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Stethorus spp: A predator of mites

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Abstract
Mites are considered as one of the major polyphagous non insect-pests which damage various crop plants causing yield and quality loss by sucking out the contents of plant sap. A major polyphagous mite specie, *Tetranychus urticae* (Koch) is classified under the family Tetranychidae which attacks on various crops and vegetables in field as well as greenhouses. Mites can be controlled by use of various acaricides, but as per present market demand, biological management of mites is getting very much attention. *Stethorus* spp. (Coccinellidae: Coleoptera) is a very efficient predator of mites being used as biological control. Larval and adult stages of *Stethorus* spp. are predatory in nature and it generally completes its life cycle in about 43 days. In general, third instar grub and adult stages are observed with the highest predatory potential for eggs, nymphs and adult stages of different mite species. Other than mites, it also feeds on aphids and their honeydew, whiteflies, floral nectars and pollens at some extent.

Keywords: coccinellid predator, *Stethorus* spp., mite predator

Introduction

Tetranychus urticae (Koch) (Acari: Tetranychidae) is polyphagous specie of the Tetranychidae, attacking vegetables in greenhouses and of several other agricultural major outdoor crops causing huge economic losses (Ripa *et al*., 2006) [51]. *T. urticae* is well adapted to different environmental conditions and is distributed worldwide, causing quantitative and qualitative losses or sometimes even whole plant gets dead due to excessive sucking of plant sap (Geest, 1985 [17]; Granham, 1985 [21]; Rott and Ponsonby, 2000 a & b [52, 53]). The important species of spider mites attacking various major crops in India are *Tetranychus urticae* Koch, *Tetranychus neocaledonicus* Andre, *Tetranychus cinnabarinus* Boisd, *Tetranychus ludeni* Zacher, *Tetranychus macferlanei* Baker and Pritchand, *Oligonychus indicus* Hirst and *Panonychus citri* McGregor (Gupta, 1985) [22]. Abundance of these mites has been seen mostly during dry months of the year and causes appreciable damage to different crops.

There are several important natural enemies attacking *Tetranychus urticae* (Granham, 1985) [21]. All known species of Order Coleoptera, Family *Coccinellidae* are predators of spider mites (Felland and Hull, 1996 [14]; Hoy and Smith, 1982 [26] and McMurty *et al*., 1970 [40]) but the coccinellids *Stethorus punctillum* Weise, *S. gilvifrons* and *S. punctum picipes* are the most effective natural enemies of the phytophagous mite species including *T. urticae*, *T. piercei*, *Panonychus citri* McGregor and *P. ulmi* (Lui and Lui 1986 [34]; Lorenzato, 1988 [33]; Wen, 1988 [63]; Pasqualini and Antropoli 1994 [43]; James *et al*., 2001 [29]; Cakmak and Aksit 2003 [9]; Perez *et al*., 2004 [46] and Gencer *et al*., 2005 [18]). Many species of ladybird beetles are major biological control agents of several insect-pests like aphids, mealybugs, scale insects, thrips and mites in different parts of the world. Some of them are specific in their choice of food while, many of them are polyphagous. A lesser known genus of ladybird beetles which is the very small sized and black coloured is *Stethorus* Weise, which are primary predators of spider mites (Acarina: Tetranychidae) and can also utilize other food such as flower nectar, pollen, honeydew and plant resins for survival (Moreton, 1969 [41]; Helle and Sabelis, 1985 [23]). Several characteristics *viz*., relatively smaller size (0.8-1.5 mm length), voracious obligatory predation, high daily oviposition rates (McMurtry *et al*., 1970) [40], longer adult longevity period (Putman, 1955) [47] and high dispersal capability (McMurtry and Johnson, 1966) [39]; Congdon *et al*., 1993) [11] make them an efficient biological control component of mites. It is also known as 'high density predator' only because the female requires abundant spider mite supplies before oviposition. Fleschner (1950) [16] studied the searching capacity of *Stethorus* species and determined that prey detection occurred by direct physical contact.

Most studies, however, paid attention on the efficacy of *Stethorus spp*. in orchards (Putman, 1955 [47]; Hull *et al*., 1977 [28]; Congdon *et al*., 1993 [11]; Felland and Hull, 1996 [14]; Roy *et al*., 1999 [54]) and less research has been carried out in the field of glasshouse biocontrol. The *Stethorus* species are relatively smaller in size and well adapted to live and search for prey (Kapur, 1948) [31]. Therefore, the addition of a winged predator that could move rapidly to spider mite 'hot spots' would be very useful.

In India, biological control of spider mites is not much attended as it has always been considered as a secondary pest. In view of above consideration, the present review article is prepared for concentrating the biological control nature of *Stethorus* spp.

Stethorus spp., a potential parasitoid of mites

Biology of *Stethorus* spp.

Eggs of *Stethorus siphonulus* Kapur were found light orange or red in colour initially, elliptical in shape, singly or in group on upper and lower leaf surface where spider mites were present and turn greyish black later before hatching. After egg deposition, hatching takes place within 2 – 3 days. (Edwin and Frank, 1974 [13]; Rattanatip *et al*., 2008 [50]). Eggs of *Stethorus tridens* were initially found reddish or whitish coloured which became dark just before some hours of hatching (Fiaboe *et al*., 2007) [15]. Eggs of *Stethorus punctillum* were found pale cream to orange coloured, oval or elongated shaped which laid singly on leaf surface. Eggs of *Stethorus punctillum* take an average of 5.50 ± 2.60 days for hatching (Arbabi and Singh, 2008) [4]. Eggs of *Stethorus pauperculus* and *Stethorus gilvifrons* were yellow in colour, shiny and elliptical in shape and became transparent just before hatching and average time period required for eggs hatching was 5.9 days (Perumalsamy *et al*., 2010 [30]; Rattanatip *et al.*, 2008 [50]). The freshly laid eggs of *Stethorus pauperculus* were smooth, elongated and bluntly rounded at both the end with pale pink to deep pink in colour which turns completely dark in colour on the day of hatching. When reared on *O. indicus*, the incubation period was 4.48 ± 0.35 days whereas 4.20 ± 0.51 days when reared on *T. urticae* (Godhani and Shukla, 2014) [19].

Stethorus siphonulus larvae were very small, fusiform and greyish black in colour initially when hatched and became yellowish brown coloured when became mature (Edwin and Frank, 1974) [13]. Fiaboe *et al*. (2007) [15] observed that during each moult in larval stage, a gluing substance was secreted at the end of abdomen that held it to the leaf surface. *Stethorus punctillum* larvae were blackish coloured with black patches and long hairs on dorsal body surface. It takes an average of 7.73 ± 3.24 days for the completion of the four larval stages (Arbabi and Singh, 2008) [4]. *Stethorus pauperculus* larval body was dorso-ventrally round while, *Stethorus siphonulus* was somewhat flat in comparison. Both were light yellow in colour when hatched and became darker coloured as nearer to maturity (Rattanatip *et al*., 2008 [50]). Average instar period strated from 1.5 (1st) and lasted up to 2.9 days (2nd), and total larval duration (1st – 4th instar) was about 8.7 days (Perumalsamy *et al*., 2010) [30]. *Stethorus pauperculus,* the newly hatched grub was typically dark brown in colour, very small and active with a number of long, brown and grey hairs all over the body. The mean duration of first, second, third and fourth instar larvae of *S. pauperculus,* was 1.55 ± 0.31 days, 1.28 ± 0.25 days, 1.83 ± 0.22 days and 2.80 ±0.24 days, respectively when reared *O. indicus*, whereas the same were 1.67 ± 0.24, 1.25 ± 0.25, 1.91 ± 0.42 and 2.55 ± 0.41 days, respectively when reared on *T. urticae* (Godhani and Shukla, 2014) [19].

Generally, pupae of *S. siphonulus, S. tridens, S. punctillum, S. pauperculus* and *S. gilvifrons* were yellowish brown in colour initially and black afterwards, obovate and flattened in shape and bearing white bristle like setae on dorsal surface. The pupal period was 3.0±0.2 days (Edwin and Frank, 1974 [13]; Fiaboe *et al*., 2007 [15]). The pupal stage of *S. siphonulus* completed only within 2.85 days, while pupal period of *S. pauperculus* lasts for 3.10 days (Rattanatip *et al*., 2008) [50]. This total pupal period ranged between 3 to 9 days with average of 3.45 ± 2.83 days (Arbabi and Singh, 2008) [4]. *Stethorus gilvifrons* pupal period on average lasted for 4.8 days (Perumalsamy, *et al*., 2010) [30]. *Stethorus pauperculus* showed the average pre-pupal period of 1.22 ± 0.25 days when reared on *O. indicus* and 1.10 ± 0.20 days on *T. urticae*. The average pupal period was 3.90±0.20 days on *O. indicus* and 3.75 ± 0.25 days on *T. urticae* (Godhani and Shukla, 2014) [19].

Edwin and Frank, 1974 [13] found that the adult of *Stethorus siphonulus* Kapur were shortly oval and convex and even the males were slightly smaller than the females. The body colour of adult was yellowish brown as tenerals and uniformly black except for the antennae, legs, mouth parts and the anterior margin of the clypeus which were found to be yellowish brown as mature adults. The adult of *Stethorus tridens* was light yellowish at time of emergence but soon turns dark brown and black afterwards. The average durations of pre-oviposition, oviposition and post-oviposition were 10.3±0.67, 31.2±4.74 and 30.2±5.24 days, respectively (Fiaboe *et al*., 2007) [15]. Newly emerged adults of *Stethorus pauperculus* and *Stethorus siphonulus* was light brown in colour which gradually changed to dark brown and black. The shape of adult was convex and oval (Rattanatip *et al*., 2008) [50]. The newly emerged adults of *Stethorus gilvifrons* were light reddish and gradually changed to black according to Perumalsamy *et al*., 2010 [30]. Male *Stethorus pauperculus* showed average adult period of 29.97 ± 2.33 days when reared on *O. indicus* and it was 27.17 ± 3.10 days on *T. urticae*. The female lived for 32.63 ± 1.83 days when fed on *O. indicus* and for 30.63 ± 2.38 days when fed on *T. urticae* (Godhani and Shukla, 2014) [19].

Feeding potential

Stethorus picipes Csy. predated *Oligonychus punicae* (Hirst) on avocado which was experimentally investigated in laboratory by Tanigoshi and McMurtry, 1977 [58] which suggested that when *T. floridanus* was introduced one to three weeks after initial infestation by *O. punicae* at prey: predator ratios of about 35:1. The most favourable results were obtained in suppressing and stabilising the prey population after introduction at 2 weeks. The feeding potatential of *S. gilvifrons* on *O. coffeae* was studied under laboratory conditions and highest consumption was by the 3rd instar grubs grubs (51.7±9.55), followed by the adult beetles (44.6±7.97) (Sarmah and Bhattacharyya, 2002) [55]. Adult females of *Stethorus japonicas* during first 20 days after emergence, exhibited mean daily consumption rates of 294.4 eggs of *T. urticae* at 25 °C (Gotoh, *et al*., 2004) [20]. Second larval instars of *S. punctillum* showed preference for spider mite larvae over nymphs and consumed more larvae. However, the third larval instars and adults exhibited strong preference towards mite eggs and there was significantly less consumption of *T. urticae* larvae by the fourth instar larvae (Ragkou, *et al*., 2004) [49]. *S. Gilvifrons* was proved as efficient predator of whitefly, *B. Tabaci* as it feeds on all stages of whitefly. *S. Gilvifrons* larva consume 525 eggs or 315 nymphs whereas adults fed on all stages of whitefly and each was able to consume 888 eggs, 575 nymphs and 414 adults when fed on either stage for 10 days (Al-Duhawi, *et al*., 2006) [2]. *S. tridens* consumed more prey when instar levels were increased and total average nymph consumption of *T. evansi* per individual was 184.1±18.02 during immature development stage. Alse daily consumption limit for adult male and female was 41.3 ± 0.80 and 67.8 ± 1.69 nymphs, respectively (Fiaboe, *et al*., 2007) [15]. There was significantly higher predating efficiency of *S. punctillum* on *Tetranychus bioculatus* (Wood-Mason) as it was ranged from 35.4 to 48.4 eggs per day. Also, the red mite consumption rate by *S. punctillum* increased when there was increase in mite density up to 30 (Taleb and Sardar, 2007) [57]. Maximum consumption of 33 *T. evansi* nymphs per day was observed per predator, *Stethorus tridens* Gordon at the highest prey density (Britto, *et al*., 2009) [8]. Highest egg predation of 50.82 per cent was observed in early summerat a prey density of 20 whereas highest immature and adult predation was noted in midsummer which was 45.41 and 47.08 per cent, respectively (Wani and Wani, 2009) [62]. The larval instars of predator consumed 361 eggs/larvae and 144 immature stage/larvae of *T. urticae*. However, the adult stage of preadtor fed on all the stages of *T. urticae* and the average consumption rate of one adult during first five days was 83.59 ± 18.1 eggs/adult and 47.1 ± 7.45 immature stage/adult. But, the consumption rate of predator declined during last days and reached to 26.2±21.3 eggs/adult and 18.6±1.08 immature stage/adult (Ahmad, *et al*., 2011) [1]. The functional response of *S. gilvifrons* female to the increasing prey stage density to 10-100 preys per patch was the curvilinear shape explaining Roger's type II response with the highest consumption rate of larval prey stage. Maximum numbers of mites that could consume by a single female of *S. gilvifrons* within 24 h period were that of 77.42 larvae (Osman and Bayoumy, 2011) [42]. Requirement of *S. pauperculus* was 548.57 ± 11.00 eggs or 38.20 ± 6.60 larva or 275 ± 6.46 nymphs or 150.07 ± 6.88 adults of *O. indicus*, whereas, 544.20 ± 8.28 eggs, or 324.97 ± 6.46 larvae or 249.07 ± 7.65 nymphs or 132.43 ± 4.36 adults of *T. urticae* (Godhani and Shukla, 2014) [19].

Alternate food

S. gilvifrons feeds on aphid honeydew in the laboratory as per Mathur, 1969 [38] and he also stated that the larvae "remain adhere to the sticky secretion". *Stethorus* spp. fed on foliar extra-floral nectarines of *Prunus padus* L. in South Korea (Pemberton and Vandenberg, 1993) [45]. The alternate food for *S. punctillum* in the absence of other food could be raisins, aphids, aphid honeydew, and peach leaf extra-floral nectar (Putman, 1955) [47]. *S. punctillum* also act as a predator of *Phorodon humuli* (Schrank) (Hemiptera: Aphididae) (Massee, 1940) [37]. As per Almatni and Khalil, 2008 [3] occationally *S. gilvifrons* fed on *Brachycaudus amygdalinus* (Schoute-den) (Hemiptera: Aphididae). However, adults and larvae *S. gilvifrons* also acts as a very efficient predators of all stages of the *Bemisia tabaci* (Gennadius) and in laboratory trials it was found that the larvae completed their life cycle on this prey alone (Al-Duhawi, *et al*., 2006) [2]. In Brazil, *Stethorus minutulus* Gordon and Chapin found to be feeding on *Delphastus* (Sticholotidinae) in cotton (Silva and Bonani, 2008) [56]. Many of the coccinellid species can exploit pollen, fungal spores and nectar as alternative food sources and addition of pollen or honey to a water-only diet doubled the longevity of adult *S. vagans*, but any of the beetles did not mate or reproduce on either of these foods (Lundgren, 2009) [35]. The longevity of adult female of *S. punctillum* was increased when fed with alternative food sources such as honey, aphids, whitefly-eggs and mixture of honey, pollen and royal jelly as compared to the control (starved females). But when the females raised on alternative foods, it did not laid eggs though longevity of adults were increased greatly (Bakr, *et al*., 2009) [6]. Even under no-prey conditions, sucrose maintained the population of *S. japonicus* properly because the females of *S. japonicus* consumed less *T. urticae* eggs and started laying eggs earlier when compared to only water conditioned *S. japonicus* (Hidenari and Ishizue, 2010) [25]. Alternative hosts of *Stethorus pauperculus viz*., groundnut aphid, whitefly eggs, water only, honey and water mixture and castor pollen and honey mixture were not found useful under laboratory conditions (Godhani and Shukla, 2014) [19].

Relative toxicity

Phenyl N-dimethoxy phosphino dithioacetyl-N-methyl carbamate was more effective at 1 lb against the lepidopteran pests of apple and exhibited low toxicity to *S. punctum*. Dinocap, azinphos-methyl and phosalone at 0.0625, 0.125 and 0.125 lb gave adequate control of Lepidopteran pests including [*Cydia pomonella* (L.), *Agyrotaenia velutinana* (Wlk.), *Platynota idaeusalis* (Wlk.) and *Choristoneura rosaceana* (Harris)] and showed little toxicity to *S. punctum* (Asquith and Hull, 1973) [5]. There was higher toxicity of carbaryl and Dursban at 0.25 lb, methiocarb (Mesurol) at 0.094 lb and Ortho 15223 (O, S-dimethyl (methoxyacetyl) phosphoramidothioate) at 0.3 and 0.6 lb against the *S. punctum* adults (Colburn and Asquith, 1973) [10]. There were highly toxic effects of aminocarb, azinphos-methyl, carbaryl, diazinon and malathion to the adults of *S. nigipes* whereas, there were non-toxic effects on this adults of *Bacillus thuringiensis*, the insecticides lead arsenate, menazon and vamidothion, the acaricides binapacryl, chlordimeform and tetradifon and the fungicides benomyl and copper oxychloride (Edwards and Hodgson, 1973) [12]. The insecticides like methomyl, carbaryl, malathion, monocrotophos, mevinphos, azinphos-methyl, leptophos and dimethoate insecticides and chlorobenzilate, dicofol and cyhexatin were proved to be highly toxic to *Stethorus loi sasaji* (Lo and Chao, 1975) [32]. Some mortality in *Stethorus* spp. was observed when fed on mites treated with dimethoate, phosalone and methyl-demeton. Even the survivors from several of these treatments showed deformations or reduced fecundity (Pavlova, 1975) [44]. Dicofol, quinomethionate (oxythioquinox) were found safe while, carbophenothion was lethal to the coccinellid *S. pauperculus* (Basavanna, 1976) [48]. Azinphos-methyl, DDT, carbaryl, endosulfan, malathion, methidathion and tetrachlorvinphos were found highly toxic whereas, vamidothion (a preparation of *Bacillus thuringiensis*), ryania, bromopropylate (phenisobromolate), chlordimeform, propargite (cyclosulfyne), amitraz (azaform), benomyl, captan, diuron [N'-(3,4-dichlorophenyl)-N,N-dimethylurea], NAA (1-naphthaleneacetic acid) and fentin hydroxide were proved non-toxic to eggs, larvae and adult stages of *Stethorus loxtoni* Britton and Lee, *S. nigripes* Kapur and *S. vagans* (Blkb.) (Walters, 1976) [61]. However, there was partial toxicity of Cyhexatin to *S. punctillum*. Bromopropylate was showing selective effect with respect to *S. punctillum* while propargite showed good selectivity (with no mortality in the laboratory) (Markovic and Zivanovic, 1988) [36]. Acephate and ethion were found to be toxic to 4th instar larvae and adult beetles of *Stethorus pauperculus*, whereas Azadirachtin was less toxic to the larvae and adults (Godhani and Shukla, 2014) [19].

Host range

Under field conditions, *S. punctillum* can be found in orchards, tree plantations, gardens, and crop fields where it feeds on two-spotted spider mite (*Tetranychus urticae* Koch) and other mites of the family *Tetranychidae* (Biddinger, *et al*., 2009) [7]. It also attacks spider mites in cultivations of greenhouses, interiorscapes, nurseries and orchards (Van Lenteren, 2003) [59]. Examples of pests attacked, other than *T. urticae*, include European red mite, *Panonychus ulmi* (Koch), spruce spider mite, *Oligonychus ununguis* (Jacobi), and southern red mite, *Oligonychus ilicis* (McGregor).

Mass culturing method

Walters (1974) [60] developed a method to mass culture different three species of *Stethorus* (*S. loxtoni*, *S. nigripes* and *S. vagans*) on *Tetranychus urtiicae* developed on potted bean plants were transferred to *Stethorus* culture as food. It resulted in three to four-fold increase in *Stethorus* population per month at 16-23 ºC. When cultured at 24 ± 0.5 ºC and 50-70% relative humidity, there was about seven-fold increase in only two generations. Initially twenty pots sown with ten bean seeds per pot are grown up to height of 30 cm and then transferred to controlled condition having 25 ± 3 ºC and 30-40% relative humidity. 10 pairs of *Stethorus* spp. were kept in 2 litre of plastic container in which eggs, different instars and adult mites developed on bean plants were transferred with the help of mite brushing machine (Henderson and McBurnie, 1943) [24]. One container of *Stethorus* can be run with mite infested nine bean leaves. Whole bean leave along with mites and eggs should not be added to the containers as the trichomes on bean leaves tear apart the integument and terminal abdominal regions of immature grubs of *Stethorus*. Containers must be cleaned every 5 to 6 weeks. Adult beetles can be stored for a few days at 10-16 ºC but longer storage without food will reduce egg laying and adult life span.

Field release

Adult beetles of *Stethorus* spp. are introduced in fields for the control of spider mite populations effectively. Generally, minimum 100 adults per infested plant at weekly interval for 3-4 weeks are released. In greenhouse condition *Stethorus* can be released at 1-4 adult beetles per square meter or 100-200 beetles per mite hotspots at weekly interval for 3-4 weeks depending on mite infestation.

Conclusion

Stethorus spp. is a very efficient predator of mites being used as biological control. Larval and adult stages of *Stethorus* are predatory in nature and it generally completes its life cycle in about 43 days. In general, third instar grub and adult stages are observed with the highest predatory potential for eggs, nymphs and adult stages of different mite species. Other than mites, *Stethorus* spp. predate on aphids and their honeydew, whiteflies, floral nectars and pollens at some extent also. Stethorus is mass cultured on *Tetranychus urtiicae* developed on potted beans at 24 ± 0.5 ºC and 50-70% relative humidity. Different chemical pesticides *viz.*, phenyl N-dimethoxy phosphino dithioacetyl-N-methyl carbamate, dinocap, azinphos-methyl, phosalone, quinomethionate, vamidothion, ryania, bromopropylate, chlordimeform, propargite, amitraz, benomyl, captan, diuron, NAA and fentin hydroxide while, natural product like azadirachtin were found relatively less toxic to *Stethorus* spp. The beetles are released at 1-4 adults per square meter or 100 adults per plant at weekly interval for 3-4 times for the control of various mites on different crops.

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