

REVIEW OF LITERATURE

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2.1 Management of insect pests in tea plantations: an analysis

Managing pest menace is posing a major challenge in present day horticulture including tea plantations worldwide. To enhance agricultural productivity, pesticides are used as the principal means of controlling the pest populations. Over the last half a century, farmers and planters have changed the food production system in order to meet the demand from the ever swelling human populace of the world. Extensive use of pesticide is one of the new inputs to the farming technique. Pesticides primarily have been adopted to reduce or prevent agricultural loss inflicted by pest, to ensure better yield and availability of food, all through the year at reasonable price (Cooper and Dobson, 2007). As estimated by Pimentel (1997), pesticide ensures about a four-fold return on the investments. Pesticide applications along with the advancement in crop variety, irrigation, soil health and mechanisation have resulted in increased crop yield ranging from 70 to 100 percent (Pretty, 2008). With the use of pesticides, developing nations like India have carved the way to green revolution and quadrupled grain production to be self-sufficient and export the surplus to earn foreign exchequer (Pingali, 2012). Pesticide applications have resulted in manyfold increase in yield of almost every crop throughout the world (Cooper and Dobson, 2007). There is a positive correlation between crop yield and the quantum of pesticide used to a certain level (WHO, 1990). Global cereals production has more than doubled in over the last half a century (Tilman et al., 2002). In general, about 700 different chemicals including pesticides, herbicides and fungicides acting on almost 95 different biochemical targets are being used to control agricultural pests. Global production and consumption of pesticide are on the rise every year (Zhang et al., 2011).

Tea plantations of India are no exception and follow global trend in terms of pesticide consumption. In most of the tea plantations, pests are conventionally managed by applying several rounds of organosynthetic pesticides (Sannigrahi and Talukdar, 2003; Gurusubramanian et al., 2008). About two dozen varieties of chemicals are infused in the tea plantations of Terai-Dooars region for managing pests and weeds (Gurusubramanian et al., 2008). For pest management, quinalphos, acephate, chlorpyrifos, monocrotophos, cypermethrin and deltamethrin are being profusely used at an average of 7.5 litres of pesticides applied per hectare per year (Roy et al., 2009a). Literature shows the consumption of synthetic pyrethroid in tea

plantations of the Dooars has also grown up steadily. For example, in 1998 the share in total pesticide consumption of the synthetic pyrethroid was 10.2% whereas, within a short span of six years, in 2004 the share rose to 40.91% (Roy et al., 2009a). Similarly, over the last two decades, pesticide use for the control of *H. theivora* has also doubled, with a concomitant increase in the cost of pest management (Gurusubramanian and Bora, 2007).

Pesticides are applied almost round the year (Plate 2.1) on a routine basis (Sannigrahi and Talukdar, 2003; Gurusubramanian et al., 2008) which is not only an economic burden to tea planters but also the principal source of chemical stress to the plantation often resulting in resurgence of primary pests (Sivapalan, 1999), secondary pest outbreaks (Cranham, 1966), resistance development (WHO, 1990; Roy et al., 2010a) and environmental contamination (Aktar et al., 2009) including undesirable residues in made tea (Chaudhury, 1999). Due to wide spectrum of toxicity, pesticides also suppress predatory and parasitic species along with other non-target organisms (Georghiou, 1972). Continuous use of synthetic pesticides is known to facilitate the development of higher tolerance or resistance in many insects (Martin et al., 2002; Komagata et al., 2010; Basnet et al., 2015). Resistance further enhances pesticide application frequencies, dosages, and decreased yields (Mullin and Scott, 1992). Pesticides create selection pressure to which the pest tends to evolve the stress evading mechanism, resulting in the development of higher tolerance or resistance and also the resurgence (Stenersen, 2004). Incidence pattern and nature of many age-old tea pests, since the inception of tea as a plantation crop have also changed with the extensive application of pesticides, newer areas being brought under tea cultivation, introduction of new technology, changed edaphic factors and pattern of precipitation, rise in average temperature of an area, and management practices (Mukhopadhyay and Roy, 2009). Despite continuous use of pesticides, reports of pest control failure are frequent from tea plantations (Gurusubramanian et al., 2008; Roy et al., 2009a). Such failures may be caused by a change in the tolerance pattern of the pest species to the applied pesticide(s). In order to mitigate the problems arising from extensive application of pesticides, Tea Board of India has brought into effect the 'Plant Protection Code, Ver. 3' from 1st January 2015 to restrict the number of chemical pesticides being used in tea plantations (Anonymous, 2014b). Implementation of the code is also expected to reduce pesticide residue and facilitate qualification of Indian

PLATE 2.1: A planter applying pesticide in a tea plantation of northern West Bengal

PLATE - 2.1



tea in stringent MRL tests set by various national and international agencies for export.

Knowledge of the tolerance level of a pest against pesticide is indispensable before the chemical pesticide is applied. Increasing the dose in an attempt to maintain the efficacy, without the knowledge of the susceptibility level of pest would lead to the waste of resources, pollution of the environment and above all causes enhancement of the pest-resistance (WHO, 1990). Pesticides acting through newer mechanisms are rarely available for replacement and moreover, they are becoming increasingly expensive due to stringent safety standards set by national and international organisations (Cooper and Dobson, 2007; Casida, 2009; Pingali, 2012). The rapid selection and spread of multiple and cross-resistance jeopardise the potential of some of the newly discovered pesticides even before they are applied. The balance between the benefits and the negative side-effect must be evaluated in each pesticide-based pest management programme (WHO, 1990). Hence, there is a pressing need to find out the better way of selecting and use of pesticide, if we are to maintain insect pest population under economic injury level sustainably by applying a reasonable amount of synthetic pesticides as a part of integrated pest management (IPM).

2.2 Development mechanism and status of pesticides tolerance in insect pests

Based on their functional group, pesticides are categorised as organophosphates, carbamates, pyrethroids, neonicotinoids, etc. Mode of action (MOA) of a pesticide is the specific way by which a pesticide kills an insect or inhibits its growth (WHO, 1990). There are primarily four basic target sites of pesticides viz., acetylcholinesterase, the voltage-gated chloride channel, the acetylcholine receptor, and the gamma-aminobutyric acid receptor (Casida, 2009). Target site of action is the exact location of inhibition, such as by interfering with the activity of an enzyme within a metabolic pathway. Resistance development is one of the serious problems of pesticide based insect pest management. Resistance is defined as the development of an ability in a meta-population of an organism to withstand doses of a toxicant which would prove lethal to the majority of individuals in a normal (susceptible) population of the species (WHO, 1990; Stenersen, 2004). Whalon and McGaughey (1998) have defined resistance as ‘the micro-evolutionary process whereby genetic adaptation through pesticide selection results in a population of arthropod, which present a

unique and often more difficult management challenges'. Resistance to pesticides by insects is one of the well known and documented cases of evolutionary adaptations to environmental changes brought about by the anthropogenic activities (Hemingway and Karunaratne, 1998). Resistance usually develops against only a single pesticide. However, it is also not uncommon in insects to develop resistance to more than one pesticide with similar or common MOA. Populations of housefly became resistant to dichlorodiphenyltrichloroethane (DDT) in the 1950s, also exhibited resistance with no previous exposure to pyrethroid pesticides used decades later, as both the pesticide have the same MOA (Sternburg et al., 1954) i.e. through the blockage of voltage-gated sodium ion channels (Soderlund and Knipple, 2003; ffrench-Constant et al., 2004). This phenomenon is known as cross-resistance. A closely related phenomenon known as multiple resistance occurs in insect populations that resist two or more pesticide classes due to the coexistence of more than one dissimilar MOA (Mullin and Scott, 1992). Insects develop this type of resistance by expressing multiple resistance mechanisms. This can happen if one pesticide is used until insects display a resistance and then another is used and the insect population becomes resistant to that one, and so on. Some populations of Colorado potato beetle, *Leptinotarsa decemlineata* is notorious for multiple resistance to more than 50 pesticides with various MOA (Mullin and Scott, 1992). Multiple resistance is less common than cross-resistance but is of greater concern as it drastically reduces the number of available pesticides that can be used to control the insect bothering humankind in question. The efficiency of pesticide-based pest control programs is largely jeopardised due to the development of such resistant traits.

Resistance in a pest population helps them to withstand the toxic effect of pesticides due to biochemical or physiological attributes that render pesticides ineffective against most individuals. For enhanced yield and greater return on the invested amount, most agriculturists blindly apply pesticides to minimise the damage caused by pests (Pimentel and Levitan, 1986). Intensive applications of pesticides along with the genetic makeup of the pest are the two most important factors responsible for the development of resistance. Genetic variations within a natural pest population may endow some individuals with traits helpful for better adaptation in surviving pesticide exposure. Insects with genes that confer resistance to a particular pesticide or class of pesticides with similar MOA survive exposure and are thereby

‘get selected’ to pass on the trait to later generations (Stenersen, 2004). Through the accumulation of such traits for generations, a population may develop resistance.

The mechanisms of resistance development in insects may be categorised into four types, which are not mutually exclusive, thus one or more mechanisms may be involved in resistance development in a particular pest population.

- i. **Behavioural resistance:** This is the very first level of resistance developed in response to the initial encounter of an arthropod pest with a pesticide resulting in an altered behaviour, which can help them to avoid future contact with the pesticide (Sparks et al., 1989; Hostetler and Brenner, 1994).
- ii. **Resistance due to barrier tissues:** Thickening of the integument of the pest may act as a barrier and result in reduced penetration of the pesticide. Thus the concentration and effect of the pesticide at the target site get reduced. Excess lipid content or presence of increased fat body cells in the body mass of a pest may provide insulation or cause sequestrations of lipophilic pesticides, thus getting away with their toxic action at the target tissue (Stenersen, 2004; Yu, 2014).
- iii. **Metabolic resistance:** Once the pesticide enters arthropod system it is rapidly metabolised and detoxified by a group of enzymes. Genetic changes such as gene up-regulation or amplification of enzyme-coding genes may lead to enhanced production of the detoxifying enzymes conferring higher tolerance or resistance. Increased quantities of detoxifying enzymes may also impart resistance by sequestering pesticides (Zhu and Luttrell, 2012; Shi et al., 2015).
- iv. **Target site insensitivity:** Each class of pesticide bind to specific target sites after entering the arthropod system. Alteration at the target site of the pesticide may occur through gene mutation and confer resistance by reduced or no binding of the pesticide at the target site. The target sites are generally the receptors at sodium ion (Na^+) channels for pyrethroids and DDT, and acetylcholinesterases (AChE) for organophosphates and carbamates. Gamma aminobutyric acid (GABA) receptor for cyclodienes and gamma HCH (Sternburg et al., 1954; Ranson et al., 2000; Hemingway et al., 2004).

Insect pests are known to develop resistance at alarmingly rapid pace. Worldwide, over 700 species of arthropods mostly insects and mites are reported to be resistant to one or more class of pesticides (<http://www.pesticideresistance.org>; accessed on

13.01.2016 and Bills et al., 2000). A strain of aphid, *Aphis gossypii* in China has been found to develop 228.59 fold resistance against deltamethrin (Cao et al., 2008).

Tea pests from India are also known to have developed resistance. Variation of resistance level to endosulfan in six populations of *Helopeltis theivora* from tea growing sub-districts of Damdim, Chalsa, Nagrakata, Binnaguri, Dalgoan, and Kalchini tea plantations in the Dooars region of northern West Bengal has been reported (Roy et al., 2009a). The population of Kalchini was reported to be the most resistant to the commonly used pesticides, indicating the severity of infestation and the higher frequency of the pesticide application for managing the pest (Roy et al., 2009b). Lepidopteran tea pests, *Hyposidra talaca* and *H. infixaria* from chemically managed tea plantations of Terai in the northern part of West Bengal are shown to have developed tolerance to synthetic pyrethroid, cypermethrin (Das et al., 2010b). Similarly, red spider mite, *Oligonychus coffeae*, a key arthropod pest of tea from various tea plantations in the Dooars and Terai also have developed a varying degree of tolerance to commonly used acaricides (Roy et al., 2010b).

2.3 Variability of defence enzymes and their role in detoxification of pesticide in insects

Detoxification of pesticide is the primary mechanism of resistance and has been aptly termed as ‘nature’s margin of safety’ (Georghiou, 1972). The detoxification of endogenous and exogenous compounds in most animals including insects is carried out by a family of enzymes known as ‘detoxifying enzymes’ or ‘defence enzymes’ as they catalyse various reactions needed for metabolising xenobiotics, providing defence against synthetic foreign chemicals including pesticides. In many arthropod pests, development of resistance to pesticide has been attributed to an increase in the activity of defence enzymes (Hernandez et al., 2002; Sun et al., 2010). Three large enzyme families, namely carboxyl/cholinesterases (CCE) also known as general esterases (GE), cytochrome P450 monooxygenases (CYP450) of phase I and glutathione *S*-transferases (GST) of phase II have been found to play a significant role in metabolism of pesticides (Hemingway and Karunaratne, 1998; Ranson et al., 2002; Stenersen, 2004; Yu, 2014). *CYP* gene family encodes a group of heme-containing monooxygenases called CYP450. Detoxification can be divided into phase I (primary) and phase II (secondary) processes. Phase I reactions consist of oxidation, hydrolysis and reduction and involves detoxifying enzymes such as GE and CYP450s (Yu,

2014). The phase I metabolites are sometimes polar enough to be excreted but are usually further acted upon by phase II enzymes. The polar products are conjugated with a variety of endogenous compounds in reactions catalysed by phase II enzymes and are subsequently excreted. GSTs play important role in phase II reactions. The most important function of biotransformation is to decrease the lipophilicity (affinity to lipids) of xenobiotics including pesticides so that they can be excreted (Yu, 2014). The pesticide stress leads to the change in defence enzyme profile of the insect pests. Defence enzyme based metabolic resistance is the most important mechanism of resistance in insects to chemical pesticides.

Metabolic resistance against pesticides has been shown to be manifested by the enhanced activity of CYP450 in many insect pests (Feyereisen, 1999). In pyrethroid-resistant insects such as *Anopheles gambiae* (Djouaka et al., 2008), *Tribolium castaneum* (Zhu et al., 2010), and *Musca domestica* (Zhang and Scott, 1996), genes of CYP6 family were reported to get up-regulated. Till date, a very little has been studied about CYP450s of the tea pest *H. theivora*. Pesticides synergized with piperonyl butoxide (PBO), an inhibitor of CYP450s have shown an increased susceptibility of the pest to various pesticides, confirming the role of the defence enzyme in metabolism (detoxification) of the xenobiotics (Roy et al., 2009b).

The enhanced production of esterases is a well-known phenomenon responsible for pesticide resistance in insects (Miller et al., 1999; Hernandez et al., 2002; Cao et al., 2008; Zhu and Luttrell, 2012). In a pyrethroid-resistant strain of tick *Boophilus microplus*, GE transcript was abundant than in susceptible one (Hernandez et al., 2002). Pyrethroid resistant mosquitoes showed elevated activity of the defence enzyme, GE (Sahgal et al., 1994). Cao et al., 2008 have shown that the up-regulation of GE gene was responsible for conferring resistance against deltamethrin in cotton aphids, *Aphis gossypii*.

Sucking pests of tea, such as *Empoasca flavescens* and *Scirtothrips dorsalis* exposed to pesticides showed an elevated activity of defence enzymes viz GE, GST and CYP450 (Saha et al., 2011). Increased activity of GE, GST and CYP450 was evident in the pesticide-exposed populations of tea mosquito bug (TMB) from both the Dooars and Terai as compared to the pesticide unexposed susceptible population from bio-organically managed tea plantations of Darjeeling (Saha et al., 2012; Basnet et al., 2015). These findings imply the metabolic basis of higher tolerance to be functional in the studied TMB populations. Enhanced activities of CYP450 and GE

possibly with increased ability of pesticide detoxification have been reported to confer metabolic resistance in many insects (Hemingway et al., 2004). Saha et al. (2012) also have reported a positive correlation between the tolerance level and the activities of GE and CYP450 in populations of TMB from tea plantations in the northern part of West Bengal. The strong dependence of pesticide tolerance on the enhanced activity of detoxifying enzymes indicates their possible pesticide sequestering role, especially GE and CYP450 in TMB. Similarly, in caterpillars of a lepidopteran pest of tea *Hyposidra talaca*, a strong positive correlation ($r > 0.9$) between the pesticide tolerance levels and activity of GE has been reported (Mukhopadhyay et al., 2014), which indicates the involvement of the defence enzyme in imparting tolerance to the pest. Pesticide-exposed populations of *H. talaca* and *H. infixaria* were found to have enhanced activity of GE in comparison to the pesticide unexposed populations (Das, 2014). Quantitative and qualitative variations in the activity of GE, depending on pesticide exposure were also reported in red spider mite (RSM), *Oligonychus coffeae* populations from Terai plantation (Sarker and Mukhopadhyay, 2008). The activities of GE and GST were reported significantly higher in the whole body homogenates of female RSM from conventional plantations as compared to the population from the bio-organically managed plantations (Das, 2014). Biochemical assay of detoxifying enzymes of pest gives an insight into the levels of their tolerance to pesticides and therefore, can serve as a useful tool in monitoring tolerance or resistance in insect pest populations.

2.4 Buildup of pesticide resistance through generations in insects: an evolutionary process

While pesticides have enormously improved the agricultural productivity and quality of human health worldwide, the evolution of resistance in many major pests, including those became pests only as a consequence of pesticide use has limited their utility (Mallet, 1989). Pesticide resistance is an evolutionary process engendered by the challenges from effective pesticides in the environment containing resistant individuals in a pest population. The evolution of pesticide resistance is one of the most convincing man-made examples of Darwinian evolution occurring over a period of a human lifespan (Lenormand et al., 1999; ffrench-Constant et al., 2004). The evolution of resistance is a phenomenon related to population genetics, influenced by complex interactions among biology of pest and ecology, properties of pesticide and

its use pattern (Georghiou and Taylor, 1977; Whalon et al., 2008). The endemic population of a pest usually comprises of biotypes with subtle differences from one another. Pesticide selection favours the fittest in the toxic environment. Selection operates at biochemical, physiological, and behavioural level as well (Georghiou, 1972). An individual with alleles or gene duplication or sometimes amplification, making the pest less sensitive to the pesticide contaminated toxic environment, the chemically managed tea plantations in the context of this thesis, will have better opportunities to reproduce. Normally, such individuals with higher resistance or tolerance are rare. Thus, the alleles responsible for conferring resistance are at very low frequencies in pest population (Mullin and Scott, 1992). Subsequent generations of pests after the selection of the individuals with resistant allele (s) by pesticides will have an increased frequency of such alleles (Roush and McKenzie, 1987). Therefore, the spread of resistance in population challenged by pesticides is inevitable (Chanda et al., 2016). Virtually every control agent, be it chemical or microbial, is prone to development of resistance in arthropods, except in those that lack exposure (Mullin and Scott, 1992). If pest organisms cannot be completely eradicated by treating with pesticide or by other means, resistance/higher tolerance will occur in the pest population in near or distant future (Stenersen, 2004). Insects are known to evolve resistance in about a decade after the introduction of a new pesticide by virtue of their genetic plasticity (Yu, 2014). The introduced toxicant present in the environment exerts a selection pressure on an insect population and only those individuals that can survive the toxic effect are able to reproduce (Stenersen, 2004). The evolution of pesticide resistance in target pests is a significant management risk. To understand the evolution of resistance in pests is an important aspect for bringing in resistance management as the understanding can enable planters to avoid or minimise and sometimes reverse the resistance development process (Mallet, 1989).

Diversity of genes belonging to different supergene families of detoxifying enzymes in the class Insecta, is an outcome of independent gene duplication event within each species after divergence from one another, suggesting the presence of same mutations in orthologous genes responsible for resistance by detoxification is only a matter of chance (Ranson et al., 2002). The extent of diversification and duplication is determined by life history and the ecology of the organism. The duplicated paralogs tend to be present in clusters rather than get dispersed throughout the genome. Besides conferring higher pesticide resistance, the expansion of the

defence enzyme supergene families may confer an increased ability of neurosensory perception, chemical detection, avoidance of natural enemies and recognition of oviposition sites in insects (Ranson et al., 2002).

Resistance to dieldrin-chlordane-gamma-BHC in malaria vector *Anopheles gambiae* from northern Nigeria is reported to show mono-factorial (implying one locus) simple Mendelian inheritance pattern with incomplete dominance (Davidson, 1956). The non-Mendelian inheritance is reported in mite pest, *Tetranychus urticae* where the resistance is reported to be controlled by mitochondrial genome (Leeuwen et al., 2008). The inheritance of insect growth regulator, pyriproxyfen resistance in arrhenotokous (haplodiploid) species such as *Bemisia tabaci* is multifactorial (polygenic). The effect of different loci on resistance is additive. The mode of inheritance is reported to be autosomal and incompletely dominant of the growth regulator. The inheritance pattern is also dependent upon the strain of the pest and may be the reason for the differential rate of resistance development (Crowder et al., 2009). Inheritance of resistance to pyrethroid in *Tribolium castaneum*, a common stored grain pest was also reported to be multifactorial (Collins, 1998). *Bacillus thuringiensis israelensis* produced Cry-toxin resistance in mosquito, *Culex quinquefasciatus* also showed multifactorial autosomal inheritance (Wirth et al., 2010).

Except for the report of accumulation of resistance to endosulphan, a cyclodiene in *H. theivora* after a repeated exposure through five generations (Roy et al., 2010a), study on the pattern of inheritance of resistance in pests of tea is lacking. There is a big research gap which needs to be filled up by researchers for proper management of resistance in tea pests.

2.5 Spiders as biocontrol agent of insect pests

There are about 40,000 species of spider known to science throughout the world (Marc et al., 1999). They are well established obligatory predators that feed on diverse prey, principally insects (Foelix, 2011) and are very effective in managing pest thereby reducing crop damage (Sunderland, 1999; Symondson et al., 2002). They are the major and the most abundant predator in many natural terrestrial ecosystems (van Hook, 1971) and most agroecosystems (Nyffeler and Sutherland, 2003) thus can be effective biocontrol agent if deployed properly (Symondson et al., 2002). Spiders are generalist predator and are often more efficient in pest control than other specialist

predators (Stiling and Cornelissen, 2005). Spider density of up to 1000 individual per square meter is reported under favourable conditions (Marc et al., 1999; Chatterjee et al., 2009) with an average abundance of 50 to 150 individuals per square meter (Marc et al., 1999). Spiders are highly resilient, long lived and readily seek new hideout after anthropogenic disturbances (processes such as harvest, spraying of pesticides etc). Quick re-colonisation of perturbed agroecosystem after harvest and pesticide application is achieved by spiders through dispersion by ballooning also known as kiting, which is a common aeronautical technique adopted by spiders for floating through the air on their own threads (gossamer threads). To release the thread, they stand on 'tiptoe' facing the wind with upwardly inclined abdomen until silk thread exudes. The thread exuded produces sufficient lift and drag for dispersal of spider (Marc et al., 1999; Foelix, 2011). Very little attention has been paid towards tapping the immense biocontrol potential of spiders in insect pest management in agriculture (Riechert and Bishop, 1990).

For centuries, spiders are being used as biological control agent for managing various pests in Chinese (Zhang et al., 2004), Israelian and European apple orchards (Marc and Canard, 1997; Chatterjee et al., 2009). Thirty-nine species of spiders are reported from apple orchards of France, providing good control of a variety of pests (Marc and Canard, 1997). Nocturnal lynx spiders such as *Anyphaena accentuate* (Anyphaenidae), *Clubiona brevipes*, *C. corticalis* and *C. leucaspis* (Clubionidae) found in fruit orchards are effective control agents of aphids and larvae of lepidopteran pest. Diurnal lynx spider such as *Ballus depressus* (Salticidae) is also reported to be an active and effective predator of aphids and lepidopteran larval pests infesting apple orchards in France (Marc and Canard, 1997). The conservation of spiders has also been found to effectively reduce crop damage by active predation on the insect pests of agroecosystems such as rice, cotton, grapes, soybean etc. (Oraze and Grigarick, 1989; Carter and Rypstra, 1995; Marc et al., 1999).

Lynx spiders (Oxyopidae) are the numerically predominating among the spider complex found in the cotton growing belt of Texas in the United States of America. They constitute >50% of the total spider species. The average density of *Oxyopes* spp. in the agroecosystem is approximately 1 – 1.5 per square meter all through the growing season. During pest outbreaks, spiders of the genus *Oxyopes* improve their predation rate (functional response) providing effective control of many pests (Nyffeler et al., 1987a). *Oxyopes salticus*, the most abundant spider in cotton

and soybean fields of the U.S feeds on various species of pests providing good control (Nyffeler et al., 1987b; Hanna and Hanna, 2013).

Sivasubramanian et al., (2009) have found *Oxyopes javanus*, a lynx spider as a predator of both sucking and chewing pests of cotton. Spiders are highly abundant in tea plantations and other agricultural fields. If their population is augmented by conserving, they can regulate many insect pests (Marc et al., 1999; Basnet and Mukhopadhyay, 2014).

The biocontrol potential of spiders is often negatively impacted by the application of the very pesticides that are intended to manage pests. Spiders are very sensitive to synthetic pesticide compared to phytophagous pests. Application of pesticide is reported to decrease both diversity as well as the density of spiders (Marc et al., 1999). Apparently, non-lethal doses of pesticides are also reported to cause a variety of sub-lethal effects that may adversely affect spiders' functional response, foraging ability, mating behaviours and even the size and development of offspring (Tietjen and Cady, 2007; Hanna and Hanna, 2013). Peng et al. (2010) and Deng et al. (2006) have reported reduced egg sac production in spiders after exposure to pesticides. Nonlethal exposure to pesticides may also interfere with the production and or reception of pheromone signals, disrupting mating, population size, prey capture and other physiological processes of life. Sub-lethal pesticide exposure disrupts communication between female and male *Oxyopes salticus* disrupting mating and courtship behaviour (Hanna and Hanna, 2014).

It is observed that, despite extensive application of pesticides for managing pests, spiders in the tea ecosystem can sustain themselves in fairly good number in terms of both diversity as well as abundance. Tea ecosystem provides enough food (prey) for the sustenance of spiders almost round the year besides providing suitable habitat. In tea agroecosystem, spiders as a predatory group largely dependent on tea pest excepting few stray species as food. Introduction, inoculation and augmentative release of natural enemies are some of the effective strategies for managing pest species in many instances (Gurr et al., 2000). Conservation of natural enemies supplemented by minimum input of synthetic chemical is expected to provide effective biocontrol of tea pests in northern West Bengal and the entire tea plantations of India. The study in this direction is an imperative for sustainable management of tea pests.