5. DISCUSSION

One of the best ways to overcome the deleterious effects of pesticides is to switch over to the use of biological control agents which results in effective control of pests without leaving any harmful effect on the environment. Owing to the great benefit of biological control agents like predator and parasitoids against insect pests, an attempt has been made to study the species Stethorus aptus (Kapur) which was newly reported as a predator of O.coffeae in tea and to evaluate their role in the natural biological control of this tea pest.

In this chapter, the findings of the present study were summarized and critically discussed the seasonal population dynamics, morphology, life cycle parameters and predatory potentiality of the coccinellid beetle Stethorus aptus (Kapur) in the light of other relevant research works done by different researchers in this field. Furthermore the effect of different pesticides and botanicals that were used for control of RSM were also discussed to know their impact on this new species in tea ecosystem that feed on tea pest O.coffeae.

5.1 Predatory potentiality of Stethorus aptus against RSM

The suitability of a biocontrol agent can be assessed by evaluating its feeding efficiency on prey. As S. aptus is newly reported predator in tea, we examine the daily consumption and prey preference of different developmental stages of S. aptus on
O. coffeae. Rate of predation by S. aptus increased gradually with the advancement of the developmental stages as reported by Perumalsamy et al. (2010) for S. gilvifrons, Ragkou et al. (2004) for S. punctillum and Gautam and Tesfaye (2002) for Chrysoperla carnea. Atlzhan et al. (1999) reported that increased prey consumption in immature stages resulted in higher reproduction rate. Among the larval instars, fourth instar grubs of the predator consumed maximum number of all the stages of RSM both in choice and no choice feeding until pupal transformation. They required more food than the previous instar due to bigger size and to accumulate energy for metamorphosis. All the life stages of S. aptus showed more preference for RSM eggs. Similar results were obtained by (Houck 1991) and Ullah (2000). Various authors (Putman 1955; Moutia 1958; Raros and Haramoto 1974; Houck 1991) demonstrated that when all the stages of prey offered together, Stethorus consumed maximum number of prey eggs as the handling time for per motile prey was higher than the egg stage. Another reason for higher consumption of eggs could be that the size of eggs is smaller than the body size of other stages and also the non motile state. However, Ragkou et al. (2004) reported that preference for prey stage varies according to the species and stage of development of the predator. Initially a newly emerge predator has low predation rate. From 4\textsuperscript{th} to 6\textsuperscript{th} day onward the rate of consumption has increased and maintained a steady state until 70\textsuperscript{th} day. Thereafter the feeding rate showed a decreasing trend. An adult predator consumed an average of 52.2±5.88 RSM per day during its adult stage. Peterson et al. (1994) noted that S. bifidus fed on T. urticae and Panonychus ulmi. Hull (1995) stated that all the developmental stages of mites were consumed by S. punctum which is similar
with our findings. Zadeh and Pormirza (1999) studied the predatory rate of different stages of *S.punctillum* on the RSM and observed that first, second, third and fourth instars and adult insect consumed 6.80±0.07, 23.50±2.40, 37.30±4.50, 92.90±4.60 and 211±5.20 mites per day which is much higher than our findings. In this study, we found that different stages of the predator prefer the egg stage of prey. This is because the egg stage comprised the major proportion of *O.coffeae* population. The preference to egg stage would be helpful to prevent the proliferation of the pest population. The higher rate of consumption and high longevity, dispersal characteristics and ability to locate RSM ‘hotspots’ by *S. aptus* adults justifies its importance as a potential biocontrol agent of insect pest in agricultural crop system.

**5.2 Impact of temperature on predator potential.**

Impact of temperature on predatory efficiency was studied in adults and late larval instars of *S. aptus* as they are voracious feeder on mite. Result suggests that the predatory potential of larva and adult of *S. aptus* increased as temperature increase from 23°C to 31°C. All the stages devoured significantly more RSM adult at 31°C compared to low temperature 15°C. Many authors (Islam and Chapman 2001; Parajulee et al., 2006; Nakahira et al., 2005) studied the relationship between temperature and response of natural enemies. Parajulee et al., (2006) stated that prey consumption of green lacewing *Chrysoperla carnea* larvae increased with increase in temperature from 15°C to 35°C. This findings are in agreement with our results. Mohaghegh et al., (2001); Mahdian et al.,(2006) ; Li et al.,(2007) ;Jalali et al., (2010) said that at high
temperature a predator increased their feeding activity and searching rate by reducing their handling time which enhance the efficacy of a predator to control target pest. The preference to larvae and nymphs of prey mites with higher feeding potential may help to control the proliferation of pest population at the field level

5.3 Influence of predator prey ratio in predation

Augmentation of natural enemies had been used to achieve efficient biological control in agro ecosystems (Stinner, 1977). The results showed that the entire tested predator prey ratio reduced mite population. However the optimum predator prey ratio of 1: 50 and 1:66 was found effective for S. aptus adult to control the population of O.coffeae. Among the larval instar the maximum reduction was observed at the ratio of 1:25. Under greenhouse condition, the predator prey ratio, 1:33 and 1:25 can gave more than 50 percent reduction of RSM. Jeyarani and Ramaraju (2012) observed that maximum consumption of T.urticae by S.pauperculus and the predatory staphylinid , Oligota sp. occurs at the predator prey ratio of 5:150. Hassan et al. (1985) reported that the green lacewing Chrysoperla carnea can control Myzus persicae on sugarbeet at the ratio of 1:5 and 1:10. Cheng (2007) reported the predator prey ratio 1:15 and 1:10 offered significant reduction of mites in papaya. In our study we have observed that the number of prey remained on the plants decreased with an increased in the population of the predator. Similar result was also stated by Arbabi and Singh (2008) on Stethorus punctillum against Tetranychus ludeni. In case of predatory mite, Amblyseius longispinosus (Evans), Jeyarani and Ramaraju (2012) reported that 5: 50 ratio was effective for the control of Tetranychus urticae population.
5.4 Functional response of *Stethorus aptus* to prey density-

An effective biocontrol agent is mainly selected on the basis of its functional and numerical responses to its prey (Holling1959). The functional response of a predator describes the relationship between the prey density and the number of prey attacked in response to the prey density (Solomon, 1949). The results exhibited type II functional response curve indicating that the attack rate of the predator is directly proportional to prey density up to an optimum range of host species. Imani and Shishehbor (2011) studied the functional response of *S. gilvifrons* to different densities of *Eutetranychus orientalis* and observed type II response for all developmental stages which was similar to our findings. The type II functional response curve has also been observed by Afshari (1998), Mehrkhou (2009) and by Matin (2008). Richardson (1977) recorded a similar curve for *S.nigripes* preying on *T.urticae*. However, Sohrabi & Shishehbor (2007) observed Type III functional response for the adults of *S. gilvifrons* feeding on *Tetranychus turkestani* Ugarov & Nikolski.

The basic factors that affect the functional response are the time of exposure to prey, search rate, identification, capture and prey consumption (Holling, 1959b). According to Athan and Guldal (2009) the handling time (T_h) is a good indicator of predation rate. In this study it was observed that T_h value for females was lower than the male and other developmental stages. The female consume maximum number of prey may be due to their bigger size and also to accumulate energy to produce eggs as suggested by Hodek and Honek 1996; Omkar and James 2004. However Imani & Shishehbor (2011)
for *S. gilvifrons* and Lee & Kang (2004), Cabral et al. (2006) and Moura et al. (2006) observed that the fourth-instar larvae were more voracious than adult females. The handling time of first and second instar larvae of *S. aptus* to adults and eggs of *O. coffeae* were found higher than the late instar. Longer handling time in early instars may be due to their small size and slow movement. Rahman et al. (2012) studied the functional response of *Neoseiulus longispinosus* against *O. coffeae* at six temperature and found Holling type II model. The predation rate was found directly proportional to the prey density. The predator spend less time on individual prey at higher prey density may be because the prey coincidently come in contact to a feeding predator that may cause the predator to discard the prey it is eating and attack another thereby increase the chance of encounter with a predator. Metz et al. (1988) said that this high prey density results in wastefull killing as the predator not consume one whole prey and partially attack multiple prey. Due to the factor such as satiation the predation rate reaches a plateau at higher prey density (Sabelis 1985).

The ability of the predator to control prey population is influenced by several factors like developmental response, utilization of alternative prey, behavioural patterns in response to predators own density and intra–guild interaction (Lester and Harmsen, 2002). Thus functional response study of *S. aptus* confirmed that prey density is one of the major regulating factors of predation. Functional response study of a predator gave an idea on the feasibility of a successful predator.
5.5 Numerical response study of *Stethorus aptus*

Numerical response study of *S. aptus* indicated a positive correlation to different prey densities of RSM. In coccinellid fecundity was greatly affected by prey abundance. The rate of oviposition increased with increased prey consumption. At minimum density of twenty mites per leaf, predator did not lay any eggs. Ladybird reared on maximum prey density produced the highest mean total eggs. Numerical response study of *Stethorus* species is very limited. A few researchers had studied the numerical response of *Stethorus* preying on spider mites. Yigit and Uygun (1986) studied the numerical response of *Stethorus punctillum* Weise feeding on *Tetranychus viennensis* Zache. Another author Sohrabi & Shishehbor (2007) studied the numerical response of different species *Stethorus gilvifrons* feeding on strawberry spider mite. Their result indicates that increase in prey density enhance the egg laying capacity of the predator which is similar to our findings. The reproductive response of *Stethorus vagans* and *Stethorus nigripes* adult to different mite egg density was observed by (Ullah 2000, Richardson 1977). Their results suggested that the gross and net fecundity of the predator increased linearly with mite density. The increase in oviposition in response to increase in prey density will enhance the effectiveness of biological control by a corresponding increase in predator population.

5.6 Seasonal abundance of *Stethorus aptus* and its prey *Oligonychus coffeae*

It is well known that the pest and natural enemy complex within a crop might undergo dynamic changes over space and time. Therefore, periodic surveillance of pests and
their natural enemies is needed for developing successful biological control programme for a pest in a particular crop system.

The population of *S. aptus* and its prey red spider mite were present throughout the year in the study area but not actively established all the time. The seasonal abundance of *S. aptus* correlated with the population fluctuation of RSM during the study period. The population of *S. aptus* was found to be increased from January and attained a peak during March (Fig1). From July the population of both RSM and *S. aptus* showed a decreasing trend till November. Our findings are in agreement with that of Perumalsamy *et al* 2010, who had reported that the population of a related species *Sthetorus gilvifrons* coincided with the abundance of *O. coffea* infesting tea. Similar findings were also obtained by Kishimoto (2002) who observed that the seasonal occurrence of spider mites and its predators (*Stethorus japonicus* Kamiya (Coccinellidae), *Oligota spp.* (Staphylinidae) and predatory thrips, *Scolothirps takahashii* Priesner (Thripidae) in three Japanese pear Orchards and reported that the population of predator was closely associated with that of the prey. Likewise Geroh and Gulati (2007) studied the population build up of *T.urticae* and its predatory coccinellid beetle *S.punctillum* on okra and observed that the predator showed two peaks which corresponds to the population peak of *T.urticae*. Roy *et al.* (2005) reported that seasonal activity of *Stethorus punctillum* Weise and the predatory mite *Neoseiulus fallacis* (Garman) were coincided with that of their prey, *Tetranychus medanieli* McGregor in
raspberry. The present results are also in agreement with the results obtained by (Raros and Haramoto, 1974) on *S.siphonulus* Kapur.

As insects are poikilothermic in nature, abiotic factors play an important role in their distribution and abundance. Temperature, relative humidity, rainfall etc influence the dynamics of mite and its predator. The present study indicated that weather factors such as high temperature, relative humidity and rainfall affect the populations of *S. aptus*. The population of predator showed a significant positive correlation with the population of RSM (*r* = 0.822), maximum temperature (*r* = 0.585) and relative humidity (*r* = 0.591) whereas it was positive but no significant correlation between minimum temperature (*r* = 0.336) and rainfall (*r* = 0.417). Studies of Perumalsamy *et al* (2010) support the present findings that population of *S.gilvifrons* showed a positive correlation with high temperature and high humidity. However according to Geroh and Gulati (2007) no any abiotic factor played any significant role in population build up of *S.punctillum* except temperature. In general, it is well established that most *Stethorus* species are considered to be 'high density predators', since they require abundant prey (Mc Murtry *et al* 1970, Mc Murtry and Johnson 1966, Putman 1955). As Mathur (1981) and Mukherjee Somchoudhary (1981) suggested, it could not bring the mite population under economic injury level but it lowered the rate of increase of pest population and delayed the appearance of foliar injury caused by mites.
5.7 Life cycle and morphometric observation of *Stethorus aptus*

Proper understanding of any organism depends on the study of its morphology, biology and ecology. From this point of view, this study was initiated to understand the biology and morphology of the *S. aptus* to differentiate it from their close relatives. Lifecycle studies and the morphometric observation of different stages of the predator are necessary to understand their behaviour for incorporation and conservation in augmentative biological control programs.

The life cycle of *S. aptus* comprised of stages starting with an egg, four larval instars, pupa and adult. The eggs were yellow orange in colour and laid in groups. The morphology of the egg was found similar with a number of other species of *Stethorus*, such as *S. vagans* (Khan et al., 2002), *S. punctillum* (Putman, 1955), *S. gilvifrons* (Mathur, 1969; Ahmed and Ahmed, 1989; Perumalsamy et al., 2010), *S. keralicus* (Daniel, 1976). *S. pauperculus*, and *S. nigripes* (Richardson, 1977). Khan et al., 2000 reported that eggs of *S. vagans* was translucent white and turned to pale-yellow colour after 4-5 h. Puttaswamy and ChannaBasavann, 1977, described that eggs of *S. pauperculus* were pale-pink to deep-pink in color which was contrast to this finding.

The larval stages of the predator are found similar with other species of *Stethorus* (Britton and Lee, 1972; Houston, 1980; Rattanatip et al., 2008; Inamullah, 2000). The four larval instars were differentiated on the basis of presence of shed exoskeletons. Dyar (1890) and Inamullah (2000) differentiate the larval instar of *S. keralicus* and *S. vagans* on the basis of head capsule. However no such measurement for other *Stethorus* species had been found under taken. The larval stages of *S. aptus* (0.62 x 0.32,
1.03 x 0.32, 1.28 x 0.41, 2.40 x 0.88 mm) was relatively bigger in size than \textit{S. vagans} i.e \textit{2nd}, \textit{3rd} and \textit{4th} larval instar (0.91 x 0.16, 1.14 x 0.22 and 1.84 x 0.41 mm) (Inamullah, 2002), but similar to \textit{S. pauperculus}, i.e 0.61 x 0.20, 1.0 x 0.32 and 1.2 x 0.4 mm for 1st, \textit{2nd} and \textit{3rd} larval instars, respectively (Puttaswamy and ChannaBasavanna, 1977). All instars possess numerous dark brown setae on their tergite with dark brown pigmentation on their dorsal surface. The colour of the larva varies among species, which would be helpful in field identification (Khan \textit{et al.}, 2002; Muma, 1955; Putman, 1955; Pasualini and Antropoli, 1994; Pollock and Michels, 2002, 2003, 2007; Biddinger \textit{et al.}, 2008a, b). Irshad (2001) stated that color of \textit{Stethorus} larvae varied from light-black to brown. Puttaswamy and ChannaBasavanna (1977) found the colour of newly hatched \textit{S. pauperculus} larva was dark brown while Rattanatip \textit{et al.}, 2008 observed transparent yellow or pale color larva. Findings on pupal form of \textit{S. aptus} was quite similar to those reported by Chazeau, 1985; Biddinger, 1993; Britton and Lee, 1972; Houston 1980, Puttaswamy and ChannaBasavanna (1977) and Chayopituk (1983). The pupal length and width of \textit{S. aptus} are larger than \textit{S. keralicus} (Daniel, 1976), \textit{S. punctum} (Colburn and Asquith 1971) and \textit{S. vagans} (Khan \textit{et al.}, 2002).

Regarding adult morphology similar observations were also reported by Puttaswamy and ChannaBasavanna (1977) for \textit{S. pauperculus}, Richardson(1977) for \textit{S. loxtoni}, Perumalsamy \textit{et al.}, (2010) for \textit{S. gilvifrons }, Khan \textit{et al.},(2002) for \textit{S. vagans}. The dorsal side of the beetle was oval in shape which gave support to the predator to move freely within the silken web of \textit{O.coffeae}.
The present study also indicated that preoviposition period of the predator decreased significantly with increasing temperature. Similar results for *Chilocorus nigritus* Fabricius and *Stethorus punctillum* Weise (Coleoptera: Coccinellidae) had also been reported (Miaoqing et al. 1999, Ponsonby and Copland 1998). The pre-oviposition period of *S. aptus* in this study was almost similar with *S. japonicas* (Mori et al., 2005), *S. punctillum* and *S. picipes* (Casey) (Tanigoshi and McMurtry, 1977; Roy et al., 2003) at or around the same temperature. In case of *S. aptus* at 27°C the preoviposition period was 5.35 days while, Fiaboe et al. (2007) reported that the preoviposition period of *S. tridens* reared at 27°C was 10.3 days which was longer than this findings. Rattanatip et al. (2008) recorded 4.81 and 4.79 days of pre-oviposition period for *S. pauperculus* and *S. siphonulus* at 30°C. Perumalsamy et al (2009) studied the life cycle of another predator of *O.coffea*, *Stehorus gilvifrons* whose pre-oviposition was found 5.30 days at 25±1°C.

The oviposition period of *S. aptus* was differed significantly from other species of *Stethorus* such as *S.siphonulus* (Raros and Haramoto, 1974), *S.vagans* (Sarkinapaibul 1974), *S. tridens*, (Fiaboe et al., 2007) and *S. japonicus*; (Mori et.al., 2005) where the oviposition periods are shorter than the present findings. The mean fecundity per female of *S. aptus* (115 to 124 eggs) found lower than those reported by Biswas et al.(2007) and Putman (1955) for *S. punctillum*, Rattanatip et al.2008 for *S. pauperculus* (240 eggs) and *S. siphonulus* (150 eggs), Perumalsamy et al., (2010) for *S.gilvifrons* (149eggs), Chazeau (1974) for *S.madecassus* (184 eggs) and Tanigoshi and McMurtry (1977) for *S. picipes* (221eggs).In our study, we observed that *S. aptus* lay their eggs
singly or in a group of 2-4 eggs which was in agreement with the report of Puttaswamy and ChannaBasavanna (1977) for *S. pauperculus* and Rattanatip et al. 2008 for *S. siphonulus*. However Raros and Haramoto (1974) reported that *S. siphonulus* deposited a single egg in a colony of spider mite which was different from our results. Aksit et al. (2007) reported total fecundity of *S. gilvifrons* differ significantly in response to various temperatures tested under the long-day photoperiod. In our study also, variation was found in fecundity at different temperature. However Ahmed and Ahmed (1989), Mori et al (2005) have reported an increase in fecundity with an increase in temperature for *Stethorus gilvifrons* and *Stethorus japonicas*.

**5.7.1 Duration of developmental stages of *Stethorus aptus***

Studies on duration of developmental stages of *S. aptus* were carried out in the laboratory. Results suggested that rate of development of the predator was inversely proportional to temperature. The incubation period of eggs depends upon atmospheric temperature, hence varies with season. This was the first report on the life history for *S. aptus* feeding on *O. coffeae*. In other species of genus *Stethorus* the incubation period of eggs varied between 3 to 5 days (Chayopituk 1983 and Puttaswamy and Channa-Basavanna 1977). The result of the findings was in the same range as those of *S. punctillum* and *S. japonica* where 3.4 and 3.2 days were noted (Jiang et al., 1982; Mori et al., 2005). Raros and Haramoto (1974) and Sarinkapaibul (1974) indicated that at 27-32°C the incubation period of *S. vagans* was 2.9 days. Aksit et al., (2007) found that the
egg incubation period of *S. gilvifrons* decreased from 6.22±0.15 to 3.41±0.07 days at 20°C to 30°C.

The larval stages of *S. aptus* were predaceous and consisted of four instars. The total larval period of *S. aptus* constituted 51% of the total developmental time, while *S. picipes* and *S. punctillum* was about 60% and 45% when reared on *Oligonychus puniceae* at laboratory conditions (Tanigoshi and McMurtry (1977) and Arbabi and Singh (2008). Like ectothermic organisms, the developmental time of *S. aptus* larva decreased at higher temperatures. Earlier studies indicated that the duration of development of larva of *S. pauperculus* and *S. siphonulus* were 7.85 and 6.11 days (Rattanatip et al.2008), *Stethorus punctillum* is 7.73 ± 3.24 days (Tanigoshi and McMurtry ,1977) respectively.

The result of this study revealed that the fourth larval instar required the longest time to develop compared to all other larval instar. Similar results were observed by Raros and Haramoto (1974) against *S. siphonulus*.

However the pupae of *S. aptus* required a range of 4 to 5 days to complete their development at 21°C followed by 3 to 4 days at 32°C which was found similar with the result of *S. punctillum* at same temperature (Biswas et al.2007).

The longevity of adult beetles were also studied in the laboratory and found that the longevity of the female was more than the male at different tested temperature.Similar results were reported by Raros and Haramoto (1974) for *S. siphonulus*, Perumalsamy *et al.* (2009) for *S.gilvifrons* and Putman (1955a) for *S. punctillum*. However Ullah (2000) reported that both sexes of *S.vagans* lived for 126 days at 12°C in Australia. The mean total developmental period of *S. aptus* feeding on *O.coffeae* in different season was
about 18.33 days which was almost similar to *S. gilvifrons* fed on *O. coffeae* (Perumalsamy *et al.*, 2009) and relatively longer than *S. pauperculus* fed on *T. urticae* (14.05 days) (Rattanatip *et al.*, 2008). *S. siphonulus* fed on *T. urticae* required only 11.25 days (Rattanatip *et al.*, 2008), *S. punctillum* fed on *T. mcdaieli* McGregor acquired a range of 12.7 days (Roy *et al.*, 2002), and *S. japonicas* fed on *T. urticae* took 12.0-12.4 days (Mori *et al.*, 2005) respectively to complete their development. The variation in development period was probably due to the quality of prey species. Kishimoto (2003) stated that development of *S. japonicus* differed greatly with prey species which was probably due to a physiological nature such as nutrients of each prey species.

On biological aspects, studies had been conducted on some species of *Stethorus* and documented that most of the species completed their lifecycle in two weeks under optimal temperature (Pavlova 1975, Singh and Ray 1977). Bravenboer (1959) and Berker (1958) studied the effect of temperature on the development of *S. punctillum*. Roy *et al.* (2002) studied development of *S. punctillum* at 12 constant temperatures and modeled their development rates at a function of temperature. The present findings were in line with the above results that higher temperature accelerates the developmental rate of the predator. The longevity of the adult recorded in this study (88.30 days at 21°C, 90.4 days at 27°C and 83.7 days at 32°C) were notably different from other species of *Stethorus*. Jiang *et al.* (1982) found that the longevity of *S. punctillum* were 32-53 days at 24-28°C whereas Biswas *et al.* (2007) found that the longevity of *S. punctillum* was 26-62 days at 23-31°C respectively. Puttaswamy and Channabasavanna (1977) reported that the longevity of *S. pauperculus* were 30-61 days at 24-26°C. Khan (2000) reported
17 to 42 days of adult duration at 12 to 30°C for S. vagans and 48-57 days for S. loi at 24°C (Shih et al. 1991). The longevity of S. gilvifrons adults preying on O. coffeae was accounted 79.38 days at 25±1°C (Perumalsamy et al., 2010).

Variations were found in the results of present study with the earlier ones. This might be due to the difference in prey species used, variation in nutritional quality of prey, or the rearing conditions as suggested by (Kaluskov and Hodek 2004).

5.7.2 Survival of S. aptus on alternate food- The longevity of adult S. aptus was found different on different alternative food they feed. The longest period was recorded (16.2) days when the predator feed on a mixture of honey and pollen. However no oviposition recorded for S. aptus when feed on any alternate foods. A similar result was reported by Hoy and Smith (1982) for S. nigripes; Helle and Sabelis (1985) for S. punctillum and S. fuerschi; Gu et al. (1996), Shoeib (2001), Bakr et al., (2009) for S. punctillum and Hiteshkumar and Shukla (2015) for S. pauperculus . But this observation is in contrast to the finding of Inam-Ullah (2000) for S. vegans, where female predator laid eggs when reared on water+pollen grains. Mathur (1969) found that S. gilvifrons consumed aphid honeydew and Putman (1955a, 1963) found that S. punctillum, eat raisins, aphids, aphid honeydew and peach leaf in the absence of other food which prolonged their adult survival and reduced egg production.

Our results suggest that, S. aptus is a mite predator that lay eggs only when feed with natural host. The alternate food could be used to maintain their population under in vitro condition when primary prey availability is less.
5.7.3 **Life table study of S. aptus** – Life table study of a predator provides information on the life history of the species and to aid in the development of control measures. There is no published information on life table studies on *S. aptus* feeding on *O. coffeae*. Results indicated that in larval stages maximum mortality was observed in the first larval instar. These results agreed with the findings of Mori et al. (2005) for *S. japonicus* and Rattanatip et al. (2008) for *S. pauperculus* (Weise) and *S. siphonulus* (Kapur). Mortality is higher at first instar than the late instar which could be due to the delicate body of early instar as suggested by Ali and Rizvi (2007a, 2010). The life table parameters of *S. aptus* revealed that *T*=41.43 days, *R₀*=65.66 times, *rₘ*=0.101 individual per day, *λ*=1.10 and *DT*=6.86 days respectively. This results were in agreement with Fiaboe et al. (2007) for *S. tridens* who found *T* and *λ* is equaled to 38.2 days and 1.11 and Rattanatip et al. (2008) for *S. pauperculus* who revealed that *rₘ*, *λ* and *DT* is equaled to 0.11, 1.12 and 6.10 days. According to their result the *T* value of *S. tridens* was 38.2 days which was shorter than 41.43 days for *S. aptus* in our findings. However the *T* and *R₀* (51.10 days and 270.49) value of *S. japonicus* (Mori et al. 2005) fed on *T. urticae* was considerably higher than the value of *S. aptus*. The *r* value (intrinsic rate of natural increase) of *S. aptus* (0.101) was found less than other species of Stethorus like *S. loxtoni* Britton & Lee (0.152; Richardson 1977), *S. madecassus* (0.155; Chazeau 1974), *S. picipes* (0.121; Tanigoshi and McMurtry 1977), *S. loi* Sasaji (0.160; Shih et al. 1991), *S. japonicus* (0.156; Mori et al. 2005) and *S. gilvifrons* (0.133; Taghizadeh et al. 2008) while larger than *S. gilvifrons* (0.066; Perumalsamy et al. 2009) feeding on *O. coffeae*. 

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Theoretically, a predator having a population growth rate equal to or greater than its prey should efficiently regulate the population of its prey (Sabelis, 1992). In biological control practice the, the ‘r’ value is one of the most important criteria in selecting biological control agents on the basis of its reproductive potential and to predict the outcome of interaction of the pest and the beneficial organism once a beneficial agent is introduced into a crop system. The ‘r’ value (0.101) of *S. aptus* feeding on *O.coffeae* was found to be lower than that of the prey (0.25) Muraleedharan et al. (2005). However, on the basis of ‘r’ value, one should not understand the efficacy of a predator, as other factors such as predation capacity, early detection ability and longevity may also equally contribute to the dynamics between the predator and its prey (Roy et al. 2003). Therefore *S. aptus* with its voracious prey consumption and admirable searching ability could have the potential to prevent the proliferation of RSM population in the field conditions in association with other natural enemies.

### 5.8 Mass culture of *S. aptus*

The predator *S. aptus* is basically a mite feeder and it lay eggs only when fed with natural host (Putman, 1955a ; Hodek,1973; Ullah,2000) Artificial diets can be used as substitute for rearing of *S. aptus*. In absence or unavailability of natural host these artificial diets can be used for maintaining the population of the predator. Artificial diet contained important ingredients for adults and larvae which can serve as substitute food for this coccinellid. But these diets showed significant impact on the predator and did not support egg laying until feed on its natural mite prey. The larval stages also could
not grow beyond IV instar and did not undergo pupation when feed on artificial diets. This may be due to hormonal change in the insect body which ceases the metamorphosis process. The results were in conformity with the observations made by Ullah (2000) who reported that the predatory coccinellid, *S. vagans* reared on pollen or honey doubled the longevity of the adults, but beetles did not mate or reproduce on these foods. Putman (1955a, 1963) found that *S. punctillum*, eat raisins, aphids, aphid honeydew, and peach leaf extra floral nectar in the absence of natural food but all of these foods had extended the adult survival and had no impact on egg laying of the predator.

Diet containing honey source supported significant survival rate of immature stages of the beetle. Being a rich source of monosaccharide and dissacharides, honey served as a vital energy reserve (Pemberton and Vandenberg, 1993) that provide better survival rate of the adult and immature stages of the predator. According to Simmons et al., 2012 honey is a convenient food source for survival of coccinellid beetle. Numerous coccinellid species can utilize pollen, fungal spores, and nectar as alternative food sources (Lundgren, 2009a, b).

The findings can be utilized for effective mass production of coccinellids predator intended for biological control of insect pests. However further studies are needed to improve the egg laying capacity and survival of *S. aptus* on artificial diet to make it a viable method for the mass multiplication of this species.
5.9 Effect of Pesticides on Stethorus aptus:

For successful integration of biological control programme in an agroecosystem, knowledge of the impact of pesticides on beneficial arthropods is necessary (Croft 1990). The susceptibility of Stethorus aptus (Kapur) to pesticides was examined in laboratory bioassays. Among the tested pesticides except hexythiazox, both bifenthin and propargite caused 100% mortality in S. aptus adults and larval stages at concentrations equivalent to field rates. Mites are important pest of tea for which pesticides are routinely applied. The study provides us information on the effect of pesticides to this important predator of tea RSM. James (2002,2003) studied the toxicity of pesticides to spider mite predator Stethorus punctum picipes in hops. The subspecies Stethorus punctum punctum was studied by Colburn and Asquith (1970, 1971, 1973) to evaluate the toxicity of a large number of pesticides against this predator. Antonelli et al. (1996) reported the toxic nature of bifentrin to S.punctum picipes which causes elimination of the predator population in Washington raspberries. Similar results were obtained for bifenthrin in the present study also. Collyer 1964 and Croft 1990 said that before the application of organophosphate and pyrethroid insecticides, Stethorus species were found as important biocontrol agent of phytophagous mites in trees and small fruits in Australia and New Zealand. Among the tested insecticides, hexythiazox was found to be less toxic to the larva and adults of S. aptus. Results of this study are in agreement with the findings of James (2003) who have reported the non–toxic nature of Hexythiazox against S.punctum picipes and H. axyridis. In laboratory bioassay test the toxicity of pesticides to bio control agents is always more (Croft 1990) as the test insect
experienced maximum contact exposure to pesticides. However in the field there are many additional factors like weather conditions and calibration of spraying equipment etc whose functions may results in more or less mortality of test insect than that obtained in the laboratory. But laboratory results provide a guide to know the impacts of pesticides on biocontrol agents in field condition. Marshall (1963) found some pesticides to be highly toxic to certain pests, but only moderately toxic to certain beneficial species when applied at moderate dosages.

5.10 Effect of botanicals on *Stethorus aptus*:

The crude plant extract possess a complex mixture of compounds which have a number of properties including insecticidal, ovicidal, antifeedant and antioviposition properties (Arivoli and Tennyson, 2013). The present study showed that the tested plant extracts were effective against RSM (published data) but had no significant impact on mortality and feeding rate of the predator under laboratory condition. Leatemia and Isman (2004) studied the toxicity of crude extracts of *Annona squamosa* against *Chrysoperla carnea* larvae and found the extract was less susceptible to the natural enemy than *Orius insidiosus*. Vasanthkumar *et al.* (2013) studied the impact of neem based pesticide, Azter and Neem Kernel Aqueous Extract (NKAE), on the prey consumption of *Mallada desjardinsi*, a predator of RSM infesting tea and found that these botanicals had no significant impact on the prey consumption. Both chemical and biological control are important for management of insect pests. Therefore emphasis should be given in the use of those pesticides which are harmless to beneficial insect but are still capable of
bringing the pest population to a level which causes no economic damage. Moreover, the biocontrol methods will be helpful to improve the existing methods for the management of *O. coffeae* in tea plantations.

### 5.11 Evaluation of *S. aptus* as an effective biocontrol agent

According to Huffaker *et al* (1969), there are some characteristics such as high searching ability, sufficient power to suppress the prey population, synchrony with the prey population, density–dependent response to its prey etc of effective biocontrol agents. The laboratory and the limited field investigations reported in this thesis shown that *S. aptus* possesses many of these attributes. The predator was found good in prey consumption. All the stages of *S. aptus* predate on different stages of RSM including egg with commendable searching ability. In the shortage of natural prey the predator was able to survive on alternate food sources. However they donot oviposit in such situation. The lack of suitable artificial diets for rearing coccinellid is a limitation to produce mass culture of natural enemies (Ullah 2000). Earlier this species was found as a predator of *P. citri*. In tea ecosystem its abundance was found in correlation with RSM population. Other abiotic factors also influence their abundance. The predator exhibits density dependent response to its prey by possessing functional and numerical response to prey density.
5.12 Summary and conclusion

The current study provides comprehensive information on the predatory potentiality, seasonal abundance and biology of *Stethorus aptus* (Kapur), the newly reported coccinellid predator of tea RSM *O.coffeae* infesting tea in North East Region. Prior to this, *S. aptus* was only found in China preying on *Panonychus citri* (McGregor) Li *et al.*, (1990). Since this predator is newly found in tea ecosystem therefore the present study is mainly focused on its biology, seasonal abundance and feeding preference on various stages of *O.coffeae* with laboratory and semi field investigations. A summary of the major outcome of this thesis work is given below-

- Studies on predatory potentiality of *S. aptus* both in free choice and no choice test indicated that all the stages of *S. aptus* were voracious feeder of RSM. Among the larval instars the fourth instar grub consumed maximum number of the prey. In adults prey consumption was found more in female than in male. Moreover, the predatory potential was found to increase with increase in temperature from 23°C to 31°C.

- The optimum predator prey ratio of 1:50 in case of adult and 1:25 in case of late larval instar were effective for successful control of mite population.

- The functional response study of all the larval instar and adult of *S. aptus* exhibited the Holling type II model when different densities of RSMs are offered.
• The reproductive response of adult *S. aptus* female was found positively correlated with mite densities. The rate of oviposition increased with increased prey consumption.

• Seasonal abundance study revealed that the population of *S. aptus* coincides with the repeated fluctuation of RSM population. The abiotic factors like maximum and minimum temperatures, average relative humidity, total rainfall etc were also influence on population build up of the predator.

• Experiment on the lifehistory of *S. aptus* feeding on RSM revealed that life stages of *S. aptus* consist of an egg, four larval instars, pupa and adult. Morphologically *S. aptus* is found similar to other species of *Stethorus*.

• Life history parameters of *S. aptus* vary with seasonal temperature. The optimum rearing temperature for this predator under laboratory conditions was found to be 27°C during autum.

• Adult longevity of the females was longer than that of the males. The total ovipositional period was recorded as 83.15±3.07 days and average fecundity was 124.2 eggs /female.

• Life table studies revealed that the intrinsic rate of natural population increase (r) of *S. aptus* was 0.101 day⁻¹, while net reproductive rate (R₀) was estimated as 65.66 eggs/female. Gross reproductive rate (∑mx) was 70.69 eggs/female, generation time (T) 41.43 days, doubling time (DT) 6.86 days and finite rate of increase (λ) 1.10 day⁻¹.
Suitability of different artificial diets was also evaluated for mass rearing of *S. aptus*. Diet containing protinex, yeast, honey and glucose could be used for the maintenance of *S. aptus* when natural host availability is less.

Results of the study on the effect of certain commonly used pesticides on *S. aptus* revealed that bifenthrin was the most toxic followed by propargite and hexythiazox.

Effect of aqueous extract of *Nyctanthes arbor-tristis*, *Phlogacanthus thrysiformis* and *Sapindus mukorossi* on prey consumption and adult mortality of *Stethorus aptus* demonstrated that these plant extracts had no significant impact on the predator.

**Conclusion:**

From the present study, it can be concluded that under laboratory condition *S. aptus* (Kapur) was found to be an effective biocontrol agent of tea RSM with high rate of prey consumption, longevity, dispersal characteristics, strong functional and numerical response to its prey, potentiality to utilize alternate food for survival and ability to locate host density area. Bio-control is environmentally safe and effective method of pest control. Conservation of this natural enemy in tea ecosystem not only help in reducing the population of RSM but also minimize the use of synthetic acaricides. Moreover integration of biocontrol methods will be helpful to improve the existing strategy for the management of *O. coffeae* in tea plantations.
However, before utilizing this biocontrol agent as one of the component of IPM of mite management in tea, more detailed research is necessary on its performance under the field conditions. Further, a simple and reliable mass multiplication technique for this predator on its natural prey needs to be developed prior to any augmentative field release.