
P. yerburiensis	*A. craccivora*	153.03 ± 3.96	11.4 ± 1.43	Joshi *et al*., 1999
P. tibialis	*T. aurantii*	160.41 ± 22.98	11.75 ± 1.94	Radhakrishnan and Muralidharan, 1993
Betasyrphus fletcheri	*A. craccivora*	342.60 ± 10.85	–	Joshi *et al*., 1999
B. linga	*A. craccivora*	398.90 ± 7.96	–	Joshi *et al*., 1999
B. serarius	*T. aurantii*	362.92 ± 83.79	11.60 ± 2.43	Radhakrishnan and Muralidharan, 1993
Dideopsis aegrota	*A. craccivora*	450.60 ± 16.39	6.81 ± 1.12	Joshi *et al*., 1999
	T. aurantii	454.17 ± 66.96	3.56 ± 0.17	Radhakrishnan and Muralidharan, 1993
Ischiodon scutellaris	*A. craccivora*	370.60 ± 7.74	607.80 ± 124.21	Joshi *et al*., 1999
	A. craccivora	898.60 ± 20.80	–	Kumar *et al*., 1996
	T. aurantii	296.66 ± 78.52	7.60 ± 1.56	Radhakrishnan and Muralidharan, 1993
	L. erysimi	882.80 ± 13.40	–	Kumar *et al*., 1996
	L. erysimi	321	–	Lal and Haque, 1965
	L. erysimi	406.20 ± 39.40	–	Roy and Basu, 1977
	R. maidis	416.90 ± 14.45	–	Singh and Mishra, 1988
	A. gossypii	618	–	Agarwala and Saha, 1986
	A. gossypii	690.20 ± 16.20	–	Kumar *et al*., 1996
	M. persicae	662.40 ± 14.20	–	Kumar *et al*., 1996
	L. erysimi	13.32 (Well fed larvae within 3 hours) 16.07 (Starved larvae within 3 hours)	–	Karnataka and Thorat, 2006
	L. erysimi	540.17	–	Mandal and Patnaik, 2006
	M. persicae	463.29	–	Mandal and Patnaik, 2006
	B. brassicae	449.30	–	Mandal and Patnaik, 2006
	L. erysimi	421	–	Devjani and Singh, 2006
	T. aurantii	155	–	Dhanapatidevi and Varatharajan, 2007
	M. persicae	581 (During November) 497 (During January)	–	Sharanabassapa *et al*., 2007
	L. erysimi	233.30±10.47	–	Ali *et al*., 2009
	R. nymphae	213.20±7.83	–	
	H. coriandri	197.90±8.15	–	
	A. craccivora	146.30±5.50	–	
Episyrphus nubilipennis	*T. aurantii*	455.54 ± 94.55	6.70 ± 1.22	Radhakrishnan and Muralidharan, 1993
E. balteatus	*T. aurantii*	358.36 ± 79.88	22.40 ± 6.78	Radhakrishnan and Muralidharan, 1993
	L. erysimi	500.20 ± 28.30	–	Kumar *et al*., 1996
	L. erysimi	510.60 ± 49.03	–	Roy and Basu, 1977
	L. erysimi	285.00 ± 14.30	–	Sharma and Bhalla, 1991
	B. brassicae	202-218	400-721	Makhmoor and Verma, 1987
	B. brassicae	235.00 ± 12.80	–	Sharma and Bhalla, 1991
	M. persicae	269.00 ± 10.10	–	Sharma and Bhalla, 1991
	M. persicae	468.00 ± 28.50	–	Kumar *et al*., 1996
	A. craccivora	752.50 ± 25.50	–	Kumar *et al*., 1996
	A. gossypii	986.80 ± 27.70	–	Kumar *et al*., 1996
	M. persicae	215	–	Devjani and Singh, 2006

Syrphid species	Prey species	Feeding potential	Fecundity (Eggs/female)	References
Eupeodes confrater (*M. confratter*)	*L. erysimi*	707.50 ± 57.50	–	Roy and Basu, 1977
	L. erysimi	984.20 ± 10.30	–	Kumar *et al*., 1996
	L. erysimi	381.00 ± 22.40	–	Sharma and Bhalla, 1991
	B. brassicae	393.00 ± 9.68	–	Makhmoor and Verma, 1989
	B. brassicae	350-393	245-535	Makhmoor and Verma, 1987
	B. brassicae	323.00 ± 7.60	–	Sharma and Bhalla, 1991
	M. persicae	527.00 ± 18.70	–	Sharma and Bhalla, 1991
	M. persicae	784.00 ± 13.30	–	Kumar *et al*., 1996
	A. craccivora	1191.8 ± 20.10	–	Kumar *et al*., 1996
	M. rosae	306	–	Verma nad Sharma, 2006
	A. fabae	64.33 (First instar larva) 6.44 (Fourth instar larva)		Sood *et al*., 2007
Syrphus pyrastri	*B. brassicae*	398.00 ± 14.70	–	Sharma and Bhalla, 1991
	B. brassicae	521.00 ± 18.40	–	Sharma and Bhalla, 1991
	M. persicae	431.00 ± 33.30	–	Sharma and Bhalla, 1991
	L. erysimi	499-592	355	Makhmoor and Verma, 1987
	A. fabae	41.78 (First instar larva) 10.67 (Fourth instar larva)		Sood *et al*., 2007
Eupeodes corollae	*B. brassicae*	274	704	Makhmoor and Verma, 1987
	B. brassicae	274 ± 5.76	–	Makhmoor and Verma, 1987
Syrphus javana	*A. craccivora*	193.3 ± 10.30	–	Patro and Behera, 2002
Eupeodes frequence	*A. fabae*	41.78 (First instar larva) 10.67 (Fourth instar larva)		Sood *et al*., 2007

Intrinsic rate of natural increase: Fertility schedules critically analyse and assess biocontrol potential of natural enemies. Makhmoor and Verma (1989), Sharma *et al*. (1994) and Sharma and Bhalla (1995) studied intrinsic rate of natural increase of three species of *Eupeodes viz*., *E. confrater*, *E. frequens* and *E. corollae*, respectively. These studies indicated that these predators have the potential to rapidly increase their population size with strong possibility of bringing about an effective check of aphid population. Population indices for two seasons (winter and summer) of *I. scutellaris* revealed that the predator had higher net reproductive rate in winter than in summer (PDBC, 1999). Similar studies on species *viz*., *P. serratus* and *P. yerburiensis* revealed that these species could produce a small population at a faster rate when environmental conditions are favorable (Joshi *et al*., 2000). These studies indicated that *Paragus* spp. can prove to be additional predators along with *I. scutellaris*, which has the ability to produce a large population but at a relatively lower pace (Joshi *et al*., 2001).

Feeding activity of adults

Apart from being predators, syrphid adults act as pollinators. Both male and female adults feed on pollen and nectar and hence have been found to visit flowers (Procter and Yeo, 1973). Gilbert (1981) while studying foraging ecology of syrphids, correlated length of tongue to the depth of corolla and suggested that, this is the factor which determines selection of flower species visited by syrphids. He further discussed diel activity of different syrphid species in relation to their size, temperature and light intensity (Gilbert, 1985).

Presence of flowering plants in the vicinity of aphid infested crop has been suggested as a means of increasing the effectiveness of syrphids as predators. However, Chamber (1986b) did not find increase in number of eggs in plots of Brussels sprouts with additional flowers placed in it. On the other hand presence of nectar (adult food) may be utilized to retain adult syrphids in areas with low prey density. Hagen *et al*. (1970) used sprays of sucrose and yeast to increase number of adult syrphids in cotton.

Flight activity: Aubert and Goudlin de Tiefenau (1981) studied flight activity in Swiss Alps by marking adults and by actual observation. They suggested that hover flies are strong flyers and can travel long distances (up to 50 km) in migratory flights. Svensson and Janzon (1984) studied migratory behaviour of *E. corollae* and suggested low aphid density to be a promoting factor for large migrations.

Mating behaviour

Mating in syrphids occur both during flight as well as at rest. Before mating, the male and female of *I. scutellaris* showed courtship behaviour of hovering mouth to mouth in the air (Joshi *et al*., 1999). Mating duration varies in different species. Makhmoor and Verma (1987) observed repeated matings in *E. balteatus*, each lasting for 1–2 seconds, whereas in *E. corollae*, it lasted for 1 – 6 hours. In *B. serarius* and *P. tibialis* copulation lasts for 10–13 minutes and in *A. nubilipennis* 30 minutes. Repeated mating each lasting for 50–65 minutes was observed in *I. scutellaris*, whereas in *P. serratus* and *P. yerburiensis*, it lasted for 15–20 minutes and in *D. aegrota*, 20–30 minutes (Joshi *et al*., 1999). Pre-oviposition period varies between 2 and 5 days in different species.

Oviposition

Mated females can be easily recognised by inflated abdomen bearing eggs, which is whitened from underside. The gravid female hovers around aphid infested plants and walks slowly near aphid colony. While searching, the female moves the antennae rapidly and extends its abdomen just before oviposition. The eggs are generally laid in the aphid colony, but as the females get older, the eggs are deposited on the surfaces of rearing cage. But, these eggs fail to hatch as they shrink due to lack of moisture (unpublished observation). The oviposition period varies considerably among different species. It lasts for about 49.7 days in *E. balteatus* and 16.9 days in *E. confarater* (Makhmoor and Verma, 1987). Joshi *et al*. (1999) recorded oviposition period of 3–4, 4–5, 5–6 and 22–23 days in *P. yerburiensis, D. aegrota*, *P. serratus* and *I. scutellaris*, respectively.

Factors affecting oviposition: Olfactory stimuli originating from aphid honey-dew and cornicle secretion, visual and mechanical cues play an important role in determining oviposition site. Eggs of Syrphini such as *E. luniger* (Meigen), *I scutellaris*, *E. corollae*, *E. balteatus* and Paragini such as *P. serratus*, *P. yerburiensis* and *P. tibialis* are laid close to or among the aphid colonies. But, members of Melanostomini are known to deposit their eggs in groups away from aphid colonies or on adjacent uninfested plants (Chambers, 1968 b,c). In addition to this, light, shade and position of aphid colony also influence the choice of oviposition site. Sanders (1980, 1981) found that *E. corollae* preferred dark to lighter areas when given a choice and also the females exhibited preference for oviposition beside colonies on vertical rather than horizontal surface. Larval feeding history is generally thought to affect the reproductive output of the female, however in *E. corollae*, Scott and Barlow (1984) found that when more aphids were offerred, larvae consumed more and produced heavier pupae. Fecundity of adults reared from these pupae was extremely variable (range, 0-1488 eggs per female) and depended mostly on adult longevity and not on larval feeding history and weight of pupae.

Effect of aphid density: The functional response, the number of eggs laid by the syrphid in response to aphid density, is important for biological control programme. Chandler (1968 d) observed that syrphids belonging to Syrphini have the ability to increase the number of eggs in response to increasing aphid number, up to a certain population density, above which the oviposition is deterred. On the other hand, *P. peltatus*, a syrphid belonging to tribe Melanostomini does not show density related oviposition response.

Sanders (1979) and Ito and Iwao (1977) also found density dependant oviposition by *E. balteatus* on cabbage.

Effect of background on oviposition: Smith (1969, 1967) investigated the effects of weeds in the crop on oviposition of syrphids, *viz*., *Melanostoma* spp., *Platycherius* sp. and *E. balteatus* in plots of Brussels sprouts. Only *Melanostoma* laid more eggs in weedy plots as compared to bare plots, whereas *E. balteatus* laid eggs preferentially in the weedy plots only when aphid density was low. On the other hand, *Platycherius* sp. preferred sprouts grown in bare soil. Horn (1981) found higher population of syrphids in plots with weeds, despite high densities of *M. persicae* in weed free plots.

Habitat preference was studied by Pollard (1971) using heavily infested Brussels sprouts grown in pots. *E. balteatus* laid more eggs on plants in crop habitat and very few in woodland, whereas *Platycherius scutains* (Meigen) and *Leucozona leucorum* Linnaeus oviposited in hedge row habitat with fewer eggs at increasing distance from hedge. He concluded that habitat outside a crop is unlikely to influence the syrphid. It is aphid density, which plays a major role in oviposition of syrphids.

Effect of presence of conspecific larvae and larvae of other predators in aphid colony: It has been found that the hoverfly females avoid ovipositing in aphid colonies in which conspecific larvae or their tracks are already present, suggesting that this behavior constitutes strategy that enables females to optimize their oviposition site and reduce competition suffered by their offsprings (Almohamad *et al.*, 2010). It has laso been found that *E. balteatus* females lay fewer eggs at sites where there were heterospecific larval tracks of *Harmonia axyridis* (Almohamad *et al.*, 2010).

Rearing techniques

Frazer (1988) listed 25 groups of arthropod predators feeding on aphids. Out of these only four groups have been mass reared for biological control, particularly Chrysopidae and Coccinellidae. Although species belonging to Syrphidae are important agents in natural control of aphids, they have never been mass cultured and rarely reared in the laboratory. *E. corollae* represents an exception (Barlow, 1979; Barlow and Whittingham, 1986). In these publications also, complete techniques for mass rearing have not been revealed. Barlow and Whittingham (1986) mentioned about collection of syrphid eggs on nylon bag filled with aphids. However, our laboratory studies on multiplication of *P. serratus*, *P. yerburiensis* and *I. scutellaris* positive results were not achieved with nylon bag. Samsoe-Petersen (1989) developed techniques for multiplication of *E. corollae* by using *Acyrthosiphon pisum* (Harris) and *Aphis fabae* Scopoli as hosts. They used glass houses with controlled temperature and humidity conditions for rearing aphids. This article, however, does not provide any information about handling of different stages of syrphids and cycle of activities to be followed, which is extremely important in multiplication techniques of any predatory insect.

In India, Joshi *et al.* (1998) developed techniques for mass multiplication of syrphids. These methods of rearing have also been found to be successful for rearing *I. scutellaris*, *Paragus serratus* (Fabricius) and *P. yerburiensis*. With suitable modifications, the rearing units may prove satisfactory for rearing other syrphid species too.

Artificial diet

Two species of syrphids *viz.*, *Episyrphus balteatus* (de Geer) and *Eupeodes bucculatus* (Rondani) have been reared on artificial diet consisting of drone honey bee powder (DP) (Iwai *et al.*, 2007). Later, it was found that addition of linoleic acid and oleic acid could improve adult emergence rate and adult body size (Iwai *et al.*, 2009).

Artificial diet for adults has been found to substantially increase in oviposition by *P. serratus*. This diet includes addition of multivitamins, clomiphane citrate and tocopheryl acetate to 50% honey (Baskaran *et al.*, 2009a). Same group of workers have also studied influence of pollen grain on fecundity of *P. serratus* (Baskaran *et al.*, 2009b).

Effectiveness of syrphids as bio-control agents in the field

Chambers (1988) defined effectiveness as the degree to which aphid increase is impeded by predators; the extent to which increasing aphid number is slowed down, held steady or reversed by action of predators (syrphids), and whether this keeps the aphid population density below the economic injury level. He outlined two methods, which are generally used for predator evaluation, qualitative and quantitative. Examination of aphid colonies for the presence of predators, predator exclusion or inclusion and observational methods with graphical analysis are qualitative methods, whereas manipulation of initial prey and predator ratios and the observation of outcome or estimate of abundance of predator are the methods employed under quantitative analysis.

Predator exclusion method: Pollard (1969) removed syrphid larvae from Brussels sprouts by hand and examined daily aphid population. *E. balteatus* and *Sphaerophoria scripta* (Linnaeus) were found to be the predators bringing down aphid population.

Way and Banks (1968) used sleeve cages to exclude predators of *A. fabae* and found syrphids to be a major factor in reducing aphid population. Similar techniques to exclude predators of *M. persicae* were adopted by Tamaki (1973). They found both syrphid and coccinellids to reduce aphid production by 95%. Similar observations were recorded by Chambers (1983) in winter wheat.

There are other methods of exclusion of predators by using selective pesticides. Carbaryl was used by Smith (1981) to kill syrphid larvae in wheat plots. Death of the larvae resulted in higher aphid numbers in sprayed plots.

Observational studies: These studies try to correlate the presence of syrphid larvae with decline in aphid population. Such experiments can not be concluded with confidence, as there are several factors which contribute to population decline. These factors are emigration of aphid alates, change in host plant physiology, impact of adverse weather conditions on aphid multiplication and effect of other natural enemies. However, such studies are still considered for the assessment of predators as these experiments are relatively easy to conduct.

Hurej (1982) recorded the presence of three species in sugarbeet on *A. fabae* and related aphid decline with it. According to Chambers *et al*. (1986) synchronisation of larval population of syrphids with *S. avenae* population results in decline of latter.

In India, Kotwal *et al*. (1984) and Sharma and Bhalla (1991) found the association of different syrphid species with cabbage aphid in mid hill regions of Himachal Pradesh. They found peak population of syrphids coinciding with peak aphid population. Radhakrishnan and Muraleedharan (1993) stated that the population density of the various syrphid predators synchronises with the abundance of *Toxoptera aurantii* (Boyer de Fonscolombe) in tea fields at Valparai.

Predator:prey ratios: Such type of studies are conducted on small scales. Wunk (1977) found that *A. pomi* population can be totally taken care of if *E. balteatus* and its prey population are maintained at 1:50 at the initial infestation level and 1:200 at later part of infestation.

Chambers (1986) found that increasing predator: prey ratios are required to control *A. gossypii* on cucumber.

In India, Kotwal *et al*. (1984) found that syrphids could contain *B. brassicae* population at a predator: prey ratio of 1: 129, but failed to do so when the ratio was 1: 1163.

Verma and Makhmoor (1987) studied the relative abundance of nine species of syrphids predating *B. brassicae* in cauliflower. They found that high activity of predators always coincided with peak aphid population but failed to check aphid population late in season. In spite of very high larval counts, predator: prey ratio never reached the desirable level.

Predator: prey ratios recorded in the field by Kumar *et al*. (1988) indicated that the level of *B. brassicae* influenced the number of syrphid species active on the mustard crop. Egg as well as larval population positively correlated with the number of aphid colonies. Dispersion of egg and larval population was non-aggregated at very low and very high aphid densities and aggregated at intermediate densities. Ratios of predator and prey population were desirable at the beginning but were not so late in crop season.

While studying relative abundance of six species of syrphids on *A. craccivora* infesting cowpea, Joshi *et al*. (1999) found a prey-dependant syrphid predator growth, often failing to reach ideal predator: prey ratio of 1:100. This emphasizes the need for aphid management by way of augmentation of syrphid predators.

Prediction model: Tamaki (1974) proposed a model for prediction of performance of predators in fields. It was used to assess reductive power of complex of predators. This model was based on relative feeding capacities and efficacy estimated in the field.

In addition to this model, Raworth (1984) suggested a model in which he employed rates of kill change with size of larvae of the predator and used an estimate of larval voracity expressed as biomass of aphids consumed. However, this model could not account for the impact of the syrphid on *B. brassicae*.

Another simulation model by Rabbing *et al*. (1979) used published data on life histories and feeding potential of syrphids. But, this model could not provide accurate data for field kills in relation to population density.

According to Raworth (1984), there is a need for studies which estimate quantitative effectiveness of hover flies, which use functional and numerical responses of the predators.

Factors affecting effectiveness of syrphids

There are several factors that affect survival and effectiveness of syrphid predators in the field. The most important are natural enemies, suitability of prey, difficulties in multiplication, etc.

Difficulties in rearing some species of syrphids: Species such as *E. balteatus* has very male biased sex ratios. Larvae collected from cabbage, cauliflower and cowpea and reared in the laboratory at PDBC during 1997-1999, yielded 100 per cent males. Also, species *viz*., *D. aegrota*, *E. confrater*, *B. linga* and *B. fletcheri* failed to mate in the laboratory and produced only infertile eggs.

Parasitism: Schneider (1969) identified egg-pupal and larval-pupal parasitoids as one of the major limiting factors for use of syrphids as biological control agents. Nine families of hymenopteran parasitoids have been identified. Dusek *et al*. (1979) and Rothray (1984) worked on some parasitoids and their host associations. The most common parasitoid is the ichneumonid, *Diplazon laetatorius* (Thunberg). Rothray (1979, 1981) studied the biology of *D. laetatorius* and found that the adult parasitoid oviposits into host eggs or first instar larva and adult parasitoid emerges through syrphid puparium. They further found that these parasitoids locate their host by responding to odours from aphid colonies and chemicals from their integument. Detailed studies have not been conducted on the effect of parasitism on biology and feeding potential of syrphid larvae. However, Rothray (1985) pointed out delayed pupation in the larvae of *S. ribesii* parasitised by the encyrtid, *Bothriothorax clavicornis* (Dalman).

In India, the extent of parasitism of syrphid pupae was reported to vary from 5 to 40 percent (Patel and Patel, 1969; Patanaik and Bhagat, 1978). Kumar *et al.* (1989) isolated two hymenopteran parasitoids, *Diaeretiella laetatorius* and *D. rapae*. The level of parasitism was as high as 35.45% in seven different species of syrphids feeding on *L. erysimi* on raya. Parasitism was higher in the crop sown late in November as compared to early sown crop. Parasitism as high as 46.4 per cent has also been recorded in Poland (Jankowska, 2004).

Bacterial pathogens: Bacterial pathogens (*Bacillus* spp.) have been found to be major mortality agents in *E. corollae* and *E. balteatus* (Verma and Makhmoor, 1989; Sharma and Bhalla, 1992). In studies conducted for two generations (winter and summer) of *E. confrater*, total mortality caused by *Bacillus* sp. was 44.49 and 55.74 per cent, respectively. Per cent mortality caused due to *Bacillus* spp. in *E. corollae* during 1986-1987 was 33.08 and 51.98, repectively.

In *I. scutellaris*, field collected 2nd and 3rd instar larvae and pupae exhibited 10.47, 26.67 and 7.12 per cent mortality due to *Bacillus* sp., respectively during winter season. Corresponding values for summer collected stages were 4.52, 30.00 and 14.29 per cent, respectively. Two species of bacteria, *viz*., *Citrobacter* sp. and *Aeromonas* sp. were isolated from laboratory cultures. Irrespective of the stage of the predator, the total mortality due to *Citrobacter* sp. and *Aeromonas* sp. was 31.25 and 21.62 per cent, respectively in winter, whereas, in summer, it was 28.5 and 21.44 per cent, respectively (PDBC, 2000). Presently efforts are being made to control these bacteria by rinsing larval rearing units with various bactericides. Recently, Likhil and Mallapur (2009) studied natural enemies of syrphids in sugarcane crop. They found a larval pupal parasitoid *Diplazon laetatorius* and three species of bacteria to be major mortality factors of syrphids.

Unsuitability of certain aphid species as prey: Some aphid species are unsuitable as food. *E. corollae* can not complete development on *Cavariella theobaldi* (Gillette Bragg), and larval mortality is high when fed on *Aphis sambusi* Linnaeus, which is also toxic to coccinellids (Ruzicka, 1975).

Ischiodon scutellaris showed high mortality (80.00 and 53.33%) in first two instars, when fed with *A. craccivora* infesting *Gliricidia maculata* Steud., but mortality was relatively lower in third instar larvae (26.66%). The per cent mortality in *P. serratus* and *P. yerburiensis* was considerably less even in first instar (6.66%). *A. craccivora* infesting *G. maculata* could not be used for feeding/rearing and for biological studies on syrphids. Similarly, syrphids can not be used as predators against this aphid (PDBC, 1997).

Difficulties in shipping syrphids: For multi-location evaluation, it is necessary to ship different stages of syrphids. *I. scutellaris* is presently being evaluated at different centers against *L. erysimi* under AICRPBC (All India Co-ordinated Research Project on Biological Control). Efforts were made to ship the eggs on aphid infested cowpea seedlings. Initial trials failed due to hatching of eggs during transit and death of resulting larvae due to lack of sufficient food. Later pupae were successfully shipped in cotton pads with feeding for resulting adults (if at all they emerge during transit). However, evaluation of adults in field is possible only in protected conditions. In open fields, the adults, shipped successfully, exhibited tendency to migrate to other fields. Hence, efforts should be made to develop shipment techniques for immature stages like eggs and early instar larvae.

Effect of pesticides: A range of pesticides can kill syrphids either by contact or by feeding on contaminated aphid prey (Azab *et al*., 1971; Kirknel, 1975). While evaluating 40 different pesticides, Hassan *et al*. (1983) found diflubenzuron to cause relatively lower mortality (less than 50%). Eggs and larvae have been found to be more susceptible as compared to pupae (Van Rensburg, 1978; Laska, 1973). Pesticides like primicarb also has been found to be harmful to different syrphid species (Proctor and Baranyovits, 1969). Effect of various botanicals and pesticides on *E. confrator* has been studied in India to find out safer pesticides in sugarcane crop (Likhil and Mallapur, 2007).

Efforts for enhancing effectiveness

Habitat manipulation for enhancing effectiveness of syrphids is gaining importance. Habitat manipulation mainly involves vegetation management which is helpful in increasing floral resources and alternate prey. Floral resources are useful in providing nectar, pollen and shelter. Vegetation providing nectar and pollen are referred as insectary cover crops. *Fagopyrum esculentum* (Polygonaceae), *Phacelia tanacetifolia* (Hydrophyllaceae) and *Labularia maritima* (Apiaceae) have been used in stripes and borders to increase abundance and activity of syrphids (Chandler, 1968b). *Senecio jacobae* (Asteracae) has been found to be effective in providing additional suitable habitat. Warm season crops (cowpea, sesbania and indigo) and cool season crops (crimson clover, arrow leaf clover and lupin) have been tried as cover crops, which act as a reservoir for aphidophaga (Bugg and Wilson,1989).

Role of intercrops like millets with bidi tobacco (Rao *et al*., 2007) and cluster bean with aubergine (Elanchezhyan *et al*., 2008) have been studied for the enhancement of syrphids. Similarly, benefits of cultivating small number of wild flowers in a classical blend of grasses and legume (Colignon *et al*., 2004); sowing flower strips (Haenke *et al*., 2009) and introduction of flowering plants in green house (Pineda and Macros Garcia, 2008a); introducing aphid infested elder hedgerow in apple orchard (Bribosia *et al*., 2005) and aphid infested barley in sweet pepper (Pineda and Macros Garcia, 2008b) have been known to attract and retaining released syrphid adults in the fields and the green houses.

Recently, in an interesting study, an introduction device for the aphidophagous syrphids *Episyrphus balteatus* (De Geer) has been developed. In this study, oviposition was artificially induced on inert surface (plastic lamella) impregnated with oviposition stimulant consisting of E (beta) farnesene and concentrated mono sugars (30%). Plastic lamella covered with syrphid eggs were then suspended on aphid infested plants. The results obtained were promising (Leroy *et al*., 2010). The use of such a ovipositional device could certainly contribute to the biological control.

Conclusion

Syrphids are one of the most important and potential natural enemies of several aphid species in many crop ecosystems. There is a need to identify the most effective syrphid species in each ecosystem and study their interaction with other natural enemies such as coccinellids, other syrphids and parasitoids.

Although, there are few studies on functional response of syrphids, numerical responses are not studied well. It is essential to have more studies in this direction in laboratories as well as in fields.

More research is needed on syrphid bioecology, in areas like searching behavior, factors affecting their foraging, and the influence of aphid semiochemicals on their effectiveness.

It is necessary to develop methods for determining the effect of temperature and other factors on their efficiency and on the factors that limit their functional and numerical response.

Development of techniques for their effective shipment and release are necessary. Release rates, stage to be released, stage which can be stored at low temperature need to be identified.

More conservation studies throwing light on effect of weeds, source of nectar and pollen, inter-cropping on effectiveness of syrphid are desirable.

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