

## Eco-friendly approaches for sustainable management of tea mosquito bug (*Helopeltis theivora* Waterhouse)

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### Abstract

One of the biggest producers and consumers of tea worldwide is India. 619,774 hectares are being used for tea cultivation. An important factor in the country's economy is tea. The tea business directly employs more than a million people, mostly in rural regions. With around USD 776 million in export revenue in 2023-24, tea is one of India's top export commodities. Significantly, around 80% of the tea produced is drunk at home. Other industries including plywood, insecticides, fertilizers, and transportation are supported by the tea business.

A major pest impacting tea crops in India, the tea mosquito bug (*Helopeltis theivora* Waterhouse) can reduce yields by 10% to 50%, depending on the intensity of the infestation and the local climate. However, the persistent resistance of pests to pesticides and the residues left by these pesticides raises serious concerns about environmental risks and human health. Thus, the focus of current research on economically viable pest control methods for India's tea plantations is on environmentally benign methods for the sustainable management of the tea mosquito insect.

**Keywords:** India, tea worldwide, USD, pesticide, mosquito, million

### Introduction

The most consumed and economically important beverage plant, tea also known as *Camellia sinensis* (L.) O. Kuntze is a perennial monoculture crop. It is cultivated in over 50 nations worldwide, with its distribution ranging from Georgia, which is located at 43°N latitude, to Nelson, South Island, New Zealand, which is located at 42°S latitude. From sea level to 2300 meters, tea may be found. China, India, Sri Lanka, and Kenya are the top producers of tea. The remaining of the world's tea crop is produced in Bangladesh, Malawi, Tanzania, Japan, Indonesia, Argentina, Vietnam, and Turkey (Roy *et al.* 2015) [34].

In India, tea, also known as "chai," is more than simply a drink; it is an essential component of the nation's culture. This country has a centuries-old passion for tea and is currently the world's second-largest producer. It provides the ideal climate for growing tea because of its varied terrain and rich cultural legacy. Indian tea is among the greatest in the world because to a number of factors, including strong regional indicators, large investments in tea processing facilities, continuous innovation, an enlarged product mix, and deliberate market expansion. As of 2022, 6.19 lakh hectares of land in India were being farmed for tea

production. India is one of the world's top tea-consuming countries, with 80% of the tea output being consumed domestically. In 2023–2024, India produced 1,382.03 million kg of tea, accounting for almost 10% of global exports and placing it among the top 5 tea exporters. India exported 250.73 million kg of tea in 2023–2024, valued at \$776 million USD (IBEF 2024) [19].

However, the tea mosquito bug (henceforth TMB), also known as *Helopeltis theivora* Waterhouse, has become a serious threat to tea plants, affecting about 80% of tea plantations and causing a significant amount of crop loss which ranges between 10–50% (Bora *et al.* 2007) [10] (Roy *et al.* 2009) [31]. During the height of the pest attack, the crop may even completely wash out the whole crop area. As a perennial crop that can last up to 100 years, tea likely gave this pest a stable environment, making it the most dreaded pest. Necrosis and drying of infested plant parts are caused by the nymphs and adults of this pest sucking cell sap from tender stems, young leaves, buds, flowers, and fruits. This causes brown or black lesions to form, while prolonged feeding causes the leaves to curl, turn black, and eventually dry out (Roy *et al.* 2008) [30]. This ultimately impacts the plant's yield.



**Fig 1:** Tea mosquito bug (*Helopeltis theivora* Waterhouse)



**Fig 2:** Tea leaves affected by Tea mosquito bug (*Helopeltis theivora* Waterhouse)

**Options for Management**

Chemical insecticides are the mainstay of TMB management in India. Pesticide residues in tea are causing a serious concern globally and several countries are revising the Maximum Residue Limit (MRL) of chemical pesticides downward. Pesticide residues reduce the competitiveness of Indian tea in the global market. To meet the expanding demand for safer tea led to the search for more effective and alternative methods to control the pest based on sound ecological principles. A well-known Kasaragod incident occurred in Kerala, where endosulfan was widely used to treat TMB, resulting in long-term health issues for the local population. As a result, the chemical endosulfan was prohibited from use in India in 2011.

According to a study conducted by Tocklai Tea Research Institute (TTRI), the oldest tea research organization in the world, located in Assam, India, the tea mosquito bug has increased its levels of detoxifying enzymes, which is assisting the pest in developing a defence against the widely used pesticides in Indian tea plantations. According to the study, the tea mosquito bug has developed dangerously high levels of resistance to deltamethrin and thiamethoxam, two insecticides that are often employed in Indian plantations. As a result, lately reported a decrease in the effectiveness of pest management obtained with the administration of these suggested pesticides.

So, in addition to being suitable and successful in controlling the pest species, management programs must not have any negative consequences for the environment or non-target organisms. Utilizing botanicals and microbial biopesticides, rotating insecticides with approved molecules, with the prudent use of chemicals, monitoring and early detection, promoting the development of natural enemies, and implementing additional cultural control techniques are all components of an integrated approach to pest management.

If one of the strategies in the multifaceted approach doesn't work, the other one works to adjust the losses. Therefore, a combined approach to lessen dependency on chemical pesticides while enhancing crop productivity and ecosystem health, sustainable pest management rose to prominence as a pest control framework supporting long term intensification of agriculture.

**Table 1:** The control measures for tea mosquito bug

Ecofriendly approaches for sustainable management of tea mosquito bug ( <i>Helopeltis theivora</i> Waterhouse)	
1	Determination of Economic Threshold Level (ETL)
2	Regular monitoring and Early detection
3	Use of pheromone trap
4	Field sanitation
5	Use of biocontrol agents
6	Use of natural enemy
7	Shade regulation
8	Pruning
9	Plucking
10	Removal of alternate host
11	Host plant resistance
12	Application of ITK
13	Water management
14	Fertilizer management
15	Trap crop
16	Use of sticky traps
17	Planting strategy
18	Chemical control
19	Spot spraying
20	Insecticide Rotation

**Determination of Economic Threshold Level (ETL)**

One of the fundamental ideas of sustainable pest management is the **Economic Threshold Level (ETL)**. In order to keep the population from reaching the Economic Injury Level (EIL), when the cost of the harm the pest causes is more than the cost of managing it, management actions should be started at the density of the pest population.

By maintaining pest numbers below the EIL, management actions implemented at the ETL assist avoid financial losses. guarantees that the possible economic loss saved justifies the expense of control measures. encourages the application of cost-effective and ecologically friendly pest management techniques (Agriculture Corn, 2023)<sup>[2]</sup>.

**Calculation of ETL**

The ETL can be calculated using the formula:

$$ETL=C/V \times DI \times K$$

Where:

- C = Cost of pest control per unit area (e.g., per acre)
- V = Market value of the crop per unit yield (e.g., per bush)
- DI = Yield loss per pest per unit area (e.g., per insect per acre)
- K = Proportion of the pest population killed by the control measure (e.g., 0.8 for 80% mortality)

For the tea mosquito insect, the Economic Threshold Level (ETL) is often regarded as 5-8% damaged new flushes/panicles. In order to minimize financial loss, control measures should be implemented as soon as the harm from the tea mosquito insect reaches this stage (Vanitha *et al.* 2020)<sup>[47]</sup>.

### Regular monitoring and Early detection

A key element of sustainable management for managing infestations of the TMB is regular close monitoring and early detection. By enabling prompt intervention, early diagnosis keeps the pest population from growing to dangerous proportions. Timely identification and treatment of infestations can greatly lessen the amount of harm done to tea plants. Early intervention is more cost-effective since it frequently calls for fewer resources and less stringent control measures. The need for chemical pesticides can be decreased by using biological and cultural control techniques more successfully with early detection. By preserving a healthy ecosystem and encouraging the use of natural pest control techniques, rapid recognition (TopPRS 2024)<sup>[45]</sup> helps a great extent.

### Use of pheromone trap

Pheromone traps are indeed an effective tool for managing TMB in tea plantations. These traps use synthetic pheromones to attract male TMB bugs, disrupting their mating behaviour and reducing the overall population. It must be installed in 8-10 pheromone traps per acre, placing them about one foot above the crop canopy for optimal catch. It is beneficial to start using the traps from the 15-day crop stage to control pests at an early stage (Srikumar *et al.* 2015)<sup>[43]</sup>.

There is a behavioural and electroantennographic responses of male tea mosquitoes to female sex pheromones, specifically identifying (Z)-3 hexenyl acetate and (E)-2-hexenol as key compounds (Sachin *et al.* 2008)<sup>[35]</sup>.

Together, researchers from the Indian Institute of Chemical Technology (CSIR) in Hyderabad and the UPASI Tea Research Institute in Valparai, Coimbatore, have created a natural product to control the tea mosquito bug. This product can draw in and eliminate this harmful pest when placed in a trap. The product is extremely effective at trapping adult male TMBs, cost-effective, and completely safe for the environment.

### Field sanitation

In addition, this insect is repelled by the potassium salts in the soil (Roy *et al.*, 2015)<sup>[34]</sup>. Potassium aids in giving plants a physiological defence against TMB. According to studies, the effectiveness of insecticides like thiamethoxam and bifenthrin against TMB is greatly increased when potassium chloride (KCl) or potassium sulphate (K<sub>2</sub>SO<sub>4</sub>) is added. Because unbalanced nutrients can make plants more vulnerable to infestations, it is essential to maintain the proper ratio of potash in the soil (Rahman *et al.*, 2014)<sup>[ ]</sup> (Shah *et al.*, 2015)<sup>[40]</sup>.

### Use of biocontrol agents

The TMB can be effectively controlled with botanical agents. Neem (*Azadirachta indica*) extracts and oil have insecticidal qualities and can be used as oviposition deterrents, repellents, and antifeedants (Dutta *et al.* 2013)<sup>[14]</sup>. They interfere with TMB's development and growth. Research has demonstrated that pongamia (*Pongamia pinnata*) seed oil is highly effective in lowering adult mortality and TMB feeding punctures.: Calophyllum (*Calophyllum inophyllum*) seed oil has shown great efficacy in raising TMB adult mortality and decreasing feeding punctures (Kumar *et al.* 2022)<sup>[21]</sup>. The oil from madhuca (*Madhuca longifolia*) seeds has good potential for TMB control as well. *Vitex negundo* leaves lower TMB mortality and feeding punctures (Roy *et al.* 2010)<sup>[32]</sup>. (Ahmed and Mamun, 2014)<sup>[4]</sup> found *Xanthium strumarium*, *Swietenia mahogany*, *Datura spp*, *Nicotina or tobacco*, *Lantana camara*, *Duranta erecta*, very effective in TMB control. Essential Oil of natural repellents such as citronella, eucalyptus, and lavender can also be used to ward off TMB. Traditionally, a variety of botanicals have been used to control pests, including rotenone, pyrethrum, essential oils, sabadilla, ryania and nicotine (Ghosh *et al.*, 2023)<sup>[16]</sup>. (Hazarika *et al.* 2009)<sup>[18]</sup> stated that for organic tea production, botanicals may play an important role and may be considered as alternative products for crop protection, particularly to manage resistance development. To effectively manage TMB, these botanical agents can be incorporated into an sustainable management strategy and are environmentally friendly.

### Use of natural enemy

The TMB can be effectively and sustainably controlled by using natural enemies. These natural enemies can aid in the control of TMB populations:

#### 1. Parasitoids:

- *Telenomus cuspidis*: By laying its eggs inside TMB eggs, this parasitoid stops the eggs from hatching (Shylesha *et al.*, 2003)<sup>[41]</sup>.
- *Chaetostricha sp.* (Trichogrammatidae): It is also an egg parasitoid (Bhat and Srikumar, 2013; Saroj *et al.* 2016)<sup>[7,37]</sup>.
- *Erythmelus helopeltidis*: Also preys on TMB eggs (Bhattacharyya *et al.* 2024)<sup>[8]</sup>.
- *Leiophron spp*: Nymphal-adult parasitoids that target TMB while it is still nymphal (Vanitha *et al.* 2021)<sup>[20]</sup>.

#### 2. Predators:

- *Chrysoperla zastrowii sillemi*: TMB is the prey of this species of green lacewing (Rabeesh *et al.*, 2024)<sup>[26]</sup>.
- *Mallada sp.*: Another predator that aids in TMB population control
- *Oxyopes sp.*: Spiders that consume TMB (Beevi *et al.*, 2008)<sup>[6]</sup> (Maya *et al.*, 2019)<sup>[23]</sup> (Das *et al.*, 2010).
- Reduviid bugs: TMB-hunting predatory insects (Bhat *et al.*, 2013)<sup>[7]</sup> (Gurusubramanian *et al.* 2024)<sup>[17]</sup>.
- Praying mantises: TMB is effectively preyed upon by these insects (Vanitha *et al.* 2016).
- lady (Coccinellidae) beetles: These are effective predators of TMB nymphs (Sarwar 2016)<sup>[38]</sup>.
- Syrphids: same impact (Sundararaju *et al.* 2000)<sup>[44]</sup>.

### 3. Pathogens:

- Entomopathogenic nematodes: TMB is infected and killed by nematodes such as *Hexameris* sp.
- *Agamermis paracaudata*: It can infect and kill the pest (Durgadas and Sambhunath, 1956)<sup>[13]</sup>.
- *Beauveria bassiana*: TMB is infected and killed by this fungus (Deka *et al.*, 2021)<sup>[12]</sup>.
- *Aspergillus tamarii*: It also kills TMB (ICAR) (Vanitha *et al.* 2021)<sup>[20]</sup> (Visalakshy and Mani, 2011)<sup>[46]</sup>.
- *Metarhizium anisopliae*: It can infect and kill TMB (Bhattacharyya *et.al.* 2024)<sup>[8]</sup>.

The green tree ant, *Oecophylla smaragdina* had high potential as a biocontrol agent against TMB (Mahapatro *et al.* 2016)<sup>[22]</sup>.

These natural enemies help maintain TMB populations at manageable levels, reducing the reliance on chemical insecticides and promoting sustainable pest management practices and also a component in the IPM strategy.

#### Shade regulation

Shade management is an important cultural practice in tea plantations that can help control TMB and other pests. Shade trees help regulate temperature by reducing the intensity of direct sunlight, which can create a less favourable environment for TMB. Maintaining an optimal level of shade helps in preserving humidity, which is crucial for tea plant health and can deter TMB. Shade trees protect tea plants from harmful UV radiation, which can stress plants and make them more susceptible to pest attacks. Fallen leaves from shade trees add organic matter to the soil, improving soil fertility and plant health. Shade trees act as windbreaks, reducing wind damage and creating a more stable environment for tea plants (Mohotti *et al.*, 2020)<sup>[24]</sup>.

Tea ecology views shade tree cultivation as a necessary evil (Ahmed and Mamun, 2014)<sup>[4]</sup>, but controlling shadow is crucial for preventing pests like tea mosquito bug (Ahmed *et al.*, 1993)<sup>[3]</sup>. Over-shaded areas should be thinned up to 8-10 meters especially during monsoon season, for sunlight and better aeration, as the TMB cannot tolerate sunlight. Studies show that 60% shaded tea plantations experience few pest attacks and higher crop yields (Roy *et al.*, 2015)<sup>[34]</sup> (e-Krishi Shiksha)<sup>[15]</sup>.

By implementing proper shade management, tea growers can create a more favourable growing environment for tea plants, reducing the incidence of TMB and other pests.

#### Pruning

By incorporating regular pruning into the pest management strategy, it can significantly reduce TMB infestations and maintain healthier tea plants.

In tea plantations, pruning is a cultural practice that effectively controls the TMB. In order to prevent TMB from hiding and laying eggs, old, infected leaves and shoots are removed through pruning. As a result, the plantation has fewer pests. Pruning keeps the canopy well-ventilated, which makes it difficult for TMB to thrive. Proper ventilation lowers humidity, which hinders the growth of pests. Pruning increases the amount of sunlight that reaches the lower portions of the tea bushes by opening up the canopy, which can help lower pest populations.

Pruning should be done from the outskirts to the centre of the TMB-infested areas. A few bushes in the centre should

remain untrimmed for a day or two in order to act as a trap for adults (Das 1965)<sup>[11]</sup>. Once the appropriate insecticides have been sprayed, these bushes should be pruned or skipped. This method contributes to effective TMB control. Removing pruning litters and maintaining field cleanliness minimizes pest shelters (Agrifarming, 2023).

#### Plucking

TMB control can be greatly aided by plucking, a crucial technique in tea cultivation. TMB prefers certain plant parts for feeding and breeding, which can be directly removed by routinely picking off the tender shoots and young leaves (Roy *et al.*, 2015)<sup>[34]</sup>. As a result, there are fewer pests on the tea plants (Roy and Mukhopadhyay, 2011)<sup>[33]</sup>. By removing the eggs, nymphs, and adults that live on the young shoots, regular plucking stops the TMB life cycle. This aids in keeping their numbers under control.

Consistent plucking keeps the tea plants robust and encourages the growth of new shoots (Satake *et al.*, 2006)<sup>[39]</sup>. By preserving adequate air circulation within the tea bushes, plucking lowers the humidity that pests prefer (Agrifarming, 2023).

One can keep a careful eye on the spot any early indications of a pest infestation by regularly plucking them. This makes it possible to use targeted pest management techniques in a timely manner. When combined with chemical spraying, black plucking and level off skiff significantly reduced the TMB infestation level and increased crop yield in comparison to using chemicals alone (Rahman *et al.* 2006).

#### Removal of alternate host

Removing host plants or hiding places is an effective strategy to control TMB populations. TMB can infest various host plants like neem, guava, and certain weeds. Removing these alternate hosts reduces the places where TMB can feed and reproduce. By eliminating host plants, you reduce the reservoirs of TMB, making it harder for the pest to spread to tea plants. Removing host plants disrupts the life cycle of TMB, as they lose their breeding and feeding grounds

(Sankarganesh *et.al.* 2023)<sup>[36]</sup> found that population growth is inhibited by keeping the plantation crops free of alternate hosts, such as jackfruit (*Artocarpus heterophyllus*), melastoma (*Melastoma sp.*), dayflower (*Commelina spp.*), sesbania (*Sesbania cannabina*), fragrant thoroughwort (*Eupatorium odoratum*), mulberry (*Morus alba*), wood-sorrel (*Oxalis acetosello*), kadam (*Anthocephalus cadamba*), oak (*Quercus spp.*), jamun (*Eugenia jambolana*), boal (*Ehretia acuminata*), Mikania (*Mikania micrantha*), golden shower (*Acacia moniliformis*), and arani (*Premna latifolia*). Weeds like *Mikania cordata*, *Bidens bitrnata*, *Emillia sp.*, *Polygonum chinese*, *Oxalis acetocella*, *Lantana camara*, and *Ixora coccinea* also causes the same (Ahmed and Mamun, 2014)<sup>[4]</sup>.

In October 2021, an infestation of TMB was found on *Anthurim sp.* (Family: Araceae), an ornamental plant that is one of the important economic flowers with export potential, in the Puttur region of Karnataka (Vanitha and Raviprasad, 2021)<sup>[48]</sup>.

#### Host plant resistance

One of the key elements of host plant resistance to insect pests is induced resistance. One important tactic for controlling TMB infestations is host plant resistance.

According to research, some tea cultivars naturally resist TMB, which can greatly lower pest damage and increase crop yield.

(Sugandhi *et al.* 2021) revealed that tea cultivars developed resistance against mosquito bug infestation, affecting enzymes poly phenol oxidase (PPO), peroxidase (POX) and ascorbate peroxidase (APX), which could serve as markers for tea plant resistance. The quantity of enzyme activities has been enhanced in TMB tolerant tea plants. A decrease in superoxide dismutase (SOD), phenyl alanine ammonia lyase (PAL), catalase (CAT) enzyme activities is clear in TMB infested tolerant tea plants

Research on clonal selection and breeding focuses on TMB susceptibility, with dark-leaved varieties more susceptible. China hybrids suffer the most (Ahmed *et.al.* 2020)<sup>[5]</sup>.

(Naskar *et.al.* 2021)<sup>[25]</sup> reviewed pest responsive tolerance mechanisms in tea, focusing on secondary metabolites and inducers produced by *C. sinensis*. Hormones like jasmonic acid, salicylic acid, abscisic acid, and ethylene modulate defence systems, aiming for sustainable pesticide development.

### Application of ITK

Several traditional techniques for managing the TMB are provided by Indigenous Technical Knowledge (ITK). In addition to being efficient, these techniques are sustainable and kind to the environment. Tea mosquito bug can be effectively managed in a tea field by applying 1% concentration of fish waste mixed with cow dung, cow urine, and water, and 7.5% concentration of Polygonum hydropiper mixed with cow urine and water. Combinations of *P. hydropiper* and fish extract were found to improve tea yield and plucking point density. TMB is treated with neem-based products such as Azadirachtin (5%) (Bhuyan *et al.*, 2017)<sup>[9]</sup>.

### Water management

In order to control the TMB infestation, water management can be very important. inadequate drainage is not only harmful to the tea crop but also creates conditions conducive to the buildup of TMB (Ahmed and Mamun, 2014)<sup>[4]</sup> (Hazarika *et al.* 2009)<sup>[18]</sup>. Therefore, proper irrigation should be applied to make sure that tea plants get enough water, particularly when it's dry. Plants that receive regular watering are more resistant to pest infestations. However, care should be taken to refrain from overwatering. Too much water can encourage pest growth. To avoid waterlogging, irrigation schedule needs to be balanced. To keep soil moist and inhibit the growth of weeds, which can act as TMB's alternate hosts, place organic mulch around the base of tea plants. Installing appropriate drainage systems lowers the chance of pest infestations by preventing water buildup around the tea plants. In certain situations, TMB populations can be managed by fogging with water diluted with insecticidal solutions.

One can successfully lower the prevalence of the tea mosquito bug on tea plantation by combining these water management techniques with other pest control strategies.

### Fertilizer management

An important factor in managing the TMB is fertilizer management. Balanced fertilization in the form of recommended amounts of potassium, phosphorus, and nitrogen has to be given to tea plants. Pest attacks are less

likely to affect healthy plants. Compost and manure are examples of organic fertilizers that can be used to enhance plant vigour and soil health. Stronger plants that can resist pest infestations are supported by healthy soil. To remedy any deficiencies that might weaken the plants and increase their susceptibility to pests, there is a need to apply micronutrients like magnesium, boron, and zinc. To support overall plant health and resilience, it is important to add foliar feeding to soil fertilization to deliver nutrients straight to the leaves. Overuse of fertilizers, particularly nitrogen, can result in weak, lush growth that attracts pests.

Tea growers can improve plant health and lessen the effects of TMB infestations by putting these fertilizer management techniques into practice.

### Trap crop

An efficient method for controlling TMB infestations is the use of trap crops. Annatto (*Bixa orellana*) is one trap crop that is frequently suggested. By planting Annatto around the tea plantation's contours, TMB can be drawn away from the tea plants, minimizing damage to the primary crop. Tea clones that are susceptible to TMB, like Tocklai vegetative clone TV1, could be used as the trap crop (Hazarika *et al.* 2009)<sup>[18]</sup>. In order to accumulate the pest adults, a few tea bushes in the centre may be purposefully left unpruned for a day or two during the pruning process. The pests are then killed by spraying them with hard insecticides. This aligns nicely with the idea that trap crops can be applied alongside pesticides (Zehnder *et.al.*2007)<sup>[49]</sup>.

The attraction of cassava (*Manihot esculenta*) and Sesbania (*Sesbania grandiflora*) is that it can draw TMB away from tea plants. Within the tea plantation, these two can be used as an intercrop with tea or as a border plant.

### Use of sticky traps

By capturing adult insects, sticky traps help lower the number of pests and lessen the harm done to tea plants. Blue sticky traps are especially good at drawing TMB, so it is advised to use them. The sticky traps should be placed all over the tea plantation, but particularly close to the tea bushes. Ten to twelve traps per hectare are advised. To make sure the traps are within the pests' reach, place them slightly above the bush canopy. To keep an eye on pest populations, check the traps frequently and replace them as necessary (Srikumar *et.al.* 2015)<sup>[43]</sup>.

### Planting strategy

In order to effectively control the TMB, planting can be done in a number of ways. To discourage TMB, tea plantations can be surrounded by and contain repellent plants like citronella or neem. Natural substances released by these plants deter pests. Compared to tea plants, trap crops are plants that TMB finds more appealing. These can be planted around tea fields to divert TMB from the tea plants and concentrate it in a particular location where it is easier to control. Growing some companion plants next to tea can improve the ecosystem and help the tea plants stay healthy. Legumes, for instance, can strengthen the soil and increase the resistance of tea plants to pests like TMB. Natural TMB predators can be supported by planting a range of plants in and around tea plantations. The TMB population is managed in part by these predators. Additionally, biodiversity increases the ecosystem's overall resilience. TMB may not thrive in a microclimate that is

created by planting shade trees. Shade trees can lessen TMB infestations by assisting in the regulation of temperature and humidity. By using these planting techniques, the incidence and effects of TMB can be decreased and a more sustainable and balanced tea plantation environment can be produced.

### Chemical control

This should be last resort and to be used in case of extreme emergency.

The latest Plant Protection Code (PPC) guidelines for chemical control against TMB in tea plantations recommend the use of specific Plant Protection Formulations (PPFs) that are approved and have Maximum Residue Limits (MRLs) set by the Food Safety and Standards Authority of India (FSSAI). The insecticides approved as per the statutory guidelines are imidacloprid 17.7 SL, thiamethoxam 25 WG, chlorpyrifos 20 EC and lambda-cyhalothrin 5 EC.

In order to lessen dependency on chemical interventions and guarantee sustainable tea production, these guidelines promote alternative control strategies like biological control and stress the prudent use of chemicals. Depending on the level of pests, application of chemicals should be done during the flushing stage and repeat as needed (Gurusubramanian *et.al.* 2024)<sup>[17]</sup>. To avoid pest resistance and reduce the impact on the environment, alternate the use of various chemicals is recommended by ICAR. The persons involved in chemical spraying operation should wear protective gear, observe suggested waiting times prior to harvesting, and abide by all safety regulations when handling and applying chemicals.

### Spot spraying

This method uses pesticides to target affected regions rather than the entire crop in order to manage the TMB. By concentrating on the precise regions where TMB is found, spot spraying minimizes the environmental effect and uses less pesticide.

To detect contaminated plants early and apply them precisely and on time, routine monitoring is necessary. Spot spraying might be less expensive than blanket spraying because it just treats the afflicted regions. The chance of pests becoming resistant can be decreased by using pesticides strategically.

Insecticide rotation is a crucial strategy to manage (TMB) and prevent the development of resistance.

### Insecticide Rotation

In order to effectively target pests and reduce the risk of resistance, insecticide rotation entails applying various insecticide classes in a predetermined order. One advantage of rotating insecticides is that it helps prevent pests from becoming resistant by alternating insecticides with various modes of action. Depending on the stage of the pest's life cycle, different insecticides may work better. The total quantity of chemicals used can be decreased by using a range of insecticides. One needs to select insecticides from various chemical classes, such as organophosphates, pyrethroids, and neonicotinoids. Then to create a schedule for switching up the insecticides so that no class is used in a row. Keep a close eye on TMB populations to assess the rotation's efficacy and make necessary modifications. Combine insecticide rotation with cultural practices and biological control, among other pest management techniques. Tea growers can effectively manage TMB while lowering the risk of resistance and environmental impact by adhering to a rotation schedule.

### Conclusion

The current study emphasizes the potential application of various ecofriendly approaches of sustainable management tea mosquito bug. This study suggests that non-chemical approaches, which are already in use by tea growers, could be significantly improved if they are rigorously examined, scientifically validated, and standardized. A number of negative effects have resulted from the ongoing use of artificial chemicals and inefficient pest management techniques, such as secondary pest outbreaks, the potential for pesticide resistance, pest resurgence, environmental contamination, harm to non-target organisms, and undesired residue in processed tea.

It is always crucial to concentrate on trustworthy pest management techniques by implementing sound sustainable strategies to reduce the risk. Biotechnological approaches, sex pheromones, tolerant varieties, and the conservation of natural enemies, along with the integration of multiple pest suppression techniques and improved research in non-chemical methods, have greater scope in managing TMB populations and have a high probability of maintaining long-term crop protection. This strategy can also aid in lowering input costs.

Considering the current state of the world, using environmentally friendly and organic pest control methods with minimum agrochemical use is a good way to lessen the negative effects of chemical pesticides.

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