MAJOR PESTS OF TEA AND THEIR INTEGRATED MANAGEMENT WITH A FOCUS ON TEA RED SPIDER MITE: A REVIEW

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ABSTRACT

Tea *Camellia sinensis* L. is an aromatic crop that has become the most popular non-alcoholic beverage drink for two-thirds of the world's population. Bangladesh contributes almost 3.0% of global tea production with high export potential through increasing the production using proper management of insect and mite pests. Tea mosquito bug, termite, thrips and looper caterpillar are the major insect pests of tea and red spider mite (RSM) is the number one mite pest. RSM draws special attention to the tea planters because of its year-round presence causing 17 to 46% crop loss. The tea gardeners use a large number of broad-spectrum synthetic pesticides to control major soil-dwelling pests (termite and other soil pests), sucking pests (thrips, jassid and scale insects), chewing pests (leaf roller, looper caterpillar and flush worm) and other minor pests. The overuse of highly toxic pesticides has incurred high pest management costs, killing beneficial arthropods, causing secondary pest outbreaks, pesticide residue and other complications in tea production. Adoption of Integrated Pest Management (IPM) programs could be possible solutions for these problems. The use of resistant varieties, timely adoption of cultural and mechanical practices (plucking, pruning, cleaning, sanitation, irrigation, drainage, weeding, etc.), physical practices (destruction of pests, yellow trap, light trap, etc.), biological control (conservation of predators, parasitoids), use of bio-pesticides, sex pheromones, entomopathogenic microbes (bacteria, virus, fungi), extracts of plant parts (neem seed kernel,mahogany, nishinda, ghato, michania, etc.) have been reported as eco-friendly pest management techniques for RSM management. In this review paper, IPM strategies for major pests especially for RSM have been suggested.

Keywords: Tea mosquito bug, tea red spider mite, termite, thrips, looper caterpillar.

INTRODUCTION

Tea is an aromatic beverage crop which is cultivated in more than 50 countries all over the world (Idris *et al.* 2020). Nowadays tea has become the most popular

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drink, second only to water (Ikenaka *et al.* 2018). Tea contains antioxidant, anti-obesity and anticancer properties (Meng *et al.* 2019). Black tea contains theaflavin 3, 3'-digallate, theaflavin 3-gallate, and procyanidin B2, which have the potential to serve as inhibitors for SARS-CoV-2 targets and could be used as therapeutic candidates (Gogoi *et al.* 2021). The tea industry in Bangladesh accounts for 3.0% of global tea production and 1.0% of the national Gross Domestic Product, generating employment for more than 4.0 million people (BTB 2020). The species *Ectropis oblique* (Lepidoptera: Geometridae), *Helopeltis theivora* (Heteroptera: Miridae) and *Oligonychus coffeae* Nietner (Acari: Tetranychidae) are the major pests of tea (Kakoki *et al.* 2018, Zeng *et al.* 2018). Different classes of pesticides have been used to manage tea pests in Bangladesh. The overuse of pesticides in crop ecosystems have resulted in higher pest management costs, secondary pest outbreaks, pesticide residues, pesticide resistance, pest resurgence, and hazards to pesticide applicators, consumers, aquatic life, wildlife, pollinators, etc. (Hill *et al*. 2017). The application of toxic synthetic pesticides has been increased for the management tea pests (Islam and Maleque 2021). The concept of IPM is a sustainable strategy for pest management (Dara 2019) that combines biological, cultural, physical, and chemical tools (USDA-ARS 2018). IPM offers a holistic and sustainable approach to pest management, aiming to minimize pesticide use while maximizing crop protection. It reduces reliance on pesticides, provides economic benefits, promotes environmental sustainability, helps manage pesticide resistance, enhances pest control, and ensures long-term sustainability of tea production. Cultural practices like pruning, plucking, sanitation, trap crop etc. can reduce pests infestation. Pests that attack stems, branches, and maintenance foliage can be minimized or eliminated by adjusting the pruning cycle to occur every two to six years (Hazarika 2009). Bush hygiene by maintaining weed free cultivation and preventing trespassing of cattle, goat, and other animals from RSM-infestation. Alternate hosts provide shelter for many pests. Hand destruction and light trap is very effective against lepidopteran pests of tea. Different plant extract act as antifeedant to sucking pest and some chewing pests (Hazarika *et al.* 2008). Sex pheromones, natural enemies like predators and parasitoids (Stiling and Cornelissen 2005), microbial agents like *Bacillus thuringiensis* (Bt) (Hazarika *et al.* 2005) have been found as the most successful microbial control options for controlling several lepidopteran pests (Stiling and Cornelissen 2005). A recent study has found bio-pesticides as effective and safe pest management option (Nandi *et al.* 2021). The aforesaid pest management options are the components of IPM. These pest management options have been derived from natural sources such as

plants, animals, bacteria, and fungi are effective and environmentally friendly. So, these techniques can be used as alternatives to synthetic chemical pesticides for the management of pests infesting tea and other crops. Implementing IPM practices can lead to achieve sustainable tea production in the country. Against this backdrop, the authors have reviewed the major pests of tea and their integrated management with a focus on tea red spider mite.

MAJOR INSECT PESTS OF TEA

Tea mosquito bug, red spider mite , thrips, jassid, aphids, bunch caterpillar, tea looper complex, shot hole borer, live wood-eating termite and scavenging termites are the tea pests (Deka *et al*. 2021), but tea mosquito bug, RSM, aphids, jassids, looper caterpillar, thrips, scales, flash-worms and termites are the major pests of tea in Bangladesh (Mamun and Ahmed 2011a).

Tea mosquito bug: Forty-one species of the genus *Helopeltis* (Hemiptera: Miridae) are described in different parts of the world, but tea mosquito bug (*Helopeltis theivora* Waterhouse) caused about 55% crop loss in Africa and 11-100% loss in Asia (Hazarika *et al.* 2009). It is the major pest due to the extent of damage with respect to quality and quantity of tea (Mamun *et al.* 2013). The 5th instar nymph (full-grown) is the most voracious feeder (Saha and Mukhopadhyay 2013). A circular ring of 0.29 to 2.51 mm is formed around the feeding spot, primarily on the leaves and new flushes. In 24 hours, the inside portion of the ring becomes translucent light brownish in color and within a few days, the spot turns dark brown, sunken and subsequently desiccates (Das *et al.* 2019). About 76-210 feeding lesions with upward curling and desiccated dieback are formed at severe infestation (Ekka *et al.* 2019). In response to the salivary enzymes, which, in presence of salivary amino acids, detoxify the defensive chemicals of the host, which in turn prevents the initiation of new shoots, thereby resulting in poor yields (Das *et al.* 2019). Each female bug can insert 500 eggs in soft plant tissues and complete life cycle within a month (Mamun *et al.* 2013). These insects are active from January to September and hibernate during winter season. Their damage is predominant in moist and shaded areas, especially after monsoon showers (Ekka *et al.* 2019).

Termites: In Bangladesh, 22.56% crop loss was recorded due to termites (Hoque *et al.* 2021). Termites feed internal plant tissues making hollow trench inside the stem filling it up with soil. Thus termites are called cancer of tea plants. Termite colony

consists of four castes viz., queen, king, soldiers and worker termite. Worker caste is the most destructive for tea. Single termite queen gives 84000 eggs day^{-1} (Hoque *et al.* 2021). Termites can be classified into (i) live wood termites, feeding living tissues and (ii) scavenging termites, feeding only dead tissues of the bush (Mamun *et al.* 2013)

Thrips: Tea thrips (Thysanoptera: Thripidae) nowadays are the major pests for tea. They are serious pests for nursery, young and mature tea. Both the nymphs and adults are destructive but nymphs do much harm. It completes its life cycle within 14-20 days (Subramaniam *et al.* 2021). They suck the cell sap making two longitudinal sand papery lines that can be seen when unfolding the young leaf and lower surface of the mature leaf. Severe feeding causes curling of leaf like boat shape and the entire area seems burnt (Zhang *et al.* 2021).

Looper caterpillar: *Hyposidra talaca* (Walk.) (Geometridae: Lepidoptera) is the most serious defoliator of tea. Eight to nine generations can be found in a year (Roy *et al.* 2017). Only the larval stage causes damage by voraciously feeding leaves of tea bushes leaving cut marks on edges of the leaves and pinholes on the leaves and in severe case the entire bush become stripped. Adult male and female moths mate on the shade tree trunk and female give 200-400 eggs on the trunk of shade tree. After hatching larvae start feeding shade tree leaves and then webbing down to the tea bushes and start voraciously feeding (Antony *et al.* 2012). The 4th and 5th instar larvae cause the most damage and on average a 4th instar looper caterpillar can eat 3.55±0.31 (cm^2) of the leaf area and 0.021±0.002g of the weight of tea leaves in terms of dry mass in 24 hrs. Whereas, a 5th instar caterpillar can eat 16.19±1.21cm^2 leaf area and 0.084±0.007g of the weight of tea leaves in terms of dry mass in 24 hrs (Prashad and Mukhopadhyay 2013).

MAJOR MITE PEST OF TEA

Tea red spider mite *Oligonychus coffeae* (Nietner) (Tetranychidae: Acari) is the major pest of tea, first discovered in 1861 (Roy *et al.* 2014). More than 12 species of tea attacking mites are reported from Bangladesh, China, India, Indonesia, Japan, Malaysia, Sri Lanka, Taiwan, and the erstwhile USSR (Roy *et al.* 2014). It is available in 48 countries and has become major pest of tea (Reza and Ahmed 2016). It is a serious threat for tea not only for Bangladesh but also for different tea producing countries (Mamun *et al.* 2013). Around 17-46 % crop loss may occur due to red spider mite (Idris *et al.* 2020). Hot and dry weather condition is favorable for

its outbreak (Vasanthakumar *et al.* 2019). It feeds chlorophyll with its piercing-sucking mouthparts from the upper surface of the leaves leaving reddish-brown marks (Plate 1a-c), causing defoliation of the bush leading to death and ultimately crop loss (Anitha *et al.* 2019). Red spider mite (RSM) outbreaks occur during dry weather, (Amarasena *et al.* 2011). Nature of pruning and skiffing, time of pruning & skiffing, degree of cleaning at pruning, height of plucking, defoliation, roadside bushes and shade trees (alternate host) are some responsible factors of RSM abundance (Roy *et al.* 2014).



(a) **(b)** **(c)**

Plate 1a-c. (a) Fresh leaf (left) and RSM infestation (right) on tea leaves, (b) Tea plantation with RSM infestation, (c) Tea plantation without RSM infestation

IPM FOR INSECT PESTS OF TEA

IPM includes all possible control measures. The components of IPM are – cultural control, physical control, mechanical control, use of resistant varieties, bio-control agent, use of microbials, pheromones, botanicals, weed control and chemical control (Deka *et al*. 2021). To control the pest infestation it's very important to have idea about Economic Threshold Level (ETL) and Economic Injury Level (EIL) (Fig. 1, Table 1) (Deka *et al.* 2021). ETL is a justification of the lowest number of a pest in a bush at which a planter should take necessary control measures to keep the pest population below the EIL and reduce the risk of yield loss and EIL is that scale which gives the planter an idea about the lowest number of a pest population that causes economic loss.

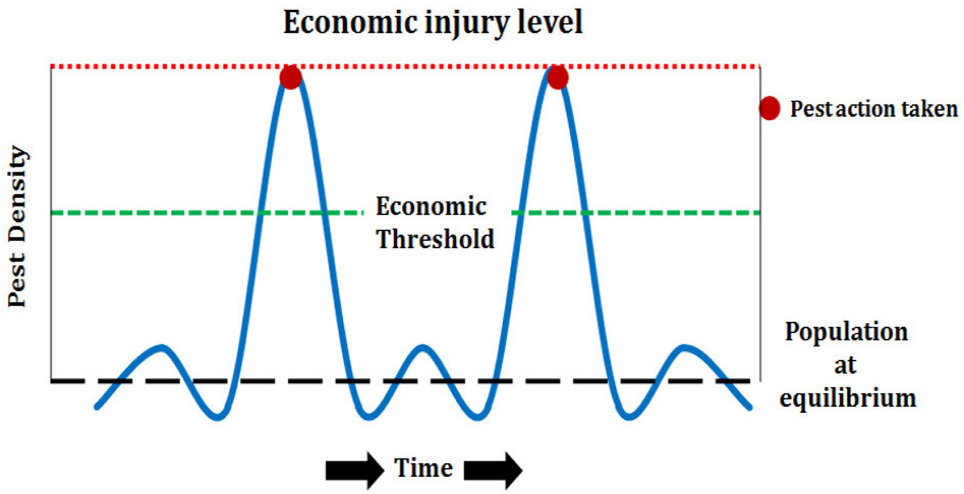


Fig. 1. Economic Threshold Level (ETL) and Economic Injury Level (EIL) (Deka *et al.* 2021).

Table 1. Economic Threshold Level (ETL) of commonly available pests of tea in Bangladesh (Deka *et al.* 2021)

Name of pests	ETL
Tea mosquito bug	5% infestation
Aphids	20% infestation
Thrips	3 thrips per shoot
Jassids	50 nymphs per 100 leaves
Looper caterpillar	4-5 lopper per plant
Flushworm, leaf rollers	5 infested rolls per bush
Red spider mite, pink and purple mites	5 mites per leaf
Termites	10% infestation
Nematodes	7 nematodes per 10 g soil

IPM components for major insect pests of tea are described below.

Cultural practices for pest control is the most primitive and effective method. It also called Planter's practice. Cultural practices like plucking, pruning, field sanitation, shade management are important practices in controlling Tea Mosquito bug, looper caterpillar.

Plucking: It is the most common practice in tea. Tea mosquito bug can be controlled by maintaining a proper plucking cycle. Tea mosquito bugs laid their eggs on the young shoots and can be removed by proper plucking of the infested shoots. The shorter the plucking round, the lower chance of pest infestation. 7-8 days plucking cycle is recommended to control the pest (Mamun *et al.* 2013). As adult and nymphs such cell sap from young leaves thrips can be controlled by minimizing the plucking round. The shorter the plucking round, the lower chance of thrips infestation (Hazarika *et al.* 2009).

Pruning: It is the most important agronomic practice in tea husbandry which is done to rejuvenate tea bushes and increase productivity in the subsequent years. Different types of pruning help to control tea mosquito bug as their eggs are removed and habitat is destroyed (Mamun *et al.* 2013). Similarly, different pruning styles help control leaf pests like thrips as their eggs are removed and habitat is destroyed (Hazarika *et al.* 2009).

Pest collection and destruction: This method is effective against looper caterpillar (Mamun *et al.* 2013). It's a very simple method where pests are collected and crushed immediately after being seen. Chrysalids are collected immediately after forking.

Field cleaning: Pruning litters invite termites and act as a shelter for different pests. So, the removal of pruning litters and proper field sanitation works are mandatory immediately after pruning (Mamun *et al.* 2013).

Shade regulation: The infestation rates of red spider mite and thrips reach high in an unshade area, whereas tea mosquito bugs infestation is high in over shaded areas (Antony *et al.* 2012). Looper caterpillars oviposit and hatch their eggs on shade trees. So, adequate number of shade trees with proper spacing and proper lopping should be maintained to keep the pest incidence below EIL.

Trap crop: Marigold as an ornamental plant should be planted on the periphery as a trap crop of red spider mite (Mamun *et al.* 2013). TV1 clone (Tocklai Vegetative) as a trap crop of tea mosquito bug decreased 73% of tea thrips in tea plantations of Japan, China, and Malawai (Hazarika *et al.* 2009). Light traps, sticky traps and yellow traps are cost-effective, eco-friendly and equally effective against all lepidopteran pests (Ahmed and Mamun 2012).

Management of alternate hosts: The plant species *Dalbergia assamica, Albizzia odoratissima, Albizzia chinensis, Derris robusta, Acacia modesta, Acacia catechu,*

Aleurities montana, Cassia auriculata, Bauhinia variegate, Carissa diffusa, Dodonaea viscosa, Lagerstroemia indica, etc. are the alternate hosts of looper caterpillar. Reducing these alternate hosts from the surrounding tea plantations can reduce the abundance of looper caterpillar.

Physical and Mechanical control: About 22.56% tea crop losses are occurred due to termite attack in tea (Hoque *et al.* 2021). Termite queen gives almost 84000 eggs day^{-1}. Thus, collection and killing of the queen from Termitaria is an effective means of termite control. Termitaria should be dug as deep as possible to find a queen and kill it. Then, the soil of Termitaria should be treated with burnt mobil (Mamun *et al.* 2013)

Biological control: Biological control involves conservation, preservation, and introduction of natural enemies (Ghimire 2021). The use of predators, parasitoids, and pathogens is one of the effective control measures against looper caterpillar.

Predators: Predators are the organisms that prey on other destructive pests and keep crops free from pest infestation (Ghimire 2021). Praying mantid, *Chrysoperla carnea*, (Lacewings) and *Oxyopes* sp. (Spider) were found effective against tea mosquito bug (Ghimire 2021). Praying mantid prey on adult moths and *reduviid* bugs are effective predators against looper caterpillar. Praying Mantid and *Chrysoperla carnea* (Lacewings) are the two effective predators of thrips (Ghimire 2021).

Parasitoids: Parasitoids are highly host-specific and holometabolous insects that parasitize the host eventually (Ghimire 2021). Parasitoids are categorized into three types- i) egg Parasitoids, ii) larval parasitoids, iii) pupal parasitoids. Parasitoids puncture into the host's egg, larva, or pupa, and after hatching larva start feeding the host. The species *Erythmelus helopeltis* was first recorded as egg parasitoid, effective against tea mosquito bug (Mamun *et al.* 2013). Braconids, bethylids, eulophids, ichneumonids, tachinids, and muscids are mostly effective against lepidopteran pests (Deka *et al.* 2021). Forty eight species of braconids parasitize tea pests, of which two species of the genus *Apanteles* are the dominant larval parasitoids of tea looper caterpillar (Mamun *et al.* 2013). *Macrocentrus homonae* is effective against tortrix and *Amblyseius deleoni* is effective against scarlet mite (Hazarika *et al.* 2009).

Botanicals: Application of botanicals is an unswerving control method against a large number of vital agricultural insect species in the IPM program (Tian *et al.* 2020). Plant-derived products such as terpenoids, flavonoids, and alkaloids act in diverse ways on insects as antifeedants, repellants, oviposition deterrents, insect

growth regulators, and in terms of toxicity and their mode of actions are diverse (Deka *et al.* 2021). Majority of these experiments were conducted in laboratory conditions. Neem (*Azadirachta indica*) is widely recommended in tea plantations against insects and mites (Roy *et al.* 2014). Extract of the plant species viz., *Acorus calamus, Cassia tora, Xanthium strumarium, Pongamia pinnata, Polygonum hydropiper, Azadirachta indica, Adhatoda vasica, Clerodendron inerme, Clerodendron infortunatum* were found effective in controlling tea mosquito bug and Matrine, an alkaloid extracted from *Sophora flavescens,* effective against piercing-sucking pests of tea (Tian *et al.* 2020). Pesticide properties in *Paullinia pinnata* aerial parts, *Polygonum hydropiper*, *Azadirachta indica* leaves and seeds, *Clerodendrum viscosum* leaves, *Capsicum annuum* fruits, *Nicotianna tabacum*, *Aegle marmelos*, and *Melia azedarach* dried leaves were reported by Bora and Bora (2022). Pesticide properties in leaf extracts of *Lantana camara*, *Xanthium strumarium* and *Acorus calamus*, *Polygonum hydropiper* and *Clerodendron infortunatum* and *X. strumarium,* were found effective in controlling red spider mite, tea mosquito bug, looper caterpillar and tea thrips. Leaf extract of *Maesa lanceolate* was reported effective (Tasisa and Gobena 2013). Pesticide attributes in the extracts of *Brassica nigra, Acokanthera schmperi, Rhamnus prinoides* and *Croton macrostachyus* were reported in Kassie (2019). The mixtures of *C. macrostachyus, Jatropha curcas* and *Phytolacca dodecandra* can be used a component of termites' IPM (Beyene and Getu 2020). The extracts of *Azadirachta indica* A. Juss, Mexican marigold, *Tagetus minuta* L., tree tobacco, *Nicotiana glauca* Graham and Jimson weed, *Datura stramonium* L. were evaluated against thrips in which tobacco showed the best performance (Fitiwy *et al*. 2015). The extracts of plant spices Tithonia, *Tithonia diversifolia* and Tephrosia, *Tephrosia vogelii* had significant effect on controlling thrips. Fresh leaf extracts with foliar application of *Azadirachta indica* L. and *Dodonae angustifolia* L. gave satisfactory mortality rate of thrips (Shiberu and Negeri 2014). The seed extract of *Abrus precatorius* showed the highest performance after *Acorus calamus* (Archunan and Pazhanisamy 2021). The extract of neem seed kernel effectively controlled thrips (Padaliya *et al.* 2018).

Microbials: Entomopathogenic microbial added new arena in IPM programs in tea. For example, entomopathogenic fungi viz., *Metarhizium anisopliae*, *Verticillium lecanii, Steinernema* sp., *Beauveria bassiana,* and *Paecilomyces fumosoroseu*s together with baculoviruses viz., nuclear polyhedrosis virus (NPV), granulosis virus (GV), bacteria viz., *Bacillus thuringiensis,* etc. were found effective against tea pests (Deka *et al.* 2021). About 82 species of viruses, more than 40 fungal

species and several bacterial species were found effective against tea pests (Roy and Muraleedharan 2014). *Cladosporium* sp., *Aspergillus niger*, *A. flavus* were recorded as pathogenic to tea mosquito bug (Mamun *et al.* 2013). *Beauveria bassiana,* mermithid nematode was also to tea mosquito bug (Ghimire 2021). *Metarhizium anisopliae* was found effective against tea mosquito bug (Anitha *et al.* 2019). The use of viruses against tea pests received more attention in the 1970s and insect-specific viruses were reported as the most effective against lepidopteran caterpillars (Roy and Muraleedharan 2014). *Bacillus thuringiensis* is most effective against lepidopteran pests of tea (Ghimire 2021).

Resistant varieties: The tea clones TV6, TV12, TV14 and TV19 clones resistant against tea mosquito bug (Das *et al.* 2017). The tea clones BT4, BT6, BT7, BT8 and BT9 were found resistant to termites (BTRI 2021).

Chemical control: Several classes of insecticides viz., synthetic pyrethroids, neonicotinoids, spinosyns, avermectins, pyrazoles, oxidizes, etc. are used to control tea pests (Deka *et al.* 2021). The correct choice of pesticides, dosage, timing, and method of application is of paramount importance for the successful control of insects and mite pests of tea (Mamun *et al.* 2013). Lists of the recommended pesticides for the management of tea mosquito bug, termites, thrips and looper caterpillar are shown in Tables 2-5 (BTRI Circular No. 142, 2017).

Table 2. Recommended pesticides for the management of tea mosquito bug in Bangladesh (BTRI Circular No. 142, 2017)

Active ingredient (a.i.)	Trade name and formulation	Target pest	Dose ha^{-1}
Dinotefuran	Joddha 20WSG	Tea mosquito bug	300 g
Deltamethrin	Decis 2.5EC	Tea mosquito bug	500 ml
Thiacloprid	Calypso 240 SC	Tea mosquito bug	375 ml
Imidacloprid	Tiddo 200SL	Tea mosquito bug	250 ml
Bifenthrin +Abamectin	NovaStar 56EC	Tea mosquito bug	500 ml
Zeta Cypermethrin	Furry 5EC	Tea mosquito bug	500 ml
Thiamethoxam + Emamectin Benzoate	Shengh Li 30SC	Tea mosquito bug	150 ml
Alpha Cypermethrin	Axis 10EC	Tea mosquito bug	500 ml
Lambda Cyhalothrin	Boxer 2.5EC	Tea mosquito bug	500 ml
Thiamethoxam	Actara 25WG	Tea mosquito bug	250 g

Table 3. Recommended pesticides for the management of termite infesting tea in Bangladesh (BTRI Circular No. 142, 2017)

Active ingredient (a.i.)	Trade name and formulation	Target pest	Dose ha^{-1}
Fipronil+Lambda Cyhalothrin	Otova 10EC	Termite	500 ml
Acetamiprid + Emamectin Benzoate	Venom 25WDG	Termite	500 g
Imidacloprid	Admire 200SL	Termite	1.50 L
Imidacloprid	Mukti 200SL	Termite	250 ml
Imidacloprid	Race 200SL	Termite	1.50 L
Thiamethoxam	Actara 25WG	Termite	250 g

Table 4. Recommended pesticides for the management of thrips infesting tea in Bangladesh (BTRI Circular No. 142, 2017)

Active ingredient (a.i.)	**Trade name and formulation**	**Target pest**	**Dose ha^{-1}**
Dinotefuran	Joddha 20WSG	Thrips	300 g
Deltamethrin	Decis 2.5EC	Thrips	500 ml
Thiacloprid	Calypso 240 SC	Thrips	375 ml
Imidacloprid	Tiddo 200SL	Thrips	250 ml
Alpha Cypermethrin	Axis 10EC	Thrips	500 ml
Chlorfenapyr	Intrepid 10SC	Thrips	1.00 L
Dimethoate	Starter 40EC	Thrips	1.00 L

Table 5. Recommended pesticides for the management of looper caterpillar infesting tea in Bangladesh (BTRI Circular No. 142, 2017)

Active ingredient (a.i.)	**Trade name and formulation**	**Target pest**	**Dose ha^{-1}**
Deltamethrin	Decis 2.5EC	Looper caterpillar	500 ml
Thiacloprid	Calypso 240 SC	Looper caterpillar	375 ml
Imidacloprid	Tiddo 200SL	Looper caterpillar	250 ml
Alpha Cypermethrin	Axis 10EC	Looper caterpillar	500 ml
Flubendiamide	Belt 24 WG	Looper caterpillar	200g
Emamectin Benzoate	Barud 5 SG	Looper caterpillar	600g
Cypermethrin	Ripcord 10EC	Looper caterpillar	500 ml
Cypermethrin	Caught 10EC	Looper caterpillar	1.00 L

IPM OF TEA RED SPIDER MITE (RSM)

RSM is one of the major pests of tea, causing 17-46 % crop loss (Roy *et al.* 2014, Srikumar *et al.* 2015, Bhuyan *et al.* 2017). For this reason, red spider mites draw more attention than other tea pests. IPM components of controlling RSM are described below.

Cultural practices: Cultural controls are first-phase control measures and the primitive methods that are used to manage pest populations (Roy *et al.* 2014). Some techniques of cultural practices are described here.

Pruning: it is an agronomic practice in tea, implemented for renovating vegetative growth to increase crop productivity in the subsequent years. This technique removes many old leaves and 'janams' from bushes which helps to reduce RSM. It has been observed that pruned areas are less attacked than skiffed areas in tea plantations (Roy *et al.* 2014). The more removal of tea leaves, the better chance of avoiding RSM attack.

Water management & drainage: Water-stressed trees and plants are less tolerant to spider mite damage. So, proper care should be taken to provide adequate irrigation. Midseason washing off trees with water can remove dust which may help prevent serious late-season mite infestation. Inadequate drainage causes waterlogging, which is harmful to tea plants and conducive to the buildup of RSM (Roy *et al.* 2014). Thus, mulching also helps to increase humidity in the field, and therefore may help control mites.

Effects of shade trees: Temperature of tea leaves under shade is 1–2 ^{o}C below ambient temperature while in the unshade areas it may go up by 2–4^{o}C. Researchers observed that optimum number of shade trees reduce leaf temperature by 10-12^{o}C at mid-day time (BTRI 2021), but unshade drought areas are more susceptible to RSM (Roy *et al.* 2014). Proper spacing with 20'×20' is recommended for reducing RSM attack (BTRI 2021).

Influence of fertilizer: The population of RSM in tea was higher on bushes receiving heavier doses of nitrogen and lower on bushes receiving more potash and phosphorus (Roy *et al.* 2014). The use of balanced nitrogen and phosphorus fertilizer is suggested by BTRI scientists for the control of RSM attacking tea.

Biological control: Conservation, production and augmentation of predators, parasitoids and pathogens are effective biological control agents against RSM, in

which about 80 species of predators, 9 species of fungal and 2 species of bacterial pathogens have been recorded as the natural enemies of RSM (Roy *et al.* 2014).

Predator: Forty seven predatory insects and mites are found to attack RSM (Das *et al.* 2010). Coccinellid beetles are the second largest group of predators of RSM, in which the ladybird beetle, *Stethorus gilvifrons* Mulsant, is a major predator (Roy *et al.* 2014). A new predatory mite *Oligota flaviceps* is identified as a predator of RSM of tea. The density of predatory mites (*Amblyseius* sp. and *Agistemus* sp.) coincided with that of the RSM population in N.E India (Kachhawa and Kumawat 2018). *Mallada desjardinsi* was found effective natural enemy of RSM (Vasanthakumar *et al.* 2019). The predatory species *Stethorus gilvifrons*, *Verania vincta*, *Jauravia quadrinotata*, *Scymnus* sp., *staphylinid* beetles, *Agistemus hystrix*, *Exothorhis caudatae*, *Cunaxa* sp., *Mallada* sp. and praying mantid were found effective against RSM (Ghimire 2021).

Microbial control: *Metarhizium anisopliae* is an effective microbe against RSM (Kumhar *et al.* 2020). *Paecilomyces fumosoroseus* and *Hirsutella thompsonii* have been found effective against RSM in India (Kachhawa and Kumawat 2018). *Verticillium lecani* was found effective microbe against RSM (Mamun *et al.* 2013). *Pseudomonas fluorescens* was found effective against RSM (Vasanthakumar *et al.* 2019).

Botanical control: Extracts of *Clerodendrum viscosum* & *Melia azedarach* were effective against RSM (Kachhawa and Kumawat 2018). Extracts of *Polygonum hydropiper* L. bears antioviposition effect on RSM (Roy *et al.* 2014). Water extracts of *Vitex negundo, Gliricidia maculata, Wedelia chinensis, Morinda tinctoria* and *Pongamia glabra* were effective against RSM (Vasanthakumar *et al.* 2012). Neem kernel, pongam kernel (Roobakkumar *et al.* 2010), garlic (Roobakkumar *et al.* 2010*), Swietenia mahagoni* seeds (Mamun and Ahmed 2011), *Pongamia pinnata* seeds, *Sophora flavescens, Acorus calamus* rhizomes (Mamun and Ahmed 2011), *Aegle marmelos* and *Clerodendron inerme* L., *Nicotiana plumbaginifolia, Phlogocanthus tubiflorus* (Hazarika *et al.* 2009), *Lantana camara* and *Terminalia chebula* (Roy *et al.* 2014) are effective against RSM. *Simarouba glauca* & *Hydnocarpus pentandra* seed oils are also effective against RSM (Bharathi and Mahendran 2021).

Chemical control: A number of pesticides have been recommended for the management of RSM in tea. List of the recommended pesticides for the management of RSM is shown in Table 6 (BTRI Circular No. 142, 2017). Chemical pesticides are to be used as a last resort of IPM approach.

Table 6. Commonly used pesticides for the management of red spider mite infesting tea in Bangladesh (BTRI Circular No. 142, 2017)

Active ingredient (a.i.)	Trade name and formulation	Target pest	Dose ha^{-1}
Propargite	Omite 57EC	Red spider mite	1.00 L
Propargite	Emimite 57EC	Red spider mite	1.00 L
Sulphur	Sulphotox 80WP	Red spider mite	2.25 kg
Sulphur	Ronovit 80WG	Red spider mite	2.25 kg
Sulphur	Sulfox 80 WDG	Red spider mite	2.25 kg
Abamectin	Ambush 1.8EC	Red spider mite	500 ml
Hexythiazox	Mite Scavenger 10EC	Red spider mite	500 ml
Fenazaquin	Magister 10EC	Red spider mite	600 ml
Spiromesifen	Oberon 240SC	Red spider mite	400 ml
Sulphur	Kumulus 80DF	Red spider mite	2.25 kg

CONCLUSION

Tea production in Bangladesh remains under ecological threats against this backdrop. IPM approaches are reviewed to decrease the overuse and misuse of toxic pesticides in tea crop protection from insect and mite pests. It is highly hoped that IPM strategies which have been reviewed would help adopt eco-friendly, effective, cost-efficient management of tea pests especially RSM. The timely use of cultural practices, botanical extracts, conservation, mass production, and augmentation of predators, parasitoids, parasites are some of the IPM components to protect tea from the pest attack. Thus, IPM programs will be more widely adopted in tea production in coming years.

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