



## Integrated pest management strategies of four major pests of tea for sustainable tea production in Bangladesh

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### ABSTRACT

This study evaluated integrated pest management (IPM) components for controlling four major tea pests (tea mosquito bug, red spider mite, thrips, and looper caterpillar) in Bangladesh through multi-location field and laboratory experiments. The study was conducted at the main farm of Bangladesh Tea Research Institute (BTRI), Srimangal, Moulvibazar, and BTRI Sub Station, Panchagarh, during April 2017 to September 2018. The experiments were set up following a completely randomized design (CRD) in laboratory conditions and a randomized complete block design (RCBD) in field conditions with three replications. Data were collected at 24, 48, and 72 hours after treatment (HAT) at laboratory conditions and 7 days intervals at field conditions following respective methods. The results revealed that under cultural control measures, light pruning (LP) significantly reduced the infestation of pests of tea other than skiff pruning. Seven days of regular plucking rounds reduced the incidence of *Helopeltis* and other foliar pests of tea. Weeding significantly reduced the infestation of red spider mite in tea. Under mechanical control measures, solar power light traps and yellow sticky traps captured a greater number of thrips, jassids, aphids, moths of the looper caterpillar, and other flying insects in the tea ecosystem. Among the botanical extracts, fresh leaves, succulent stems, and seeds of Bishkatali, Bhat, Burweed, Garlic, Lantana, Mahogani, and Tobacco demonstrated strong insecticidal properties. The host plant resistance trials revealed that clones BT1, BT2, and BT15 were less susceptible to *Helopeltis*; BT5, BT6, and BT17 showed relatively high resistance to red spider mite, while BT3, BT4, BT8, BT9, BT12, BT13, BT14, BT15, BT18, BT19, and BT20 were less infested by thrips. The bio-control agent, *Bracon hebetor*, as a larval parasitoid, effectively suppressed looper caterpillar populations. Microbial pesticides *Metarhizium anisopliae* and *Pseudomonas fluorescens* significantly reduced red spider mite population, while *Bacillus thuringiensis* significantly reduced looper caterpillar population. These findings collectively support a robust, eco-friendly IPM framework for sustainable tea cultivation in Bangladesh, reducing pesticide dependency, lowering production costs, and promoting environmental safety.

**Keywords:** Tea, Pests, IPM, Plant Extract, Bio-control, Sustainable, Tea Production

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### Introduction

Tea (*Camellia sinensis* L.) is one of the most important cash crops of Bangladesh, representing a vital component of the national economy, rural employment, and export earnings. Now, there are 171 tea estates and more than 8,000 small tea gardens having about 67,000 hectares of tea plantation producing about 93.04 million kg of finished tea per annum with an average yield of about 1,554 kg per hectare in



Bangladesh (BTB, 2025). The tea sector contributes significantly to Bangladesh's national economy and rural employment (BTB, 2025). However, tea cultivation faces numerous biotic challenges, particularly from a wide range of arthropod and non-arthropod pests, which cause significant economic losses and threaten sustainable production. Moreover, a characteristic feature, viz., the performance of shade trees, ancillary crops, forests, a uniformity of cultural practices such as sequential pruning cycles, weekly plucking rounds, weeding, mulching, etc.,

has a greater impact on the subsequent colonization, stabilization, and distribution of pests (Mamun, 2019). In Bangladesh tea, 25 insects, 4 mites, and 12 species of nematodes have been recorded (Mamun and Ahmed, 2011a; Paul *et al.*, 2017).

Among them, tea mosquito bug, red spider mite, thrips, and looper caterpillar are considered the four most destructive pests of tea in Bangladesh. Major insect pests of tea recorded in Bangladesh are shown in Fig. 1.

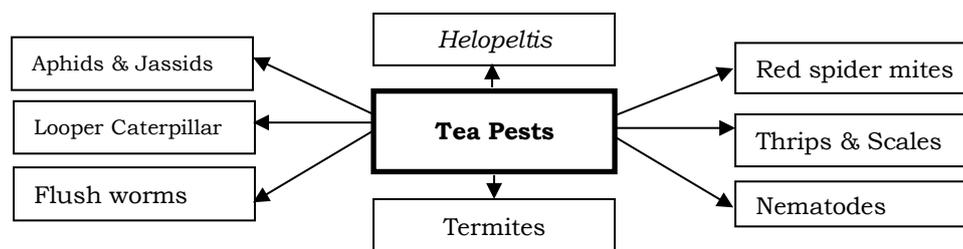


Fig. 1. Major insect pests of tea in Bangladesh (Mamun and Ahmed, 2011a).

The tea mosquito bug, *Helopeltis theivora* Waterhouse (Hemiptera: Miridae) is the most serious pest of tea in Bangladesh, damaging tender shoots, buds, and leaves by sucking cell sap, leading to distortion and withering of the flush, resulting in both quantitative and qualitative losses (Mamun, 2011). The red spider mite, *Oligonychus coffeae* Nietner (Acarina: Tetranychidae), one of the most persistent and damaging mites in Bangladesh tea, feeds on both leaf surfaces, causing discoloration, defoliation, and reduction in photosynthetic efficiency (Mamun *et al.*, 2016). Thrips, *Scirtothrips dorsalis* Hood. (Thysanoptera: Thripidae) attack young leaves and buds, leading to leaf curling, bronzing, and stunted growth, especially in nursery, young tea, and tea bushes recovering after pruning (Mamun and Ahmed, 2011a). The looper caterpillar, *Hyposidra infixaria* Walker (Lepidoptera: Geometridae), is a major defoliator, particularly in the northern tea-growing regions of Bangladesh, with severe infestations capable of stripping entire bushes of foliage (Ahmed *et al.*, 2010; Paul *et al.*, 2016). About 10-15% of its crop could be lost by various pests, particularly insects, mites, and nematodes (Rattan, 1992; Sana, 1989; Ahmed, 2005). It may be extended to as high as 50% when pest attack/ disease incidence is very severe.

Management of pests, diseases, and weeds is an important operation in sustainable tea cultivation. To combat these problems,

different groups of pesticides like organochlorine, organophosphate, synthetic pyrethroids, organocarbamates, and some unclassified groups have been used in the tea fields since 1960. In this perspective, chemical control of pests is a dominating feature in Bangladesh tea (Alam, 1999). Different groups of pesticides of different formulations are for the control of major pests of tea in Bangladesh (Ali *et al.*, 2021). Chemical pesticides have been used for a long time, but have serious drawbacks, such as direct toxicity to beneficial insects, fish, and human beings; pesticide-induced resistance, health hazard and increased environmental, social costs, and undesirable pesticide residue in made tea. Therefore, managing these pest populations within an economic threshold level is important, for which application of pesticides becomes imperative in an Integrated Pest Management (IPM) system (Danzinger, 2000; Mamun and Ahmed, 2011a).

Integrated Pest Management (IPM) offers a holistic and sustainable approach by combining cultural, mechanical, biological, botanical, and host plant resistance strategies to maintain pest populations below economic injury levels. The principle of IPM is the rational and judicious use of chemical pesticides only when necessary, thereby minimizing adverse effects on the environment, human health, and beneficial organisms (Gurusubramanian, 2005). In tea cultivation, IPM practices encompass a wide range of integrated approaches, including

cultural measures (plucking, pruning, shade tree regulation, weeding, maintenance of proper irrigation and drainage, trap cropping, and application of balanced fertilizers), mechanical methods (light traps, sticky traps and pheromone traps), host plant resistance (selection and cultivation of pest tolerant clones), botanical extracts (derived from indigenous plants), bio-control agents (predators and parasitoids), and entomopathogens (fungus, bacteria, and

virus) (Painter, 1951; Muraleedharan *et al.*, 2001; Mamun and Iyengar, 2010). These methods have been extensively evaluated against the major insect pests of tea and have become integral components of IPM programs in many tea-producing countries worldwide (Ahmed *et al.*, 2009; Babu, 2012; Mamun and Ahmed, 2011a; Mamun *et al.*, 2014; Ara Begum *et al.*, 2022).



Fig. 2. Components of the IPM package for major pests of tea (Mamun and Ahmed, 2011a).

Despite the potential of these eco-friendly practices, limited research has been undertaken in Bangladesh to comprehensively evaluate and integrate these diverse IPM components against major tea pests. Hence, the present study was designed to develop and validate an eco-friendly IPM strategy for managing four major tea pests, i.e., tea mosquito bug, red spider mite, thrips, and looper caterpillar, through a combination of cultural, mechanical, host plant resistance, botanical, and biological control methods (Fig. 2). By integrating these control methods, the present study seeks to provide a viable pathway to reduce synthetic pesticide loads, mitigate residue risks, ensure consumer safety, and secure the long-term economic and environmental sustainability of the Bangladesh tea industry.

## Materials and Methods

A series of experiments was carried out to develop an Integrated Pest Management (IPM) strategy for the four major insect pests of tea in Bangladesh during April 2017 to September 2018 at the main farm of Bangladesh Tea Research Institute (BTRI), Srimangal, Moulvibazar, and BTRI Sub Station, Panchagarh, for a multi-location trial. Four major foliar pests of tea, i.e., tea mosquito bug, red spider mite, thrips, and looper caterpillar, were selected for the study.

## Evaluation of some cultural control measures against tea mosquito bug, red spider mite, thrips, and looper caterpillar in tea

*Effect of pruning operations on the incidence of tea mosquito bug, red spider mite, thrips and looper caterpillar in tea*

An experiment was conducted to determine the effect of different pruning operations on the incidence of tea mosquito bug, red spider mites, thrips, and looper caterpillar infesting tea at the Panchagarh substation of BTRI during the period from January 2018 to June 2018. The experiment was set up following a randomized complete block design (RCBD) with three replications. Different types of pruning operations, i.e., Light Pruning (LP), Deep Skiff (DS), Medium Skiff (MS), and Light Skiff (LS), were made in the respective plots according to Dutta (1960) and BTRI (1986), and these different types of pruning cycles were considered as treatments. The untouched/unpruned section was considered as control. Each plot with 5 m x 5 m, having 30 bushes was separated by two buffer rows of non-experimental tea. Systematic random sampling was made on the leaf count method (Mamun *et al.*, 2016). Pretreatment observation was made before the pruning operation was performed. Post-treatment data on the infestation of pests were recorded at a weekly interval up to 12 weeks.

### *Effect of plucking systems on the incidence of Helopeltis*

An experiment was carried out to know the effect of plucking systems (hand plucking) as a cultural control measure against *Helopeltis* in tea at Bangladesh Tea Research Institute (BTRI) substation, Panchagarh, and small tea growers' field during March 2018 - June 2018. The experiment was set up following a randomized complete block design (RCBD) with three replications. Four treatments, such as T<sub>1</sub>: 7 days interval of plucking, T<sub>2</sub>: 10 days interval of plucking, T<sub>3</sub>: 15 days interval of plucking, and T<sub>4</sub>: 20 days interval of plucking, were considered in the study. Each treatment was replicated thrice. Percent (%) shoot infestation by *Helopeltis* was collected at a weekly interval.

### *Effect of weeding as a cultural measure for the control of red spider mite in tea*

An experiment was carried out to know the effect of weeding as a cultural control measure against red spider mite in tea at BTRI substation, Panchagarh, during January - June 2018. The experiment was set up following RCBD with three replications. Each plot measured 5 m × 5 m and contained 30 tea bushes. Four treatments, such as T<sub>1</sub>: Weeding, T<sub>2</sub>: Weeding + Spraying of miticide, T<sub>3</sub>: No weeding + Spraying of miticide, and T<sub>4</sub>: No weeding (control), were considered in the study. Pest populations were assessed using a systematic random sampling method based on leaf counts (Mamun *et al.*, 2016). Pretreatment observation was made before the weeding operation was performed. Post-treatment observations on the infestation of mites were recorded at weekly intervals up to 4 weeks.

### **Evaluation of different traps, such as solar light traps and sticky traps, against thrips and looper caterpillar in tea**

An experiment was carried out to evaluate the solar light traps and sticky traps as mechanical control measures against thrips and looper caterpillar in tea at BTRI main farm, Srimangal, and BTRI substation, Panchagarh, during 2017-2018. The experiment was set up following RCBD with three replications. Three treatments, such as light trap (T<sub>1</sub>), yellow sticky trap (T<sub>2</sub>), and blue sticky trap (T<sub>3</sub>), were considered in the study. Solar-powered light traps were used

overnight to attract the flying pests of tea, i.e., thrips and moths of caterpillar. UV lights (220 V, 18 W, 5.2 nm; Philips) in the light traps were used in the experiment. The two light traps in the pair were placed approximately 600 m apart. Yellow and blue sticky traps were placed in the infested sections. Bright yellow or blue colour corrugated plastic boards were cut into small pieces (12" x 12") and both sides coated with a thin film of a sticky adhesive. The Yellow and blue sticky traps were placed in the tea field above the bush canopy (plucking table) at an angle of 60° facing against the wind by securing them on top of bamboo sticks. 10 sticky traps per 1000 m<sup>2</sup> were used in the study. A total of 100 traps are required per hectare. Post-treatment observations on the attraction of pests were recorded at weekly intervals up to 4 weeks.

### **Screening of tea clones against Helopeltis, red spider mite and thrips in tea**

An experiment was carried out to screen the susceptibility of different tea clones against *Helopeltis*, Red spider mite and Thrips at the clonal block of BTRI main farm, Srimangal, Moulvibazar, during May 2017 to September 2018. Susceptibility to *Helopeltis*, Red spider mite and Thrips of different tea clones released by BTRI, namely, BT1- BT20, was evaluated against these pests infesting tea. These twenty Bangladesh Tea (BT) clones were considered as treatments (T<sub>1</sub>-T<sub>20</sub>). The experiment was laid out in RCBD and replicated thrice. Each plot with 5 m x 5 m, having 30 bushes. From the clonal block of BTRI, the percent infestation of different pests was estimated every month by randomly sampling, observing, and monitoring by using the following formula:

$$\text{Leaf infestation (\%)} = \frac{\text{Number of infested leaves} \times 100}{\text{Total number of leaves}}$$

### **Evaluation of some indigenous plant extracts against Helopeltis and red spider mite**

An experiment was conducted both in the Entomology Laboratory, the main farm of BTRI, Srimangal, Moulvibazar, and BTRI Substation, Panchagarh during March 2018 and June 2018. Fresh leaves, succulent stems, and seeds of Akonda (*Calotropis procera*), Basok (*Adhatoda vasica*), Bishkatali (*Polygonum hydropiper*), Bhat (*Clerodendron infortunatum*), Burweed (*Xanthium*

*strumarium*), Castor bean (*Ricinus communis*), Datura (*Datura metel*), Garlic (*Alium sativum*), Lantana (*Lantana camara*), Mahogani (*Swietenia mahagoni*), Nishinda (*Vitex negundo*) and Tobacco (*Nicotiana tabacum*) were collected locally from nearby areas of the campus following the method of Mamun and Ahmed (2011b). Each plant material was dried under shade and powdered by using an electric grinder and passed through a 20 mesh sieve and kept in a 1 kg capacity polypropylene bag. 150 g of each powdered plant material was taken into a 1 litre capacity conical flask and 500 ml of distilled water was added to it and shaken for 8 hrs in a mechanical shaker and then kept for 24 hrs. The extract was separated using fine muslin cloth and then filtered. The filtrate was collected in a 1 litre capacity conical flask and the volume was made up to 500 ml by adding distilled water. This was considered a stock solution. Three different concentrations of each plant extract (5.0, 7.5, and 10.0%) were prepared with water from the stock solution.

**Laboratory bioassay:** The experiment was designed in a completely randomized design (CRD) with three replications. Different plants were considered as treatments. In case of *Helopeltis*, a direct toxicity test by the topical application method was conducted according to the method of Talukder and Howse (1993) with slight modification. One microliter ( $\mu\text{l}$ ) of prepared solution was applied to the dorsal surface of the thorax of each *Helopeltis* using a micropipette. Ten adult insects, including five male and five female per replication, were treated and each treatment was replicated thrice. In addition, the same number of insects were treated with water only for control. After treatment, the insects were transferred into 9 cm diameter petri dishes (10 insects/petri dish) containing tea shoots (two leaves and a bud). Insect mortalities were recorded at 24, 48 and 72 hours after treatment (HAT). In case of red spider mite, the detached leaf culture method of Helle and Sabelis (1985) with slight modifications was followed. Each concentration of plant extracts (2.5, 5.0 and 10.0%) was sprayed onto the adaxial (upper) and abaxial (lower) surfaces of the leaf using a glass atomizer. Original data were corrected by Abbott's (1987) formula.

**Field evaluation:** A field trial was conducted to evaluate the efficacy of different plant extracts against *Helopeltis*, red spider mite and thrips at BTRI main farm, BTRI Sub Station and Farmers' tea field at Panchagarh. Randomized complete block design (RCBD) with three replications was followed. Each plot with 5 m x 5 m, having 30 bushes. Each plot in the experiment was separated by two buffer rows of non-experimental tea. Thirty bushes per replication were considered for each treatment, along with an unsprayed control. 25 kg of powder of collected dried plant/plant parts, adding with 250 ml adjuvant (soak), were taken in 50 liters of water overnight; Extract and filter through fine cloth and add 500 liters of water; Spray the solution in a one-hectare area of tea plantation with a knapsack hand sprayer. In the experimental plot, 62.5 g of powder is needed in 1.25 litres of water. In the case of *Helopeltis*, one hundred shoots were randomly collected from the harvested shoots of each plot and infested shoots were counted. A shoot was considered infested if it contained even a single feeding spot. In case of mite, pest populations were assessed at a weekly interval by collecting 10 mature leaves at random from each block and from each leaf; mites were counted using a mite brushing machine (Model-Leedom Engineering, USA) and a Stereomicroscope. The effectiveness of the plant extracts was calculated by using Henderson and Tilton's (1955) formula.

#### **Potential effects of *Bracon hebetor* as a bio-control agent for sustainable management of the looper caterpillar**

An experiment was carried out to determine the efficacy of the bio-control agent, *i.e.*, *Bracon hebetor* (I-Bracon) as a larval parasitoid, against the looper caterpillar infesting tea in laboratory conditions. The caterpillar was collected from different sections of the BTRI main farm and Bilashcherra Experimental Farm and reared in the Entomology Laboratory, BTRI. The *Bracon hebetor* @ 5 adults/30 larvae was considered as a treatment with three replications. The potentiality of parasitoids on the mortality of the looper caterpillar was studied. Mortality data of the looper caterpillar were collected at 24, 48, and 72 hours after release (HAR) in the laboratory conditions.

### Evaluation of entomopathogens against red spider mite and looper caterpillar

*Evaluation of two commercial entomopathogens (microbials) against red spider mite in tea*

An experiment was carried out to evaluate the potential of two microbial biopesticides (entomopathogens), viz., *Metarhizium anisopliae* and *Pseudomonas fluorescens*, against red spider mite, *Oligonychus coffeae*, infesting tea in laboratory and field conditions at the Entomology Laboratory and BTRI main farm, respectively. The Red spider mite was collected from different sections of the BTRI main farm and reared in the Entomology Laboratory, BTRI, on a susceptible tea clone, BT2, by following the detached leaf culture method of Helle and Sabelis (1985) with slight modifications. The mite pests were reared on tea leaves in rectangular jars (9.5 cm x 7.5 cm x 20.0 cm). The entomopathogens @ 0.5, 1.0 & 1.5 ml/L, concentration, are considered as treatments (T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>). The experiment was set up following CRD with three replications. Each concentration of entomopathogens (5.0, 1.0 and 1.5 ml/L) was sprayed onto the adaxial (upper) and abaxial (lower) surfaces of the leaf using a glass atomizer. Data were collected at 24 HAT, 48 HAT, and 72 HAT in the laboratory condition. A field experiment was set up following RCBD with three replications. Each plot with 5 m x 5 m, having 30 bushes. Each plot in the experiment was separated by two buffer rows of non-experimental tea. Thirty bushes per replication were considered for each treatment, along with an unsprayed control. Mite populations were assessed at a weekly interval by collecting 10 mature leaves at random from each plot and from each leaf; mites were counted using a mite brushing machine (Model-Leedom Engineering, USA) and a stereomicroscope.

*Evaluation of Bacillus thuringiensis against the looper caterpillar in tea*

A laboratory experiment was conducted to determine the bioefficacy of *Bacillus thuringiensis* (Antario 32K) against the looper caterpillar at the Pest Management Laboratory, BTRI substation, Panchagarh, during May 2018 - July 2018. The dosage of the *Bacillus thuringiensis* was 1.0g, 1.5g, and 2.0g per litre of water against the looper caterpillar and was considered a treatment.

Each treatment was replicated thrice. Mortality data were collected at 24 HAT, 48 HAT, and 72 HAT in the laboratory condition.

**Data analysis:** Data obtained from laboratory and field experiments were analyzed using appropriate statistical procedures according to the respective experimental designs. Prior to analysis, all datasets were tested for normality and homogeneity of variance, and square root ( $\sqrt{x}$  and  $\sqrt{x+1}$ ) transformations were applied where necessary. Analysis of variance (ANOVA) was performed for experiments conducted under RCBD and CRD to evaluate treatment effects. Treatment means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level of significance ( $p < 0.05$ ). In cultural and mechanical control experiments, pest incidence was expressed as percentage infestation or mean pest population per leaf or shoot, while trap efficiency was assessed based on the mean number of insects captured per trap per week. Screening of tea clones was based on mean percentage infestation over the study period, and clones were classified according to their relative susceptibility. All results are presented as means  $\pm$  standard error (SE). Statistical analyses were conducted using R software (version 4.1.0; R Core Team, 2021), and graphical representations were prepared using Microsoft Excel (2010) where necessary to illustrate treatment effects.

## Results and Discussion

### Evaluation of some cultural control measures against *Helopeltis*, red spider mite, thrips and looper caterpillar in tea

*Effect of pruning operations on the incidence of Helopeltis, red spider mite, thrips and looper caterpillar in tea*

Pruning is one of the vital cultural operations in tea culture. Result revealed that the pruning operations were significantly ( $F=241.55$ ,  $p < 0.05$ ) reduce the incidence of *Helopeltis*, red spider mite, thrips and looper caterpillar populations in tea. It was also observed that the incidence of all the pest populations was found to be the lowest in LP (1.24 - 3.21%), where the highest population was in the LSK section (18.33 - 22.41%) (Fig. 3). However, there was no significant effect on individual pruning operations among the pest populations.

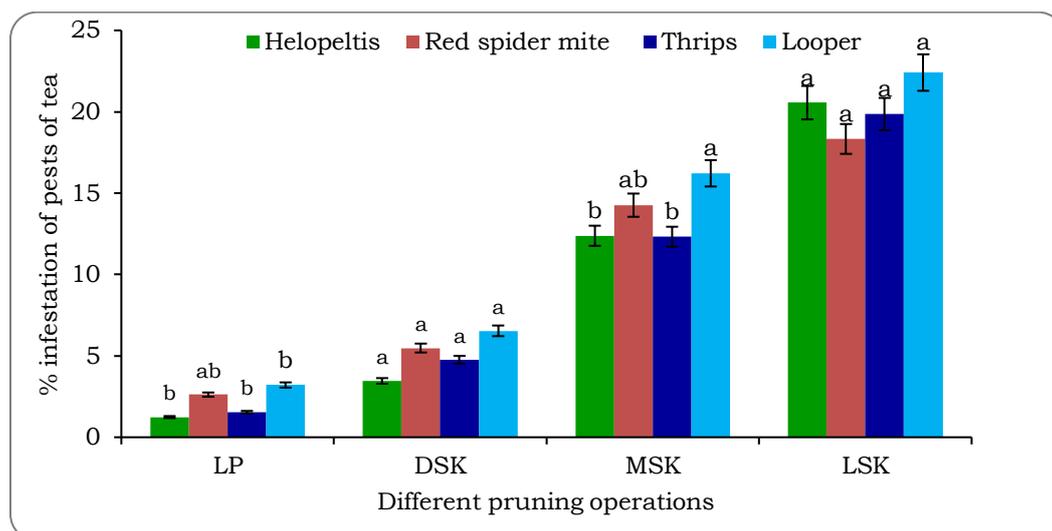


Fig. 3. Percent (%) infestation of pests of tea in different pruning operations. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

Light Skiff (LS) helps remove unproductive shoots and eggs of *Helopeltis* and thrips (Rabindra, 2012). The effect of pruning has been demonstrated for *Xyleborus formicatus* in Sri Lanka (Sivapalan, 1985). Similar works have been done for *Brevipalpus phoenicis* in Kenya and *Oligonychus coffeae* in North East India by Rattan (1992) and Das (1960), respectively. Ahmed and Mamun (2012) also found similar trends in the case of major pests of tea in Bangladesh. Harrison (1937) also concluded that tea left unpruned (skiffed) and carrying much old leaf and banjhi growth is especially susceptible to red spider mite. So, Light pruning (LP) significantly reduced the infestation of pests of tea than skiff treatments.

#### *Effect of plucking systems on the incidence of Helopeltis*

The results revealed that the plucking interval significantly ( $F=93.79$ ,  $p < 0.05$ ) reduced the *Helopeltis* infestation. Therefore, the incidence of *Helopeltis* was found to be less in 7 days plucking sections than in other treatments (Fig. 4). So, seven-day plucking can help to control the pest populations of *H. theivora*, by removing either egg deposited in the young stems or larvae present in the young leaves.

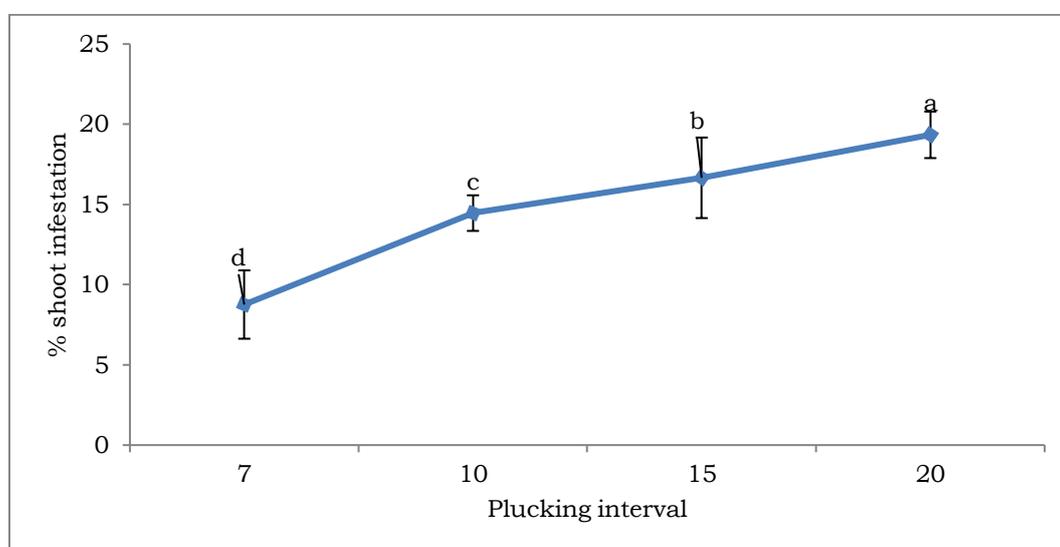


Fig. 4. Effect of plucking systems on the incidence of *Helopeltis*. Vertical bars at lines indicate the SE value. The different small letters on the lines are significantly different by DMRT ( $p < 0.05$ ).

However, plucking intensity is important; the higher the intensity, the greater the reduction in pest population. Consistent plucking keeps the tea plants robust and encourages the growth of new shoots (Sasidhar and Sanjay 2000; Satake *et al.*, 2006). Intensive removal of stalks during plucking will reduce the incidence of this pest. For the control of tea mosquito bug a frequent plucking schedule is recommended to remove inserted eggs and early nymphs (Roy *et al.*, 2015).

#### *Effect of weeding as a cultural measure for the control of red spider mite in tea*

The result revealed that weeding significantly ( $F=45.11$ ,  $p<0.05$ ) reduced the infestation of red spider mite in tea. From the study, it was found that weeding followed by spraying showed the highest reduction of mite (from 44.62 to 4.20) than the other treatments within the four weeks of time (Table 1).

Table 1. The effect of weeding on the population of red spider mite in tea.

Treatment	Pre-treatment observation (No. of mites / 10 mature leaves)	Post-treatment observation (No. of mites/ 10 mature leaves)			
		1 <sup>st</sup> week	2 <sup>nd</sup> week	3 <sup>rd</sup> week	4 <sup>th</sup> week
T <sub>1</sub> : Weeding	41.22	50.60±0.76b	58.20±0.81b	64.80±0.88b	73.40±0.94b
T <sub>2</sub> : Weeding + Spraying	44.62	17.60±0.40d	13.60±0.36d	8.60±0.22d	4.20±0.16d
T <sub>3</sub> : No weeding + Spraying	47.38	23.20±0.48c	30.20±0.56c	34.80±0.62c	44.20±0.72c
T <sub>4</sub> : No weeding	38.34	72.80±0.94a	89.20±0.98a	105.60±1.24a	122.40±1.36a

Within the column values followed by different small letters are significantly different by DMRT ( $p<0.05$ )

No weeding (T<sub>4</sub>) plots suffer too much from red spider mites. It was found that areas, which are periodically cleaned of weeds, suffer less from red spider mite than unclean/weeded areas. Weed-free tea cultivation reduces the infestation of red spider mite in tea. Saraiva *et al.* (2015) also control the physic nut mite by adopting weed management practices. So, the growth of host plants, jungles, and weeds in and around tea fields should be controlled and this will help reduce the growth of pest populations infesting tea.

#### **Evaluation of different traps, such as solar light traps and sticky traps, against thrips and looper caterpillar in tea**

Result revealed that solar power light trap captured significantly ( $F=1080.18$ ,  $p<0.05$ ) the highest number of moths (82.85/trap) of looper caterpillar, *Hyposidra infixaria* at 21 days intervals (Fig. 5). Pest captures increased progressively over time. On the other hand, yellow sticky traps captured significantly ( $F=127.68$ ,  $p<0.05$ ) the highest number of thrips, *S. dorsalis* (64.88/trap) than blue sticky traps (55.00/trap) at 21 days interval (Fig. 6). However, the traps also captured a large number of non-target insects.

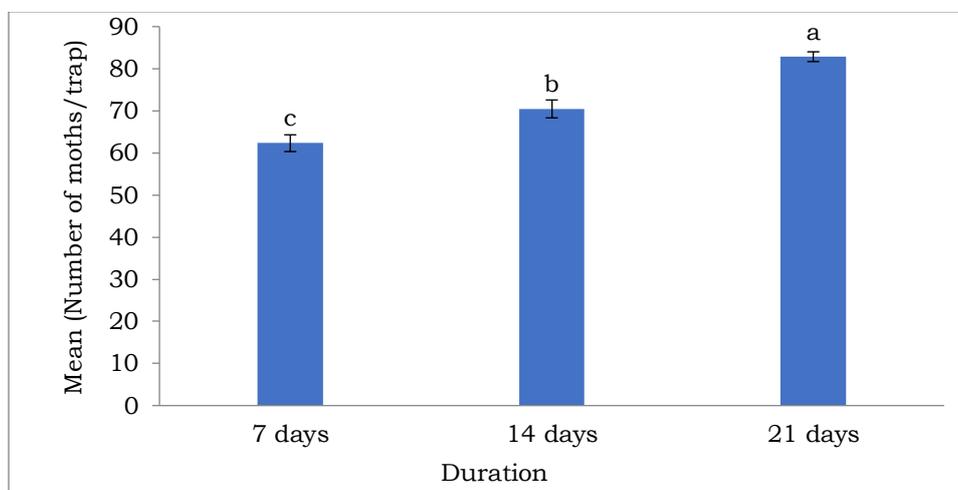


Fig. 5. Performance of solar-powered light trap against looper caterpillar moth in tea. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p<0.05$ ).

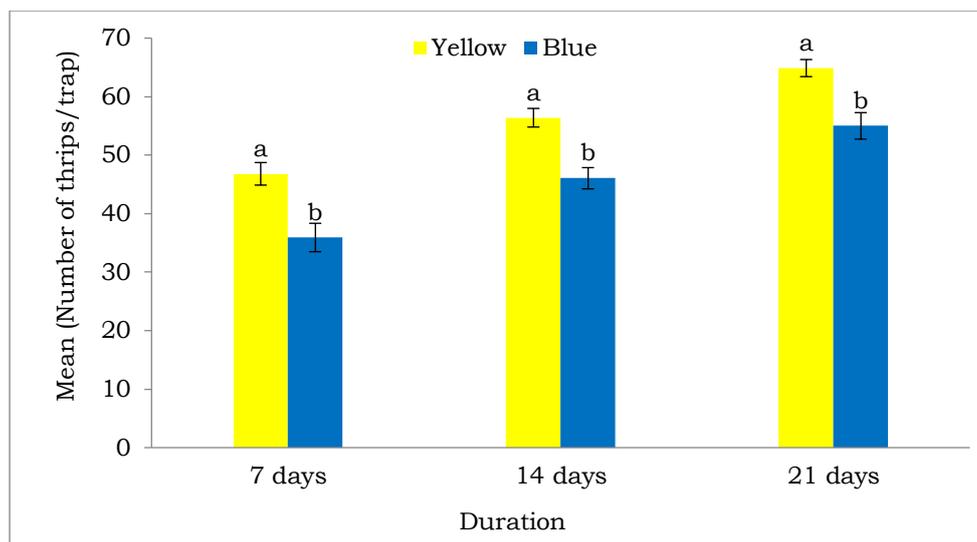


Fig. 6. Performance of yellow and blue sticky traps against thrips in tea. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

Several authors agree with the present findings on the solar light trap and the yellow sticky trap against tea pests. [Al Mamun \*et al.\* \(2023\)](#) studied that the solar-based LED light trap might have the potential to reduce a great number of tea pests in the tea garden. [Uesugi and Sato \(2013\)](#) found that counting adults of tea spiny whitefly on a yellow sticky trap is an efficient method for detecting this species at a low density and is therefore useful for monitoring at the early invasion stage. The results from [Sen \*et al.\* \(2016\)](#) revealed that the use of yellow sticky traps in tea plantations has no detrimental effect on the natural enemy population of tea pests. Therefore, the planters can use such a trap in their tea fields without any hesitation. This sticky trap works best for sucking pests and helps in trapping the population of thrips, jassids, white flies, and adults of tea mosquito bugs. [Shi \*et al.\* \(2021\)](#) suggested that yellow sticky cards and light traps have limited capacity to control tea green

leafhoppers. By capturing adult insects, sticky traps help lower the number of pests and lessen the harm done to tea plants. Another study in South India revealed that blue sticky traps are especially good at drawing tea mosquito bug ([Srikumar and Radhakrishnan, 2015](#)).

#### **Screening of tea clones against *Helopeltis*, red spider mite and thrips in tea**

Susceptibility to BTRI released tea clones, namely, BT1, BT2, BT3, BT4, BT5, BT6, BT7, BT8, BT9, BT10, BT11, BT12, BT13, BT14, BT15, BT16, BT17, BT18, BT19 & BT20, against major pests of tea i.e., *Helopeltis*, Red spider mite and Thrips, was studied. The maximum pest population of *Helopeltis*, Red spider mite and Thrips obtained from all three replicates of each clone are presented in Figures 7-9. These numbers indicate the relative resistance or susceptibility of the clones to the respective pest infestation.

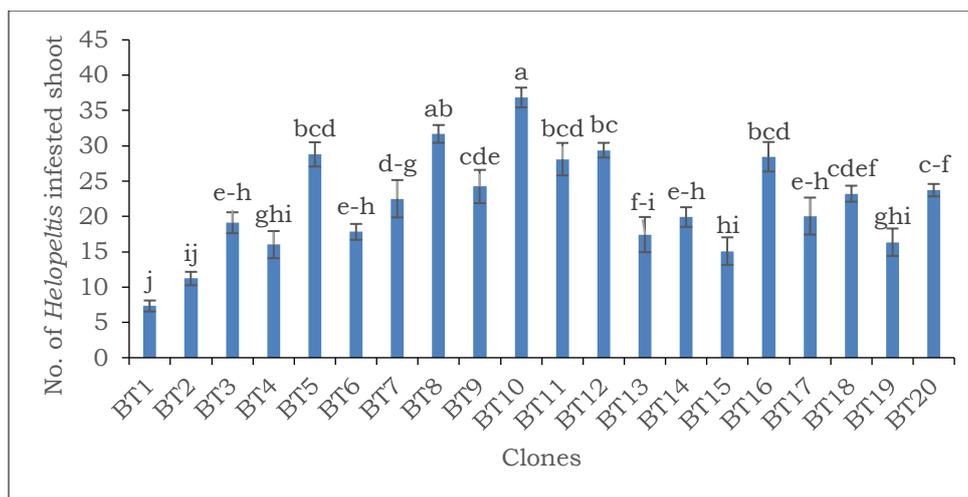


Fig. 7. Clonal susceptibility against *Helopeltis*. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

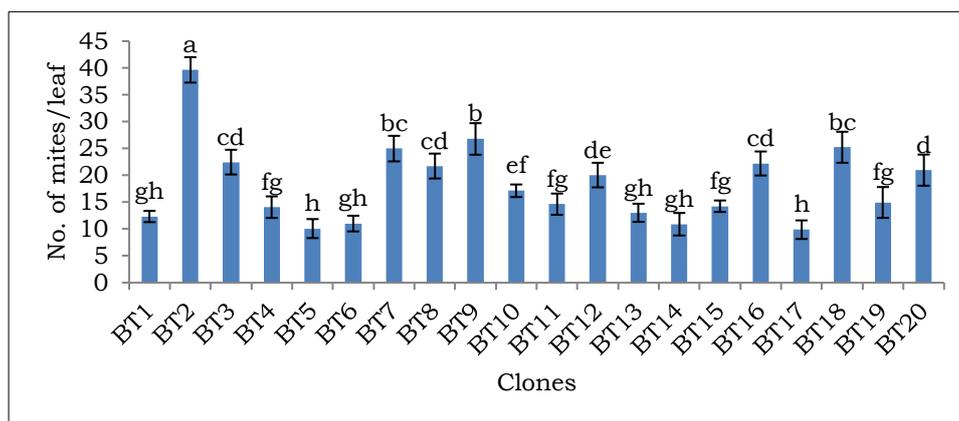


Fig. 8. Clonal susceptibility against Red spider mite. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

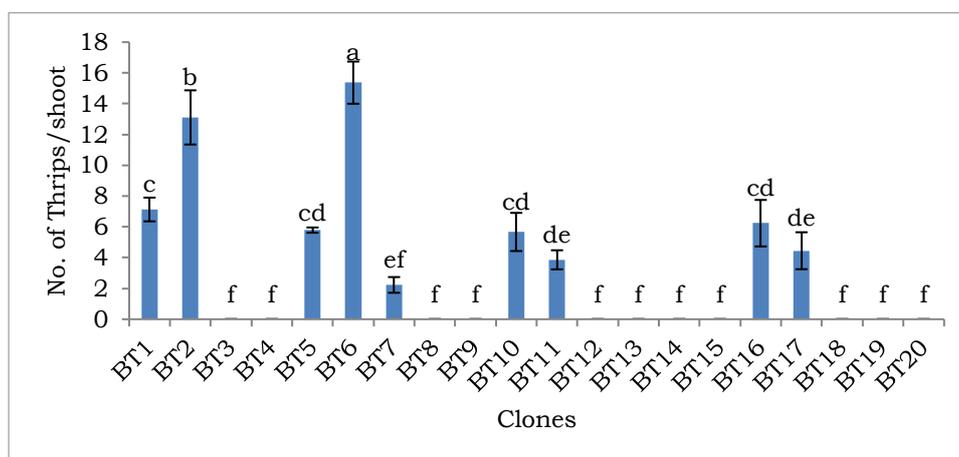


Fig. 9. Clonal susceptibility against Thrips. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

Result revealed that BT1, BT2 & BT15 clones were found less ( $F=12.90$ ,  $p < 0.05$ ) attacked by *Helopeltis* compared to other clones (Fig. 7). BT5, BT6 & BT17 clones were found less ( $F=36.00$ ,  $p < 0.05$ ) attacked by Red spider mite (Fig. 8). BT3, BT4, BT8, BT9, BT12, BT13, BT14, BT15, BT18, BT19, BT20 were

found less ( $F=35.40$ ,  $p < 0.05$ ) infested by thrips (Fig. 9). The average pest population varied significantly in the different clones. The significant variability in damage may perhaps be attributed to physical or biological traits of the agrotypes and clones. Since the light coloured varieties are more

affected than the dark-leaved varieties. Research on clonal selection and breeding focuses on susceptibility, with dark-leaved varieties more susceptible to the sucking pests. China hybrids suffer the most (Ahmed and Mamun, 2014). Similar observations were also reported to the tea mosquito bug,

*H. theivora*, made by Sudhakaran (2000), Chowdhury *et al.* (2008); the termite by Ahmed *et al.* (1999), and Thrips, *S. bispinosus* by Mahendran (2011). Thirugnanasuntharan and Amarasinghe (1990) in Sri Lanka and Sudarmani (2004) in India studied the susceptibility of different

tea clones to *Oligonychus coffeae*. In South India, UPASI-3 and UPASI-12 are more susceptible to mite attack, whereas the leaves of UPASI-6 and UPASI-10 harbored few mites. In Sri Lanka, the clones MT 18 and TRI 2027 are resistant, while the clones CY 9 and DT 1 are susceptible to the mite pest. Sivapalan *et al.* (1980) studied the susceptibility of different tea clones to *Glyptotermes dilatatus*.

#### Evaluation of some indigenous plant extracts against *Helopeltis* and red spider mite

Table 2. Mean mortality percentage of *Helopeltis* and red spider mite treated with different plant extracts under laboratory conditions

Name of the plant	Dose (%)	Mean mortality rate (%)	
		<i>Helopeltis</i>	Red spider mite
Akonda	5.0	54.21±2.62j	55.96±3.72h
	7.5	57.74±1.47hij	58.80±2.86fgh
	10.0	65.55±3.58a-j	67.26±2.84a-h
Basok	5.0	56.04±3.61ij	58.02±3.69gh
	7.5	59.28±1.73f-j	61.21±2.95d-h
	10.0	67.17±1.40a-i	68.12±0.67a-h
Bishkatali	5.0	61.48±2.88d-j	63.68±1.99b-h
	7.5	64.71±3.82a-j	66.85±2.45a-h
	10.0	73.85±0.27abc	73.90±1.27abc
Bhat	5.0	60.47±1.11d-j	62.71±0.80b-h
	7.5	63.98±1.91b-j	65.93±2.42a-h
	10.0	72.18±2.80a-d	72.95±1.10a-d
Bur-weed	5.0	63.22±2.84b-j	65.96±1.92a-h
	7.5	66.77±1.99a-i	68.80±2.53a-g
	10.0	76.13±2.51a	76.76±0.92a
Castor bean	5.0	57.62±2.64hij	59.86±1.70e-h
	7.5	61.01±3.96d-j	62.87±4.04b-h
	10.0	68.77±1.48a-h	69.91±2.64a-g
Datura	5.0	58.24±2.79g-j	60.34±1.82e-h
	7.5	61.41±2.60d-j	63.51±1.99b-h
	10.0	69.59±1.84a-h	70.53±2.69a-f
Garlic	5.0	59.64±0.91e-j	61.98±1.90c-h
	7.5	63.42±1.74b-j	65.03±0.65a-h
	10.0	71.51±2.80a-e	72.13±3.01a-e
Lantana	5.0	58.66±1.88g-j	60.72±2.85d-h
	7.5	61.96±2.68d-j	63.85±1.88b-h
	10.0	70.05±0.90a-g	70.95±2.75a-f
Mahogani	5.0	62.16±1.73c-j	64.82±2.13a-h
	7.5	65.71±0.89a-j	67.62±1.44a-h
	10.0	74.83±2.45ab	75.00±3.25ab
Nishinda	5.0	56.74±0.58ij	59.01±1.62fgh
	7.5	59.93±1.79e-j	62.16±2.16c-h
	10.0	67.78±2.22a-i	69.20±1.61a-g
Tobacco	5.0	59.16±2.79f-j	61.43±1.93d-h
	7.5	62.56±1.60c-j	64.33±2.79b-h
	10.0	71.06±1.80a-f	71.59±2.00a-e

Mean of three observations; Within the column values followed by different small letters are significantly different by DMRT ( $p < 0.05$ )

The different plant extracts ( $F=2.05$ ,  $p < 0.05$ ) and concentration ( $F=37.20$ ,  $p < 0.05$ ) showed significant effect on the mortality *Helopeltis* and Red spider mite at 24, 48 and 72 hours after treatment. Result revealed that Bur-weed extract possessed the highest (76.13 and 76.76%) toxic effect, whereas Akonda

extract possessed the lowest (65.55 and 67.26%) toxic effect under laboratory conditions at the highest (10.0%) concentration, respectively (Table 2). A similar trend of toxicity was found at 5% and 7.5% concentration.

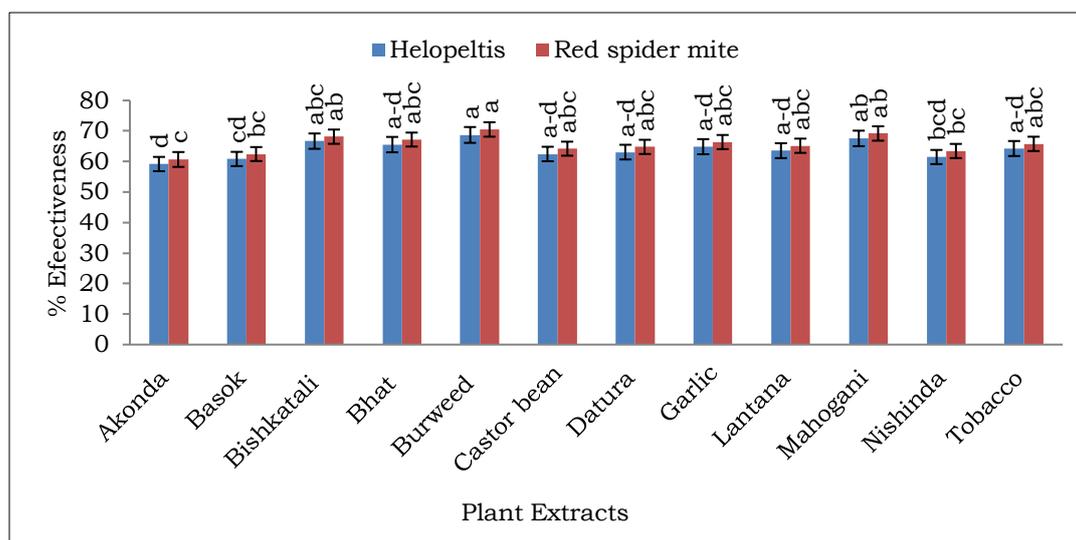


Fig. 10. Field efficacy of some indigenous plant extracts against *Helopeltis* and Red spider mite. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

Result revealed that all the plant extracts have pesticidal properties to reduce pest infestation. The order of the toxicity of plant extracts against *Helopeltis* & red spider mite infesting tea in Bangladesh context were Bur-weed>Mahogani>Bishkatali>Bhat>Garlic>Tobacco>Lantana>Datura>Castor-bean>Nishinda>Basok>Akonda (Fig. 10). Similar observations were also reported to the tea mosquito bug, *H. theivora*, made by Radhakrishnan (2005); Mamun *et al.* (2013); the red spider mite, *O. coffeae* by Mamun *et al.* (2015), and Thrips, *S. bispinosus* by Mahendran (2011).

#### Potential effects of *Bracon hebetor* as a bio-control agent for sustainable management of the looper caterpillar

Result revealed that parasitism of *B. hebetor* was found at 24 hours after release (HAR) (48.13%) and the maximum mortality (93.60%) of looper caterpillar by the larval parasitoid of *Bracon hebetor* was found at 96 (HAR) in the laboratory condition (Fig. 11). Further experiment should be conducted at field level for the confirmation of the parasitism of the biocontrol agents (Ghosh Hajra, 2002). However, the *Bracon hebetor* may be used as a larval parasitoid for the control of looper caterpillar infesting tea as one of the strong IPM components.

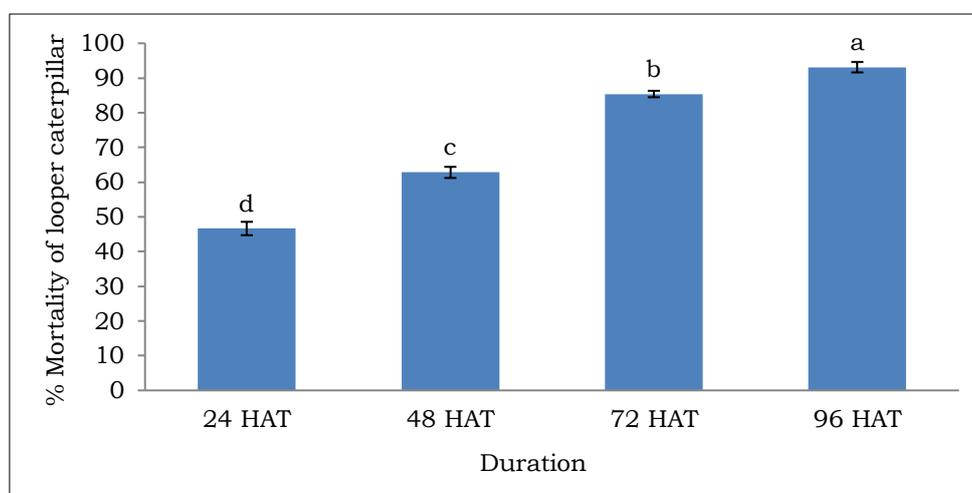


Fig. 11. Percent mortality of looper caterpillar by the larval parasitoid of *Bracon hebetor* at laboratory conditions. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p < 0.05$ ).

Similar results were found by [Hoque \*et al.\* \(2023\)](#). Bio-control agent, *Bracon hebetor* as a larval parasitoid, was very effective against the looper caterpillar and significantly reduced the pest population. Result revealed that the parasitism of *B. hebetor* was found to be very effective, and the maximum mortality (98.42%) of looper caterpillars by the larval parasitoid of *B. hebetor* was found 21 days after release in the field conditions. [Chandraker \*et al.\* \(2023\)](#) found the release of cocoons of *B. hebetor* @ 8500 cocoons (85 Bracocards) ha<sup>-1</sup> was the most effective for managing diamondback moth (*Plutella xylostella*) larvae on cabbage crop.

### Evaluation of entomopathogens against red spider mite and looper caterpillar infesting tea

*Evaluation of two commercial entomopathogens against red spider mite in tea*

Results revealed that both entomopathogens showed a toxic effect on red spider mite in tea and significantly reduced the mite population. In laboratory conditions, significantly ( $F=85.34$ ,  $p<0.05$ ) the highest mortality (78.69%) of red spider mites was found in *M. anisopliae* at 1.5 ml/L of water at 72 HAT. On the other hand, *P. fluorescens* showed significantly ( $F=44.93$ ,  $p<0.05$ ) the highest mortality (71.46%) at 72 HAT (Fig. 12). A Similar trend was also found at 24 HAT and 48 HAT after spraying of entomopathogens. Satisfactory efficacy of *M. anisopliae* (54.61-78.69%) was also found than *P. fluorescens* (47.63-71.46%) for control of red spider mite using three different concentrations of entomopathogens at the field level (Fig. 13).

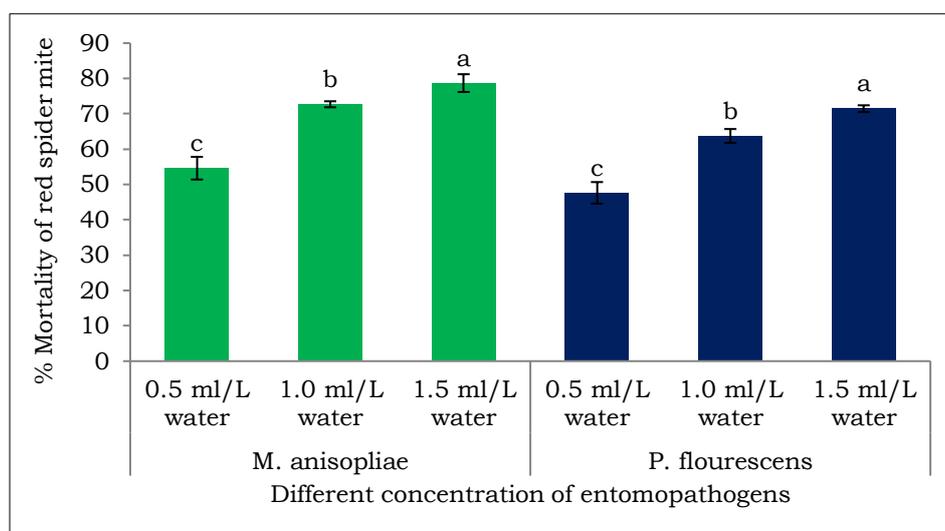


Fig. 12. Mortality (%) of red spider mite using two entomopathogens at laboratory conditions. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p<0.05$ ).

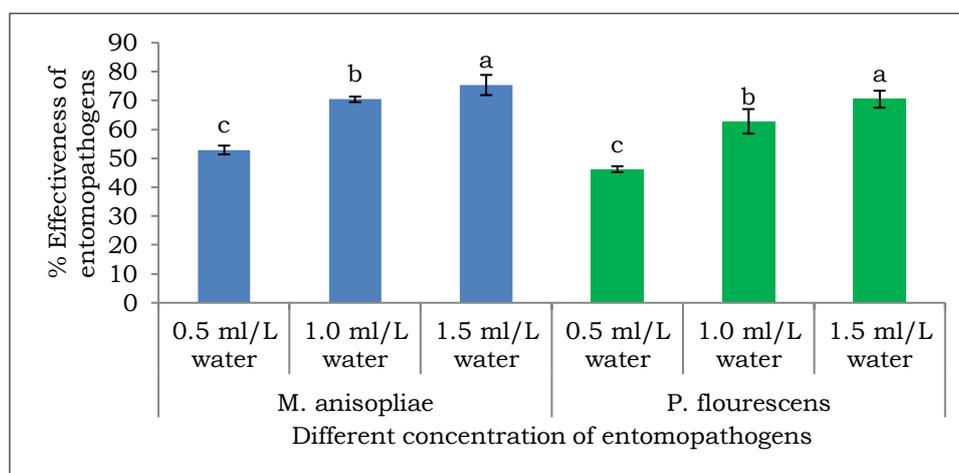


Fig. 13. Effectiveness (%) of two entomopathogens against red spider mite at field conditions. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p<0.05$ ).

Mamun *et al.* (2014) found that entomopathogens, viz., *Beauveria bassiana*, *Metarhizium anisopliae*, *Streptomyces avermitilis*, *Paecilomyces fumosoroseus*, *Verticillium lecanii*, and *Pseudomonas fluorescens* @ 5.0 g/L, 5.0 g/L, 2.0 ml/L, 5.0 g/L, 5.0 g/L, 4.0 g/L, respectively, significantly reduced mite population in tea both in laboratory and field conditions in Bangladesh. Deka *et al.* (2022) found that aqueous suspension of entomopathogen revealed that 1000 and 1200 ml doses of *Metarhizium anisopliae* s.l. 5% AS each in 400 L of water/ha significantly reduced *O. coffeae*'s population in the tea gardens of Dooars and Darjeeling regions, India. Ahmed and Mamun (2013) also found the satisfactory results using *Metarhizium anisopliae* against termites infesting tea. Gurusubramanian *et al.* (1999) also found the satisfactory results using *Beuveria bassiana* against termites infesting tea. Babu *et al.* (2008) found satisfactory result using *Verticillium lecanii* against tea thrips in tea

plantation in South India. Roobakkumar *et al.* (2011) evaluated the biocontrol efficacy of the bacterium, *Pseudomonas fluorescens* was against the red spider mite, *Oligonychus coffeae* in laboratory conditions and found satisfactory results.

#### *Evaluation of Bacillus thuringiensis against the looper caterpillar in tea*

Results revealed that both the dose ( $F=46.46$ ,  $p<0.05$ ) of *Bacillus thuringiensis* and hours after application (HAT) ( $F=142.93$ ,  $p<0.05$ ) significantly reduced the looper caterpillar population. In laboratory conditions, the maximum mortality (88.84%) of the looper caterpillar was found using *B. thuringiensis* @ 2.0 g/L at 72 HAT (Fig. 14). A Similar trend was also found at 24HAT and 48HAT at other concentrations after spraying of entomopathogens. Therefore, *Bacillus thuringiensis* can be used for the control of the looper caterpillar infesting tea in field condition.

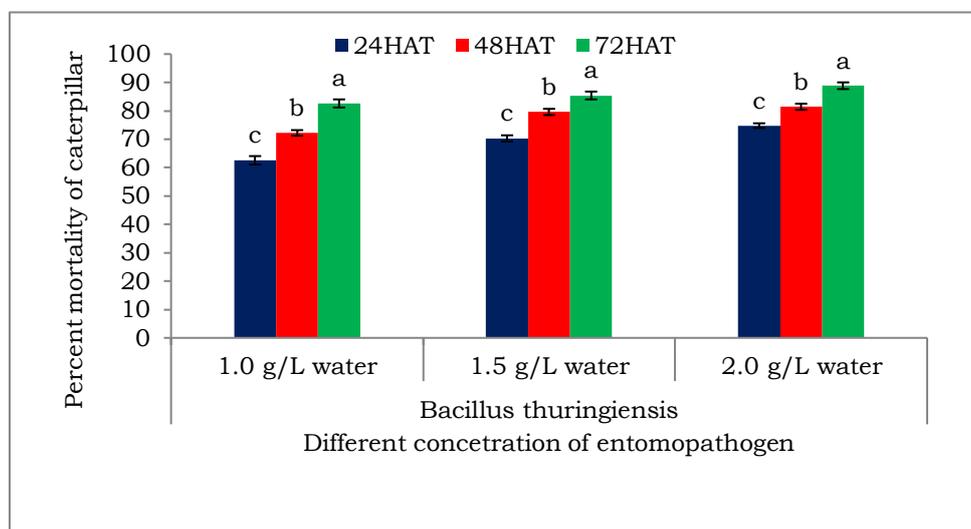


Fig. 14. Percent mortality of the looper caterpillar using *Bacillus thuringiensis* at laboratory conditions. Vertical lines at each bar indicate the SE value. The different small letters on the bar are significantly different by DMRT ( $p<0.05$ ).

*Bacillus thuringiensis* (Bt) is a naturally occurring bacterium that produces proteins toxic to certain caterpillars. Bt-based biopesticides can be used to target specific lepidopteran pests in tea gardens (Hazarika and Saikia, 2023). *Bacillus* sp. acted as a natural population (Lepidoptera: Zygaenidae) and lymantrid regulatory agents against the bunch, *Andraca caterpillars*, Wlk. (Lepidoptera: Bombycidae); looper, *Buzura suppressaria* Guen (Lepidoptera: Geometridae); red slug, *Eterusia magnifica* Butl. (Lepidoptera: Zygaenidae) and lymantrid caterpillars, *Euproctis* spp.

(Lepidoptera: Lymantriidae) from May to August in NE India (TRA, 1994; Hazarika *et al.*, 1994; Hazarika *et al.*, 2005). Therefore, *Bacillus thuringiensis* (Bt) can be integrated with the other components of the IPM programme.

#### Conclusion

Comprehensive and scientifically validated IPM techniques have been developed for the sustainable management of major tea pests in Bangladesh. Cultural control measures such as plucking, pruning, and weeding have been evaluated and standardized as effective

practices against tea mosquito bug, red spider mite, and thrips infestations in tea. In addition, extensive screening of tea clones has identified resistant and susceptible varieties against these key pests, thereby facilitating the development of pest-resistant planting materials. Mechanical control measures, including the use of solar-powered light traps and yellow and blue sticky traps, have been successfully evaluated for their efficacy in capturing looper caterpillars and thrips within tea ecosystems. Moreover, indigenous plant extracts exhibiting insecticidal properties have been tested, standardized, and recommended as eco-friendly alternatives to synthetic pesticides for the management of tea mosquito bug, red spider mite, and thrips. Biological control strategies have also been integrated into the IPM framework. The larval parasitoid *B. hebetor* has been evaluated for its effectiveness against the looper caterpillar, while commercial entomopathogenic formulations such as *M. anisopliae*, *P. fluorescens*, and *B. thuringiensis* have demonstrated significant efficacy against red spider mite and looper caterpillar infestations. These environmentally sound IPM strategies collectively contribute to sustainable pest management in tea cultivation. Their large-scale adoption by tea planters will reduce dependence on chemical pesticides, lower production costs, and promote the production of pesticide-free, high-quality tea for both domestic and international markets.

### Recommendation

The need-based, judicious, and safe application of pesticides is the most vital aspect of chemical control measures within the IPM framework. This approach emphasizes the development of IPM skills that promote environmental safety through systematic crop health monitoring, adherence to established Economic Threshold Levels (ETL), and conservation of natural biological control agents before resorting to the use of chemical pesticides as a last resort. Future IPM programs in tea should increasingly focus on habitat management, the utilization of underexplored natural enemies such as predators, parasitoids, and entomopathogenic organisms, and the adoption of novel biorational pesticides. Furthermore, the judicious management of conventional pesticides to delay resistance development and extend their efficacy remains a critical consideration. Additionally, the application of semiochemicals for pest monitoring and

disruption, coupled with the integration of information technologies, will further enhance the precision and sustainability of tea pest management.

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**Author contributions:** The authors confirm their contribution to the paper as follows: study conception, methodology, and design: Mohammad Shameem Al Mamun and Md. Jahangir Alam; Data collection: Mohammad Shameem Al Mamun and Md. Jahangir Alam; Data analysis and interpretation of results: Mohammad Shameem Al Mamun, Md. Jahangir Alam, and Shovon Kumar Paul; original draft manuscript preparation: Mohammad Shameem Al Mamun and Md. Jahangir Alam. All authors reviewed the results and approved the final version of the manuscript.

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