ISSN 0971-6831
Online ISSN 0974-4541

Pest Management in Horticultural Ecosystems

Volume 30 Number 2 December 2024

Association for Advancement of Pest Management in Horticultural Ecosystems (AAPMHE)
ICAR-Indian Institute of Horticultural Research
Hesaraghatta Lake P.O., Bengaluru - 560089, India
(NAAS 2024 Rating : 5.14)
Journal Website : https://pmhe.in

Pest Management in Horticultural Ecosystems

(An international bi-annual scientific journal, published by the Association for Advancement of Pest Management in Horticultural Ecosystems (AAPMHE), Bengaluru, India)

All papers and editorial matters are to be addressed to the Chief Editor, Division of Crop Protection, ICAR - Indian Institute of Horticultural Research, Bengaluru-560 089, India. E-mail: **editorphme@gmail.com**

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Acknowledgement: **AAPMHE acknowledges the financial support from the Indian Council of Agricultural Research, New Delhi.**

COVER PHOTOS : Whitefly fauna on guava in Kerala
(Credit : : Dr. A.M. Nimisha, Kerala Agricultural University, Thrissur, Kerala)

Journal Website :https://pmhe.in

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Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 227-234 (2024)
DOI Number : 10.5958/0974-4541.2024.00034.9

REVIEW ARTICLE

Pheromones in Aphids: A Review

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ABSTRACT: Aphids release an alarm pheromone on being attacked by predators to signal other members of the colony to evacuate and to make sure they do not become preys to natural enemies. This pheromone induces the individuals to produce winged offsprings which can fly away from the plant to avoid predators. The most common constituent in the alarm pheromone was found to be (E) – β – Farnesene. It is also found that these pheromones released by the Aphids can be a trail for attracting natural enemies towards colonies and hence causing self harm. As this pheromone can cause harm to the aphids themselves, it is of a great advantage to plants which produce (E) – β – Farnesene as one of the volatiles suspected to be a naturally resistant against Aphid infestations. Plants releasing this volatile are found to be protecting their sap against these aphid infestations as these pests are able to perceive these volatiles and avoid sucking the sap and disperse to avoid being attacked by enemies.

Keywords: Aphids, pheromones, (E) – β – farnesene, nepetalactol, nepetalactone

INTRODUCTION

Chemical signals and pheromones in particular play a very important role in agricultural pest management and help in improving the potential of various insecticides and drastically reduce the harmful effects on the environment (L. J. Wadhams. 1990). Aphids are polyphagous sucking pests which are capable of attacking various plants and causing severe damage. They suck the sap of the plants and produce toxic saliva over the plants leading to decrease in the plant's ability to conduct photosynthesis and also transmit plant viruses causing various diseases (Sarah H. Dewhirst *et al.,* 2010). They also produce excreta in the form of Honeydew which leads to growth of moulds in the host plants (Jia Fan *et al.,* 2015). Aphids are considered to be model organisms to study olfaction and chemical ecology. During higher temperatures they live in small groups and reproduce by parthenogenesis Mondor *et al.,* 2000). When aphids are attacked by natural enemies they produce an alarm pheromone after which they display behavior of producing winged forms that leave the plant or they just walk away to another plant with better nutrition due to predator pressure. This sticky secretion is produced by a pair of cornicles present on the dorsal surface of their body. This prevents their predators and parasitoids from feeding on them. This is also in indication for other members of the colony to move away from the host and get away from danger (Michael H. *et al.,* 2006). Some of the plants are also found to be producing volatiles having the same composition as that of the Aphid alarm pheromone which may be known to prevent these pests from settling on the plant and leads to a reduced nutrition intake by them which prevents their reproduction (Kunert *et al.,* 2010). This pheromone not only acts as a signal between aphid individuals but also acts as an interacting medium between aphids and plants and aphids and their natural enemies (Vandermoten *et al.,* 2012). On examination of various aphids species, studies suggest that 21 out of 23 species contain (E) – β – Farnesene in their pheromones (Huili Qiao *et al.,* 2009). The release of these alarm pheromone component may not only be beneficial to the aphids but also can be damaging because they will have to leave the host plant loosing out on food supply, increased risk of high mortality in individuals due to relocation and inviting predators to be attacked. To avoid these damages as much as possible the aphids may release the alarm pheromones only when physically attacked by the natural enemies and not when they detect predators indicating that they have a chance to preserve life and food (Christoph Joachim *et al.,* 2013).

PLANT VOLATILES AGAINST APHID INFESTATIONS

Volatiles mediate interactions occurring between the plants, aphids and the external environment. Plants have to capacity to show defense against various pathogens and pests by the ability to change their gene expression

and metabolism rate (Martin de Vos *et al.,* 2010). Volatiles released by plants help in protection from pest infestations like that of aphids. As the constituents in the plant volatiles are found to be the same as the alarm pheromones produced by aphids, the plant is sought to be gaining a benefit from this due to a decrease in the aphid feeding and reproduction rates. This urges the aphids to produce more number of winged off springs which show behavior of leaving the host plant. This type of behaviour has been observed in Pea and Cotton species of aphids (Grit Kunert *et al.,* 2010). Studies by (Grit Kunert *et al.,* 2010) reveal that the continuous production of these volatiles from plants might not have a direct effect on these pests. It was found that some natural enemies of aphids may be attracted to these volatiles which may have a positive effect of controlling the infestations on aphid host plants.

It is also well documented that plant volatiles like 2-Phenylethanol produced a response in the olfaction of aphid predators and parasitoids like lacewings which attract them towards the aphid host plants as a beneficiary act to get rid of infestations. Studying the olfactory responses between in the prey's host plant and the predators helps in development of efficient biological control in the field of agriculture to prevent invasive and harmful pests (Zhu *et al.,* 2005). Pyrethrum flowers are found to be attracting aphid predators like ladybugs by producing (E) – β – Farnesene indicating this pheromone helps predators find aphid preys and acts as a natural biological control. They exhibit defense mechanism from aphids by the production of these pheromones protecting the flowers which is the most important part of any plant (Jinjin Li *et al.,* 2019). Some species of wild potato are found to be metabolizing (E) – β – Farnesene as a volatile component due to which it acts as a natural resistance against aphid infestations (Huili Qiao *et al.,* 2009). Aphid parasitoid behavior of how they are attracted to their prey by chemical cues can be studied by using volatiles released by plants like mimicking pheromones produced by aphids like (E) – β – Farnesene (Alarm pheromone) and Nepetalactone (Sex Pheromones). Using these pheromones to attract these parasitoids can be used as a Bio-Control in Agriculture to stop aphid infestations on important economic plants (Ameixa *et al.,* 2011). In nature, plants follow a 'push and pull theory' where the volatiles push the aphid pests away and pull the natural enemies towards themselves for the environmental benefit. This helps in the study of aphid to plant, aphid to aphid, aphid to natural enemies and natural enemies to plant interactions (Jia Fan *et al.,* 2015).

PRODUCTION OF WINGED FORMS OF APHIDS

Studies demonstrated by (Grit Kunert *et al.,* 2005) show that when these aphids are exposed to artificial alarm pheromones just like the ones they produce naturally, this resulted in production of winged aphids in groups which was referred to as 'crowding'. Wild potato has found to be producing (E) – β – Farnesene which acts as a natural repellent against aphids. (Michael H. *et al.,* 2006) suggests that this phenomenon can be used to as a technique of crop protection from aphids by genetically modifying the crop to produce (E) – β – Farnesene. On exposure to (E) – β – Farnesene under laboratory conditions aphids were found to be producing good number of winged off-springs, but studies by (Hatano *et al.,* 2010) suggest that there was also a high proportion of winged individuals produced under field conditions. Sometimes production of winged morphs are also induced by the females if they are under some sort of stress like overcrowding of individuals on the host or non-availability of food on the host plant. In the case of Pea aphids, it was found that there is an increased production of winged individuals in large colonies due to more of physical contact among them which triggers the competition for food and space. Winged morphs are produced less in number in smaller colonies due to lower physical contact among individuals (Hatano *et al.,* 2010). Aphids in which the antennae were removed did not perceive (E) – β – Farnesene component of the alarm pheromone and did not produce wings to leave the host plant indicates that the pheromone signals could be perceived only by the olfactory system (Jia Fan *et al.,* 2015). Winged forms of Aphids also termed as 'alate' forms are not considered to be strong fliers but they can manage to fly to a good distance by drifting along with the wind. As aphids are pests that transmit plant viruses, some of them which are dependant on insect vectors for transmission can rely on these 'alate' forms of aphids which not only transmit diseases to other parts for the plant but also to different plants (Martin de Vos *et al.,* 2010).

A MUTUALISTIC RELATIONSHIP BETWEEN APHIDS AND ANTS

Aphids and ants are found to be engaging in a relationship of mutualism as ants get a continuous supply of honey dew, an excretion produced by aphids which is rich in carbohydrates and water and functions to be their good source of nutrition whereas in return aphids acquire protection and sanitation from the ants as they clean up all the trails of honey dew. Aphids show behavior of dispersal from the host plants by forming

winged individuals when attacked by predators, but this may lead to loss of food supply to the ant colony. Hence the ants come up with various strategies to decrease their dispersal. These various strategies may include applying hormones on the aphids nymphs to prevent wing formation and to prevent them from flying away. The fire ants apply trial pheromones along the route that they take which leads them to the food source and this trail is maintained until the trail leading to the food source is not available anymore (Tian Xu *et al.,* 2021). (Verheggen *et al.,* 2012) suggested that ants have shown orientation and attraction towards the pheromones released by aphids which has been proved with olfactometer and choice assays while other volatiles did not show any response. Ants in association with aphids show behavioral responses on the abdomen of the aphids to generate increased release of honeydew and on exposure to the components present in the alarm pheromone of the aphids they prepare themselves to attack aphid predators as they provide protection to them. Ants are found to be locating their aphid partners for food by using low levels of the alarm pheromones produced by aphids when they are not attacked by predators. When aphids are attacked they tend to produce high amounts of alarm pheromone which urge the ants to show aggressive behavior intending to kill the aphids predators. On application of (E) – β – Farnesene, ants in mutualistic relationship with aphids are seen to be becoming very aggressive and attacking the aphid predators to protect them (Eduardo Hatano *et al.,* 2010). When aphids are attacked by predators they constantly release the alarm pheromone containing (E) – β – Farnesene which is perceived by the neighboring aphids in the colony and they disperse from the colony immediately as a result of threat but when the colony is attended by ants, the aphids do not disperse as they exhibit a mutual relationship and depend on the ants for protection (Acar *et al.,* 2001).

SEX PHEROMONES AND OTHER PHEROMONES

Mature individuals on the colonies release sex pheromones which attract mates of conspecific species for sexual reproduction. Other pheromones they release are found to be called Aggregation pheromone. This is released when a single individual has landed on a new host plants and signals others indicating them about food availability (Dewhirst *et al.,* 2010). Aphid females produce sex pheromones to attract sexually mature males but predators and parasitoids like lacewings adults are also found to be getting attracted by these sex pheromones called Nepetalactol. Many aphid species belonging to the Family Aphidae produce sex pheromones that consist of a mixture of Nepetalactol and Nepetalactone belonging to the category of Iridoids (Cyclopentanoids) (Dewhirst *et al.,* 2008). Sexual female aphids produce Nepetalactol in their sex hormones which also function as Aggregation hormones which aid in accumulation of large population to ease the process of mating. This not only helps in females finding male mates but also allows them to look for various locations to produce their sexual female progeny (Park *et al.,* 2000). It is also observed that during summer and autumn season *oculata* species of lacewings are found to be attacking Soyabean aphids and are specifically located in the regions of their prey presence indicating that aphid pheromones are having a major role to play in attracting predators (Zhu *et al.,* 2005). Pheromones produced by herbivorous insects are detected by their various natural enemies and assist in prey localization and can be termed under the category of Kairomones (Christoph Joachim *et al.,* 2015). *P. humuli* species of male aphids are found to be responding to sex pheromones from a distance of three meters indicating they can locate their mates from a long distance. Electro-antennogram studies reveal that the primary Rhinaria in aphids (hairless region at the tip of the snout) detect a number of volatiles and sex pheromones at different positions of the antennae. In contrast to these studies the secondary Rhinaria are found to be detecting only sex pheromones in sexually mature females (Gynoparae) and males (Tom *et al.,* 2004).

Alarm pheromones produced by aphids having (E) – β – Farnesene can have both positive and negative effects. The production in of this in an overcrowded colony can help in dispersal of individuals but the constant release of this can invite trouble to aphids by attracting predators and natural enemies. Studies show that female hoverflies being one of the major predators for aphids lay eggs not depending upon the number of prey in the colonies but completely depend on the amount of evoking pheromone substances produced by the aphids and also the concentration of volatiles produced by the host plants (Almohamad *et al.,* 2008). (Verheggen *et al.,* 2008) demonstrates that the alarm pheromone produced by aphids can not only be trigger predator attacks but can also be released and accumulated in response to some odor signals released by other colony members in aphid juveniles during their developmental stages. When a colony experiences a potential threat by certain predator aphids they may have to adapt to such contagious responses as a small amount of pheromone released by very few aphids may not be enough to warn the entire colony. However when the *Acyrthosiphon pisum* species of aphids were exposed to alarm pheromone signals

they showed a typical behavior of moving away and the results showed that they did not produce the excess of pheromone to warn the other colonies indicating that the contagious responses of (E) – β – Farnesene does not occur (Verheggen *et al.,* 2008). Lures containing aphid sex pheromone components like Nepetalactol and Nepetalactone were used for field evaluation to check for aphid abundance. Results indicated that though there was a variance in the aphid population there was a significant decrease their abundance due to attraction of parasitoids and natural predators causing a drop in their numbers. Thus utilizing the semio-chemicals derived from the host or prey can function as a good natural bio-control in avoiding pests on crops in field conditions (Yoshitaka Nakashima *et al.,* 2016).

Studies conducted by (Boo *et al.,* 2003) in the fields of Korea revealed that the lacewing species *Chrysopa cognata* being a major aphid natural predator was highly attracted to the aphid sex pheromone component Nepetalactol than the other component Nepetalactone. When both the component chemicals were mixed to check for responses, the number of *Chrysopa cognata* increased in the trap along with the increase in the concentration of Nepetalactol but the number of was never found to be higher than the count achieved when Nepetalactol was used alone (Boo *et al.,* 2003). Vials containing Aphid sex pheromone component was used as a technique to check for attracting aphid parasitoids in field conditions. These vials containing the pheromone components were placed at different distances from the aphid infested plants to analyze at what particular distance the parasitoids would get attracted to aphids. Traps placed next the infested plants or at a short distance from it showed a significant increase in the attacks on aphid colonies whereas the traps placed at a far distance showed no effect on the parasitoid attraction indicating that they could not perceive the pheromones at very long distances. Observations indicated that the placement of these vials having the pheromone components increased the attacks on aphids by natural enemies. These experiments give a proof that the natural enemies of aphids are not just attracted by the pheromone trap but are found to be actively attacking the aphids around the spaces of the trap to mummify them (Glinwood *et al.,* 1998). Other than the major component (E) – β – Farnesene which is a sesquiterpene in the aphid alarm pheromone there are also many other components like Monoterpenes and analogs which have not been investigated as much as (E) – β – Farnesene. It was discovered that the combination of all these multiple components were attracting a large number of predators when compared to only a single component of (E) – β – Farnesene. The attractiveness of these predators also increased with increase in the concentrations of the multiple components (Yaoguo Qin *et. al.,* 2022).

In recent times, efforts have been made to conserve natural bio-control processes which involves enhancing the natural populations of aphid natural enemies to control infestations on economically important agricultural and horticultural crops. For locating their hosts, aphid natural enemies use the chemical information produced by their host. Infested plants with aphids were found to be inducing the neighboring un-infested plants to produce the same volatiles containing pheromones which could attract natural enemies. This was a behaviour shown by the infested plant to increase the signal potential to attract more predators. This behavior was physiologically induced by the infested plants when the rhizosphere of both the plants came in contact with each other when grown together in a same pot and the roots came in contact with each other (Wilf Powell *et al.,* 2003). Studies indicate that the attraction experienced by predators to the pheromones released by the hosts are not always uniform.

The concentrations released completely depend on the type, intensity and the species that are involved in the attack. In the case of aphids, natural predators like ladybugs were found to be attracted to smaller concentrations of (E) – β – Farnesene and attacked the hosts very quickly when compared to lacewings which required higher concentrations (Joachim *et al.,* 2013). Lady beetles are considered to be one of the key factors used as bio-control to protect major crops from aphid infestations and also various other pests. Studies suggest that they can perceive (E) – β – Farnesene produced in the aphid alarm pheromone indicating that they have evolved along with a strong sensory system which can detect odors released by their prey. Lady beetles respond to various odors like these when they are in need of food, shelter and a host to reproduce. It is said that Lady beetles adults and larvae not only respond to olfactory signals but can also locate their host prey by recognising colours (EB Acar *et al.,* 2001). It was found that juvenile aphids tend to release large amounts of (E) – β – Farnesene in their alarm pheromones when compared to reproductively active adults as they reside in large clusters of colonies and are more likely to be predated when adults tend to move away from the host to different places. As the aphids develop there is surely in increase in the size of the droplets released by their cornicles but there is no increase in the concentration of (E) – β – Farnesene.

The adult aphids emit a lower concentration of (E) – β – Farnesene in their pheromone droplets when compared to the juveniles or pre-reproductive aphids. Reasons for this can be stated as pre-reproductive aphids are immature and can invest most of their metabolism into producing the alarm pheromone as they have low reproductive values. Another reason can be that younger aphids can be very easily killed by predators and natural enemies whereas adults are capable of leaving the host quickly by flying away or dropping off (Mondor *et al.,* 2000). Sometimes the amount of alarm pheromone emitted by the aphids may not be enough to alert all the individuals as the odor may get diluted along with the blowing wind. To overcome this the un-attacked aphids may also release more alarm pheromone in response to the signals received by the attacked individuals to double the amount and to also alert a large number of individuals from threat. This phenomenon still remains to be unknown as to whether they show such behavior or not. But amplification of the pheromones, instead of being beneficial may also turn out to be risky as they may invite more number of predators to the colony due to strong and concentrated emission (Eduardo Hatano *et al.,* 2008). Orchids come under the category of deceptive flowers which get the service of pollination by the pollinators but do not give the pollinators anything in return for the service provided. They often get their services done by the pollinators by deceiving them either by visual, olfactory or both.

The terrestrial orchid species *Epipactis veratrifolia* emit fragrances which mimic the alarm pheromones produced by aphids attracting aphid natural enemies like hoverflies for pollination services. These hoverflies are considered to be beneficiary insects to the orchid flowers and show oviposition behavior of laying eggs which is also derived from the aphid produced kairomones. (E) – β – Farnesene is considered to be one of the major components of the aphid alarm pheromone but there are also other terpenoids which also conduct the action of alarm pheromones. A very common species of aphids in the Middle East called *M.Viciae* produces α- and β-pinene, and β-myrcene as a component in their alarm pheromones. The odor of these components were found to be very similar to the odor produced by the orchid flowers *Epipactis veratrifolia*. Studies suggest that orchid flowers do not mimic one particular species of aphid pheromones as they do not produce the exact amount and composition of pheromones produced by a specific species. This type of mimicry by the orchid flowers are completely justified as all the hoverfly species do not feed on one particular species of aphids (Johannes Stokl *et al.,* 2010). The pheromones produced in insects are considered to be in very small and trace amounts making it difficult to identify them, as they are also associated with various other substances. Gas Chromatography (GC) serves to be a highly efficient technique in the identification of various complex and natural substances but other additional techniques are also required along with it to isolate the biological products in the component. Small fractions of biological material obtained from the Gas Chromatography has been used for assay experiments to test the activity of insect antennae in the Electro-antennogram (EAG) (Wadhams *et al.,* 1990). As a defense mechanism Aphids have also shown a behavior of smearing the droplets released by their cornicles containing the alarm pheromone along the body of the predator which alerts the colony members of an approaching predator (Ezra G. Schwartzberg *et al.,* 2008).

Aphids when reared in isolation under laboratory conditions produced less amount of alarm pheromones when compared to aphids reared along with other members. This behavior indicates that they prefer social environments and utilize the signals given by their neighbors to stimulate the pheromone production (Verheggen *et al.,* 2009). Genetically modifying plants with genes to produce volatiles similar to the Aphid alarm pheromone (E) – β – Farnesene is gaining importance in recent times as a good biocontrol agent to protect plants from infestations. This process has been successfully achieved by developing the hexaploid wheat cv. Cadenza. The volatiles released by this crop has shown successful results by preventing aphids from infesting and also attracts aphid natural enemies by the chemical odor (Bruce *et al.,* 2015).

ODORANT BINDING PROTEINS

The peripheral nervous system of insects consist of Odorant binding proteins (OBP) which regulate the antenna to detect various olfactory and gustatory senses (Qian Wang *et al.,* 2021). OBP help in perceiving different odors and aids in their discrimination (Huili Qiao *et al.,* 2009). They conduct chemo-sensation and chemical signals to identify volatiles on their host plant and also to locate their mates using sex pheromones (Qian Wang *et al.,* 2021). The hydrophobic volatile compounds in the environment are proposed to be transmitted to the insect olfactory system through these OBPs (Jia Fan *et al.,* 2017). OBPs transport the odor fragrances through the sensory neurons of the insect olfactory system. Their sensory receptors contain proteins of high concentrations but do not interact with each other in

localized areas. Knocking down the genes involved in the OBP production showed that the Aphids were still being repelled by the production of (E) – β – Farnesene (Qian Wang *et al.,* 2021).

Among insects aphids specifically use their receptors in the primary and secondary Rhinaria present in the antennae to detect odors (Tom W. Pope *et al.,* 2004). Studies indicate that OBP3 and OBP7 may be involved in the aphid olfaction for perceiving (E) – β – Farnesene in the alarm pheromone. *Rhopalosiphum padi* species of aphids were used to study the responses of olfaction for (E) – β – Farnesene and volatiles extracted from crushed aphids. Results indicated that *Rhopalosiphum padi* was repelled by both (E) – β – Farnesene and the volatiles extracted from the crushed aphids (Jia Fan *et al.,* 2017). Odorant receptors (ORs) are one of the sensitive chemosensory systems identified in aphids aiding in the perception of pheromones (Ruibin Zhang *et al.,* 2017). ORs are basically complexes that are present in the insect olfactory system consisting of a large number of odor specific receptors and odor specific co-receptors (Orco) (Fan *et al.,* 2015). An odorant receptor called ApisOR5 found to be expressing in the antennal segment of the aphids shows response to (E) – β – Farnesene when expressed along with Orca, an odorant receptor co-receptor. ApisOR5 is one of the receptors belonging to the large subfamily of odorant receptors (Zhang *et al.,* 2017).

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MS Received: 20 June 2024
MS Acceptance: 18 September 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 235-242 (2024)
DOI Number : 10.5958/0974-4541.2024.00047.6

Whitefly fauna (Hemiptera: Aleyrodidae) associated with guava (*Psidium guajava* L.) in Kerala, India

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ABSTRACT: This study documents the whitefly species associated with guava in Kerala, India, to facilitate early detection and management approaches. Extensive surveys were carried out in all five agro ecological zones of Kerala from 2020 to 2023. Eight species of whitefly were recorded infesting guava *viz*., *Aleurodicus dispersus*, *Aleurodicus rugioperculatus*, *Aleurothrixus floccosus*, *Paraleyrodes bondari*, *Paraleyrodes minei*, *Aleuroclava psidii*, *Aleurotracheulus tuberculatus*, and *Dialeuropora decempuncta*. The distribution and host range and morphological descriptions of the fourth instar puparia of the species are provided.

Keywords: Guava, whitefly, distribution, morphological description, Kerala

INTRODUCTION

The guava (*Psidium guajava* L) is a tropical fruit tree that originated in Central America but is now widely grown in many tropical and subtropical areas worldwide, because of its nutritional, commercial, and therapeutic qualities. India is the leading producer of guava in the world with an annual production of 4.92 million tonnes contributing to its importance in food security and local economies (Goswami *et al*., 2024). The fruit is rich in nutrients like calcium and phosphorus that promote health and wellness. It is high in other vital minerals, as well as vitamins A, C, and several B vitamins. Guava leaves and other plant parts are also used in traditional medicine to treat a range of diseases, such as diabetes, gastrointestinal disorders, and inflammation. In addition, the tree can be grown in a variety of climatic conditions due to its adaptability to different growing conditions.

Whiteflies (Hemiptera: Aleyrodidae) are tiny, sap-sucking insects representing a major threat to crops worldwide. They are well-known for their ability to multiply quickly which harms host plants considerably. Whiteflies suck the plant sap by piercing plant tissue and extracting nutrients which then weaken the plant and lead to stunted growth, yellowing, and withering. Apart from causing direct feeding damage, whiteflies also excrete a sticky substance called honeydew, which encourages the growth of sooty mould on plant surfaces. This mould lowers photosynthesis as well as the aesthetic and commercial value of the affected plant. Moreover, may species of whiteflies are vectors of several plant viruses, which exacerbates their negative impact on agricultural output.

Guava plants are highly susceptible to whitefly infestations, which can cause significant economic loss. The interaction between guava plants and whiteflies is complex and whiteflies often coexist with other species. In India, 13 whitefly species were reported from guava which includes *Aleurodicus dispersus* Russell, *Aleurodicus rugioperculatus* Martin, *Paraleyrodes bondari* Peracchi, *Paraleyrodes mine*i Iaccarino, *Aleurocanthus rugosa* Singh, *Aleuroclava citrifolii* (Corbett), *Aleuroclavapsidii* (Singh), *Aleurolobusmarlatti* (Quaintance), *Aleurolobuspsidii* Jesudasan & David, *Aleurothrixus floccosus* (Maskell), *Dialeuropora decempuncta* (Quaintance & Baker), *Fippataleyrodes rajmohani* Pushpa and Sundararaj and *Minutaleyrodes minuta* (Singh) (David *et al*., 2021). In 2019, a highly invasive woolly whitefly, *Aleurothrixus floccossus* (Maskell), was reported on guava from Calicut, Kerala (Sundararaj *et al*., 2020). Subsequently, it has spread quickly throughout the state within a short period. A similar invasion of the whitefly species, *A.dispersus* was recorded earlier in Kerala (David and Regu, 1995). Hence, it is important to monitor and document the whitefly fauna, for the early detection and identification of any exotic species.

MATERIALS AND METHODS

Purposive surveys were conducted from 2020 to 2023 in all five agro ecological zones of Kerala. Whitefly-infested guava leaves along with nymphs, puparium, pupal cases, and adults were collected by exercising the infested shoots using secateurs. The samples were placed in polythene bags separately, by furnishing the details of collection such as date of collection, locality

and GPS coordinates. The collected samples were then brought to the Insect Systematics Laboratory, Department of Agricultural Entomology, College of Agriculture Vellanikkara, KAU and assigned accession numbers.

The leaf samples from different accessions were carefully examined under a microscope (Leica EZ4HD) and the puparium was slide-mounted for morphological characterisation, to establish the identity of the species. The adult whiteflies in the samples were preserved in 70 and 100 percent ethyl alcohol, and puparium in 70 percent alcohol, separately, for future studies.Permanent mounts of the whitefly puparium were made by following the procedure suggested by Martin (1987).Care was taken to mount only one specimen per slide to avoid more than one species on a slide. Slides were dried at room temperature for about 3- 4 weeks and labelled. The slide-mounted specimens were observed under a research microscope (RADICAL, RXLr-4) to study the key taxonomic features (Martin, 2004; Martin, 2005). The studied specimens are available in the collection of the Insect Systematics Laboratory, Department of Agricultural Entomology, College of Agriculture, Vellanikkara, Kerala Agricultural University (KAU).

RESULTS AND DISCUSSION

In this study, eight different species of whiteflies were recorded widely infesting guava in Kerala. They are, spiralling whitefly, *Aleurodicus dispersus* Russell, rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin, woolly whitefly, *Aleurothrixus floccosus* (Maskell), Bondar's whitefly, *Paraleyrodes bondari* Peracchi, *Paraleyrodes mine*i Iaccarino, Asian guava whitefly, *Aleuroclavapsidii* (Singh), *A. tuberculatus* Singh and bread fruit whitefly, *Dialeuropora decempuncta* (Quaintance and Baker). The host plants, distribution and important morphological characters of the species are detailed below.

1. Spiralling whitefly, *Aleurodicus dispersus* Russell

Material examined: India: Kerala, 5 puparia from Vellanikkara, Thrissur (10.5486111^{0}N, 76.2830556^{0}E); 8 puparia Alathur, Palakkad (10.638888^{0}N, 76.5613889^{0}E); 3 puparia at Balussery, Kozhikode (11.504676^{0}N, 75.813017^{0}E).

Host: There are 481 host plants worldwide, with 298 of them being found in India (David *et al*., 2021); these consist of fruit trees, vegetables, ornamental plants, and other crops of different families.

Distribution: Widely distributed throughout the world (Martin, 2004) and in India (Srinivasa, 2000)

Morphological characters (Plate. 1): *Aleurodicus dispersus* Russell, 1965. The Florida Entomologist, 48: 49 - 54.

A. dispersus adults are about 2 mm long and have a yellow body and white wings coated in a powdery, waxy substance. Eggs are yellowish and a characteristic spiral egg-laying pattern on the underside of leaves. They go through four instars covered in white, waxy filaments that give them a cotton look.

Taxonomy of fourth instar puparium: *Aleurodicus dispersus* Russell, 1965. *The Florida Entomologist,*48: 49 - 54. *Margin*. Smooth, not dentate.

Pores: Four abdominal compound pores present: the size decreases from abdominal segment 3 to abdominal segment 6, the largest is around 45 micrometers in diameter, the smallest is about 28 micrometers. The 8-shaped pores in a single row from the body margin. Sub marginal double-rimmed notched pores in a single row; wide-rimmed pores distributed 1 or 2 deep between septate and double-rimmed pores; wide-rimmed pores in a single row between the 8-shaped and the double-rimmed pores; septate pores present in median and sub median area of most segments.

***Vasiform orifice*:** Chordate; lingula is large, blunted, and excerted with four setae

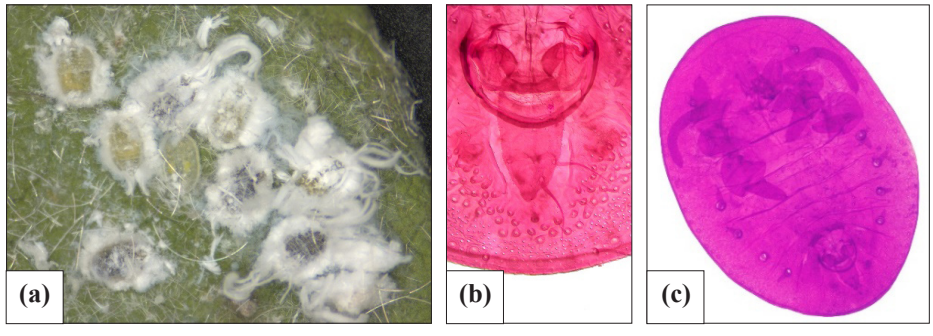

Plate.1. (a) Colony of *Aleurodicus dispersus* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

2. Rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin

Material examined: India: Kerala, 5 puaparia of *A. rugioperculatus* from Adoor, Pathanamthitta (9.398354^{0}N, 76.788646^{0}E); 7 puparia from Majeswar, Kasaragod (12.753252^{0}N, 74.948014^{0}E).

Host: *Aleurodicus rugioperculatus* is highly polyphagous with 118 hosts from 43 plant families including economically important crops (Francis *et al*., 2016). Following its accidental introduction, a wide host range was recorded for *A. rugioperculatus* from Kerala including coconut, banana, and guava (Shanas *et al*., 2016). In India *A. rugioperculatus* was reported in 80 host plants from 38 families (David *et al*., 2021).

Distribution: Since its first discovery in Florida, USA, in 2009, the *A. rugioperculatus*, has rapidly expanded its worldwide distribution. (Stocks, 2012). It was reported recently from India, particularly in Kerala, Tamil Nadu, and Karnataka as an invasive pest of coconut (Shanas *et al*., 2016).

Morphological characters (Plate. 2): The adults of *A. rugioperculatus* measure about 2 mm long, with a yellowish body covered in a waxy, powdery substance. They can be distinguished by their rugose pattern when laying eggs. The infestation is often indicated by the accumulation of sooty mold on leaves and fruits, resulting from the honeydew excreted by the whiteflies.

Taxonomy of fourth instar puparium: *Aleurodicus rugioperculatus*, Martin, 2004. *Zootaxa*, 681: 1-119.

***Margin*:** Smooth *Chaetotaxy.* Posterior marginal setae present; 12 pairs of sub marginal setae

***Pores*:** 7 pairs of compound pores are present including larger cephalic and first four pairs of abdominal pairs with central processes dagger-shaped, and protruding just beyond pore rim; the last two posterior pairs reduced, Broad, sub marginal dense band of wide-rimmed pores forming mesially-directed lobes present; band interrupted below apex of lingula. Subdorsum with a reticulated pattern from cephalothorax to abdomen.

***Vasiform orifice*:** broadly chordate, slightly emarginate to either side of lingula; operculum broadly elliptical; lingula apically acute.

3. Woolly whitefly, *Aleurothrixus floccosus* Maskell

Material examined: India: Kerala, 8 puaparia of *A. floccosus* from Kottarakkara, Kollam (8.981482^{0}N, 76.810939^{0}E); 5 puparia from Mannuthy, Thrissur (10.536111^{0}N, 76.2608333^{0}E).

Host: *A. floccosus* is highly polyphagous feeding on more than 20 families of host plants (Malumphy *et al*., 2015). In India, it was reported from guava plants by Sundararaj *et al*. (2020).

Distribution: Maskell first reported *A. floccosus* in 1895 from specimens taken on *Guaiacum officinale* from Jamaica (Martin and Mound, 2007). In India, it was first reported from Kerala (Sundararaj *et al*., 2020). Now it is distributed in all the five agro ecological zones of Kerala.

Morphological characters (Plate. 3)**:** *Aleurothrixus floccosus* Martin. 1987. *Tropical Pest Management,* **33** (4): 298 - 322

Pupa typically has white wax threads covering it and are highly noticeable on heavily infested leaves. Puparia are covered in fluffy wax and range from pale white to brown

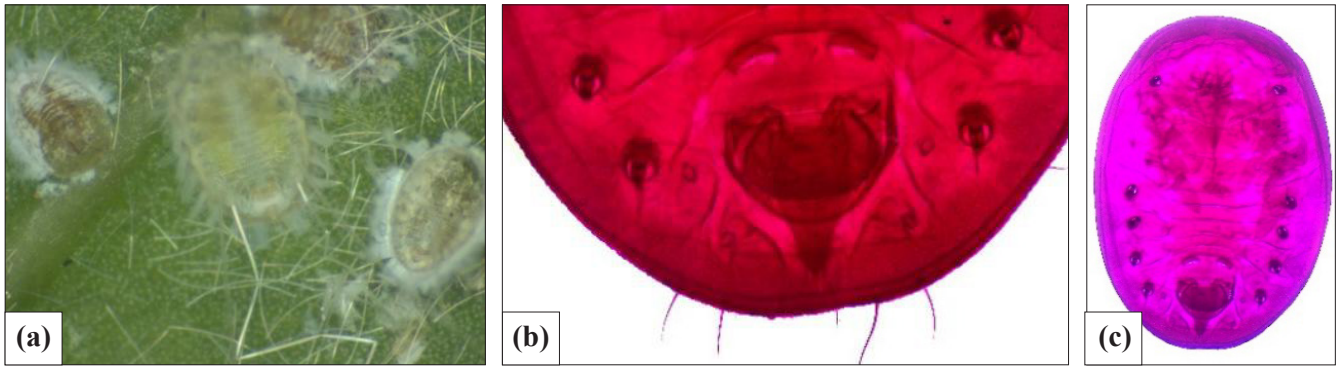

Plate.2. (a) Colony of *Aleurodicus rugioperculatus* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

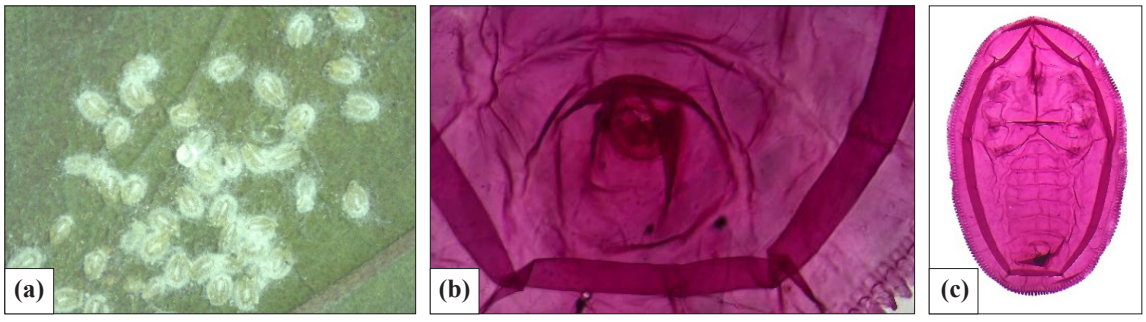

Plate .3. (a) Colony of *Aleurothrixus floccossus* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

Taxonomy of fourth instar puparium:

***Margin*:** regularly toothed each tooth with a basal gland, and thoracic tracheal pore regions without any alterations.

***Submargin*:** widely separated from the dorsal disc by the sub marginal/sub dorsal fold.

***Vasiform orifice*:** transversely elliptical, operculum similarly shaped nearly filling the orifice.

4. Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi

Material examined: India: Kerala, 4puparia of *P. bondari*on *Psidium guajava* from Kottarakkara, Kollam (8.981482^{0}N, 76.810939^{0}E); 9 puparia from Palode, Thiruvananthapuram (8.7536111^{0}N, 77.0277778^{0}E).

Host*: P. bondari* has a broad host range, infesting a variety of plants across multiple families. Significant hosts include economically important species like *Mangifera indica* (Anacardiaceae), *Cocos nucifera* (Arecaceae), and *Psidium guajava* (Myrtaceae). These diverse plant families highlight the wide adaptability of *P. bondari* and its potential impact on agriculture and forestry (Vidya *et al*., 2019).

Distribution: *P. bondari* was initially identified on Brazilian citrus in the Neotropics, (Peracchi 1971). Vidya *et al.* (2019) identified and confirmed Bondar's nesting whitefly, *P. Bondari* from the Indian mainland and Andaman Nicobar Island. It is widely distributed in all the agro ecological zones of Kerala.

Morphological characters (Plate. 4)**:**

Paraleyrodes bondari Peracchi 1971. *Archos Mus Nacional do Rio de Janeiro*, 146-148.

The adult whiteflies rest within a fluffy small nest, which resembles a bird's nest, thus the genus is usually referred to as Bondars nesting whiteflies. Also, the adults with oblique "X"-shaped grey wings and the peculiar fuzzy wax surrounding the pupa are the characteristic features of *P. bondari*.

Taxonomy of fourth instar puparium:

***Margin*:** Smooth

***Pores*:** One larger cephalic pore, four abdominal compound pores about, and an outer ring with ovoid cellular facets that resemble stylized flower petals. Two to three discoidal pores are associated with the two reduced abdominal pores which are half the size of the larger abdominal pores and comprise 7 to 8 flower petal-like facets (Peracchi 1971; Martin 2004).

***Vasiform orifice*:** tongue-like lingula is extended beyond the posterior margin vasi form orifice with two pairs of apical setae.

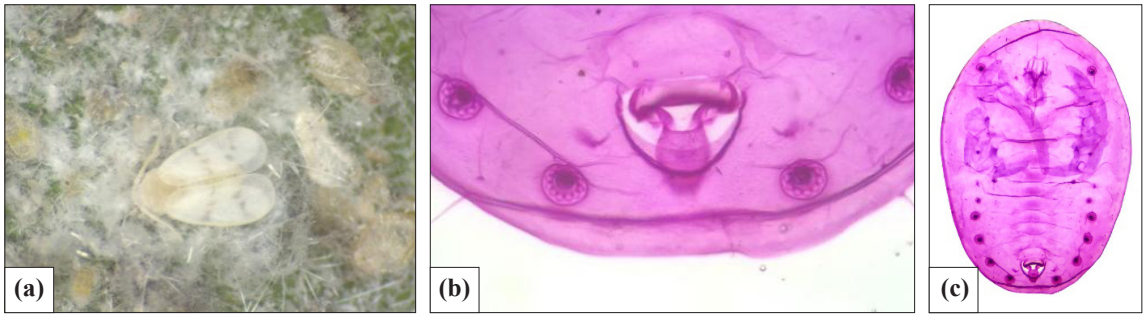

Plate .4. (a) *Paraleurodes bondari* adult on guava (4x)
(b) Vasi form orifice (40x) (c) Slide mounted fourth instar puparium (10x)

5. Nesting whitefly, *Paraleyrodesminei* Iaccarino

Material examined: India, Kerala-5 puparia of *P. minei*from Odakkali (10.0930556^{0}N, 76.5602778^{0}E) and 7 puparia from Palath, Kozhikode (11.33711^{0}N, 75.8272^{0}E).

Host: *P. minei*, is a highly polyphagous pest that feeds on various host plants including fruit guava. In India *P.minei* exhibits a diverse host range, infesting plants from various families, making it a significant pest across multiple environments. Economically important families include Arecaceae, Anacardiaceae, Myrtaceae, Combretaceae, Heliconiaceae, Musaceae, Myrtaceae, Rubiaceae (Sujithra *et al*., 2019; Mohan *et al*., 2019)

Distribution: All *Paraleyrodes* species are thought to be originated from the neotropical region, even though this species was initially reported from Syria on citrus in 1990 (Iaccarino, 1990). *P. bondari* and *P. minei* are two of the extremely mobile *Paraleyrodes*species that have been found worldwide. Mohan *et al*. (2019) reported *P. minei* from Kayamkulam in Kerala.

Morphological characters (Plate. 5): *Paraleyrodesminei* Iaccarino (Iaccarino, 1989: 131-149) (Martin, 1996: 1856)

Adult whiteflies are small and construct relatively less-denser woolly wax nest than that of *P. bondari*. Occurrence of cream-coloured egg clusters with short stalks and flat creamy-yellow nymphs with prominent fibreglass strands from the dorsum, are some characteristic features for the identification of *P. minei*.

Taxonomy of fourth instar puparium:

***Margin*:** Smooth

***Submargin*:** 14 pairs of hair-like setae arranged in a row.

***Pores*:** One large cephalic compound pore, four large and two small abdominal compound pores are present. compound pores with conspicuous flower petal structures, parameres pointed at the tip with swollen mid-region.

***Vasiform orifice*:** The operculum partially covers the lingula and the vasiform orifice. The tongue-like lingula is extended beyond the posterior margin vasiform orifice with two pairs of apical setae.

6. Asian guava whitefly, *Aleuroclava psidii* (Singh)

Material examined: India: Kerala, 6 puparia of *A. psidii*from Adhur, Kasargod (12.561639^{0}N, 75.181002^{0}E); 3 puparia from Tavanur(10.8530556^{0}N, 75.9866667^{0}E).

Host: In India, *A. psidii* has been reported from different plant families which include Moraceae, *Morus alba* Linn. (David and Regupathy, 2004); Myrtaceae, *Psidium guajava* Linn. (Singh, 1931); Rubiaceae, *Oxycerosrugulosus* (Thwaites) Tirveng., *Tarenna asiatica* (Linn.) Kuntze ex K. Schum; Salicaceae, *Scolopia crenata* (Wt. and Arn.) Clos; Dipterocarpaceae, *Dipterocarpusindicus* Bedd; Menispermaceae, *Tiliacora acuminata* (Lam.) Hook. f. & Thoms.; Verbenaceae, *Clerodendrum* sp. (Dubey and David, 2012); Theaceae, *Schima wallichii* (DC.) Korth. (Lalneihpuia and William, 2011)

Distribution: *A. psidii* is widely distributed in India, particularly in areas with guava cultivation including Bihar (Singh, 1931); Andhra Pradesh (Rao, 1958); Tamil Nadu (David and Subramaniam, 1976); Karnataka (Dubey andSundararaj, 2005); Kerala (Pushpa and Sundararaj., 2010).

Morphological characters (Plate. 6)**:** *Aleurotracheluspsidii* Singh, 1931. Memoirs of the Department of Agriculture in India, Entomological Series, 12 (1): 61.

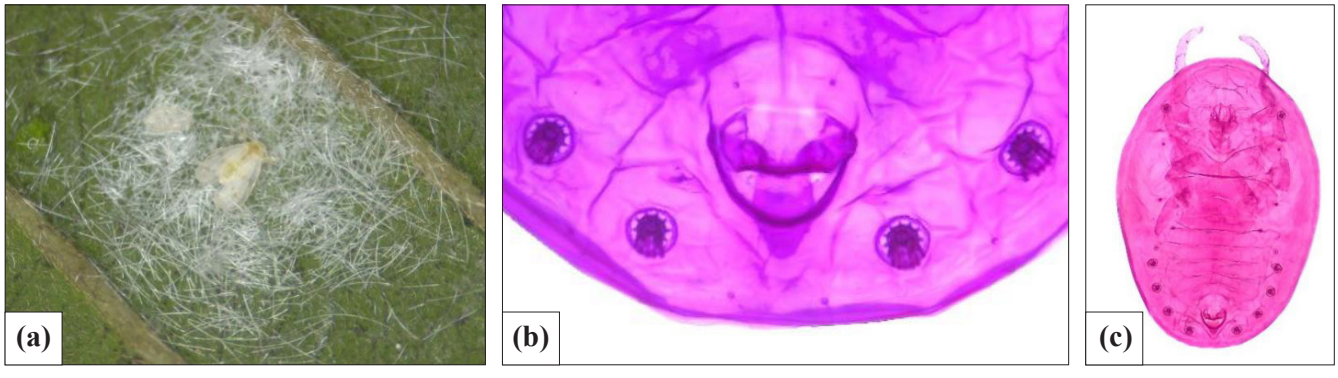

Plate.5. (a) *Paraleurodes minei* adult on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

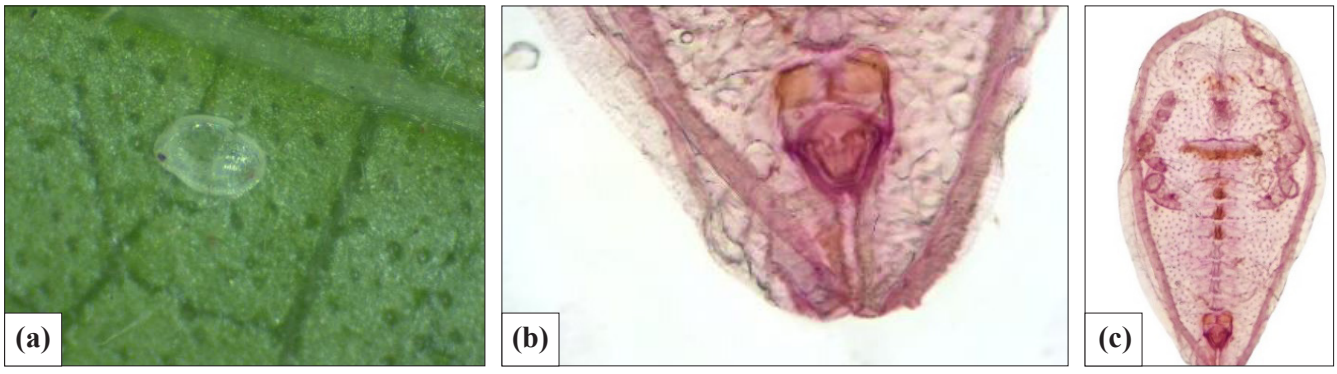

Plate.6. (a) Puparium of *Aleuroclava psidii* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

Puparium is small, white, pyriform shaped; found scattered on the leaf's undersurface.

Taxonomy of fourth instar puparium:

***Margin*:** faintly crenulated

***Submargin*:** submarginal area differentiated from dorsal disc by an elevated fold with many microtubercles. The microtubercles on cephalothorax appearing in T-shaped pattern.

***7. Aleurotracheulus tuberculatus* Singh**

Material examined: India: Kerala, 3 puaparia of *A. tuberculatus* from Vellanikkara, Thrissur (10.5486111^{0}N, 76.2830556^{0}E); 8 puparia from Kothamangalam, Ernakulam (10.057002^{0}N, 76.636883^{0}E)

Host: *A. tuberculatus* exhibits a wide host range, including a diverse array of plant species across multiple families. Major families include Calophyllaceae, *Mesua nagassarium* (Burm); Fabaceae, *Bauhinia racemosa* (Lam.) and *Dalbergia* sp.; Geraniaceae, *Pelargonium* sp.; Malvaceae, *Helicteresisora* Linn., Moraceae, *Ficus* sp. and *Morus alba* Linn.; Portulacaceae, *Portulaca oleracea* Linn.; Rubiaceae, *Tarenna asiatica* (Linn.). (Dubey and David, 2012).

Distribution: Singh (1933) described A. *tuberculatus* for the first time from India. *A. tuberculatus* is primarily distributed in India and is mainly in the Western Ghats, particularly within Kerala, with additional occurrences in the Andaman Islands and neighboring regions.

Morphological characters(Plate. 7)**:** *Aleurotrachelus tuberculatus* Singh, 1933. *Oriental Insects*, 25: 290. Puparia is black, elliptical, or oval

Margin: marginal tooth is conical or sharply pointed. The raised median abdominal area with a rachis from the margin

Chetotaxy: Cephalic setae, meso, and metathoracic setae reaching beyond the puparial margin. The submedian area of the cephalothorax with a pair of longitudinal folds overlaying legs.

Vasiform orifice: elevated rectangular vasiform orifice with a pair of eighth abdominal setae.

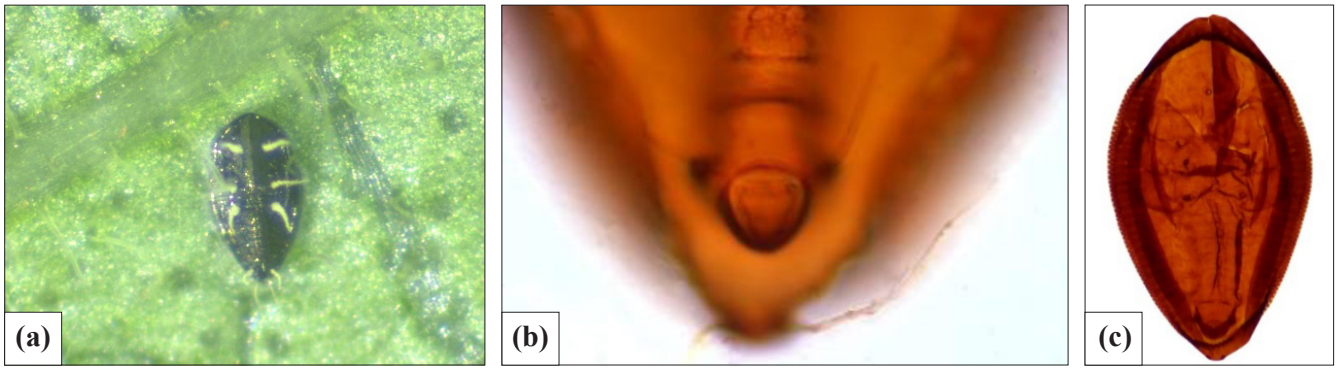

Plate.7. (a) Puparium of *Aleurotracheulus tuberculatus* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

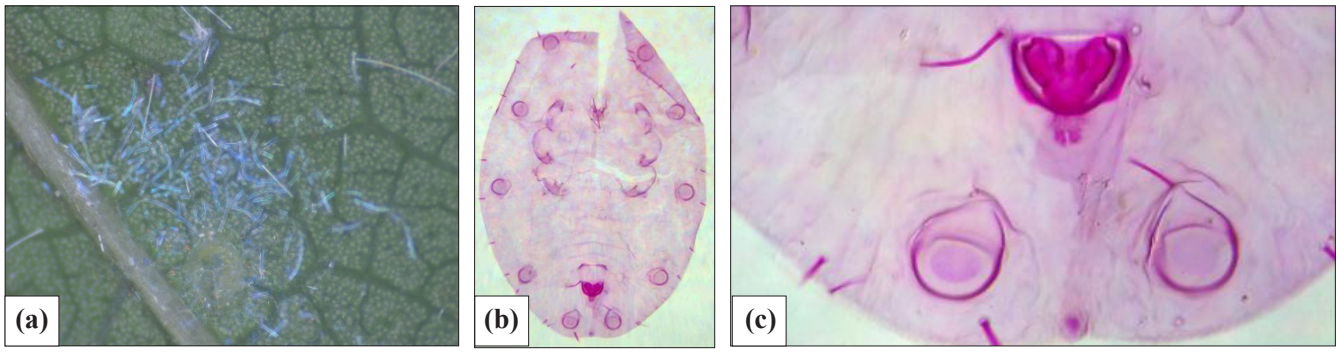

Plate.8. Puparium of *Dialeuropora decempuncta* on guava (4x)
(b) Vasiform orifice (40x) (c) Slide mounted fourth instar puparium (10x)

8. Breadfruit whitefly, *Dialeuropora decempuncta* (Quaintance and Baker)

Material examined: India: Kerala, 4 puaparia of *D. decempuncta*from Kattussery, Palakkad (10.626787^{0}N, 76.55097^{0}E) 7 puparia from Choondal, Thrissur (10.620567^{0}N, 76.099525^{0}E).

Hosts: *D. decempuncta* exhibits a wide host range. In India, it has been reported from 59 host plants from 24 families. Major families include Myrtaceae, Anacardiaceae, Annonaceae, Euphorbiaceae, Fabaceae, Lauraceae, Moraceae*etc* (David *et al*., 2021)

Distribution: *D. decempuncta* is native to Asia (Evans, 2008) It has been recorded in several regions within the country - Andaman and Nicobar Islands, West Bengal, Sikkim. In Kerala, it is reported from Thrissur, Kozhikode districts.

Morphological characters (Plate. 8)**:** Adults with banded wings, puparium suboval, pale with blue iridescent wax secretions

Taxonomy of fourth instar puparium:

***Margin*:** with tooth-like corrugations, tracheal pores present

***Submargin*:** 1 to five pairs of large submarginal discoidal pores present a caudal furrow indistinct, 12 pairs of spearhead-like setae are present.

***Vasiform orifice*:** subcircular, operculum nearly filling orifice.

CONCLUSION

This study documents the occurrence and distribution of eight whitefly species infesting guava in Kerala viz., *A. dispersus*, *A. rugioperculatus*, *A. floccosus*, *P. bondari*, *P. minei*, *A. psidii*, *A. tuberculatus*, and *D. decempuncta* which reflect the host range and adaptability of whiteflies.

The study emphasizes the urgent need for vigilant monitoring and early detection of whitefly species, particularly invasive species like *A. floccosus* and *A. rugioperculatus*, which have been shown to spread quickly throughout the state. Identifying these species, supported by taxonomic keys and morphological characteristics, provides vital information for developing targeted management strategies. Further research must be done to study the ecological interactions between these whiteflies and their natural enemies as well as the impact of climate change on their population dynamics.

ACKNOWLEDGMENT

The authors are grateful to the Kerala Agricultural University for providing facilities for the conduct of this study.

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MS Received: 29 September 2024
MS Acceptance: 25 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 243-250 (2024)
DOI Number : 10.5958/0974-4541.2024.00048.2

Fruit-piercing moths of genus *Eudocima* Billberg, 1820 (Lepidoptera: Erebidae: Calpinae) in Nepal, and an observation of sweet orange losses due to *E. phalonia* in Sindhuli, Nepal

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ABSTRACT: Fruit-piercing moths are developing serious insect pests in the horticultural fruits of Nepal. Asia, Africa and Australia, in global scenario, are suffering of these moth pests in horticulture. An authentic documentation developed of these pests out of different scattered scientific sources in Nepal and published elsewhere is the objective of this review paper. Analytical results of the dominantly primary fruit-piercing moth species of genus *Eudocima* Billberg, 1820 recorded in the national physiological regions in course of the moth surveys and their collections by the national and international institutions on the spatial duration from 1968 to 1998 are presented in this paper. Eight species of *Eudocima*, namely *E. homaena* (Hubner), *E. hypermnestra* (Stoll), *E. materna* (Linnaeus), *E. okurai* (Okano), *E. phalonia* (Linnaeus), *E. salaminia* (Cramer), *E. sikhimensis* (Butler) and *E. tyrannus* (Guenee) are found spread over the different altitude regimes of the physiological regions ranging from 450 to 3540 m of four provinces, namely Koshi, Madhesh Pradesh, Bagmati and Gandaki of Nepal. Siwalik hill (200-1000 m), Middle hill (1000-2000 m), Upper hill (2000-3000 m) and High mountain (3000-4000 m) of the country, respectively, are found to exist fruit piercing moths, *E. homaena*, *E. hypermnestra*, *E. phalonia*, and *E. salaminia* (4 species); *E. homaena*, *E. materna, E. okurai, E. phalonia, E. salaminia, E. sikhimensis* and *E. tyrannus* (7 species); *homaena*, *E. materna, E. phalonia*, *E. salaminia, E. sikhimensis* and *E. tyrannus* (6 species), and *E. materna, E. phalonia,* and *E. salaminia* (3 species). *E. phalonia* and *E. salaminia* moths are reportedly existed right from Siwalik hill to High mountain physiological regions of Nepal. A preliminary estimate of sweet orange (*Citrus sinensis*) mean loss in the selected orchards during the local outbreak in 2023 of *E. phalonia* in the Kamalamai Municipality, Ward 3 and Golanjor Rural Municipality, Wards 2, 4 and 5 of Sindhuli district was 82.0 ± 5.8%.

Keywords: Nepal, citrus, *Eudocima* spp., fruit piercing moth, horticulture

INTRODUCTION

Globally there are 47 reported species of fruit piercing moths of genus *Eudocima* Billberg, 1820 (Lepidoptera: Erebidae: Calpinae) (Zilli *et al.,* 2017; Zaspel and Branham, 2008; Zilli and Hogenes, 2002; Reeves *et al.,* 2017), and Nepal enlists 8 species out of them (Joshi and Manandhar, 2001; Joshi and Adhikari, 2024; Bänziger, 1987; Haruta, 1993, 1994; Yoshimoto, 1995, 1998). *E. apta* (Walker [1885], a tropical fruit-piercing moth occurring in Central America, northern South America and the Caribbean, is recently recorded (in 2016) for the first time in Florida, USA (Reeves *et al.,* 2017). *E. apta* is also reported in USA as far north as Vermont (Gilligan and Passoa, 2014).

Eudocima spp. are frequently occurring fruit-piercing moths damaging to horticultural fruits in the Asian countries and the Pacific islands (Vargas-Fonseca *et al.,* 2020), Africa, South America, South-east Asia and Australia (Hattori, 1969). These moths are polyphagous, and, reportedly, feed on at least 50 cultivated fruit crops (Fay, 2002; Davis *et al.,* 2005; Reeves *et al.,* 2017). Fruits damages incurred of these moths fetch 19 to 95% depending on an abundance of moths in the fruit orchards (Fay and Halfpapp, 2006). Highly sclerotized proboscis often equipped with barb, hooks or cutting ridges is a special moth part of these calpine moths that enable them to pierce into skin and feed on the fluids of fruits (Hilgartner *et al.,* 2007; Zaspel *et al.,* 2011). The moths of genus *Eudocima* remain active during September to November and most fruit damages occur in orchards in this duration (Bhumannavar and Viraktamath, 2012). The fruit-piercing moths are the strong flyers, and cover a long distance from orchards to their breeding grounds (Bosch, 1970).

MATERIALS AND METHODS

With an objective to assess the present status of fruit-piercing moths of *Eudocima* spp. in Nepal, this review paper has been scripted with the help of pertinent

research papers developed of Banziger (1987) and six volumes of Toshiro Haruta edited, "Moths of Nepal, 1992, 1993, 1994, 1995, 1998 and 2000. National Entomology Research Centre (NERC) published, "Reference Insects of Nepal" is also referred for the collected and preserved *Eudocima* spp. specimens in the Entomology Museum, NERC, Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal. Research materials supportive to the Nepalese *Eudocima* spp. have been collected from the online placed research papers in Journals by virtue of the Google Scholar search machine. Similarly, the latest reports on the local outbreak of *Eudocima phalonia* in the command area of Junar (Sweet orange) Superzone, Prime Minister Agriculture Development Project, Sindhulimadi, Sindhuli, Bagmati Pradesh are also the referred materials for the paper. Also included is the *E. phalonia* outbreak status report of the Nepal Government's Plant Protection Officer in the Plant Quarantine and Pesticide Management Centre, Ministry of Agriculture and Livestock Development, Nepal.

RESULTS AND DISCUSSION

A checklist of *Eudocima* species (Lepidoptera: Erebidae: Calpinae) from Nepal

1. *Eudocima homaena* (Hübner, [1823] 1816) (= *Othreis homaena,* [1816])

Distribution: Nepal (Chitrei, Pheksinda and Okhaldhunga, Koshi Pradesh) (Haruta, 1994).

Distribution elsewhere: India, Sri Lanka, Myanmar, Taiwan, the Nicobars, Peninsular Malaysia, Borneo, the Philippines and Christmas Island (Wikipedia, 2021; Zilli *et al.,* 2017)

Remark: First record from Chitrei, 2450 m, 1♀, 28. vi 1963 (Haruta, 1994).

2. *E. hypermnestra* (Stoll, 1780)

Distribution: Nepal (Godak, Koshi Pradesh) (Yoshimoto, 1995).

Distribution elsewhere: India, Sri Lanka, Thailand (Zhang, 1994)

Remark: First record from Godak, 450 m, 1♀, 1♀, 3-5. i. 1994 (K. Suzuki) (Yoshimoto, 1995).

3. *E. materna* (Linnaeus, 1767)

Distribution: Nepal (Phulchoki, Lalitpur, Bagmati Pradesh; Taplejung, Chitrei, Koshi Pradesh; Langtang, Rasuwa, Bagmati Pradesh) (Haruta, 1993; Haruta, 1994; Yoshimoto, 1995; Banziger, 1987).

Distribution elsewhere: India, Sri Lanka, Australia, Fiji, New Zealand, Venezuela, Sierra Leone, Zimbabwe; widespread in old world tropics (Zhang, 1994).

Remark: First record from Chitrei, 2450 m: 1♂, 1 ♀. 28-29, vi. 1963 (Haruta, 1994).

4. *E. okurai* (Okano, 1964)

Distribution: Nepal (Godavari, Lalitpur, Bagmati Pradesh) (Banziger, 1987; Haruta, 1993).

Distribution elsewhere: Taiwan; Oriental distribution (Zilli and Hogenes, 2002).

Remark: First record from Godavari, 1520-1570 m: 26 ♂, 1 ♀. Sept. 1984 to June-July, 1985; found piercing plums and peaches (Banziger, 1987). Larvae of *E. okurai* reared on *Holboellia latifolia* (Lardizabalaceae) developed a life of 5-6 days egg stage, 3-7 days larval stage and 14-16 days pupal stage in Nepal. Larve rejected plants were *B. asiatica*, *M. napaulensis*, *M. siamensis*, (Berberidaceae), *Cocculus laurifolius, C. orbiculatus* (= *trilobus*), *Percampylus glaucus, St. elegans, St. oblate* (= *St. kerrii*), *Tinomiscium petiolare*, *Tinospora baenzigeri*, *Tinos. crispa*, and *Tinos. sinensis* (Banziger, 1987).

5. *E. phalonia* (Linnaeus) (= *Othreis fullonia* [Clerk])

Distribution: Nepal (Godavari and Phulchoki, Lalitpur, Bagmati Pradesh (Joshi and Manandhar, 2001; Haruta, 1993; Banziger, 1987); Godak, Pheksinda, Basantapur and Chitrei, Koshi Pradesh; Jiri and Sindhulimadi, Bagmati Pradesh) (Haruta, 1994); Pokhara, Kaski, Gandaki Province (Yoshimoto, 1998); Dhungeni, Dhading and Langtang, Rasuwa, Bagmati Pradesh (Yoshimoto, 1995)).

Distribution elsewhere: Southeast Asia, Australia, New Zealand and the Pacific (Waterhouse, 1997)

Remark: First record from National Botanical Garden, Godavari, 1515 m; 1 specimen, 16.viii. 1968 (N. Kumar) (Joshi and Manandhar, 2001). Recent host plants of *E. phalonia* included 62 species of fruits and weeds (Plantwise Plus, 2020). The moths (n = 5) observed piercing peach, 16, 22, 26, 30.6.1985 in Phulchoki, Lalitpur (Banziger, 1987).

6. *E. salaminia* (Cramer, [1777])

Distribution: Nepal (Godavari and Phulchoki, Lalitpur, Bagmati Pradesh (Haruta, 1993; Banziger, 1987); Pheksinda, Basantpur and Chitrei, Koshi Predesh (Haruta, 1994); Pokhara, Kaski, Gandaki Pradesh (Yoshimoto, 1998); Dhungeni, Dhading, Rasuwa, Bagmati Pradesh (Yoshimoto, 1995).

Distribution elsewhere: Indo-Australian tropics (Australia, Fiji, New Zealand, India, Pakistan, Papua New Guinea, Sri Lanka, and Vanuatu) (Holloway, 2005).

Remark: First record from. Godavari, 3 specimens, 14.9.84, 28.6. and 2. 7 .85; 2 specimens from mercury vapour lamp, 20. and 27.8.84, 1520-1570 m; found piercing plum, peach and *Rubus acuminatus* (sanu ainsalu) (Banziger, 1987). Larvae of *E. salaminia* found eating on *Stephania japonica* (Menispermaceae) in Sauraha (150 m, Terai), Chitwan, Bagmati Province and Godavari (Banziger, 1987).

7. *E. sikhimensis* (Butler, 1895) (= *Adris sikhimensis*)

Distribution: Nepal (Chitrei and Okhaldhunga, Koshi Pradesh) (Haruta, 1994).

Distribution elsewhere: Indo-Australian tropics (Australia, Fiji, New Zealand, India, Pakistan, Papua New Guinea, Sri Lanka, and Vanuatu) (Holloway, 2005).

Remark: First record from Okhaldhunga, 1700 m: 1 ♂, 17. ix 1990 (Haruta, 1994).

8. *E. tyrannus* (Guenee, 1852) (= *Adris tyrannus* [Guenee])

Distribution: Nepal (Godavari and Phulchoki, Lalitpur, Bagmati Pradesh) (Haruta, 1993; Banziger, 1987).

Distribution elsewhere: India (Hampson 1894), Russia (Zaspel and Brahman 2008).

Remark: First record from Godavari 1 specimen from mercury vapour lamp, 20.8.84, 1520-1570 m; found 29 specimens piercing plum and peach, and 2 specimens piercing berries of

Rubus acuminatus (sanu ainselu) (Banziger, 1987). Larvae of *E. tyrannus* found eating on *Berberis asiatica* (Berberidaceae) in Nagarjung Forest (1650-1850 m), Kathmandu, above Sundarijal (1600 m), Kathmandu; on *Mahonia napaulensis* and *B. asiatica* (Berberidaceae) in Godavari (1520 m), Lalitpur: on *Holboellia latifolia* (Lardizabalaceae) in Phulchoki (2000 m), Lalitpur (Banziger, 1987).

Fruit-piercing moths of genus *Eudocima* Billberg, 1820 in different altitude regimes in Nepal (1968 to 1998)

The distribution of eight species of fruit-piercing moths in the genus *Eudocima* Billberg, 1820 with reference to different altitude regimes ingrained in the physiographical regions, namely Terai plain (Below 200 m), Siwalik hill (200-1000 m), Middle hill (1000-2000 m), Upper hill (2000-3000 m) and High mountain (3000-4000 m) is presented in Table 1. The described fruit-piercing moths, namely *E. homaena, E. hypermnestra, E. maternal, E. okurai, E. phalonia, E. salaminia, E. sikhimensis* and *E. tyrannus* are recorded in different places in Siwalik hill, Middle hill, Upper hill and High mountain of Nepal from 1968 to 1998 (Joshi and Manandhar, 2001; Joshi and Adhikari, 2024; Bänziger, 1987; Haruta, 1993, 1994; Yoshimoto, 1995, 1998).

1. *E. homaena*

E. homaena revealed it being a fruit-piercing moth preferring to ecological habitats of Siwalik hill (1000 m), Middle hill (1700 m) and Upper hill (2450 m), respectively, in Pheksinda, Okhaldhunga and Chitrei, Koshi Pradesh) (Haruta, 1994) (Table 1).

2. *E. hypermnestra*

E. hypermnestra preferred to an ecological habitat of Siwalik hill (450 m) in Godak, Koshi Pradesh (Yoshimoto, 1995) (Table 1).

3. *E. materna*

E. materna revealed it being a fruit-piercing moth preferring to ecological habitats of Middle hill (1800 m), Upper hill (2450 m) and High mountain (3500 m), respectively, in Taplejung (Koshi Pradesh), Chitrei (Koshi Pradesh) and Phulchoki (Bagmati Pradesh), and Langtang, Rasuwa, Bagmati Pradesh) (Haruta, 1993, 1994; Yoshimoto, 1995; Banziger, 1987) (Table 1).

4. *E. okurai*

E. okurai preferred to an ecological habitat of Middle hill (1520-1570 to1600 m) in Godavari and Godavari (near), Lalitpur, Bagmati Pradesh (Haruta, 1993; Banziger, 1987) (Table 1).

5. *Eudocima phalonia*

E. phalonia revealed it being a fruit-piercing moth preferring to ecological habitats of Siwalik hill (450 to1000 m), Middle hill (1515 to 1600 m), Upper hill (2275 to 2450 m) and High mountain (3540 m), respectively, in Godak + Sindhulimadi, Sindhuli, Bagmati Pradesh + Pheksinda + Pokhara; Godavari; Phulchoki + Basantpur + Jiri + Chitrei: Langtang + Dhungeni. (Banziger, 1987; Joshi and Manandhar, 2001; Haruta, 1993, 1994; Yoshimoto, 1995, 1998) (Table 1).

6. *E. salaminia*

E. salaminia revealed it being a fruit-piercing moth preferring to ecological habitats of Siwalik hill (850 to1000 m), Middle hill (1520 to 1600 m), Upper hill (2275 to 2450 m) and High mountain (3540 m), respectively, in Pokhara + Pheksinda; Godavari; Phulchoki + Basantpur + Chitrei: Dhungeni. (Banziger, 1987; Haruta, 1993, 1994; Yoshimoto, 1995, 1998) (Table 1).

7. *E. sikhimensis*

E. sikhimensis preferred to ecological habitats of Middle hill (1700 m) in Okhaldhunga and Upper Hill (2450 m) in Chitrei (Haruta, 1994) (Table 1).

8. *E. tyrannus*

E. sikhimensis preferred to ecological habitats of Middle hill (1520-1600 m) in Godavar and Upper Hill (2075- 2275 m) in Phulchoki (Haruta, 1993; Banziger, 1987) (Table 1).

The fruit-piercing moth, *E. phalonia* in Nepal

E. phalonia, then named as *Othreis fullonia* Clerk, has been reported in Nepal from Godavari, Lalitpur as early as in 1968 (Joshi and Manandhar, 2001). *E. phalonia* is a noted economic pest of horticultural fruits in the tropical and subtropical areas of Africa, Asia and Oceania (Cochereau, 1977; Denton *et al.,* 1999). This species of fruit-piercing moth has been ranked as the fourth worst insect among 157 insect pests in agriculture in the South-West Pacific Region that includes part of Southeast Asia, Australia, New Zealand and the Pacific (Waterhouse, 1997). Most fruits and some vegetables are its principal host crops (Waterhouse, 1997). Recent host plants of *E. phalonia* included 62 species of fruits and weeds (Plantwise Plus, 2020). Outbreak of this species of fruit-piercing moth depletes the fruit harvest to a tune of more than 80% (Cochereau, 1977; Cotterell, 1940; Box, 1941; Dodia *et al.,* 1986). This moth is of migratory in nature with a possession of an inherent capability of powerful flying (Sands and Schotz, 1991).

Host adaptation of, *E. phalonia*

Indigenous wild plants are the main feeding host plants to the larvae of the fruit-piercing moths (Neubecker, 1962; Forsyth, 1966). The host plants to larvae of *E. phalonia* belong to only the vines of the family Menispermaceae (the moonseed plants) in Asia, Africa and Australia (Reddy, *et al.,* 2005; Ramkumar *et al.,* 2010; Muniappan *et al.,* 1994). *Anamirta cocculus, Cocculus hirsutus, Stephania glabra, S. glandulifera, S, japonica, Tiliacora acuminata, Tinospora cordifolia, T. sinensis* are some of the moonseed plants in Nepal (Shrestha, 1998) which are potential host plants for the larvae of *E. phalonia*. The larvae of *E. phalonia* are also reported to thrive on *Leea indica* (Vitaceae) as an alternative host plant in Malaysia and Thailand (Leong and Roland, 2011; Roland *et al.,* 2012). Nepal also has *L. indica* along with a couple of its different species like *L. acquata*

Table 1. Distribution of fruit-piercing moths of genus *Eudocima* in physiographic regions of Nepal, 1968 to 1998.

Physiographic region (MASL)	*Eudomica* sp. fruit-piercing moth							
	E.homaena	***E.hypermnestra***	***E.materna***	***E.okurai***	***E.phalonia***	***E.salaminia***	***E.sikhimensis***	***E.tyrannus***
Terai plain (Below 200)						150 m*		
Siwalik hill (200-1000)	1000	450			450, 500, 850, 1000	850, 1000		
Middle hill (1000-2000)	1700		1800	1520 to 1600	1515, 1600	1570, 1600	1700	1520, 1600,
Upper hill (2000-3000)	2450 m		2450		2100, 2075-2275, 2350, 2450, 2650	2275, 2350 2450	2450	2075- 2275
High mountain (3000-4000)			3500		3500, 3540	3540		
Himalaya (Above 4000)								

masl = meter above sea level
Data source: (Bänziger, 1987; Haruta, 1993, 1994; Yoshimoto, 1995, 1998).
*Larva on *Stephanis japonica* (Menispermaceae)

and *L. macrophylla* (Shrestha, 1998). The plants of genus *Erythrina* (Fabaceae) are the principal host plants to the larvae of *E. phalonia* in countries in the Pacific Region where several plants belonging to the Menispermaceae are present but decline feeding on them (Cochereau, 1977; Muniappan *et al.,* 1994; Muniappan *et al.,* 2002; Reddy *et al.,* 2007; Reddy *et al.,* 2005). The plants of genus *Erythrina* (Fabaceae), namely *E. arborescens, E. stricta* and *E. suberosa* are also present in Nepal (Shrestha, 1998). The *E. phalonia* moths (n = 5) are observed piercing peach in Phulchoki, Lalitpur (Banziger, 1987).

Local outbreak of *E. phalonia* in citrus orchards, Sindhuli, Nepal

Recently, in 2019, a multitude of fruit-piercing moths was observed in a mean-looking status in sweet oranges in the citrus orchards in Sindhuli district, Nepal (Joshi and Adhikari, 2019). The targeted moth was indentified *E. phalonia* (Fig. 1a) with the help of DNA bar-coding procedure conducted in Nepal that the sequence can be accessed in NCBI Genbank with accession no. PP101850.1 for *Eudocima phalonia* (NCBI, 2024). Local outbreak of *E. phalonia* was experienced in the citrus orchards in Golanjor Rural Municipality, and Kamalamai Municipality, Sidhuli district in 2023. Mean estimated loss of sweet oranges in Golanjor Rural Municipality and Kamalamai Municipality, in Sindhuli was $\bar{x} = 82.0 \pm 5.8$ (Table 2; Fig. 1b, Fig. 2). Likewise, the damage caused by this pest was reported and resulted in substantial citrus fruit losses. In order to protect citrus fruit, concerned stakeholders in the district are working for an adoption of applicable recommended management measures.

Fig. 1. (a) Fruit-piercing moth, *Eudocima phalonica*, and (b) the sweet orange losses incurred of this moth in Golanjor citrus orchards, Sindhuli, Bagmati Pradesh, Nepal

Fig. 2. Sweet orange fruits damaged of *E. phalonia* fruit-piercing moths in Golanjor citrus orchards, Sindhuli, Bagmati Pradesh, Nepal

Table 2. Estimated yield losses caused by fruit-piercing moth, *E. phalonia,* incurred sweet orange losses in some parts of Nepal, 2023

Orchard owner	Locality	Number of productive trees	Estimated fruit loss (%)
Gorakh Shrestha	Kamalamai-3, Swara	30	80
Prakash Lungeli	Golanjor-5, Chisapani	15	90
Dipak Sapkota	Golanjor-5, Khaniakharka	40	60

Ambika Thapa	Golanjor-5, Chisapani	115	60
Kalpana Bhujel	Golanjor-5, Nayakharka (Kaphalbotebari)	192	98
Bishnu Lal Shrestha	Golanjor-4, Pheda (Lamidanda pakha)	200	97
Lal Bahadur Shrestha	Golanjor-4, Pheda	18	98
Yadav Thapa	Golanjor-2, Bhadaure (Pipalbotegairabari)	190	60
Yam Bahadur Sinjali	Golanjor-4, Tamaure (Maibari)	200	95
Mean estimated fruit loss (%±SE)			**$\bar{x}$ = 82.0 ± 5.8**

Source: Junar Superzone, PMAMP, PIU, Sindhuli (2023); modified).

CONCLUSION

Fruit-piercing moths, particularly the species of the genus *Eudocima*, pose a significant and emerging threat to fruit crops in Nepal, as well as in Asia, Africa, and Australia. This review has synthesized and documented a diversity of eight primary fruit-piercing moths among *Eudocima* spp. (globally 47 spp.), namely *Eudocima homaena, E. hypermnestra, E. materna, E. okurai, E. phalonia, E. salaminia, E. sikhimensis* and *E. tyrannus,* and their distribution across different altitudinal regimes ingrained in the physiographical regions of Nepal, from the Terai plain (150 m) to the High mountains (3540 m). Notably, *E. phalonia* is found highly frequented fruit-piercing moth from the Siwalik hill (450 -1000 m) to the High Mountain (3540 m) in Nepal. Likewise, *E. salaminia* is found frequented from the Terai plain (150 m) to the High Mountain (3540 m). Wild flora consisting of *Anamirta cocculus, Cocculus hirsutus, Stephania glabra, S. glandulifera, S, japonica, Tiliacora acuminata, Tinospora cordifolia, T. sinensis* (family Menispermaceae) are found to be the potential host plants to the larvae of the most prevalent *Eudocima phalonia* fruit-piercing moth in Nepal. Similarly, alternative wild host plants for the larvae of *E. phalonia,* namely *Leea indica*, *L. acquata* and *L. macrophylla* (Vitaceae) and *Erythrina arborescens, E. stricta and E. suberosa* (Fabaceae) are also naturally available in the wilds of Nepal. The severe impact of fruit piercing moth is evidenced by the estimated 82.0 ± 5.8% loss of sweet oranges in the selected orchards during a local outbreak of *E. phalonia* in Sindhuli district in 2023. As this pest continues to threaten fruit production, it is imperative to strengthen monitoring, research, and integrated pest management strategies to mitigate the future fruit damage, and protect Nepal's horticultural industry.

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MS Received:15 July 2024
MS Acceptance: 20 August 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 251-256 (2024)
DOI Number : 10.5958/0974-4541.2024.00039.0

Light cum suction trap based IPM for the management of South American Tomato Moth, *Phthorimaea absoluta* (Meyrick, 1917)

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ABSTRACT: South American Tomato Moth, *Phthorimaea absoluta* is a key pest of tomato causing a yield loss of 80-100 per cent. Over relying on synthetic insecticides, as a primary option for managing this devastating pest has resulted in the development of resistance to the novel insecticides too. In this direction by integrating different IPM tools, wherein Light cum Suction Trap (LCST) as one of the component was evaluated against *P. absoluta*. Efficacy of LCST was found 5 times higher trapping of insect when compared to conventional light trap without suction mechanism. In LCST, 8496 moths were trapped as against 1674.67 moths in conventional trap. Further the integration of the LCST with the IPM module resulted in significant reduction of tomato fruit damage. The IPM implemented plots recorded a tomato fruit damage of 12.05 and 8.79 per cent in two seasons which was significantly lower than the control plots (up to 35.87 %). The findings suggests that, IPM module by including light cum suction trap, egg parasitoid *Trichogramma pretiosum*, need based spray of insecticides resulted in effective management of *P. absoluta*.

Keywords: *Phthorimaea absoluta*, IPM, light cum suction trap, *Trichogramma*

INTRODUCTION

Biological invasions have been a significant social and economic consequence in the agricultural settings due to increased challenges with the globalization (McNitt *et al.*, 2019). The South American Tomato Moth, *Phthorimaea absoluta* which was first reported from India in 2014 has been a serious pest on the Tomato crop and is reported to cause an economic yield loss of 100 per cent, if timely management interventions are not followed (Sridhar *et al.*, 2014; Sankarganesh *et al.*, 2017). The solanaceae family is the main host of the insect and is reported on *Solanum nigrum, S. tuberosum, Capsicum annuum* apart from Tomato, *S. lycopersicum* (Bawin *et al.*, 2016). The insect is potential of expanding its range radius by an average of 600 km per year (Campos *et al.*, 2017) and is reported in China and Turkey other than India which shares almost half of the tomato growing land area worldwide (Desneux *et al.*, 2011; Zhang *et al.*, 2020). Ecological Niche modeling of the insect has shown a high niche expansion in Asia (38%) and Europe (19 %) indicating the spread of populations in new climatic areas (Yuan *et al.*, 2024). Globally, Chemical control is the primary option for the management in spite of its various disadvantages *viz*., non target effects on the beneficial arthropods and insecticide resistance (Roditakis *et al*., 2018; Grant *et al.*, 2019). Other environmental friendly approaches have registered a good amount of results in managing the pest but it is a long way ahead to promote the use of those options due to its delayed results, financial assistance *etc.* Integrated Pest Management (IPM) which involves various eco-friendly tactics and sensible use of pesticides serves as a solution to overcome the consequences.

The phototactic behavior of the insects helps in designing of the traps and this serves as a sustainable tool for the management of pest. This approach serves to be a great option for managing *P. absoluta*, adults being nocturnal. Among different light traps evaluated for the management of the *P. absoluta*, Incandescent yellow bulb of 60 W was most efficient in attracting the insects and was identified as an important component of IPM (Sridhar *et al.*, 2018). In order to reduce the escape of the attracted insects to the light trap, light cum suction trap was designed. The addition of suction force to the light trap offers a provision of preventing the escape of insects attracted to the light source. By including light cum suction trap (LCST) along with other Integrated Pest Management options, an IPM module was designed and was evaluated for the effective management of *P. absoluta.*

MATERIALS AND METHODS

The efficacy of LCST in attracting *P. absoluta* was evaluated simultaneously in three polyhouses at ICAR-IIHR, Bengaluru located at 13° 8' 18.8088" N, 77° 28' 40.4040" E. The conventional light trap was included for the comparison and number of adult *P. absoluta* attracted was observed for ten nights, regularly. Further, IPM module was designed by including effective tools against *P. absoluta* as identified during the year 2019 with slight modifications (Sridhar *et al*., 2019) and by including LCST as a major component. The IPM trials

were carried out in *rabi*-summer seasons of 2019-20 and 2020-21 under open field conditions. The IPM evaluation experiment was laidout in one acre and a Non IPM plot was maintained with same tomato variety, 500 m away. Tomato hybrid 'Arka Rakshak' was planted with a spacing of 75 X 45 cm. The crop was grown by following recommended package of practices except plant protection aspects. The detailed components of the plant protection module (IPM) includes – Selection of pest free planting material, Clean cultivation and destruction of infested plant parts; Installation of Light cum suction Trap with incandescent bulb 60 W @ 5 per ha and pheromone traps @ 8 per acre immediately after transplanting ; Release of *Trichogramma pretiosum/T. chilonis* - egg parasitoid (100000/Ac – distributed in 5 weeks, starting from first notice of *Phthorimaea* adults in pheromone/light traps); Encouraging *Nesidiocoris tenuis* as predator; Use of microbials, *Bacillus thuringiensis* (1ml/l) or *Metarhizium anisopliae* @ 3 ml/l; Application of botanicals and chemicals *i.e.,* Azadirachtin 1 % EC @ 4 ml/l (when the incidence is low). Need based spray of spinetoram 12 SC / spinosad 45 SC (1.25/ 0.3 ml/l) or flubendiamide 480 SC (0.3 ml/l) or indoxacarb 14.5 SC (0.75 ml/l) in rotation, keeping in view the mode of action (during higher incidence).

Five sprays of need based insecticides were taken up in rotation with an interval of 2 weeks during the experimental period. Observations were made on damaged fruits due to *P. absoluta* in the IPM and non IPM plots at each harvest and per cent fruit damage was estimated. Healthy and damaged yield was calculated per hectare basis. For assessing the difference between IPM module and Non IPM (Farmers practice), the observational data was subjected to t-test.

RESULTS AND DISCUSSION

Efficacy of light cum suction trap in trapping the adult moths of *P. absoluta* over conventional light trap (Polyhouse trial)

In all the three trials evaluated LCST showed significantly higher trapping of *P. absoluta* adults over conventional light trap (($t = 8.23$, $P < 0.05$). The LCST captured a total of 8496 adult moths in ten nights and the number was five times higher than the moths captured in the conventional light trap (1674.67 moths). The details of mean no. of adults captured at each night are furnished in Table 1. The principle behind the suction of insects is mainly due to suction mechanism. The differential pressure between the fan that links to the air outside with suction port exerts a suction force on the target pest (Han *et al.*, 2024). The findings of the study were in accordance with Cocco *et al.* (2012) who evaluated the effectiveness of light trap equipped with 2 black light tubes and downdraught suction motor against *P. absoluta* and revealed a reduced population density and damage during the summer-winter season**.** Similarly, the findings of the Girardeau *et al*. (1952) who reported that light cum suction trap with 30 W black light fluorescent tubes were effective in trapping night-flying insects proves the effectiveness of suction trap.

Table 1: Relative efficacy of 'Light cum suction trap (LCST)' over conventional light traps in trapping *P. absoluta* adults (mean of three trials)

Number of nights	No. of adults trapped in LCST	No. of adults in normal light trap (conventional)
1	1361.33	340.00
2	440.33	206.67
3	482.00	154.67
4	1131.67	165.67
5	679.00	126.67
6	675.33	88.67
7	846.33	84.00
8	1112.67	193.67
9	917.00	155.67
10	850.33	159.00
Total	8496.00	1674.67
Mean	849.60	167.47
Sig. (P=0.05)		**
t value		**8.23**

** Significant at 1%

Impact of IPM module against *P. absoluta* damage and tomato yield (Open field)

The IPM module evaluation against *P. absoluta* in two seasons revealed a significant difference between IPM Module and Non IPM module (t = 3.49, P <0.05 and t = 2.37, P<0.05), where there was a significantly lower fruit damage in IPM module (Table 02). During first year, the mean per cent tomato fruit damage in IPM Plot was 12.05 per cent and significantly lower when compared to the non IPM plots (34.14 %). Similarly, during second year trial also, a maximum of 35.87 per cent damage was observed in non IPM plots as against only 8.79 per cent damage in IPM Plots. In addition, highest healthy tomato yield was recorded in IPM fields when compared to Non IPM plots in both the years (t = 7.36, P<0.05 and t = 6.64, P<0.05) (Table 3). In first and second years, the total healthy tomato yield recorded in IPM plot was 75.19 and 76.13 t/ha, respectively and was found superior to non IPM plots (51.17 and 46.87 t/ha, respectively). The overall findings reveal that the IPM interventions significantly reduced the damage to tomato fruits due to *P. absoluta* and reduced the insecticide spray by 50 percent.

The benefit-cost ratio (BCR) worked out revealed that IPM module recorded a BCR of 3.87 and 4.03, respectively in First year and Second year, respectively.

Table 2: Impact of IPM module against *P. absoluta*

No. of Harvests	First Year % fruit damage		Second Year % fruit damage	
	IPM	Non IPM	IPM	Non IPM
1	9.23	26.08	5.37	30.16
2	11.94	25.24	10.71	27.20
3	15.05	29.49	12.91	27.91
4	9.56	31.74	7.75	30.15
5	10.86	36.42	10.19	34.09
6	12.82	37.67	8.00	38.76
7	12.87	39.85	6.82	48.10
8	13.53	39.62	8.58	50.57
Total	12.05	34.14	8.79	35.87
t-value (0.05)	3.49*		2.37**	

* Significant at 5% ** Siginificant at 1%

Table 3: Impact of IPM module on healthy tomato yield (t/ha)

No. of Harvest	First Year		Second Year	
	IPM	Non IPM	IPM	Non IPM
1	7.38	4.11	3.7	2.57
2	8.48	6.19	5.55	3.8
3	9.31	6.01	9.11	5.14
4	9.93	7.29	10.48	6.37
5	11.08	7.84	11.45	7.50
6	11.22	7.81	12.31	6.84
7	9.61	6.52	12.31	6.84
8	8.18	5.41	11.24	7.81
Total	75.19	51.17	76.13	46.87
Sig. (P=0.05)	**		**	
t-value	7.36		6.64	

** Siginificant at 1%

The success of the IPM module is attributed to the incorporation of various effective components such as raising healthy seedlings, mechanical destruction, use of botanicals, microbials at early stage of infestation, light cum suction traps from transplanting stage of the crop itself, pheromones and eco-friendly molecules that are proved to be effective in managing *P. absoluta* population. The raising of the healthy seedlings, clean cultivation serves to be critical considerations as the damage to the crop by *P. absoluta* is possible from seedling stage to final harvest of the crop. The bio controls plays a significant role in managing the pest populations. Release of egg parasitoids decreases the insect population in the initial days of the crop and in turn reduces further damage. The adoption of the *T. pretiosum/T. chilonis* egg parasitoid and encouraging the predator *N. tenuis* have resulted in significant reduction of the pest. Efficacies of these biocontrol agents against *P. absoluta* were observed in earlier studies by different authors (Faria *et al.,* 2007; Calvo *et al.*, 2012; Sridhar *et al.,* 2019).

The studies with *T. pretiosum* has resulted in 45 and 28 per cent parasitization of the *P. absoluta* eggs (Faria *et al.,* 2007; Sridhar *et al.*, 2019). Further, the combination of LCST and Pheromone traps resulted in significant reduction of moths (both male and females). Our previous findings regarding LCST efficiency and the findings of Cocco *et al.* (2012) supports the present findings in reducing the pest damage. With reference to the Entomopathogens, several studies on *Bacillus thuringiensis* (Bt) and *M. anisopliae* insecticide formulations have demonstrated their efficacy in controlling *P. absoluta* larvae without any side effects on beneficial arthropods (Pires *et al.*, 2010; Molla *et al*, 2011; Hashemitassuji *et al.*, 2013; Contreras *et al.*, 2014; Erol *et al.*, 2021). The botanical, Azadirachtin 1 % EC has registered 69.87 per cent reduction in live mines and is found to be effective against the *P. absoluta* (Sridhar *et al.*, 2016). Studies from others conducted with different insecticides *viz*., spinetoram, spinosad, flubendiamide and indoxacarb were reported as effective against *P. absoluta* (Roditakis *et al.*, 2013; Abdelgaleil *et al.*, 2015; Dilipsundar and Srinivasan, 2019; Erol *et al.*, 2021). Hanafy and El-Sayed (2013) has reported higher toxic effect of spinetoram and spinosad with the lower leaf infestation. Similarly, the application of spinosad at 120 g a.i./ha has resulted in 99.8 per cent reduction of damage after 28 days of application (Bratu *et al.*, 2015). Further, application of indoxocarb has reported 67 and 56 per cent of reduction in damage in the tomato fields (Berxolli and Shahini, 2018). Patel and Mehta (2019) have reported 77.05 per cent mortality of *P. absoluta* by the application of Flubendiamide 480 SC.

The IPM incorporated plots registered a healthy tomato yield of 75.19 and 76.13 t/ha with a BCR of 3.87 and 4.03 in two seasons, respectively and is line with the studies conducted by Kumar *et al.* (2020) who recorded a yield of 40.62 t/ha with BCR of 2.50 with an IPM approach consisting of traps, botanicals and synthetic insecticides.

Thus the present study confirms the efficacy of the Integrated Management of *P. absoluta,* wherein LCST played an important role in attracting both male and female moths of the pest thereby reducing the infestation levels. Further, the inclusion of other IPM practices like mechanical, physical (pheromone traps), biological (*B*t and *M. anisopliae*) and chemical (Insecticides) components effectively contributed for the reduction in *P. absoluta* population levels and served as an effective strategy for its management.

ACKNOWLEDGEMENTS

The authors are thankful to the Director, ICAR-IIHR, Bengaluru for providing facilities for the studies.

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MS Received:11 September 2024
MS Acceptance: 12 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 257-262 (2024)
DOI Number : 10.5958/0974-4541.2024.00048.2

Seasonal abundance of bud borer on sapota and its management in coastal Andhra Pradesh

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ABSTRACT: Studies were conducted on seasonal incidence of sapota bud borer, *Anarsia achrasella* and efficacy of various insecticides against sapota bud borer during 2023-24 at Dr. YSRHU- HRS, Venkataramannagudem. Results indicated that per cent bud damage was maximum during second fortnight of March (21.57 %) and minimum in second fortnight of October (4.70 %). Correlation studies showed that there was a significant positive correlation between bud damage and maximum temperature (0.85**) whereas, minimum temperature (0.43^{NS}) showed non-significant positive correlation. Maximum relative humidity (-0.47*) showed significant negative correlation with the per cent bud damage while remaining weather parameters *viz*., minimum relative humidity and rainfall showed non-significant negative correlation. Evaluation of insecticides against sapota bud borer indicated that novaluron 10 EC @ 1ml/l found superior among all the treatments with the lowest sapota bud damage (3.63 %) which was followed by spinosad 45 SC @ 0.3 ml/l (5.24 %). Whereas, emamectin benzoate 5 SG @ 0.4 gm/l (6.22 %) and flubendiamide 480 SC @ 1 ml/l (7.75 %) also proved significantly effective over botanicals and *Bacillus thuringiensis* in reducing the sapota bud damage.

Keywords: sapota, bud borer, *Anarsia achrasella*, Kalipatti, per cent bud damage, seasonal incidence, bio efficacy, insecticides

INTRODUCTION

Sapota, also known as the sapodilla (*Manilkara achras*), is native to Mexico is an important tropical fruit belongs to Sapotaceae family. India is the world's largest producer of sapota with an area of 78.6 thousand hectares and production of 822 thousand MT (Horticultural Statistics at Glance, 2020-21). Gujarat, Andhra Pradesh, Maharashtra, Karnataka, Tamil Nadu, Kerala, Uttar Pradesh, Haryana, Punjab, and West Bengal are the main growing states of sapota crop (Vijayaraghavendra and Basavanagoud, 2017). There are 33 insect and mite pests in India that affect sapota trees among which bud borer, *Anarsia achrasella* Bradley (Lepidoptera: Gelechiidae) is found to be significant pest, reported to cause bud damage to the tune of 36.9 - 46 % (Jayanthi *et al.,* 2006) However, the persistent flowering and fruiting pattern of sapota under agro- farming practices over a wider area, and monoculture of kalipatti variety enhances the incidence of insect pests.

In Andhra Pradesh, sapota crop is being cultivated in 12.88 thousand hectares with the production of 193.20 thousand tonnes (Horticultural Statistics at Glance, 2020-21). In addition, farmers do not practice spraying of insecticides for the control of pests on sapota and information on population dynamics of bud borer and other pests on sapota is meagre. Earlier, Sunitha *et al*., 2020 reported that leaf webber (*Nephopteryx eugraphella*), bud borer (*A. achrasella*) and seed borer (*Trymalitis margarias*) are major pests on sapota in coastal Andhra Pradesh.

MATERIALS AND METHODS

The present investigation was carried out at Horticultural Research Station of Dr. Y.S.R. Horticultural University, Venkataramannagudem (16.83°N latitude and 81.5°E longitude) during August 2023 to June 2024. During the investigation, no insecticidal sprays were imposed to the trees. The experiment was designed in Randomized Block Design (RBD) with three replications and statistical analysis was done by using OPSTAT (Sheoran *et al*., 1998). Sapota trees with 25 years old of Kalipatti variety were selected for the trial. In order to compute percent bud damage, total and number of damaged buds per ten shoots in four directions of each tree/replication, were examined for the presence of bud damage and counted total buds and number of damaged buds at fortnight intervals.

Bio-efficacy of seven insecticides against bud borer on kalipatti variety of sapota was taken up in Randomized Block Design (RBD) with three replications. Two sprays were given at fortnight intervals. Per cent bud damage due to bud borer was calculated by counting total number of buds and number of the damaged buds. Ten shoots in four directions /tree were randomly selected and the per

cent bud damage was calculated one day before spray, 3, 7 and 15 days after spray. This trial was conducted with eight treatments.T_1 - Azadirachtin 10,000 ppm @ 2 ml/l, T_2 - Pongamia oil 1% @ 10 ml/l, T_3 - Novaluron 10 EC @ 1 ml/l, T_4 - Emamectin benzoate 5 SG @ 0.4 gm/l, T_5 - Spinosad 45 SC @ 0.3 ml/l, T_6 - *Bacillus thuringiensis* WG @ 2gm/l , T_7 - Flubendiamide 480 SC @ 1 ml/l and T_8 - Control.

RESULTS AND DISCUSSION

Seasonal incidence of sapota bud borer

A perusal of the data indicated that per cent bud damage due to bud borer was ranged from 4.70 to 21.57 per cent from August 2023 to June 2024 (Table 1 & Fig. 1). During first fortnight of August, 10.00 per cent bud damage was noticed and gradually decreased to the lowest during second fortnight of October (4.70 %). There was slight increase in bud damage from first fortnight of December (5.37 %) to second fortnight of January (8.31 %). Further, the per cent bud damage has been increased from first fortnight of February (13.79 %) and continued till second fortnight of March (21.57 %) with peak level of infestation. Later, the per cent bud damage has been gradually declined and minimum bud damage was reported during second fortnight of June (11.05 %).

The correlation studies (Table 2) indicated that there was a significant positive influence between the per cent bud damage and maximum temperature (0.85^{**}). However, minimum temperature (0.43^{NS}) reported non-significant positive effect on per cent bud damage. Remaining weather parameters minimum relative humidity (-0.01^{NS}) and rainfall (-0.30^{NS}) showed negative correlation on per cent bud damage. However, maximum relative humidity (-0.47^{*}) showed significant negative correlation with the per cent bud damage. The present results are in consonance with the findings given by Sathish *et al*. (2014), Vijayaraghavendra and Basavanagoud, (2016) who reported the minimum per cent bud damage during October. In contrast, Ghirtlahre *et al.* (2015), reported that the lowest bud damage was recorded during August. Bisane (2018) reported the peak infestation of bud damage during February under Gujarat conditions. Similar to our findings, Dongre (2011), Sathish *et al*. (2014), Vijayaraghavendra and Basavanagoud (2016) and Gajera *et al*. (2023) revealed that the maximum per cent bud damage was recorded during the second fortnight of March. However, Ghirtlahre *et al*. (2015) stated that the maximum bud damage was reported during November. The present findings are in agreement with Deshmukh (2001), Bisane (2018), Khambhu and Bisane (2017), Satish *et al*. (2014), Sushil Kumar and Bhatt (2002) and Gajera *et al.* (2023) who indicated that there was a significant positive correlation between the bud borer incidence and maximum temperature. In contrast, Ghirthalre *et al*. (2016) and Thumar *et al*. (2015) presented that the bud borer damage showed negative correlation with maximum temperature. Similar to our results, Deshmukh (2001) and Vijayaraghavendra and Basavanagoud (2016) reported that there was a significant negative correlation between per cent bud damage and relative humidity.

Table 1. Seasonal occurrence of sapota bud borer, *A. achrasella* on sapota var. Kalipatti in relation to abiotic factors during 2023-24

Year	Month	Fortnight	Maximum temperature (°C)	Minimum temperature (°C)	Maximum relative humidity (%)	Minimum relative humidity (%)	Rainfall (mm)	Bud damage (%)
2023	August	I	35.76	24.74	70.85	26.27	40.40	10.00
		II	35.88	25.10	71.30	25.00	28.60	6.54
	September	I	33.64	23.79	72.67	26.73	5.40	7.23
		II	32.78	23.89	79.86	30.93	16.90	7.54
	October	I	35.30	22.14	80.13	27.47	4.30	6.23
		II	34.52	22.18	82.34	37.41	0.90	4.70
	November	I	32.80	22.38	83.83	34.93	6.00	5.42
		II	32.51	22.21	83.45	35.53	2.60	6.34
	December	I	29.00	20.02	84.00	34.93	1.20	5.37
		II	29.17	17.82	84.00	34.00	0.00	7.70

2024	January	I	30.07	18.32	83.50	40.07	0.00	7.84
		II	32.84	18.26	83.67	31.09	0.00	8.31
	February	I	35.44	19.27	82.78	41.27	0.00	13.79
		II	37.22	20.36	72.93	35.07	0.00	19.19
	March	I	39.96	22.91	76.47	35.20	0.00	20.42
		II	40.72	23.27	79.38	27.44	0.00	21.57
	April	I	42.59	24.58	74.67	27.13	0.00	20.57
		II	44.27	26.55	75.00	26.27	0.00	18.63
	May	I	43.18	29.47	74.60	32.33	0.30	19.59
		II	40.04	27.86	75.60	46.31	1.30	17.46
	June	I	34.20	25.47	71.34	43.42	0.05	13.42
		II	34.54	24.18	70.17	39.47	0.02	11.05

Table 2. Correlation analysis between bud borer, *A. achrasella* and weather parameters on Kalipatti variety of sapota during 2023-24

Variety	Maximum temperature (°C)	Minimum Temperature (°C)	Maximum RH (%)	Minimum RH (%)	Rainfall (mm)
Kalipatti	0.85**	0.43NS	-0.47*	-0.01 NS	-0.30 NS

**Correlation co-efficient at 1% level of significance
*Correlation co-efficient at 5% level of significance

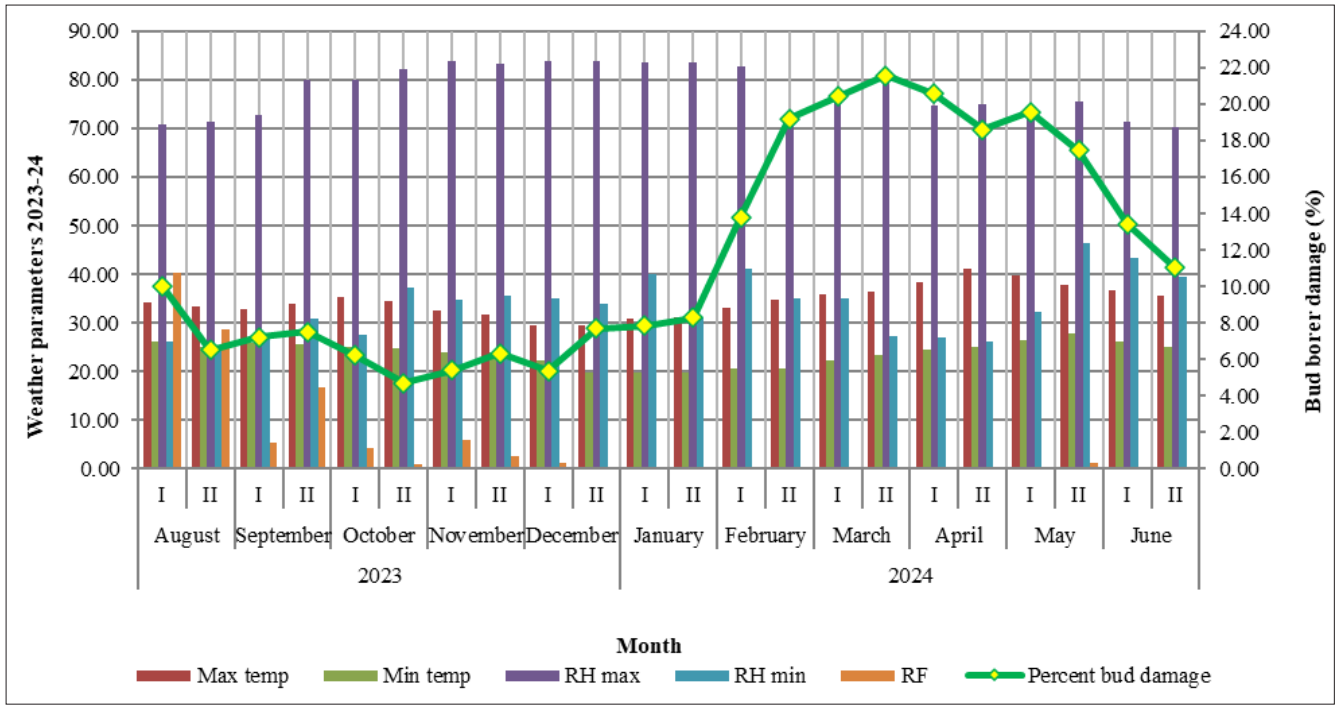

Fig. 1. Per cent bud damage due to sapota bud borer in relation to abiotic factors during 2023-24

Bio-efficacy of different insecticides against sapota bud borer, *A. achrasella*

The results revealed that per cent bud damage was ranged from 23.28 % to 24.82 % on one day before spraying (Table 3 and Fig. 2). The data on per cent bud damage also showed that all the insecticidal treatments, bio-agents and botanicals were significantly superior to control in suppressing the bud borer damage during two sprays. Three days after first spray, the lowest per cent bud damage (15.90 %) was recorded in novaluron 10 EC treatment followed by spinosad 45 SC (15.48 %) which were on par with each other. Whereas, emamectin benzoate 5 SG (18.81 %) and flubendiamide 480 SC (18.27 %) were found as next best treatments and statistically on par with each other in reducing the bud borer damage. Seven days after first spray, similar trend was observed, novaluron 10 EC (13.53 %) and spinosad 45 SC (13.82 %) recorded lowest per cent bud damage. Similarly, emamectin benzoate 5 SG (15.64 %) and flubendiamide 480 SC (16.07 %) were statistically on par with each other. Fifteen days after first spray, the lowest per cent bud damage was recorded in novaluron 10 EC (12.96 %), spinosad 45 SC (14.16 %) and emamectin benzoate 5 SG (15.55 %) which were statistically at par with each other and showed significant control in sapota bud damage.

After three days of second spray novaluron 10 EC (9.33 %) was the best treatment followed by spinosad 45 SC (10.51 %) which was significantly on par with each other. Seven days after second spray, three chemicals, novaluron 10 EC (6.64 %), spinosad 45 SC (8.18 %) and emamectin benzoate 5 SG (9.23 %) recorded as best treatments, and statistically on par with each other and significant over botanicals and *Bt*. Further, fifteen days after two sprays at fortnight interval, novaluron 10 EC (3.63 %) reported least bud damage. Next to novaluron 10 EC, spinosad 45 SC (5.24 %) recorded lowest bud damage and it was statistically on par with other two insecticides, emamectin benzoate 5 SG (6.22 %) and flubendiamide 480 SC (6.75 %). Among the treatments, two botanicals (azadirachtin 10,000 ppm and pongamia oil 1%) and microbial insecticide, *Bt* showed significant reduction in per cent bud damage over control however, did not show superior efficacy when compared to remaining treatments on 3rd, 7th and 15th days after spray during first and second spray. The results obtained in the present study were in line with the findings of Bisane *et al*. (2017) and Bisane *et al*. (2019) who revealed that novaluron 10 EC @ 0.005 % was found effective against sapota seed borer by recording the lowest per cent fruit damage. Efficacy of novaluron 10 % EC against insect pests on mango (Nayanathara, 2020) and against spotted pod borer, *Maruca vitrata* (Kishore, 2020) and bihar hairy caterpillar, *Spilosoma obliqua* on Cluster bean (Meena *et al*. 2020) are well documented. Patil and Kumar (2023) reported that novaluron 10 EC @ 300 ml/ha was found to be the most effective insecticide against sapota seed borer. Similar to our findings, Ghirtlahre *et al*. (2015) mentioned that spinosad 45 SC @ 0.0169 % was the best insecticide against sapota bud borer, *A.achrasella* while Vijayaraghavendra and Basavanagoud (2017) proved that spinosad 45 SC was very effective over Emamectin benzoate 5 SG and flubendiamide 480 SC against sapota fruit borer, *Phycita erythrolophia* on kalipatti variety. While Shilpa *et al*. (2023) presented that flubendiamide 39.35 SC @ 0.2 ml/l and Emamectin benzoate 5 SG @ 0.3 g/l were most promising insecticides against sapota bud borer as these chemicals could report the lowest per cent bud damage. In addition, the efficacy of Emamectin benzoate 0.4ml / lit against sapota bud borer has also been described by Muthiah and Indiragandhi (2023). Present findings in our trial were in confirmation with Suchithrakumari *et al*., 2018 who stated that flubendiamide 480 SC was highly effective against sapota midrib folder, *Banisia myrsusalis* with the lowest leaf infestation and Azadirachtin, 10000 ppm was least effective among all the treatments. It has been reported that pongamia oil @1 % against sapota bud borer (Bisane *et al*. 2017) and pongamia oil @ 0.03% against sapota seed borer (Ghirtlahre *et al*. 2015) were found least effective.

Table 3. Evaluation of insecticides against sapota bud borer (*Anarsia achrasella*) during 2023-24 at HRS, Venkataramannagudem

	Treatments	Dosage per litre	Per cent bud damage (%) by Sapota bud borer						
				1st Spray			2nd Spray		
			1DBS	3DAS	7DAS	15DAS	3DAS	7DAS	15DAS
T_1	Azadirachtin 10,000 ppm	2 ml	23.83 (29.21)	20.51 (26.92)	19.92 (26.50)	18.71 (25.62)	15.35 (23.06)	14.84 (22.64)	10.79 (19.17)
T_2	Pongamia oil 1%	10 ml	23.85 (29.22)	22.04 (27.99)	19.92 (26.50)	18.76 (25.65)	17.24 (24.52)	15.45 (23.12)	13.69 (21.70)
T_3	Novaluron 10 EC	1 ml	23.65 (29.08)	15.90 (23.49)	13.53 (21.57)	12.96 (21.09)	9.33 (17.78)	6.64 (14.91)	3.63 (10.90)
T_4	Emamectin benzoate 5 SG	0.4 gm	23.56 (29.03)	18.81 (25.29)	15.64 (23.29)	15.55 (23.19)	12.04 (20.29)	9.23 (17.67)	6.22 (14.43)
T_5	Spinosad 45 SC	0.3 ml	23.79 (29.18)	15.48 (23.16)	13.82 (21.81)	14.16 (22.09)	10.51 (18.90)	8.18 (16.61)	5.24 (13.22)
T_6	*Bacillus thuringiensis* WG	2 gm	23.62 (29.06)	19.68 (26.33)	18.68 (25.59)	18.10 (25.16)	15.80 (23.41)	12.50 (20.70)	9.01 (17.44)
T_7	Flubendiamide 480 SC	1 ml	23.28 (28.83)	18.27 (25.29)	16.07 (23.60)	15.91 (23.38)	10.48 (18.72)	9.76 (18.17)	6.75 (14.89)
T_8	Control	-	24.82 (29.87)	23.93 (29.28)	22.91 (28.58)	21.20 (28.26)	20.78 (27.13)	20.37 (26.79)	23.24 (28.79)
	C.D.		NS	0.96	1.24	1.75	2.59	1.81	1.94
	SE(m)		0.33	0.31	0.41	0.57	0.85	0.59	0.64
	SE(d)		0.47	0.44	0.57	0.81	1.20	0.84	0.90
	C.V.		1.97	2.09	2.85	4.10	6.76	5.09	6.26

NS: Non significant *DBS: Day before spray **DAS: Days after spray
*Values in parenthesis are transformed from arc sin.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Y.S.R. Horticultural University, Venkataramannagudem, Andhra Pradesh for providing necessary facilities during the study period.

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MS Received: 27 September 2024
MS Acceptance: 12 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 263-270 (2024)
DOI Number : 10.5958/0974-4541.2024.00035.5

Efficacy of *Neoseiulus longispinosus* (Acari: Phytoseiidae) in controlling red spider mite, *Tetranychus macfarlanei* Baker & Pritchard on Cucumber: Laboratory and Field Studies

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ABSTRACT: Studies were conducted to evaluate the effectiveness of the predatory mite, *Neoseiulus longispinosus* (Evans) (Acari: Phytoseiidae) against the emerging red spider mite, *Tetranychus macfarlanei* Baker & Pritchard (Acari: Tetranychidae). The study involved laboratory and field trials with different predator–prey ratios of 1:25, 1:50, 1:100, and 1:200. Laboratory trials revealed that hundred per cent reduction of prey mites was achieved at 10 and 12 days after predator release at ratios of 1:25 and 1:50, respectively. Recommending ratios of 1:25 and 1:200 to the farmer were deemed uneconomical. Field trials were conducted with the two other most effective predator–prey ratios, 1:50 and 1:100, and both ratios resulted in a greater than 99% reduction in the prey mite population 20 days after predator release. The study concluded that *N. longispinosus* is an effective and sustainable biocontrol agent for spider mites on cucumber plants. Recommending predator–prey ratios of 1:50 or 1:100 to farmers can lead to significant reductions in pest populations and is cost effective.

Keywords: Tetranychidae, horticulture, predator–prey ratio, biological control

INTRODUCTION

It has long been known that biological control is a reliable and sustainable method of managing pests. Several species of predatory mites are efficient biological control agents against pestiferous mites, insects, and nematodes. In many agro ecosystems, predatory mites are crucial biological control agents for spider mites (Yanar *et al.*, 2019). Phytoseiidae is one of the largest predatory mite families in the order Mesostigmata and includes several potential predatory species. The inoculative release of predatory mites from the family Phytoseiidae is an alternate method of controlling spider mite populations to pesticides. The value of phytoseiid mites for regulating spider mite populations has been well documented (Huffaker *et al.*, 1970; McMurtry *et al.*, 1970).

The predatory mite, *Neoseiulus longispinosus* (Evans) (Acari: Phytoseiidae) has been proven to be the most efficient at controlling spider mites in diverse crops. It has a wide range of distributions and can adapt to hot temperatures within polyhouses in South Indian climates (Mallik *et al.*, 1999). Commercial use of available predatory mites within the context of IPM programs has gained popularity as an economically viable pest management method for greenhouse crops (Vila and Cabello, 2014; Calvo *et al.*, 2015; Van-Lenteren *et al.*, 2018).

Numerous studies have been conducted on the biological control of spider mites in vegetables with the use of predatory mites (Gerson and Weintraub, 2007); However, research specifically focussing on the control of the red spider mite, *Tetranychus macfarlanei* Baker and Pritchard (Acari: Tetranychidae) on crops such as cucumber is scarce. Cucumber (*Cucumis sativus* L.) is an important creeping vine in the Cucurbitaceae family, the fruits of which are used as vegetables and green salads. Cucumber thrives in India's warm climate, and the southern states of Karnataka, Tamil Nadu and Andhra Pradesh are the major producers of cucumber crops. This crop is susceptible to various insect and mite pests, of which *T. macfarlanei* is the more serious pest. Mites colonize the underside of leaves and cause damage by piercing the cells and sucking out the cell contents. In Karnataka, it appears in moderate to severe form on cucumber and other vegetable crops in and around Bengaluru (Latha *et al.*, 2019).

Biological control with the predatory mite, *N. longispinosus* was attempted for the control of the spider mite *T. macfarlanei* and was found to be promising (Anonymous, 2020). The possibility of an interference component between phytoseiid predators and their prey is an essential part of the debate over whether phytoseiids can reduce excessive populations of prey mites (Laing

and Osborn, 1974). Predator's functional and numerical responses decline with high numbers of prey (Chant 1961; Mori and Chant (1966); Kuchlein 1967; Mori 1969). The present investigation aimed to determine the potential efficacy of this predator on prey mites. The research on the effectiveness of *N. longispinosus* has demonstrated that it is more promising to employ this predatory mite to manage spider mites on crops like cucumber, pointed gourd, banana, brinjal, okra, rose, carnation, and gerbera in India(Anonymous, 2020). However, additional studies are still needed to determine the efficacy of this predator in controlling spider mites on a variety of vegetable and ornamental crops grown under protected conditions as well as in open fields. Considering this, a study was conducted to determine how well *N. longispinosus* controlled *T. macfarlanei* on cucumber plants through biological control.

MATERIALS AND METHODS

Maintenance of mite cultures

Stock cultures of both the spider mite *T. macfarlanei* and the predatory mite *N.longispinosus* were maintained in the laboratory of the All-India Network Project on Agril. Acarology, UAS, Bengaluru, Gandhi Krishi Vignana Kendra. Excised cucumber leaves were placed abaxial side up on wet foam sheets in 12"×10"×2" plastic trays. In plastic trays, prey mites from the stock culture were released and allowed to develop on excised cucumber leaves. The leaves were changed every 5 to 6 days or whenever they started to dry. To keep the foam sheets moist and the cucumber leaves fresh, the trays were watered every day. Many of these trays were kept throughout, and some of them were utilized for predatory mite multiplication. Cucumber leaves infested with prey mites were plucked from a living plant and piled onto a tray. Subsequently, the predatory mites were released from the stock culture. These predatory mites were allowed to feed and multiply in the same trays.

Laboratory testing of the effective predator-prey ratio for controlling the spider mite *T. Macfarlanei*

The predator-prey ratio required to manage the spider mite, *T. macfarlanei* on cucumber plants was studied in the laboratory by releasing the predatory mite *N. longispinosus* at different predator-prey ratios on spider mite–infested cucumber leaves in plastic trays. In the experiment, there were four replications and five treatments in a completely randomized layout. The treatments included a predator-prey ratio of 1:25, 1:50, 1:100, 1:200, and the control without releasing any predators. Excised cucumber leaf blocks of 2"×2" were placed on the abaxial side up on a saturated foam sheet in plastic trays of 10"×8"×2". One leaf bit was placed in each tray, and 20 such trays were used for the whole experiment. On each leaf, 200 *T. macfarlanei* mites collected from the stock culture were released at all stages. For each tray in the first set of four trays (treatment 1), 8 gravid females of *N. longispinosus* were tested; for the second set of four trays (treatment 2), 4 predatory mites were tested; for the third set of four trays (treatment 3), 2 predatory mites were tested; for the fourth set of four trays (treatment 4), 1 predatory mite was released to serve as a 1:25, 1:50, 1:100 and 1:200 predator-prey ratio, respectively; and for the fifth set of four trays (treatment 5), no predators were released to serve as the control. The predatory mites were allowed to feed on the prey mites. The cucumber leaf bits were replaced with fresh bits as if they were dry, and the prey and predatory mites on the dried leaf bits were subsequently transferred back to the fresh leaf bits. The trays were watered daily to maintain the foam sheet in a water-saturated condition and to prevent the escape of prey and predatory mites from the arena. Observations of the number of prey and predatory mites on leaf bits were recorded at 2,4, 6, 8, 10, and 12 days after the predator was released. The values were square-root transformed by adding 0.5 and were analysed by one-way ANOVA using R Software (version 4.0.3) (2020-10-10).

Field test of the effective predator–prey ratio for controlling the spider mite *T. macfarlanei* on cucumber plants

The effective predator-prey ratio required to control *T. macfarlanei* on cucumber plants in the open field was evaluated after releasing the predatory mite *N. longispinosus* at two predator-prey ratios on spider mite–infested cucumber plants. Of the four predator-prey ratios tested in the laboratory, two ratios, 1:50 and 1:100, which were most effective at suppressing *T. macfarlanei* in the shortest possible time, were selected for the field study. There were three treatments in the experiment, including the control. The cucumber crop was raised in the field at Zonal Agricultural Research Station, GKVK, Bengaluru, following all the standard agronomic practices. In the experiment, three rows were arranged, each comprising 15 isolated cucumber plants that served as 15 replicates. The cucumber variety used was Suchitra 45, a popular variety among farmers around Bengaluru. The crop was sprayed with the selective insecticides imidacloprid and flubendiamide at their recommended field dosages to control sucking and chewing insects during the crop growth period. Because there was no natural infestation of spider

mites on the crop, the cucumber plants were artificially infested with the laboratory-maintained spider mite *T. macfarlanei*@30 mites/leaf at twenty days after the sowing. The spider mites were allowed to establish themselves on the crop. The predatory mites were released at a predator-prey ratio of 1:50 to 15 plants in a row fifteen days after the introduction of the prey mites, and in another row of 15 plants, the predators were released at a 1:100 predatory-prey ratio. The third row was left without releasing the predators to serve as the control. The predatory mites in both treatments were allowed to multiply on the prey mites. Observations of the total number of prey mites on cucumber plants were noted down at five-day intervals until all the prey mites were exhausted or their number reached a minimum threshold. For recording observations, one leaf from each cucumber plant was collected, and in the laboratory, the total number of mites present on the entire leaf was counted under a Zeiss Stemi 2000C stereo zoom microscope. By multiplying by the total number of leaves on each plant, the total number of prey mites per plant was calculated. The per cent reduction in prey mites over the control for both predatory: prey ratios were calculated using the formula suggested by Henderson and Tilton (1955). Following the release of the predatory mites, data was analyzed on the total number of prey mites observed and the percentage reduction over the control at various intervals.

RESULTS AND DISCUSSION

Determination of the effective predator–prey ratio for controlling the spider mite *T. Macfarlanei*

A total of five treatments were used in the laboratory study to determine the effective predator-prey ratio required to control the spider mite *T. macfarlanei* on cucumber plants by releasing the predatory mite *N. longispinosus*. The treatments include four predator-prey ratios of 1:25, 1:50, 1:100, and 1:200 on excised cucumber leaves in plastic trays, with no predators serving as the control treatment. The data recorded on the mean number of prey and predatory mite eggs+active stages on cucumber leaf bits in trays at 2, 4, 6, 8, 10, and 12 days after the predatory mites were released are given in Table 1 and depicted in Fig. 2.

In the scenario where predatory mites were introduced at predator-prey ratios of 1:25, predatory mite populations increased steadily until the eighth day and the peak population was marked on the same day. In treatments with predator–prey ratios of 1:50 and 1:100, there was a

Table 1. Influence of the predator:prey ratio on the populations of *Tetranychus macfarlanei* (prey mite) and *Neoseiulus longispinosus* (predator) on cucumber leaf discs in the laboratory

Predator: prey ratio	Mean number of *T. macfarlanei* after predator release (eggs + active stages)						Mean number of *N. longispinosus* after predator release (eggs + active stages)					
	DAY 2	DAY 4	DAY 6	DAY 8	DAY 10	DAY 12	DAY 2	DAY 4	DAY 6	DAY 8	DAY 10	DAY 12
1:200	308.50^{a} (17.55)	315.75^{a} (17.75)	246.00^{b} (15.66)	192.75^{b} (13.87)	107.25^{b} (10.34)	60.25^{b} (7.73)	3.75^{c} (2.06)	7.25^{c} (2.78)	9.00^{d} (3.08)	19.50^{d} (4.47)	21.50^{d} (4.68)	32.25^{a} (5.72)
1:100	189.75^{b} (13.78)	164.50^{b} (12.83)	120.00^{c} (10.93)	71.25^{c} (8.38)	33.00^{c} (5.62)	8.00^{c} (2.38)	6.00^{c} (2.53)	10.50^{c} (3.31)	12.75^{c} (3.64)	27.50^{c} (5.29)	28.75^{c} (5.41)	32.00^{a} (5.68)
1:50	155.75^{b} (12.45)	109.50^{c} (10.42)	80.25^{cd} (8.92)	43.00^{cd} (6.51)	4.50d (2.03)	0.00^{c} (0.71)	13.50^{b} (3.73)	24.25^{b} (4.96)	26.75^{b} (5.21)	40.00^{b} (6.36)	37.75^{b} (6.18)	20.25^{b} (4.54)
1:25	139.75^{b} (11.84)	88.50^{c} (9.42)	61.50^{d} (7.86)	18.75^{d} (4.37)	0.00^{d} (0.71)	0.00^{c} (0.71)	21.25^{a} (4.66)	35.50^{a} (6.00)	38.25^{a} (6.22)	61.00^{a} (7.84)	46.75^{a} (6.87)	19.75^{b} (4.46)
Control	336.50^{a} (18.35)	383.75^{a} (19.60)	559.00^{a} (23.64)	647.75^{a} (25.45)	608.00^{a} (24.66)	483.00^{a} (21.98)	0.00^{d} (0.71)	0.00^{d} (0.71)	0.00^{e} (0.71)	0.00^{e} (0.71)	0.00^{e} (0.71)	0.00^{c} (0.71)
F Test	**	**	**	**	**	**	**	**	**	**	**	**
SEM ±	0.45	0.47	0.52	0.52	0.50	0.53	0.12	0.13	0.12	0.11	0.11	0.24
CD (P=0.05)	1.37	1.41	1.56	1.56	1.52	1.60	0.35	0.38	0.37	0.34	0.35	0.72

Values within columns with the same alphabetical superscript are not significantly different (P=0.05).
The figures in parentheses are square root-transformed values.
** indicates significance (@ P=0.01)

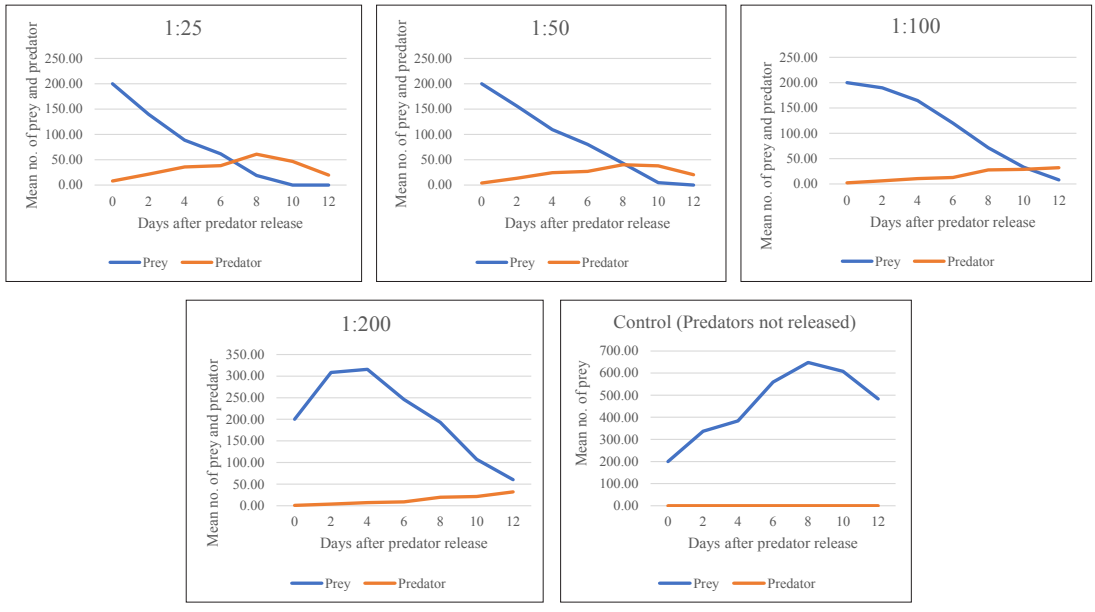

Fig.1. Influence of predator: prey ratio on the population of *Tetranychus macfarlanei* and *Neoseiulus longispinosus* eggs+ active stages on cucumber leaves in the laboratory

continuous increase in the predatory mite population until 8 and 12 days respectively. Subsequently, the population of predatory mites became stable without any further increase because of the non-availability of prey mites (Fig. 2).

In treatment 1:200, a persistent decline in the prey mite population was observed from day 2 to day 12 after the initial release of predatory mites. However, effective reduction of the prey mite population was not achieved even beyond day 12.In the control, the prey mites were allowed to multiply without the interference of predatory mites and the prey population consistently rose for the first 8 days, after which it slightly declined. This reduction can be attributed to limited available space for mite establishment and insufficient nutrient support in the leaf substrate for sustaining prey mite culture.

Determination of the effective predator-prey ratio for controlling the cucumber spider mite *T. macfarlanei* in the field

The predatory mite *N. longispinosus* was released at two predator-prey ratios on cucumber plants infested with the spider mite *T. macfarlanei* in the field to determine the effective predator–prey ratio. Considering the feasibility of mass production as well as its effectiveness in suppressing the prey population in the shortest possible time, two predator–prey ratios, 1:50 and 1:100, among the four ratios tested in the laboratory, were taken to the field to test their effectiveness. These two treatments, along with a control (treatment without releasing predatory mites), were tested in the field after releasing *N. longispinosus* on *T. macfarlanei*-infested cucumber plants. The cucumber plants were artificially infested with the prey mite *T. macfarlanei* on a 20-day-old cucumber crop. The predatory mites were released 15 days after infestation with the prey mites at ratios of 1:50 and 1:100 in the first two treatments. The third treatment served as a control in the absence of predatory mites.

Observations of the total number of prey mites per leaf and per plant at 5, 10, 15, and 20 days after the predator release are given in Table 2 and Table 3, respectively.

Table 2: Mean no. of prey mites/leaf on different days after the release of predators

Predator: prey ratio	Before release	5 DAR	Per cent reduction over control (%)	10 DAR	Per cent reduction over control (%)	15 DAR	Per cent reduction over control (%)	20 DAR	Per cent reduction over control (%)
1:100	217.00	307.10	0.42	244.20	47.05	124.10	81.05	6.40	99.30
1:50	212.63	265.10	12.27	182.70	59.57	78.60	87.75	1.80	99.80
Control	232.90	331.00	-	495.00	-	702.80	-	974.80	-

Table 3: Mean no. of prey mites/plant on different days after the release of predators

Predator: prey ratio	Before release	5 DAR	Per cent reduction over control (%)	10 DAR	Per cent reduction over control (%)	15 DAR	Per cent reduction over control (%)	20 DAR	Per cent reduction over control (%)
1:100	7694	10831	11.42	9110	51.48	4753	83.63	258	99.36
1:50	7622	9956	17.81	7274	60.89	3193	88.46	80	99.80
Control	7842	12463	-	19137	-	28479	-	41007	-

There was a continuous decline in the number of prey mites at both predator-prey ratios from 5 to 20 days after the predatory mites were released. A continuous decrease in the number of prey mites per plant was noticed for both predator-prey ratios from 5 to 20 days after the release of predatory mites (Fig. 3).The percentage reductions in the prey population, relative to the control population, exhibited a discernible ascending trend commencing five days post-release, indicating a consistent trend of multiplication with respect to predator-prey ratios. (Fig. 4).Furthermore, at a predator-prey ratio of 1:50 as opposed to 1:100, the rate of decline in the prey mite population was higher. Nonetheless, by 20 days following the introduction of the predatory mites, the percentage decrease in the prey population compared to the control population surpassed 99% for both predator-prey ratios, indicating the effectiveness of both ratios in controlling prey mites within 20 days after the predatory mites were released. In contrast, there was a continuous rise in the population of prey mites in the control.

RESULTS AND DISCUSSION

The efficacy and optimum predator-prey ratio of predatory mites, *N. longispinosus,* for controlling red spider mites, *Oligonychus coffeae* Neither, in infesting tea were studied by Rahman *et al.* (2011). They found that predator-prey ratios of 1:33 and 1:50 were effective in the laboratory, and a 1:25 ratio was found to be effective in the greenhouse. These authors showed that *N. longispinosus* could be used as a successful biocontrol agent for *O. coffeae* in tea through augmentation. In the present study, complete control of the prey mite

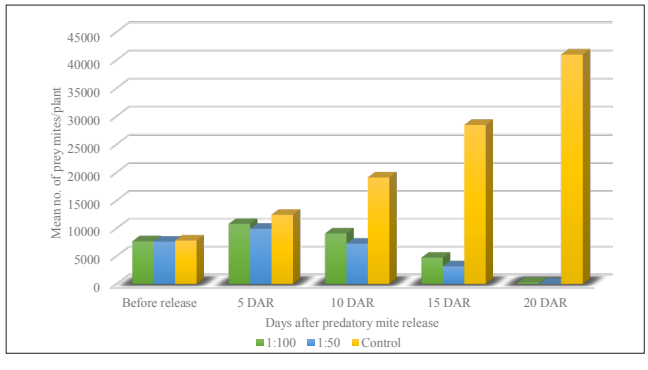

Fig. 2 Effect of predator: prey ratio on the population of *T. macfarlanei* (prey) on cucumber plants in the field

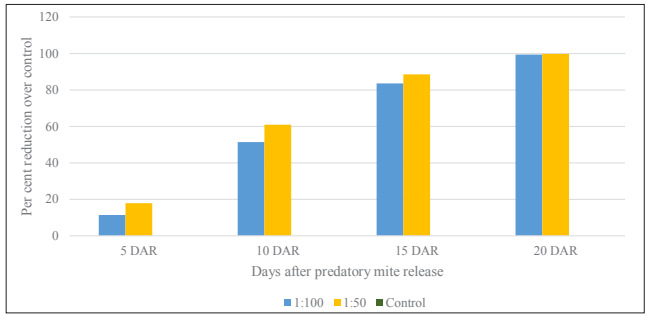

Fig. 3 Effect of predator: prey ratio on the population reduction of *T. macfarlanei* (prey) on cucumber plants in the field

T. marfarlanei was achieved rapidly at 1:25 and 1:50 predator-prey ratios within 10 and 12 days after the predatory mites were released. The small changes in the duration of complete control of spider mites may be attributed to changes in the prey mite species and the plant host. Nevertheless, the consistent rise in the population of predatory mites over the course of 12 days post-release is attributed to prolonged access to prey mites within the 1:200 ratio. The findings by Mondal *et al.* (2020) underscore that the extended longevity of *N. longispinosus* on *T. macfarlanei* renders the prey mite a conducive host for the predator.

The results of the study conducted by Rao *et al.* (2017) indicated that the release of *N. longispinosus* at predator-prey ratios of 1:10, 1:20, and 1:30 could indicate the rapid multiplication of *Tetranychus urticae* Koch, but the plants that received a predator-prey ratio of 1:50 had a greater number of spider mites (40.56/cm^2) with a low pooled mean reduction of 20.62%. In contrast, the results of the present study showed that a predator-prey ratio of 1:50 was the most effective for controlling *T. macfarlanei* on cucumbers in the field. Narrow ratios were not evaluated in this study since they are not cost-effective for farmers to utilize in the field. In the present study, ratios for the field study were determined after completing the laboratory trials.

Lenin and Bhaskar (2019) studied the efficacy of *N. longispinosus*in managing *T. urticae* on cucumbers under laboratory and polyhouse conditions. The results of these studies showed that prey mites were eliminated by the seventh and tenth days at predator-prey ratios of 1:5 and 1:10, respectively, and at wider ratios ranging from 1:20 to 1:100, total elimination of the prey population was not achieved up to ten days after predator release, but there was a significant reduction in the prey population. A study conducted by Rahman and Azariah (2011) also indicated the proficiency of 1:33 and 1:50 ratios under laboratory conditions, while 1:25 was effective in polyhouse conditions. The population of predatory mites in 1:25 after day 8 reached satiation because of the non-availability of prey mites indicating Holling's type II model (Holling, 1959; Ibrahim and Rahman, 1997).However, due to economic considerations, the recommendation of a 1:25 ratio for field conditions was deemed impractical, hence the ratios 1:50 and 1:100, along with a control (treatment without releasing predatory mites), were tested in the field and are proved effective.In a study akin to ours conducted by Ibrahim *et al.* (2006), they observed a 98.70% reduction in *T. urticae* after introducing *Neoseiulus cucumeris* (Oud.) on cucumber over two months. In our current investigation, we achieved a noteworthy 99% reduction in *T. macfarlanei* population in less than a month, underscoring the prowess of *N. longispinosus* as a highly effective predator in the Indian context.

CONCLUSION

The current investigation aims to establish the effectiveness of *N. longispinosus* in managing the spider mite, *T. macfarlanei*. While numerous studies have underscored the potential of this predator, the majority have been conducted in laboratory settings, with a few in polyhouses. This study marks the initial effort to deploy *N. longispinosus* for *T. macfarlanei* control in open field conditions. Despite several limitations in the field experiment, it represents the first successful endeavor in employing *N. longispinosus* to combat this troublesome mite. Future research should concentrate on standardizing commercial aspects such as the packaging and field release of predators. This is a challenging task due to the obligate nature of the predator, and addressing this challenge will be crucial for advancing the application of *N. longispinosus* in pest control.

ACKNOWLEDGEMENT

We would like to extend our sincere thanks to the All-India Network Project on Agricultural Acarology (AINPAA) for providing the necessary logistics and research facilities for conducting this study. Their support has been invaluable in enabling us to carry out our research efficiently and effectively. We also express our gratitude to the staff of AINPAA for their assistance and cooperation during the course of this research.

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MS Received: 27 August 2024
MS Acceptance: 10 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 271-275 (2024)
DOI Number : 10.5958/0974-4541.2024.00038.4

Fruit fly species diversity in selected fruit crops in Andhra Pradesh, India

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ABSTRACT: A study to document the diversity of fruit fly species infesting selected fruit crops *viz.,* mango, guava, custard apple and ber in Rayalaseema region of Andhra Pradesh was conducted at College of Horticulture, Anantharajupeta during 2023-24. Random collection of infested fruit samples through roving survey in potential crop growing areas of Annamayya, Ananthapuramu, Chittoor and Nandyal districts of Rayalaseema was done for rearing and further species identification. The study revealed that infestation of three major fruit fly species *viz*., *Bactrocera dorsalis*, *Bactrocera zonata* and *Bactrocera correcta* in these crops. In four districts, highly predominant species in all these crops is *B.dorsalis* with infestation percentage ranging from 45-64.7, followed by *B. correcta* (20.0-31.42%) and *B. zonata* (11.66-33.33%). In ber crop, it was found that, there is complete displacement of ber fruit fly, *Carpomyia vesuviana*, a monophagous species by genus *Bactrocera*. This displacement may be due to wide host range and adaptability of *B. dorsalis* complex in fruit crops. This is also a first report on ecological species displacement of Carpomiya vesuviana by Bactrocera dorsalis complex in ber crop from Andhra Pradesh.

Keywords: Fruit flies, species, mango, ber, custard apple, guava

INTRODUCTION

India's varied climate supports the growth of a wide range of fresh fruits and vegetables. It is the second largest fruit producer globally, following China. The country generates 11.21 MMT of fruits from an area of 7.05 Mha. Uttar Pradesh and Madhya Pradesh lead in guava and ber production with 983.59 t and 121.76 t, respectively while, Andhra Pradesh ranks fourth and fifth in ber and guava production, contributing 335.11 t and 59.30 t, respectively (NHB, 2022)

Mango, *Mangifera indica*, (Anacardiaceae) often called as the "King of Fruits," is a key fruit crop in India. Guava (*Psidium guajava*), also known as the "Apple of the Tropics" or "Poor man's apple," is another significant fruit. Custard apple (*Annona squamosa*) is an edible tropical and arid fruit also called "Sugar apple." Ber (*Zizyphus mauritiana*) is also an arid fruit with nutritional properties known as "Indian jujube, Red dates, Indian plum and Korean date". Despite high production levels, significant losses occur in these fruit crops due to several factors. Abiotic stresses like extreme temperatures (both hot and cold), water shortages, soil salinity, and heavy metal contamination contribute to various levels of yield losses. Additionally, insects pests as biotic factors also hinders the production.

Fruit fly infestations cause substantial yield losses in mango, guava, and ber, sometimes reaching up to 65-80% (Jena *et al.* 2022). Similarly, in custard apple losses can range from 25-50% if harvested at the mature ripe stage, with losses potentially increasing upto 80% during severe infestations (Math *et al.,* 2017).

Bactrocera dorsalis, a major fruit fly species attacks over 300 cultivated and wild fruit crops compared to the other species. It's damage levels range upto 80% in mango, 50% in guava and 58-70% in custard apple fruits (Choudhary *et al.,* 2017). *Bactrocera correcta* (Bezzi, 1916), another major species affecting over 70 types of fruits and melons across 35 plant families in tropical and subtropical areas. Key hosts include guava, mango, cashew, cherry, jujube, orange, banana, carambola, and wax apple. In Northern India, guava is heavily infested by fruit fly species, *B. zonata*, *B. dorsalis*, and *B. cucurbitae*. In contrast, *B. correcta* has emerged as a significant threat in South India, potentially causing up to 80% damage. (Jana and Idris (2020).

Ber, *Ziziphus mauritian* is a tropical fruit crop. The crop is being infested by several pests, which, include the fruit fly (*Carpomyia vesuviana* Costa), Meridarchis scyrodes Meyr, chafer beetle (*Holotrichia consanguinea* Blanch), and bark-eating caterpillars (*Indarbela tetraonis* Moore and *I. quadrinotata* Walker) (Karuppaiah *et al.,* 2015; Haldhar *et al.* (2016a). Among them fruit fly, *Carpomyia vesuviana* Costa, is the most severe threat to the ber trees. This fruit fly species was noted as monophagous pest specifically targets *Zizyphus species* in arid and semi-arid regions of Oriental Asia, including India, the Middle East, Temperate Asia, China, and Southern Europe (He *et al.,* 2010). Lakra (1998) reported

six species of fruit flies, *Corpomyia vesuviana* Costa, *Caprpmoyia zizyphae* Agarwal & Kapoor, *Bactrocera dorsalis* Hendel, *B. correcta* Bezzi, *B.zonata* Saunders and *Bactrocera spp*. on ber in India.

MATERIALS AND METHODS

The study was carried out at the College of Horticulture, Anantharajupeta, and the Horticultural Research Station, Ananthapuramu, Dr. YSR Horticultural University, located in Southern Agro climatic Zone of Andhra Pradesh, at an elevation of 162 MSL, 13.980° N latitude and 79.400° E longitude. The fruit collection for species diversity studies was done through roving survey method, which was carried out during 2023-24 across multiple farmer fields in the Ananthapuramu, Nandyal, Chittoor and Annamayya districts within the Rayalaseema region of Andhra Pradesh.

Fifty fly infested ber fruits (two seasons Nov 2023 and June 2024) and twenty mango, custard apple and guava fruits each were collected from each farmer's field. These fruits were brought to the laboratory at the COH, Anantharajupeta, where they were placed in plastic tubs containing 5-10 cm deep layer of sand, later these plastic tubs were placed in rearing cages (25 x 25 x 25 cm). Within 3-4 days, the mature maggots inside the fruits pupated in sand mixture. The newly formed pupae were then collected and transferred to plastic bottles (12 x 6 x 8 cm) with sand to allow adult fly emergence. Adult flies began to emerge within 8-9 days. Once the flies are emerged, they were fed by placing cotton swabs soaked in a 10% honey solution inside the bottles for two days, which facilitated the sclerotization and body coloration process. The reared flies were collected with a fine camel brush and were segregated based on their district of collection, killed and stored in 70% ethyl alcohol solution for further taxonomic studies.

RESULTS AND DISCUSSION

Fruit fly species identification was done using microscope (10x, 40x magnification), through the taxonomic keys given by Billah *et al.* (2009) and David and Ramani (2011). Further, samples collected from different districts were sent to NBAIR, Bengaluru for confirmation. From the study three species *viz., Bactrocera dorsalis*, *Bactrocera correcta* and *Bactrocera zonata* were identified and scientifically documented based on the following taxonomical and morphological characteristics of their head, thorax, wings and abdomen.

***Bactrocera dorsalis* (Hendel):** Adult fly is bigger than a housefly. Males measuring 5-6.5 mm in length, while females 5-6.7 mm.

Head: Head with reduced chaetotaxy, lacking ocellar and post cellar setae. First flagellomere was atleast three times longer than breadth. Face yellowish marked with a dark round spot in each antennal furrow.

Thorax: The scutum is mainly black, with the exception of lateral yellow vittae, and yellow postpronotal lobe and notopleurae. The scutellum, on the other hand, is entirely pale in color, although occasionally it may have a narrow black line across the base. Additionally, it possesses anterior supra-alar setae and prescutellar acrostichal setae.

Wings: Vein Sc abruptly bent forward at nearly $90^{0,}$ beyond this bend and ending at subcoastal break. Costal margin of the wing is with a distinct colored band from the end of vein Sc to just beyond the end of vein $R_{4+5.}$ Cross veins r-m and dm-cu without a complete covering of microtrichia.

Legs: All femora are fulvous, with the apices of the femora exhibiting a red-brown coloration.

Abdomen: All tergites are distinct and separate from each other. Tergite 5 is characterized by a pair of slightly depressed areas. In males, there is a row of setae called pectin on each side of tergite 3. Abdominal tergites 3 to 5 feature a prominent black 'T'-shaped mark, while the postpronotal lobes lack any setae.

***Bactrocera correcta* (Bezzi):** Often termed as the 'guava fruit fly', this adult fly is a vividly colored small insect, measuring approximately 5-5.5 millimeters in length.

Head: The face features a pair of elongated black spots arranged transversely, nearly meeting at the center to form a black band. The third antennal segment is notably three or more times longer than its width.

Thorax: The mesonotum is primarily black, yet the central part is adorned with gray pubescence, featuring three faint narrow black vittae. Adjacent to these, there are two broad lateral yellow post-sutural vittae. Notably, there is no medium vitta present. The scutellum is yellow in color, with a narrow black band at its base.

Wings: The fore wings are transparent, with a discontinuous or extremely narrow costal band extending from R_{2+3} to the apex, where it expands into a spot. There's a small oval dark brown spot across the apex of R_{4+5}. The subcoastal cell appears yellow, with a faint hint of yellow

along the costal margin at the apex of cell R_1. Additionally, there's a narrow brown spot at the lower apex of cell R_3 and the upper apex of cell R_5. The cubital cell faintly shows yellow, with no developed cubital streak.

Legs: Predominantly yellow, hind tibiae exhibit a notable keel-like protrusion on the posterior dorsal surface just before the apex.

Abdomen: The abdomen displays a reddish-brown coloration on the dorsal side, with black basal markings on terga 2 and 3, and a central black stripe extending from terga 3 to 5. Tergum 5 bears a pair of black oval spots, while tergum 3 features a pectinate structure. The sterna of both sexes are uniformly yellow.

***Bactrocera zonata* (Saunders):** The adult fly, approximately the size of a housefly, exhibits a predominantly red-brown hue and measures between 5 to 6 millimeters in length.

Head: Face reddish in color with big oval brownish black- facial spots in the antennal furrow.

Thorax: Thorax with reddish brown scutum and two parallel sided post sutural vittae which are yellow in color extending posteriorly to the level of intra-alar setae. Scutellum yellow colored with narrow black basal band with a pair of prescutellar bristles.

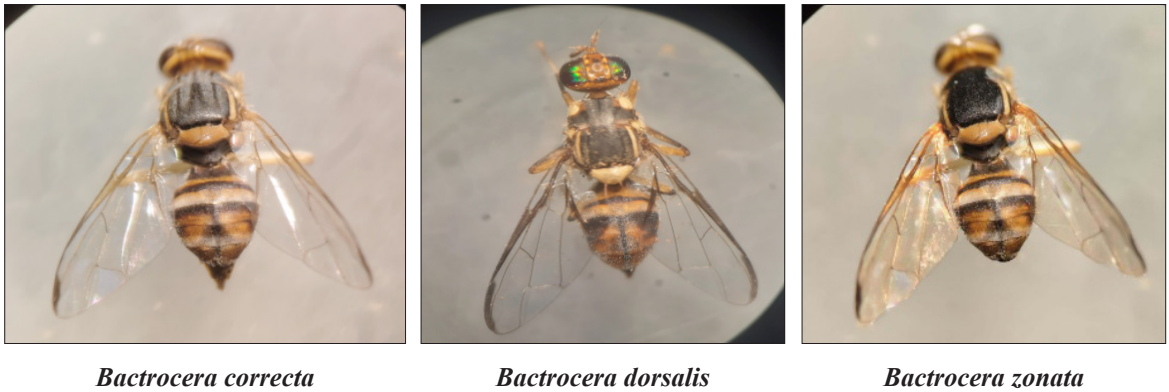
Wings: The fore wings exhibit a costal band, which may be either discontinuous or include an extremely narrow section distal to the apex R_{2+3} before expanding into a narrow isolated spot at the wing apex. A raised area is observed in the narrow basal part of the wing cell, lacking microtrichia. Notably, there is an absence of an "anal streak," characterized by the lack of a diagonal colored band across the base of the wing aligned with cell bcu.

Legs: All femora are fulvous, with the apices of the femora exhibiting a red-brown coloration.

Abdomen: Typically, there exists a pair of dark marks on tergite 3, with no medial dark line except for tergite 5. Males possess a pecten on tergum 3.

Table 1: Fruit fly species composition of various fruit crops in different districts of Rayalaseema region

Crop	District	Fruit fly species (%)		
		B. dorsalis	***B. correcta***	***B. zonata***
Mango	Annamayya	58.18	25.45	16.36
	Chittoor	64.70	23.52	11.76
Guava	Annamayya	45.0	21.67	33.33
	Chittoor	51.6	20.0	28.4
Custard apple	Ananthapuramu	56.25	22.91	20.83
	Nandyal	45.71	31.42	22.85
Ber	Ananthapuramu	57.69	26.92	15.39
	Nandyal	60.0	28.33	11.66



Bactrocera correcta ***Bactrocera dorsalis*** ***Bactrocera zonata***

Fig.1. Adult flies of different fruit fly species

***Bactrocera correcta* elongated black spots arranged transversely**

***Bactrocera dorsalis* with big dark round facial spots**

***Bactrocera zonata* with oval brownish-black facial spots**

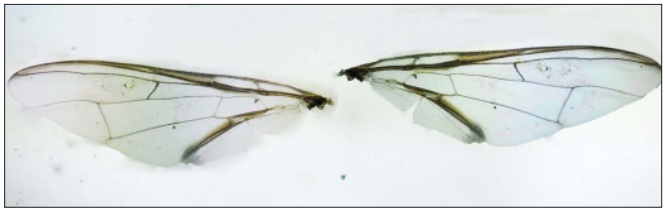
Fig.2. Head with facial spots in different fruit fly species

***Bactrocera correcta* with black basal markings on terga 2 and 3**

***Bactrocera dorsalis* with prominent black 'T'-shaped mark**

***Bactrocera zonata* with no medial dark line except for tergite 5**

Fig.3. Structure of abdomen in different fruit fly species



***Bactrocera dorsalis* with distinct colored band from end of vein Sc to end of vein R_{4+5}**

***Bactrocera zonata,* lacking microtrichia and absence of an anal streak.**

***Bactrocera correcta* with extremely narrow costal band, where it expands into a spot with microtrichia**

***Bactrocera correcta* hind tibia with keel like process**

Fig.4. Wing characters of different fruit fly species

CONCLUSION

Three fruit fly species are found, affecting fruits of mango, guava, ber, and custard apple crops in four Rayalaseema districts *viz*., Ananthapuramu, Chittoor, Nandyal, and Annamayya. These species differ in few taxonomic and morphological characters, presence of complete costal band on the R_{2+3} vein at the wing apex in *Bactrocera dorsalis;* smaller size, black in coloration, with transverse black facial spots forming a band across face and a distinctive keel-like structure on its hind tibiae in *Bactrocera correcta*. *Bactrocera zonata* is characterized by its discontinuous costal band on wings, with a pair of prescutellar bristles in thoracic region. Within the four districts, the most predominant species in all these crops is *B. dorsalis* with infestation percentage ranging from 45- 64.7, followed by *B. correcta* (20.0-31.42%) and *B. zonata* (11.66-33.33%). However, in ber there is no record of *Carpomyia vesuviana* in two seasons collections, though it is a monophagous pest of ber. The complete displacement of *Carpomyia vesuviana* by *Bactrocera dorsalis* complex in ber crop was found. This is also a first report on ecological species displacement of *Carpomyia vesuviana* by *Bactrocera dorsalis* complex in ber crop from Andhra Pradesh.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. YSR Horticultural University for providing liberal research facilities and finance.

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MS Received: 21 September 2024
MS Acceptance: 5 December 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 276-282 (2024)
DOI Number : 10.5958/0974-4541.2024.00051.6

Seasonal occurrence and management of litchi fruit and shoot borer, *Conopomorpha sinensis* (Bradley)

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ABSTRACT: A field trial was conducted consecutively for two years at ICAR-National Research Centre on Litchi, Mushahari, Muzaffarpur; Bihar, india to study the population build-up, compute yield losses caused by litchi fruit and shoot borer, *Conopomorpha sinensis* (Bradley) and its management through newer insecticides. Initial presence of litchi fruit & shoot borer was noticed in 13th standard week (5.33 pupae/ 10 shoot) and maximum number of pupae (9.33 pupae/10 shoot) were observed in 15th standard week. Negative correlation was observed with T_{Max} while positive correlation was observed with T_{Min} and RH (%) for population build-up of litchi fruit & shoot borer. Fruit bearing was maximum (33.17/ shoot) with 10% level of infestation and minimum (10.00 fruits) at 80% level of infestation against 40.33 fruits in control. Fruit retention at harvest stage was maximum (21.00) with 10% level with minimum 2.00 fruits at 100% level against 27.33 fruits in control. Mean weight of infested fruit was 17.35g against 24.33g of healthy fruit. At harvest stage, minimum fruit infestation (0.33%) was observed in two treatments namely,spinosad 45 SC (1.75 ml/5l) and flubendiamide 39.35 SC (1.5 ml/5l) followed by spinetoram 11.7 SC (1ml/l) with 0.67 % infestation against 12.33 in control. Thus, newer insecticide molecules, namely spinetoram, flubendiamide, novaluron 5.25% +indoxacarb 4.5%, Triazophos 35 %+ deltamethrin 1% EC and spinosad can be incorporated against litchi fruit & shoot borer management programme.

Keywords: Litchi fruit & shoot borer, *Conopomorpha sinensis*, seasonal incidence, insecticides, pest management

INTRODUCTION

Litchi, *Litchi chinensis* Sonn is a commercial fruit crop of India, also considered as the queen of the subtropical fruits due to its eye-catching pink/red colours and flavoured juicy aril. The fruit has high nutritive value and excellent pulp (aril) quality known for its characteristics flavor and taste (Kumar *et al*. 2015). Additionally, litchi is gaining more momentum among the farmers due to its adoptability in integrated farming system (IFS) module, particularly in low lying areas (Kumar *et al*. 2014, Patel *et al*. 2020_a, Patel *et al*. 2020_b). This important crop is attacked by various insect pests which cause considerable damage resulting in reduced yield and marketability of fruits (Srivastava *et al*. 2015_a). Among them litchi fruit and shoot borer (*Conopomorpha sinensis* Bradley; Lepidoptera: Gracillariidae) is a major pest, responsible for infestation at different crop phases *viz*., leaf/shoot (09-70%) and fruit (25-60%), resulting severe economic loss (Srivastava *et al*. 2016). The insects (larvae) damage the newly emerged shoot during September- October resulting in failure of shoot to bloom. Further, it punctures the peduncle of fruits (both developing as well as mature) during April-May resulting to heavy loss through early fruit drop and appearance of excreta/larvae, when fruit is cut/opened after ripening (Reddy *et al*. 2016, Srivastava *et al*. 2018).Eco-friendly insect pest management is crucial for achieving sustainable food production. Several environmentally conscious and sustainable approaches to pest control should be prioritized to protect crops while minimizing negative impacts on pollinator bees and beneficial organisms. These methods include the use of botanicals (Divekar *et al.,* 2022; Divekar *et al.,* 2024), host plant resistance (HPR) (Divekar *et al.,* 2019), plant secondary metabolites (Divekar *et al.,* 2022), bio-control agents (Divekar P. 2023; Shinde *et al*., 2021), defense proteins (Divekar *et al.,* 2023), and safer chemical control options (Kodandaram *et al.,* 2024).

The population build-up pattern and computation of the yield losses are the two major prerequisites for scheduling a successful IPM programme. Additionally, to overcome the ill effects of conventional insecticides *viz*., resistance to insecticide, outbreak of secondary pests, harmful to non-target organisms, health hazards and problems related to environmental pollution; newer molecules with selective action, safer to non-target

organisms and environmentally sound may be explored to protect this important cash crop. Therefore, series of experiments were carried out during 2018-19 to 2019-20 to study the population build-up pattern, effect of different level of infestation on fruit retention and fitness of safer/newer insecticides against *Conopomorpha sinensis* Bradley.

MATERIALS AND METHODS

Present study was conducted at experimental farm of ICAR-National Research Centre on Litchi, Muzaffarpur, Bihar (latitude and longitude of 26°5'87"N and 85°26'64" E, respectively at altitude of 210m asl) during 2018-19 to 2019-20.

Study the population build-up of litchi fruit & shoot borer during fruiting season: To study the population build-up of litchi fruit & shoot borer during fruiting season 30 shoots and/or fruits were selected randomly from selected trees and brought to the laboratory. The samples were equally distributed and put in three different jars having mouth covered with muslin cloth. The jars containing 10 fruits and/or shoots were kept in the BOD till the pupa emerged from the sample or the specimens dried completely. Daily observations were recorded where presence of pupa was considered as infestation. Total no. of pupae from each jar was used for data analysis.

Computation of losses caused by litchi fruit & shoot borer: The losses caused by litchi fruit & shoot borer, differentlevels of infestation (0.00 to 100%) caused by the ~~pest~~ were identified by conducting trial in Randomized Block Design (RBD) at ICAR-NRCL Research Farm. With in treatment five units of each sample were considered as one replication. Observations were recorded on panicle length (cm), panicle diameter (cm), panicle paracladia (no.), fruit lets at initial stage (no.) and fruit retention at harvest stage (no.). At harvest stage, ten healthy and ten infested fruits were brought to the laboratory for analysis. Observations on fruit weight, peel weight, pulp weight and seed weight were recorded to quantify the loss caused by litchi fruit & shoot borer.

Study the efficacy of newer insecticides against litchi fruit & shoot borer: A separateexperiment was conducted in RBD with 6 treatments and four replications *viz*., T_1- Spinetoram 11.7 SC (0.012%); T_2- Flubendiamide 39.35 SC (0.012%); T_3- Novaluron 5.25 % +Indoxacarb 4.5 % SC (0.0098%); T_4- Triazophos 35 %+ Deltamethrin 1% EC (0.072%); T_5- Spinosad 45 SC (0.016%) and T_6- Control (without spray) to evaluate the efficacy of various insecticides against litchi fruit & shoot borer in cv. Shahi. One foliar spray of neem-based formulation was given at the time of panicle emergence before flowering to avoid egg laying by the moth. Three sprays of all the insecticides were applied at different interval during April-May. First spray was given at clove size fruit, second spray at cardamom size fruit (after fifteen days of first spray) while third spray was given at 10 days after second spray (about 15 days before harvest). Spraying was done on outer as well as inner canopy in all the direction on the tree with the help of power sprayer having hollow cone nozzles. Observations were recorded based on damaged fruit at early stage, mid stage and harvesting stage. To observe the borer infestation at early stage (clove size fruit) and mid stage (cardamom size fruit), the fallen fruits were collected from each treatments and cut/open with the help of sharp knife. At fruit maturity, 100 fruits from each treatment were plucked randomly for recording observation. The peduncle of harvested fruit was removed and presence of larva or their excreta was considered as infested fruits (Srivastava *et al*. 2017). The damage was assessed based on the weight of total number of fruits and damaged fruits in the different treatments and the percent damage was worked out.

The data was analysed statistically using statistical software SPSS version16.0. Data recorded were compared by the means of critical differences at five per cent level of significance in field studies.

RESULTS AND DISCUSSION

Population build-up of litchi fruit & shoot borer during fruiting season: The incidence of litchi fruit & shoot borerwas recorded from the standard week 11th to 22nd and observations were correlated with weather data. The first presence of litchi fruit & shoot borer was noticed in 13th standard week (5.33 pupae/ 10 shoot) and maximum number of pupae (9.33 pupae/10 shoot) were observed in 15th standard week. An increasing trend was observed in population build-up of fruit & shoot borer up to 15th standard week followed by decreasing has been noticed with minimum population (1pupa/10 fruit) during 22nd standard week (Figure-1). In relation to weather parameters negative correlation was observed with $T_{Max,}$ while positive correlation was observed with T_{Min} and RH (%) for population build-up of litchi fruit & shoot borer (Table 1). It is clear from the data recorded during the cropping season, that the weather parameters have established relation with the incidence of fruit & shoot borer. The moderate temperature (32.80-32.84°C) coupled with high humidity (80.00%) have positive

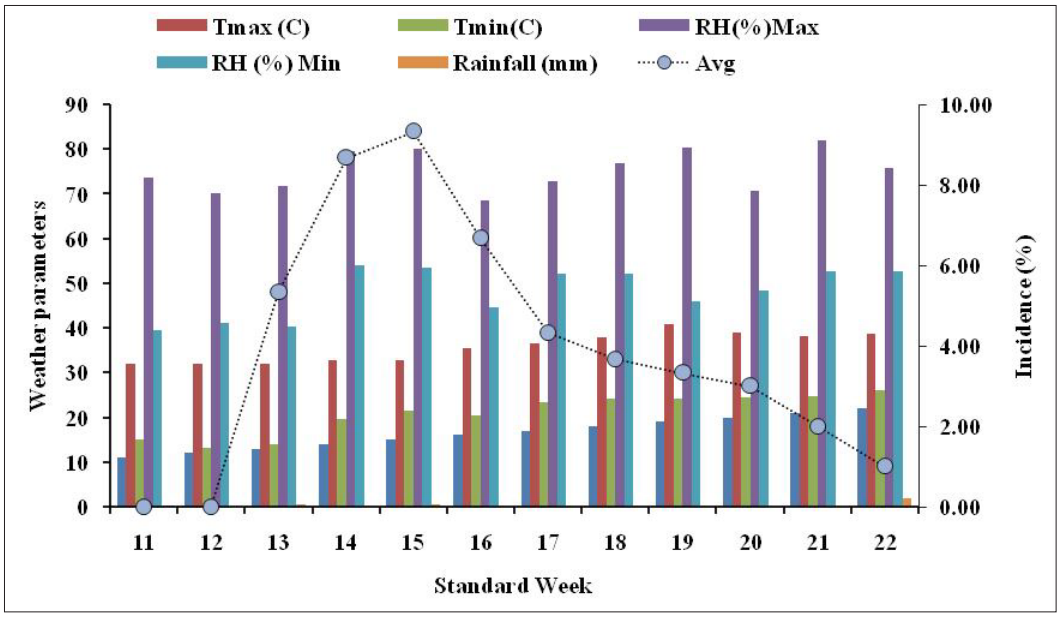

Fig.1. Relationship of weather parameters with incidence of litchi fruit & shoot borer

Table 1: Effect of weather parameters on the incidence of litchi fruit & shoot borer during the fruiting season

Parameters	Equation	R^2 Value
T_{max} vs Incidence	y = -0.216x + 11.68	R^2 = 0.045
T_{min} vs Incidence	y = 0.145x + 0.746	R^2 = 0.040
RH (%) $_{Max}$ vs Incidence	y = 0.003x + 3.704	R^2 = 0.9E-05
RH (%) $_{Min}$ vs Incidence	y = 0.083x + 0.003	R^2 = 0.046
Rainfall (mm) vs Incidence	y = 0.116x + 3.907	R^2 = 0.000

correlation with population build up of litchi fruit & shoot borer. The weather factors are responsible for the population upsurge of fruit & shoot borer in the field conditions. But, other environmental factors were also been responsible for the incidence. Similar to our findings, Srivastava *et al.* (2017) also reported that occurrence of intermittent rains during fruit growth and development, which might have created the congenial environment for borer survival resulting higher borer population than usual days. From present study it may be concluded that intermittent rains favors population increase of fruit & shoot borer and temperature also plays crucial role. Presence of larvae in shoot/ panicle was noticed up to 16th standard week, after which it was shifted to fruit, clearly showed that pest preferred fruit over shoot/panicle. This study gives preliminary information which needs to be further intensifying with detailed observations, field biology and simulation studies. Less infestation of litchi fruit & shoot borer was noticed during study period due to non favorable climatic conditions for population build-up of pest.

Computation of losses caused by litchi fruit & shoot borer: Effect of different level of infestation (0-100%) caused by fruit & shoot borer are presented in Table-2. Data clearly showed that, there is no significant difference on infested panicle length of litchi shoots caused by fruit & shoot borer. However, maximum infested panicle length (45.67cm) was observed with 20% infestation level followed by 30% level of infestation with 41.33 cm panicle length along with minimum 35.30cm infestation due to 90% level of infestation against 45.70cm healthy panicle length in control (0.00% infestation level). However, significant effect was observed on panicle diameter due to fruit & shoot borer infestation. Maximum panicle diameter (0.49 cm) was noticed with 10 % level of infestation followed by 0.48 cm diameter with 20 % level of infestation and minimum (0.39 cm) due to 60 % level of infestation against 0.52 cm diameter in control (0.00 % infestation level). Further, in case of paracladia study no significant effect of infestation level was observed due to fruit & shoot borer infestation. Maximum no. of paracladia (16.00) was recorded with 50 % level of

Table 2: Effect of different level of fruit & shoot borer infestation on panicle size and fruit retention in litchi

Level of infestation	Mean of panicle length (cm)	Mean of panicle diameter (cm)	Mean of panicle paracladia (no.)	Fruit retention at initial stage (no.)	Fruit retention at harvest stage (no.)
100 %	36.93	0.42	15.67	12.33	2.00
90 %	35.30	0.40	13.33	15.33	5.67
80 %	36.60	0.40	14.00	10.00	2.67
70 %	37.43	0.41	14.33	14.00	4.67
60 %	37.43	0.39	15.67	15.00	3.67
50 %	35.70	0.41	16.00	28.17	8.33
40 %	40.43	0.47	14.00	29.00	10.67
30 %	41.33	0.46	15.33	30.83	12.00
20 %	45.67	0.48	15.67	30.00	15.00
10 %	40.20	0.49	15.00	33.17	21.00
0 %	45.70	0.52	16.00	40.33	27.33
SEm (±)		0.025		0.39	1.53
CD (P=0.05)	**NS**	0.075	**NS**	1.15	4.54

Table 3: Effect of infestation of litchi fruit borer on weight of fruit components in litchi

Parameters (mean of 10 fruits)	Fruit weight (g)	Peel weight (g)	Pulp weight (g)	Seed weight (g)
Healthy	24.33	2.74	17.51	4.08
Infested	17.35	2.39	11.33	3.63
SE (Healthy)	1.88	0.24	0.24	0.08
SE (Infested)	0.95	0.04	1.05	0.11

infestation followed by 15.67 paracladia was observed at three different level of infestation (100, 60 and 20% level of infestation) with minimum paracladia (13.33) at 90 % level of infestation against 16.00 paracladia in control. In case of fruit bearing potential, a significant difference was recorded at different level of infestation due to fruit & shoot borer (Table 2). At early stage Maximum no. (33.17 fruits/panicle) of fruit bearing was noticed with 10 % level of infestation followed by 30.83 fruits with 30 % level of infestation along with minimum (10.00 fruits) due to 80 % level of infestation against 40.33 fruits in control. A precise mark difference on fruit retention at harvest stage was noticed at different level of infestation. Maximum no. of fruits (21.00) were observed with 10 % level of infestation followed by 15.00 fruit due to 20% level of infestation with minimum 2.00 fruits at 100 % level of infestation against 27.33 fruits in control (no infestation.). No. of fruit retention increased with decreasing the level of infestation is due to less fruit drop in healthy panicle/shoot.Moreover, as per accessible literature no such work has been conducted so far and therefore, to compute yield losses and establish Economic Threshold Level (ETL) against litchi fruit & shoot borer a series of experiments may be conducted.

Effect of fruit & shoot borer infestation on weight of fruit components were examined in the laboratory (Figure-2). Results clearly demonstrate that fruit borer reduce the fruit weight. Mean weight of infested fruit was 17.35 g against 24.33 g of healthy fruit. Similarly,

Table 4: Efficacy of newer insecticides against litchi fruit borer & shoot borer

Treatments details	Fruit infestation (%)			Yield (kg/ tree)
	Early stage	Mid stage	Harvest stage	
T_1- Spinetoram 11.7 SC (0.012%)	0.67 (4.58)	0.67 (4.58)	0.67 (4.58)	48.67 (44.22)
T_2- Flubendiamide 39.35 SC (0.012%)	1.33 (6.47)	0.33 (3.29)	0.33 (2.65)	50.00 (44.98)
T_3- Novaluron 5.25 % +Indoxacarb 4.5 % SC (0.0098%)	0.33 (3.29)	0.00 (0.00)	1.33 (6.47)	49.00 (44.41)
T_4- Triazophos 35 %+ Deltamethrin 1% EC (0.072%)	3.00 (9.96)	0.67 (4.69)	1.00 (5.68)	49.33 (44.60)
T_5-Spinosad 45 SC (0.016%)	0.00 (0.00)	0.00 (0.00)	0.33 (3.29)	50.33 (45.17)
T_6-Control	5.67 (13.73)	9.33 (17.78)	12.33 (20.54)	41.00 (39.80)
SEm (±)	0.73	0.13	0.20	1.25
CD (P=0.05)	1.56	0.67	0.81	4.00

*values in parenthesis are angular transformed

pulp weight of healthy fruit was also significantly more (17.51 g) against weight of infested fruit (11.33). However, no significant difference was noticed on peel weight while, healthy fruit registered less weight (2.74 g) against 2.39 g of infested fruit. Correspondingly to peel weight, no significant difference was observed with seed weight, as weight of healthy fruit seed was 4.08 against 3.63 g of infested ones (Table-3). Therefore, based on above findings it may be concluded that fruit & shoot borer considerably reduces the bearing potential of the litchi tree as well as reduce the fruit weight.

Study the effect of newer insecticides against litchi fruit & shoot borer: All the treatments significantly reduced the fruit borer infestation in comparison to control during the period of experimentation. No infestation was observed in treatment with spinosad 45 SC (0.016%) which is closely followed by novaluron 5.25 % +indoxacarb 4.5 % SC (0.0098%)with 0.33 % infestationat early stage against 5.67 in control (Table - 4). At mid stage, 0.00 population was observed in both the treatments [spinosad 45 SC (0.016%); novaluron 5.25 % + indoxacarb 4.5 % SC (0.0098%) followed by flubendiamide 39.35 SC (0.012%)) with 0.33 % infestation against 9.33 in control. At harvest stage, minimum infestation (0.33%) was observed in two treatments namely spinosad 45 SC (0.016%) and flubendiamide 39.35 SC (0.012%) followed by spinetoram 11.7 SC (0.012%) with 0.67 % infestation against 12.33 in control. The results are in line with the findings of Srivastava *et al*. (2017) who recorded minimum (2.23%) litchi fruit borer infestation with novaluron 0.015% against 16.90 % in control. Field efficacy of IGRs, spinosad and flubendiamideare quite effective in regulating lepidopteran pests at very low doses due to their advance chemistry, good persistence and novel mode of action. (Srivastava *et al.,* 2004, Sreedhar 2019). Additionally, insecticidal combinations with different properties such as nature and action, are more effective against target pests (Reddy *et al.,* 2018). Further, these molecules are less hazards as comes under green umbrella as per toxicity level and therefore, safer to natural enemies and environment while spraying in field (Tohnishi *et al*., 2005, Srivastava *et al.,* 2007). Similarly, Srivastava *et al.* (2015b) also reported flubendiamide, chlorantraniliprole, neonicotinoids and pyrethroids are highly effective against lepidopteran pests of litchi. The results are also in line with the findings of Srivastava *et al.* (2016) who reported that the three spraying of flubendiamide and/or thiacloprid or chlorantraniliprole at recommended dose kept the litchi fruit & shoot borer infestation below threshold level and care other insect pests too.

From this study, it can be concluded that intermittent rains favors population build-up of fruit & shoot borer and temperature also plays crucial role. Further, fruit & shoot borer considerably reduces the bearing potential of the litchi tree as well as reduce the fruit weight. Newer molecules, namely spinetoram, flubendiamide, novaluron 5.25 % +indoxacarb 4.5 %, Triazophos 35 %+ deltamethrin 1% EC and spinosad may be incorporated against litchi fruit & shoot borer management programme.

ACKNOWLEDGEMENTS

The authors are thankful to Director, ICAR-NRC Litchi, Muzaffarpur, for providing the necessary facilities required to carry out present investigation.

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MS Received: 05 October 2024
MS Acceptance: 25 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 283-287 (2024)
DOI Number : 10.5958/0974-4541.2024.00052.2

Entomopathogenic nematode (EPN), *Heterorhabditis indica* proved effective against mango stem borer, *Batocera rufomaculata* De Geer

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ABSTRACT: Laboratory and field studies were conducted at ICAR- Indian Institute of Horticultural Research, Bengaluru, India during 2020-23 to evaluate the efficacy of native strains of two species of entomopathogenic nematodes (EPN), *viz*., *Heterorhabditis indica* and *Steinernema carpocapsae* against larvae of mango stem borer, *Batocera rufomaculata* De Geer (Coleoptera: Cerambycidae). Bioassay studies revealed the virulence of all five strains tested and based on the LC_{50} value (10.72), *H. indica* (IIHR-2) was selected to be the most effective one and further evaluated under *in vivo* and field conditions. Similar efficacy levels were recorded when it was tested against larvae reared on drumstick twigs to simulate natural habitat of stem borer larvae. Finally, IIHR-2 strain of *H. indica* was evaluated under field conditions by injecting the EPN suspension into the trunks of mango trees infested with stem borer. An insecticide treatment was maintained as a standard check. The EPN has resulted in 81.72% reduction in stem borer damage by larvae of *B. rufomaculata* compared to 90.80% with insecticide. Though it was marginally lower that chemical treatment, considering the merits of non-chemical treatments to the environment and sustainable crop management, EPN can be recommended as an effective component of stem borer management. This is the first insight into establishing the efficacy of EPN against mango stem borer, *B. rufomaculata* under laboratory and field conditions.

Keywords: Entomopathogenic nematode, *Heterorhabditis*, mango, stem borer, *Batocera rufomaculata*

INTRODUCTION

Stem borers of the genus *Batocera* (Coleoptera: Cerambycidae) are one of the serious pests of mango in India (Veeresh, 1989). Among different species reported, *Batocera rufomaculata* De Geer is the most destructive and frequently found borer in mango orchards. Besides mango, it attacks fig, jackfruit, mulberry, papaya, apple, etc. (Butani, 1979; Tandon and Verghese, 1985). Generally the older trees of more than fifteen year old or those already weakened from other causes, either pathological or environmental, are more vulnerable to attack by stem borers. The damage in mango ranges from 5-25% and up to 40% damage was also recorded under high density planting. If not managed in time, stem borer can kill an entire productive plant thus causing huge economic losses. In the recent past, stem borer infestation has been increasing in all major mango belts across the country (Reddy and Rashmi, 2022). Female beetle lays eggs singly on the main trunk of relatively older mango trees. After hatching from the egg, the neonate larva initially feeds under the bark. The larvae feed through the sapwood and make tunnels of about 2-3 cm width which interfere with sap flow and affect foliage and production. Normally the attack goes unnoticed till a branch or two start shedding leaves and drying up. A hole with dripping sap, and chewed plant tissues and frass either extruding from bark or fallen on the ground around trunk are symptoms visible in advanced stages of infestation. The damage results in yellowing of branches followed by drying and die back of terminal shoots and branches ultimately leading to the death of whole tree (Butani, 1979).

In order to kill the grub inside the stem/trunk, injecting an insecticide into stem is a widely followed practice. Insecticide is either injected directly or a cotton dipped in insecticide solution is inserted into active holes and plugged with mud (Reddy and Shivananda, 2021). Dichlorvos was the most widely used chemical for stem injection. However its use was prohibited by the Government of India with effect from 31 December 2020 for its adverse effects on non target organisms and environment (vide Notification S.O. 3951(E) dated 08.08.2018 of the Gazette of India). Being cryptic in nature, managing trunk borers is a challenging task. Keeping in view the growing interest in organic or chemical free crop production, it was felt that identifying a safer and sustainable alternative would be ideal and entomopathogenic nematodes are an option.

Entomopathogenic nematodes (EPN) have considerable potential as biological control agents of a number of cryptic insect pests (Kaya, 1985; Arthers *et al*., 2004) and several strains of *Heterorhabditis* spp.

showed activity against Coleopteran insects (Fallon *et al.*, 2004; Chandel *et al.,* 2005; Nagesh *et al.,* 2006). Rapid host mortality is the most desirable feature of EPN thus reducing the extent of insect damage to crops (Kaya and Gaugler, 1993). The EPNs have symbiotic relationships with bacteria that are species specific. On locating a host insect, they enter through the natural openings as well as by rupturing the insect cuticle to finally reach the haemocoel (Gaur and Mohan 2005). Infected insects are often flaccid, and turn colour to orange, yellow or brown or a brownish-red to brick red. The EPNs have a potential in inundative and inoculative releases and with little adverse effects on environment and non-target organisms (Bathon, 1996). Considering the need of a safer means to manage stem borer in mango, present study was undertaken to evaluate native strains of EPN against mango stem borer.

MATERIALS AND METHODS

Laboratory and field studies were conducted at ICAR-Indian Institute of Horticultural Research, Bengaluru during 2020-23 to evaluate the efficacy of native strains of EPN against larvae of mango stem borer, *B. rufomaculata*.

EPN Cultures

Four native strains of *Heterorhabditis indica* (IIHR 1,2,3 and 4) and one strain of *Steinernema carpocapsae* (IIHR-1) isolated from the fields of ICAR-IIHR, Bengaluru were maintained at the Nematology Laboratory, ICAR – IIHR, Bengaluru. The EPN strains were cultured on the final instar larvae of greater wax moth, *Galleria mellonella* as per Woodring and Kaya (1998). Using white traps, the emerging infective juveniles (IJ) were harvested within three days of first emergence and viable EPN were tested under laboratory conditions against the grubs of mango stem borer. Based on the efficacy recorded under laboratory bioassay studies, they were taken forward for further testing on lab host and ultimately in the field.

In vitro bioassay of EPN strains against mango stem borer:

The EPN suspension containing infective juveniles (IJ) of five strains including four of *H. indica* and one strain of *S. carpocapsae*) (Table 1) was applied @ 0, 10, 50 and 100 IJs per larva on double layer of moistened filter paper kept in a petridish. Second instar larvae of *B. rufomaculata* from the lab culture being maintained at the Entomology laboratory of ICAR-IIHR were used for testing. Ten larvae were exposed to each concentration by releasing one larva in each petri plate with EPN treated filter paper. Larvae were observed for mortality after 72h of exposure. The LC_{50} was calculated for all strains based on per cent mortality in different concentrations.

In vivo evaluation against stem borer larvae reared on lab host

The strain-2 of *H. indica* selected based on bioassay studies was evaluated for its bioefficacy against third and fourth instar larvae of *B. rufomaculata*. The stem borer, *B. rufomaculata* was reared on the laboratory host, drumstick, as per the procedure standardized by Reddy and Varun Rajan (2021). The solution of EPN was injected into drumstick twigs @ 10^4 IJs per hole containing lab cultured larvae of stem borer. Generally twigs with stem borer grubs exhibit symptoms of damage through droppings of excreta and chewed plant tissues around twig. Efficacy of EPN was ascertained by observing the feeding symptoms daily till they were stopped or otherwise. When dropping of chewed stem tissues in powder form were completely stopped, it was considered that larvae died and hence feeding was stopped. These were compared with untreated twigs (Fig. 1B). There were five twigs with one larva inside each for treated and untreated conditions.

Field Evaluation

After ascertaining the efficacy under laboratory conditions, the strains were tested under field conditions. For this, 12 mango trees of about thirty year old (cv. Alphonso) with active stem borer infestation were selected in 2021-22 and 10 trees in the following year 2022-23. This variation was due to limited availability of borer infested trees. The suspension of EPN (10 ml) was injected into stem borer holes on mango tree trunks @ 10^4 IJs/hole (Fig. 2A). After injecting EPN suspension, holes were plugged with mud. The treatment was done two times at five days interval. Though only one application was given, it was repeated in the field as precise location of larvae inside trunk is not known and to increase the chance of insect coming in contact with the EPN suspension. Insecticide solution (imidacloprid 17.8 SL diluted with water @ 10 ml/L) was also injected into other 10 trees as standard check. Six infested trees were maintained as untreated control. Two trees were considered as one replication. Borer chewed plant tissues and excreta dropped on the ground around the trunk of all trees under testing were removed daily from the day treatment was imposed and were observed for one week. In case of EPN treated trees, they were observed for one week after second application. Wherever fresh droppings were stopped, it was considered as borer larvae were

Table 1. Virulence of different strains of EPN against mango stem borer, *B. rufomaculata* recorded in bioassay

EPN Strain	$X^2_{(n-2)}$	b	SE	LC_{50}	Lower limits	Upper limits
H. indica (IIHR strain 1)	1.86	7.13	0.60	16.72	13.92	19.24
H. indica (IIHR strain 2)	1.33	4.28	0.87	10.72	7.55	12.97
H. indica (IIHR strain 3)	0.19	5.76	1.13	12.05	9.82	13.79
H. indica (IIHR strain 4)	2.84	2.74	0.38	18.20	10.32	30.79
Steinernema carpocapsae (IIHR strain 1)	6.32	3.66	0.54	13.41	10.34	15.99

dead due to treatment. The number of trees where fresh damage was stopped out of total treated was recorded and per cent protection was calculated. The significance of difference was tested through ANOVA at 5% level of significance.

RESULTS AND DISCUSSION

Bioassay studies

All the five tested strains of EPNs had caused 100 per cent mortality of grubs of *B. rufomaculata* under *in vitro* conditions. Completely deformed and colour changed larvae were observed after 72 h of exposure (Fig. 1A). This gave an indication that the strains of both the species of EPN used were effective against stem borer grubs. However their virulence varied and the LC_{50} values of five strains ranged from the lowest 10.72 with *H. indica* (IIHR-2) to the highest 18.20 of H. indica (strain 4) (Table 1). Based on these values, *H. indica* (IIHR-2) was identified as the most virulent one and taken forward for *in vivo* and field evaluation. Earlier, Fallen *et al.* (2006) reported up to 58% mortality of larvae of a Cerambycid, Cottonwood borer, *Plectrodera scalator* (Fabricius) caused by EPN in filter paper bioassays.

In vivo evaluation of EPN using a lab host of stem borer

When the suspension of EPN *H. indica* (IIHR-2) was injected into drumstick twigs containing stem borer larvae, there was complete cessation of feeding in eight twigs which accounted to 80% control of borer damage. It was ascertained by cut opening and observing the larvae inside the drumstick twig after a week. On contrary, larvae continued feeding and developed into adult in untreated twigs. Efficacy of EPNs *viz*., *Heterorhabditis bacteriophora* and *Steinernema carpocapsae* against longicorn beetle was established through similar studies by Sharifi et al. (2014) against the rosaceae longhorned beetle, *Osphranteria coerulescens* who found that, EPNs were able to penetrate and reproduce within *O. coerulescens* larvae. They used apricot tree branches, where both species of EPN penetrated into the larval galleries and located and killed the larvae of *O. coerulescens* in their natural habitat deep inside the branches. Present findings are also on similar lines where strain of *H. indica* was capable of reaching to larvae of *B. rufomaculata* inside drumstick twigs. This outcome has led to further field studies to evaluate their potential under the environmental conditions in which *B. rufomaculata* larvae are found on mango.

A. Dead larvae in bioassay

B. Treated and untreated drumstick twigs with larvae feeding inside

Fig. 1. Laboratory evaluation of EPN against stem borer, *B. rufomaculata*

Field evaluation

Data presented in table 2 reveal that both EPN and insecticide treatment had significantly reduced the borer infestation. Out of 12 trees treated with EPN suspension, larval feeding inside the trunk was stopped in 10 trees in 2021-22, and eight trees out of 10 trees in 2022-23. This equates to a mean reduction of 81.72 per cent in borer damage. Effect of EPN on borer larvae was further confirmed by extracting larvae and observing for symptoms of EPN infection (Fig. 2B). In case of insecticide treatment, borer feeding was stopped in 11 trees out of 12 and 9 trees out of 10 in 2021-22 and 2022-23 respectively which accounts for 90.80 per cent reduction. Though the efficacy of insecticide treatment was marginally but significantly higher (90.80%) than EPN treatment (81.72%), considering the merits of non-chemical treatments to the environment and sustainable crop management, EPN can be recommended as an effective component of stem borer management. This is an encouraging result as in some cases, the efficacy of EPNs recorded under bioassay tests could not be sustained under field conditions (Fallen *et al.,*2006).

Based on the findings of our study, it can be summerized that stem injection of EPN suspension of *H. indica* (IIHR-2) is effective in significantly bringing down stem borer, *B. rufomaculata* damage in mango. Further large scale multiplication and multilocation testing would help in taking forward this technology as a safe and sustainable component of integrated pest management of mango. This is the first insight into establishing the efficacy of EPN against mango stem borer, *B. rufomaculata* under laboratory and field conditions.

A. Stem injection of EPN suspension **B. Dead larvae infected by EPN**

Fig. 2. Field evaluation of EPN against stem borer, *B. rufomaculata* in mango

Table 2. Effect of stem injection of entomopathogenic nematode, *H. indica* on damage caused by stem borer, *B. rufomaculata* in mango

S. No.	Treatment	2021-22		2022-23		Mean per cent protection
		No. of trees treated	No. trees where larval feeding stopped	No. of trees treated	No. trees where larval feeding stopped	
1.	EPN (*H. indica*)	12	10	10	8	81.72
2.	Imidacloprid 17.8 SL (Std. check)	12	11	10	9	90.80
3.	Untreated Control	6	0	6	0	0.00
	S. Em ±					1.71
	CD (p = 0.05)					5.36

ACKNOWLEDGEMENT

Authors thank the Director, ICAR-Indian Institute of Horticultural Research, Hesaraghatta Lake, Bengaluru for providing facilities and support to the study.

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MS Received: 15 September 2024
MS Acceptance: 20 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 288-292 (2024)
DOI Number : 10.5958/0974-4541.2024.00043.0

Biology and morphometrics of cocoa mealy bug, *Planococcus lilacinus* (Cockerell)

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ABSTRACT: Investigation on the biology of Cocoa mealy bug, *Planococcus lilacinus* was carried out at College of Agriculture, Navile, UAHS, Shivamogga during 2016-17 and study revealed that the fecundity of mealy bugs ranged from 130 to 288 eggs per female with mean±SD of 216.5±47.17. Female mealy bugs had only three instars, while the males had four instars. Total nymphal duration ranged from 16 to 24 days with mean±SD of 20.17±3.52. The total life cycle of the female mealy bug, *P. lilacinus* ranged from 27 to 41 days and that of males ranged from 20 to 32 days with mean±SD of 33.83±5.54 and 26.22±5.79, respectively.

Keywords: Cocoa mealy bug, biology, fecundity, instars, life cycle

INTRODUCTION

Cocoa is the third important beverage crop next to coffee and tea, and is the third highest traded commodity in the world. Cocoa is the dried and fully fermented fatty seed of the Cocoa tree from which chocolate is made. "Cocoa" can often also refer to the drink commonly known as hot chocolate. This Cocoa has several constraints for attaining its maximum yield potential, which include the problem of pest and diseases, nutritional imbalance, water stress etc. Among these problem of pests would bring about loss in the yield to the greater extent. Though over 150 different insects are known to feed on Cocoa, only about 2 per cent are of economic importance. However, when Cocoa is introduced into a new area, a previously unrecorded pest almost invariably attacks it. Mirid bugs such as *Helopeltis antonii* Signoret, *H. bradyii* Waterhouse are the most significant and widely occurring insect pests of Cocoa. The Cocoa pod borer and mealy bugs are the major pests in South East Asia. Mealy bugs are generally not only major pest themselves, but are well known vector for viruses that are known to transmit Cocoa swollen shoot virus (Strickland, 1951). Mealy bugs are one of the destructive insect pests and damage a wide range of horticultural and agricultural crops such as Cocoa, Coffee, Guava, *Solanum* spp, citrus (Bodenheimer, 1951). There have been about 175 genera belonging to 74 families of mealy bugs described so far (Ben-Dov, 2007). But a few are known to cause more severe damage. Many species of mealy bugs (Hemiptera: Pseudococcidae) have become serious invasive pests when introduced into new areas beyond their native (or natural) distribution (Miller *et al*., 2002). *Planococcus lilacinus* Cockrell is polyphagous and is common in southern Asia where it attacks fruit trees and is often important on coffee in southern India. About ten species of mealy bugs are known to attack Cocoa crop (Campbell, 1983). There exists a sexual dimorphism in mealy bugs. Females pass through three nymphal instars and males will undergo four nymphal instars (Babu and Azam, 1987). There are no concentrated research studies on biology of cocoa mealy bug. Hence, the present research on biology of Cocoa mealy bug, *Planococcus lilacinus* (Cockerell) was undertaken.

MATERIALS AND METHODS

Collection and maintenance of culture

The laboratory experiment was conducted in the Department of Agricultural Entomology, College of Agriculture, Navile, UAHS Shivamogga. Biology of the pest was carried out on tender Cocoa pods collected from the Cocoa plants in the field. The maximum and minimum temperatures during the study period were 27.25 °C and 18.2 °C, respectively. The relative humidity morning (RH-I) and evening (RH-II) were 60.5 and 32.6 per cent, respectively.

To know the biology of mealy bug, *P. lilacinus* on Cocoa, small healthy tender pods were brought from the field and washed thoroughly with wet cotton to remove dirt and other particles on the pods. The egg mass and neonate crawlers identified in the field were brought to the laboratory (Vennila *et al*., 2010) and were released on fresh mature pod to establish pure culture, and were kept undisturbed until they attain adult stage. The full grown adult females and fourth instar males were collected and released separately on fresh cocoa pods for further studies.

Pre-oviposition period, Fecundity and Incubation period

To study the pre oviposition period we released a pair of male and female mealybugs on each pod in replications.

They were observed for the appearance of the ovisacs (mass of eggs). Later, the period up to the formation of first ovisac was considered as pre-oviposition period which was covered by cottony woolly mass.

In the above set of experiment after noting the pre oviposition period, the adult females were undisturbed and left for production of ovisacs. The ovisacs from individual females were taken separately and were observed under microscope for the number of eggs until the end of their fecundity period.

Twenty freshly laid eggs from ovisacs were collected and placed separately on tender pods with the help of Camel hair brush into the petri plates containing fresh pods. The period between egg laying to egg hatching was taken as the incubation period.

Duration of different stages

After the eggs hatched into nymphs, the duration of different nymphal instars from first to third instar nymphs was recorded by observing the moulted skin at the end of each instar (Satpute *et al*. 2011). After the end of third instar, they were observed for the presence of wing buds. If the wing buds were found, they were designated as males (Maheshkumar and Balikai, 2009), otherwise as females. Longevity of adult male and female was recorded. The morphometric data, length and width of the mealy bugs at each instar was observed with ocular lens fixed to the microscope. The weather parameters like relative humidity and temperature during the rearing period were recorded.

RESULTS AND DISCUSION

Pre-oviposition period, oviposition period and fecundity

The pre-ovipositional period of *P. lilacinus* ranged from 4 to 7 days with an average of 5.50 ± 1.41 days during summer season. Oviposition period ranged from 5 to 8 days with an average of 6.33 ± 1.22 days (Table 1). Our results were nearly similar to the results obtained by Maheshkumar and Balikai (2009) where the pre-oviposition period of *M. hirsutus* on pumpkin ranged from 6 to 7 days with an average of 6.4 ± 0.56 days.

The ovisacs from individual females were taken and were observed under microscope for the number of eggs in each ovisac until the completion of their oviposition period where each female individual laid eggs in ovisacs and sometimes in group of batches. The fecundity ranged from 130-288 eggs per female with an average of 216.5 ± 47.17 eggs (Table 1). Some females also reproduced parthenogenetically and such females produced first instar nymphs directly. Previous findings of Babu and Azam (1987) showed that *Maconellicoccus hirsutus* laid minimum of 114 eggs and maximum of 509 eggs. The parthenogenetic reproduction which was observed in our experiment was in line with the prior findings of Vennila *et al*. (2010) who reported that parthenogenesis was also dominant in cotton mealy bug, *Phenacoccus solenopsis*. Parthenogenetically reproduced females showed dynamic patterns of fecundity where in the number of crawlers per female ranged from 128 to 812 with a mean of 344 ± 82.

The fresh laid eggs were translucent yellowish or light yellow in colour. They were elongated and oval in shape. The translucent eggs became pinkish yellow in colour towards hatching. The incubation period of cocoa mealy bug varied from 3-5 days in the month of February with an average of 4.05 ± 0.86 days (Table 1). The results of Mani (1986) showed that, the average incubation period for grape mealy bug was 5.15 days and our results are quite close to their findings.

Table 1. Pre-oviposition period, fecundity and incubation period of *Planococcus lilacinus*

Pre-oviposition period		Oviposition period		Fecundity		Incubation period	
Range (days)	Mean±SD (days)	Range (days)	Mean±SD (days)	Range (Eggs/female)	Mean ±SD	Range (days)	Mean±SD (days)
4-7	5.50±1.41	5-8	6.33±1.22	130-288	216.5±47.17	3-5	4.05±0.86

Duration of nymphal period at different nymphal instars of *Planococcus lilacinus*

Nymphal stage	1st instar	2nd instar	3rd instar	4th instar (only male)	Total nymphal period
Range (days)	3-5	3-5	7-10	3-4	16-24
Mean ± SD (days)	4.40±0.49	4.16±0.50	8.11±1.83	3.5±0.70	20.17±3.52

Number of sample, n=20

Duration of nymphal stages

The results on duration of different nymphal instars on Cocoa pod observed during the experimental period are represented in Table 1. It was observed that females had only three instars while the males had four instars. The present results are in agreement with the previous findings of Seni and Sahoo (2011) who investigated the biology of mealy bug, *Rastrococcus iceryoides* (Green) on Citrus, and recorded that the female and male nymphs moulted thrice and four times, respectively. Satpute *et al*. (2011) also reported that the female mealy bugs of *P. solenopsis* had three nymphal instars whereas the males possessed a pupal stage.

Soon after the hatching of eggs, the first instar nymphs became translucent yellowish in colour, and after a day they turned to pinkish yellow. The neonate nymphs (a day old crawlers) were oval in shape and they were highly motile with diagonally held antennae. The nymphal duration of first instar ranged from 3 to 5 days with an average of 4.40 ± 0.49 days (Table 1). The mean length of first instar nymph ranged from 1.0 to 1.65 mm with an average of 1.44 ± 0.29, and the body width ranged from 0.57 to 0.93 mm with an average of 0.68 ± 0.08 (Table 2). Towards the end of first instar, the crawlers colour started turning pinkish white and were slow in movement.

Table 2. Morphometric data of Cocoa mealy bug, *Planococcus lilacinus*

Insect stage	Mean length (mm)		Mean width (mm)	
	Range	Mean ± SD	Range	Mean ± SD
1st instar	1.0-1.65	1.44±0.29	0.57-0.93	0.68±0.08
2nd instar	2.25-3.12	2.87±0.35	1.18-1.72	1.48±0.16
3rd instar	4.64-6.75	5.61±0.61	2.40-3.14	2.71±0.26
4th instar (male)	3.0-3.10	3.05±0.07	1.02-1.11	1.06±0.65
Adult female	7.0-8.84	7.94±0.75	2.75-4.10	3.76±0.92
Adult male	3.5-3.8	3.65±0.21	2.15-2.20	2.17±0.12

Number of sample, n=20

The second instar nymphs were larger in size than first instar nymphs and the body was pinkish in colour with appearance of white with waxy secretions on the body. It was sluggish and became stationary on some part of the pod. The duration of second instar nymph ranged from 3 to 5 days with a mean of 4.16 ± 0.50 days. The body length ranged from 2.25 to 3.12 mm with an average of 2.87±0.35. The body width ranged from 1.18-1.72 mm and the average was 1.48±0.16 (Table 2). The second instar nymph was pinkish in colour with mealy matter covering all over the body and settled at one place.

Soon after the moulting of second instar nymph, the third instar mealy bug increased its size and the duration of third instar nymph (last instar for female) lasted for longer time compared to other instars for 7 to 10 days and the average was 8.11 ± 1.83 (Table 1). Their mean body length ranged from 4.64 to 6.75 mm, with an average of 5.61±0.61. Similarly the body width ranged from 2.40 to 3.14 mm and the average was 2.71±0.26 (Table 2).

Fourth instar nymph was observed only in males. Since the male to female ratio in mealy bugs is very high, fewer males were found. Fourth instar period ranged from 3 to 4 days with an average of 3.5 ± 0.70. There was gradual reduction in the size of the males in this stage where the mean length ranged from 3.0 to 3.10 mm and average was 3.05 ± 0.07. The width ranged from 1.02-1.11 with a mean of 1.06 ± 0.65 (Table 2). The fourth instar had the small wing buds visible under stereomicroscope and mealy matter covered fully in the posterior region.

The present results on duration of different nymphal instars are in line with the earlier findings of Muthulingam and Vinobaba (2013) who reported that the nymphal duration of *P. solenopsis* lasted for an average of 3.24 ± 2.11, 4.75 ± 3.28, 5.20 ± 0.45 days for first, second and third instars, respectively. They also noticed that males had four instars as compared to females, which had only three instars.

Total nymphal duration ranged from 16 to 24 days and the average duration was 20.17 ± 3.52 days (Table 1). Tanwar *et al*. (2007) carried out the biology of *M. hirsutus,* and reported that the total nymphal duration of mealy bugs lasted for 22–25 days. Seni and Sahoo (2011) who worked on the biology of Citrus mealy bug, *R. iceryoides* (Green) reported that the female and male nymphs moulted thrice and four times, in 18-24 days and 16-22 days, respectively.

Adult longevity

After completion of the third instar, the newly formed adult females were large and the body was soft, distinctly segmented and settled completely at one place. Three thoracic and ten abdominal segments were clearly visible in spite of mealy matter covering the body. The head was covered with white mealy secretions. Adult males had a pair of antennae and a pair of wings, with reddish black abdomen. From the end of the abdomen, a pair of thread like filaments arised, which were clearly visible under the microscope. The longevity of adult female ranged from 8-12 days with a mean of 9.61 ± 1.16 days and for adult male it was 1-3 days with a mean of 2.0 ± 1.41 days (Table 3). Satpute *et al*. (2011) reported that the range of longevity of an adult female as 10 to 13 days on cotton twigs per leaves. Muthulingam and Vinobaba (2013) reported that, the longevity of males of *P. solenopsis* ranged from 1 to 2 days with an average of 1.5 ± 0.5 days.

Table 3. Total life cycle of *Planococcus lilacinus* on Cocoa pod

Insect stage		Range (days)	Mean ± SD (days)
Incubation period		3-5	4.05 ± 0.86
Nymphal stage		16-24	20.17 ± 3.52
Adult longevity	**Female**	8-12	9.61 ± 1.16
	Male	1-3	2.0 ± 1.41
Total Life cycle	**Female**	27-41	33.83 ± 5.54
	Male	20-32	26.22 ± 5.79

Total life cycle

The total life cycle of the female mealy bug, *P. lilacinus* ranged from 27-41 days with a mean of 33.83 ± 5.54. Total life span of the male mealy bug was in the range of 20-32 days with an average of 26.22 ± 5.79 days (Table 3). These results were in accordance with the previous findings of Muthulingam and Vinobaba (2013) who found that total life cycle of cotton mealy bug ranged from 23 to 30 days with an average of 27.41 ± 1.10 days. Varikou *et al*. (2010) also reported the mean total developmental time from egg to adults for females of *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) on table grape leaves as 39.87 days at 30 °C.

CONCLUSION

Present study revealed that the fecundity of mealy bugs ranged from 130 to 288 eggs per female. Female mealy bugs had only three instars, while the males had four instars. Total nymphal duration ranged from 16 to 24 days. The total life cycle of the female mealy bug, *P. lilacinus* ranged from 27 to 41 days and that of males ranged from 20 to 32 days. Since the fecundity is quite high, it is needed to tackle the pest at initial stage to avoid the menace caused by this pest to cocoa plants.

ACKNOWLEDGEMENT

Authors are thankful to the authorities of Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga for providing necessary facilities, guidance and help during this research study.

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MS Received: 29 October 2024
MS Acceptance: 12 December 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 293-297 (2024)
DOI Number : 10.5958/0974-4541.2024.00041.8

Baseline Susceptibility of *Tetranychus truncatus* (Prostigmata:Tetranychidae) to acaricides

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ABSTRACT: *Tetranychus truncatus* Ehara (Tetranychidae), a globally distributed phytophagous mite, infests various plants, including many economically important crops. In Kerala, it has been identified as a major pest on vegetable crops. Continuous monitoring of the field populations for susceptibility to various acaricides is needed to understand the status of resistance in them. Studies were conducted to assess the baseline susceptibility of *Tetranychus truncatus* (Prostigmata:Tetranychidae) to acaricides. The present study generated baseline data for *T. truncatus* to acaricides *viz*., spiromesifen (1.2 ppm), fenazaquin (2.9 ppm), diafenthiuron (1.6 ppm), fenpyroximate (2.6 ppm) chlorfenapyr (1.0 ppm), propargite (2.3 ppm) and hexythiazox (36.1 ppm).

Keywords: *Tetranychus truncatus*, spider mite, base line data, acaricides

INTRODUCTION

Spider mites (Acari) inhabit a diverse array of environments and pose a significant threat to numerous commercially cultivated vegetable crops and ornamental plants (Al-Atawi, 2011). Prevalence of extended drought periods and elevated temperatures experienced in the recent past has fostered optimal conditions for these tiny arthropods, enabling their populations to surge at an alarming rate. *Tetranychus truncatus* Ehara (Tetranychidae), a phytophagous mite distributed globally, infests a wide variety of plants, including many that are economically significant for agriculture (Bolland *et al*., 1998; Migeon and Dorkeld 2024). It has been reported from 12 countries across the Afrotropical, Australasian, Oriental and Palearctic regions (Migeon and Dorkeld, 2024). However, its distribution is mostly reported from Asian countries, including Guam, Marianas, China, Indonesia, Philippines, Taiwan, Thailand, Vietnam, Iran, Japan India and Korea (Ullah *et al*., 2021). This mite has a wide range of potential host plants, 92 species in total, which includes many major crops such as rice, maize, cassava, and cotton (Migeon and Dorkland, 2024).

In India, *T. truncatus* was first recorded from the North western Himalayan regions of Jammu and Kashmir and Himachal Pradesh in 1983 on *Dahlia* sp. It was later found in Karnataka on cultivated and wild *Morus* species (Srinivasa *et al*., 2012). In Kerala, it has been identified as a major pest on vegetable crops like okra, cucumber, and amaranthus (Bennur *et al*., 2015), as well as on several ornamental plants (Prakash *et al*., 2022). This species poses a serious threat to crops due to its ability to reproduce rapidly and cause extensive damage through sap extraction.

The mite primarily colonizes the undersides of leaves, feeding on sap and causing yellowing and drying of foliage. Farmers use different novel acaricides to control this pest. However, recent studies have revealed that populations of *T. truncatus* collected from vegetable fields in Kerala exhibited reduced susceptibility to commonly used acaricides, including fenazaquin, spiromesifen and diafenthiuron (Bachhar *et al*., 2019). This trend indicates the development of acaricide resistance in this mite species. To address this issue, it is crucial to introduce alternative acaricides with different modes of action to which the mite populations have not been exposed. Spider mites can develop resistance to newly exposed chemicals after few continuous exposures (Vassiliou and Kitsis, 2013; De Rouck *et al*., 2023). Therefore, continuous monitoring of the field populations for susceptibility to various acaricides is warranted. To assess the level of susceptibility in field populations, bioassay studies to compare the LC_{50} values for field-collected populations with those of susceptible populations (baseline susceptibility), maintained in laboratory conditions is essential.

The present study aimed at determining the baseline susceptibility of *T. truncatus*to different acaricides with different modes of action.

MATERIALS AND METHODS

The culture of *T. truncatus*, which was being maintained in the laboratory without any exposure

to acaricide molecules for about more than ten years (approximately 300 generations), was used in the study as the susceptible population. To generate baseline susceptibility data, the susceptible population was tested for dose response to the seven different acaricides that belong to different chemical classes (Table1).

The bioassay studies were performed on adult mites using the leaf dip method (Roy *et al.,* 2010) for all acaricides, except spiromesifen and hexythiazaox where protonymphs were tested for susceptibility (Mattupurath *et al.,* 2023). Technical grade chemicals purchased from Sigma-Aldrich were used for the bioassay. A stock solution (10 ml) of each acaricide was prepared using acetone and distilled water (1:1), and five different required concentrations (decided based on a broad range bioassay) were obtained by the serial dilution method.

Mulberry leaf disc of 3x3cm^2 was dipped in the respective test solution for 15 seconds and left for shade drying for 20 minutes. In the control treatment, leaf disc was dipped in a mixture of acetone and distilled water (1:1). After shade drying, leaf disc was placed on a wet cotton pad kept in a Petri dish (150x15mm). Three replications were maintained for each treatment. Twenty-five adult female mites collected from the laboratory culture were released onto each leaf disc, using a camel hair brush. A thin layer of Vaseline was applied along the edges of the leaf disc, to prevent the mites from moving out of the disc (Alzoubi and Cobanoglu, 2010). In the case of spiromesifen and hexythiazox, nymphicidal assay was conducted with 25 protonymphs by topical application method. Potters tower was used to spray the chemical on 2x2 cm^2 mulberry leaf bit (Van Pottelberge *et al*., 2009).

Observations on the mortality of the mites were recorded after 24 and 48 h of treatment, following the criteria given by Beers *et al.* (1998). Mites that could move freely on gentle probing with a fine brush were considered alive, while dead and moribund mites that could not move beyond their body length were considered dead. Mortality data recorded at 24 h were used to determine concentration-mortality responses for all acaricides except spiromesifen and hexythiazox. For these two chemicals, the mortality data at 48 h were used. The median lethal concentration (LC_{50}) values were calculated by Probit analysis (Finney, 1971) using Polo Plus 2.0 software (LeOra software, 2002).

Table 1. Acaricides used for bioassay studies on *Tetranychustruncatus*

Insecticide	Chemical group	IRAC MoA Group
Chlorfenapyr	Halogenated pyrroles	Uncouplers of oxidative phosphorylation via disruption of the proton gradient (13)
Diafenthiuron	Thiourea	Inhibitors of mitochondrial ATP synthase (12, 12A)
Propargite	Sulfite ester	Inhibitors of mitochondrial ATP synthase (12, 12C)
Spiromesifen	Tetramic acid derivatives	Lipid synthesis regulation (23)
Fenazaquin	Quinazoline	Mitochondrial complex I electron transport inhibitors (21)
Hexythiazox	Thiazolidinone	Mite growth inhibitors affecting CHS1 (10)
Fenpyroximate	Phenoxypyrazole	Mitochondrial complex I electron transport inhibitors (21)

(IRAC, 2024)

RESULTS AND DISCUSSION

The baseline data generated in the present study for spiromesifen, fenazaquin, diafenthiuron, chlorfenapyr, diafenthiuron, propargite and hexythiazox are furnished in Table 2. The acaricides varied in their toxicity to *T. truncatus*. Among the tested acaricides, chlorfenapyr exhibited the lowest LC_{50} value of 1.0 ppm, indicating its potency even at minimal concentrations. This halogenated pyrrole compound disrupts ATP production by targeting oxidative pathways in mitochondria, leading to the mortality of exposed mites. Nicastro *et al.* (2013) studied the stability of resistance and cross relationships for chlofenapyr in *T. urticae* collected from cotton and papaya, by comparing susceptibility with laboratory maintained population. Results showed LC_{50} value of 1.478 (mg l $^{-1}$ of a.i) for chlorfenapyr in susceptible population which is higher than the value obtained in the present study. Herron *et al.* (2004) documented the first chlorfenapyr control failure against *T. urticae*attributing

it to resistance development. They compared the LC_{50} values between resistant and susceptible populations, noting that the susceptible population exhibited an LC_{50} value of 0.017 ppm.

Spiromesifen (Tetramic acid derivative) and Diafenthiuron (Thiourea compound) exhibited high efficacy against *T. truncatus* with LC_{50}values of 1.2 ppm and 1.6 ppm, respectively. Naveena *et al.* (2022) evaluated the magnitude of resistance developed in two spotted spider mite, *T. urticae* in Tamil Nadu. They conducted bioassays on susceptible populations and compared the LC_{50} with field collected populations. The study reported anLC_{50} of 0.15 ppm for chlorfenapyr, 2 ppm for spiromesifen and 0.22 ppm for diafenthiuron in a susceptible population maintained in the laboratory, without any exposure to chemicals. Additionally, baseline studies conducted on *Polyphagotarsonemus latus* after 70 generations without chemical exposure revealed an LC_{50} value of 0.4 ppm for diafenthiuron (Augustine *et al*., 2022).

In the present study, Fenazaquin and Fenpyroximate demonstrated effective acaricidal properties with LC_{50} values of 2.9 ppm and 2.6 ppm, respectively. Noor and Sreenivasa (2020) generated baseline data for *T. urticae* assessing its susceptibility to various acaricides in susceptible population. Their study recorded an LC_{50} of 0.22 ppm for fenazaquin and 0.92 ppm for spiromesifen after the 90th generation. Mohin *et al.* (2018) evaluated the susceptibility of *T. urticae* to selected acaricides in a laboratory-maintained susceptible culture (128th generation). They reported LC_{50} values of 0.18 ppm for fenazaquin, 0.20 ppm for propargite, 0.42 ppm for chlorfenapyr, 0.30 ppm for dicofol, 0.30 ppm for diafenthiuron, 0.29 ppm for spiromesifen, and 0.32 ppm for abamectin. In the present study, hexythiazox showed least toxicity compared to others. Hexythiazox, a chitin synthesis inhibitor, exhibited significantly elevated LC_{50} values of 36.1 ppm in the present nymphicidal assay, indicating that while it remains effective, it requires higher concentrations compared to the more potent options.

Kumari *et al.* (2017) generated baseline data for *T. urticae* and evaluated the adulticidal and nymphicidal effects of various newer and conventional acaricides on susceptible laboratory strain of *T. urticae*. The study identified abamectin as the most toxic to adults, with an LC_{50} of 0.39 ppm, followed by fenpyroximate (5.67 ppm), spiromesifen (12.53 ppm), chlorfenapyr (32.24 ppm), propargite (77.05 ppm) and dicofol (146.65 ppm). Hexythiazox showed the least adult toxicity. For nymphal mortality, abamectin again led with 96.05%, followed closely by dicofol (94.51%), hexythiazox (90.24%), propargite (90.00%), chlorfenapyr (89.33%), and fenpyroximate (86.84%).

The baseline susceptibility data generated for *T. truncatus* in the present study can serve as a reference data for monitoring susceptibility trends in field populations of the mite species, periodically. Development of resistance in the field populations can be thus be detected at a very early stage, so that corrective measures can be initiated.

Table 2: Baseline Susceptibility of *Tetranychus truncatus* to acaricides

Acaricide	LC_{50} (ppm)	Slope ± SEM	χ2	df
Fenazaquin	2.9 (2.2-3.8)	1.209 ± 0.271	2.519	3
Spiromesifen	1.2 (1.0-1.3)	2.149 ± 0.325	2.830	3
Diafenthiuron	1.6 (1.4-1.9)	2.611 ± 0.524	1.450	3
Fenpyroximate	2.6 (2.4-3.1)	2.844 ± 0.775	0.342	3
Propargite	2.3 (2.1-2.7)	2.358 ± 0.413	1.912	3
Chlorfenapyr	1.0 (0.9-1.2)	2.625 ± 0.415	2.110	3
Hexythiazox	36.1 (33.5-39.5)	3.993 ± 0.751	0.600	3
Dicofol	24.6 (19.7-29.9)	1.733 ± 0.294	0.661	3

LC_{50} = Concentration (ppm) calculated to give 50% mortality

ACKNOWLEDGEMENT

The authors are thankful to Kerala Agricultural University, Kerala State Council for Science, Technology and Environment (KSCSTE) and ICAR - All India Network Project on Agricultural Acarology for providing the laboratory facilities and funding the research.

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MS Received: 23 October 2024
MS Acceptance: 20 December 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 298-302 (2024)
DOI Number : 10.5958/0974-4541.2024.00042.4

Evaluation of acaricides against two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) infesting rose under field conditions

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ABSTRACT: Field experiments on evaluating the effectiveness of new molecules of acaricides against *Tetranychus urticae* infestation on rose crop was conducted during summer 2021-22 and 2022-23 at Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India. The results of the experiment indicated that cyenopyrafen 30 SC @ 0.80 ml/l was effective acaricide in reducing the mite population. The next best acaricides in their efficacy were fenpyroximate 5 EC @ 2.0 ml/l and diafenthiuron 50 WP @ 1.0 g/l. In terms of bio-efficacy, considering the pooled data on per cent reduction of the mite population compared to the untreated control, the order is: cyenopyrafen 30 SC (87.04 %) > fenpyroximate 5 EC (82.73 %) > diafenthiuron 50 WP (80.98 %) > chlorfenapyr 10 SC (77.93 %) > spiromesifen 240 SC (75.93 %) and > ethion 50 EC (69.09 %). Higher benefit cost ratio of 2.54 was recorded in cyenopyrafen 30 SC @ 0.80 ml/l followed by fenpyroximate @ 2 ml/ l (2.42) and diafenthiuron @1 gm/l (2.25).

Keywords: Acaricides**,** cyenopyrafen 30 SC, fenpyroximate 5 EC, *Tetranychus urticae,* rose

INTRODUCTION

Rose cultivation in India is gaining increasing popularity due to the rising demand for cut flowers, resulting in higher commercial profits. The major global producers of cut rose flowers include the Netherlands, dominating with 70 per cent share in the world export market, followed by Colombia (12%), Israel (6%) and Italy (8%). In India, roses take the top position in the export trade, generating a market worth $178.60 million in the international arena (Manjula, 2005). In India, the area dedicated to rose production covers 29.41 thousand hectares, with a total rose production of 465.95 thousand metric tons (Anonymous, 2021). Commercial rose cultivation faces numerous challenges including both biotic and abiotic factors. Among the biotic factors, insect-pest infestations are particularly detrimental. Sucking pests, with spider mites like *Tetranychus* spp. being a primary concern, significantly reduce flower yields. The Two-Spotted Spider Mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae) holds the distinction of being the most economically significant plant-feeding mite globally. TSSM is a major pest in various cropping systems around the world affecting vegetables, fruits and ornamental plantsin both protected and open environments (Migeon and Dorkeld, 2010). It is a generalist feeder, capable of feeding on over 3,800 plant species (Migeon and Dorkeld, 2020). Both nymphs and adults of TSSM feed on plant sap, causing a reduction in chlorophyll levels and results in yield loss. The indiscriminate and continuous use of acaricides for *T. urticae* management has led to the emergence of resistant populations in over 40 countries (Georghiou and Lagunes, 1991).To develop economically viable management strategies aimed at reducing the environmental burden of pesticides and effectively managing resistance, a thorough understanding of effectiveness of newer acaricdes molecules essential. In view of this, a study on evaluation of efficacy of newer acaricdes molecules against spider mite on rose under field conditions was carried out.

MATERIALS AND METHODS

The field experiment was conducted in a farmer's field at Surahonne, Nyamati taluk, Davangere district, Karnataka during 2021- 22 and 2022-23. The experiment was laid out in Randomized Complete Block Design (RCBD) with seven treatments including untreated control with three replications. The acaricides evaluated in the study included spiromesifen 240SC @0.80 ml, chlorfenapyr 10SC @ 1.0 ml, diafenthiuron 50WP @ 1.0 gm, fenpyroximate 5EC @ 1.0 ml, cyenopyrafen 30 SC @ 0.80 ml and ethion 50 EC @ 2.50 ml. The treatments were imposed when the rose crop was uniformly infested with natural spider mite population. The acaricides were sprayed by using a hand operated high volume knapsack

sprayer fitted with a hallo cone nozzle. Second spraying of acaricides was taken up 15 days after first spray. The observations on number of mites per leaf were recorded from five randomly selected plants. From each plant, six leaves were sampled representing top, middle and bottom canopy and kept separately in labeled polythene bags and brought to the laboratory. Observations were recorded using stereo-binocular microscope before spraying as pre-count and post-treatment count on third, seventh and tenth day after imposition of treatments. The data was subjected to ANOVA for a Randomized Complete Bock Design (RCBD) with square root transformation. The results were interpreted at a five percent significance level using ICAR WASP (Web Agri Stats Package) 2.0 software. Percent reduction over untreated control was calculated, and the data of two years was pooled for a better interpretation of a valid conclusion.

RESULTS AND DISCUSSION

During 2021-22, the data of before treatment imposition indicated elevated mite counts per leaf across all treatments, with no statistically significant difference among them. Subsequently, a progressive reduction in the mite population was observed subsequent to the implementation of treatments. The mean mite population of first and second spray recorded during 2021-22 indicated that the lowest mean mite population of 7.90 mites per leaf was recorded in the cyenopyrafen 30 SC @ 0.80 ml/L followed by fenpyroximate 5 EC @ 1.0 ml/L with 9.48 mites per leaf and diafenthiuron 50 WP @ 1.0 g/L (11.27 mites per leaf). The highest mean mite population of 56.65 mites per leaf was recorded in control plots followed by ethion 50 EC @ 2.5 ml/L (16.18 mites per leaf) and spiromesifen 240 SC @ 0.80 ml/L (13.61 mites per leaf). However in all the treatments, the mean mite population was significantly lower when compared to control. The per cent mortality of mites was highest in cyenopyrafen 30 SC @ 0.80 ml/L with 86.06 per cent followed by fenpyroximate 5 EC @ 1.0 ml/L which recorded 83.26 per cent mortality and diafenthiuron 50 WP @ 1.0 g/L with 80.10 per cent mortality. The lowest per cent mortality of 71.43 was observed in ethion 50 EC @ 2.5 ml/L followed by spiromesifen 240 SC @ 0.80 ml/L (75.98 per cent) and chlorfenapyr 10 SC @ 1.0 ml/L (78.50 per cent) among different acaricides.

During 2022-23, the mean mite population and the per cent mortality in different treatments followed same trend as in the case of 2021-22. The lowest mean mite population of 6.73 mites per leaf was recorded in the cyenopyrafen 30 SC @ 0.80 ml/L followed by fenpyroximate 5 EC@ 1.0 ml/L with 9.95 mites per leaf and diafenthiuron 50 WP @ 1.0 g/L (10.89 mites per leaf). The highest mean mite population of 53.51 mites per leaf was recorded in control plots followed by ethion 50 EC @ 2.5 ml/L (21.69 mites per leaf) and spiromesifen 240 SC @ 0.80 ml/L (16.48mites per leaf). However in all the treatments, the mean mite population was reduced significantly when compared to control. The highest per cent mortality of 87.42 was recorded in cyenopyrafen 30 SC@ 0.80 ml/L followed by fenpyroximate 5 EC @ 1.0 ml/L which recorded 81.40 per cent and diafenthiuron 50 WP @ 1.0 gl/L (79.65 per cent). The lowest per cent mortality of 59.46 was observed in ethion 50 EC @ 2.5 ml/L followed by spiromesifen 240 SC@ 0.80 ml/L (69.21per cent) among the acaricides treatments.

Table1. Bio-efficacy of acaricides against two spotted spider mite, *Tetranychus urticae* in rose under field condition (2021-22)

Treatments	Dosage ml/g/l	Mean number of mites per leaf									Mean	Per cent reduction
		1st spray					2nd spray					
		DBS	3DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS		
Spiromesifen 240 SC	0.8	41.71 (6.50)	17.80 (4.28)^{e}	10.99 (3.39)^{e}	13.49 (3.74)^{e}	16.89 (4.17)^{e}	13.03 (3.68)^{e}	10.43 (3.31)^{b}	11.11 (3.41)^{e}	15.14 (3.95)^{e}	13.61	75.98
Chlorfenapyr 10 SC	1.0	47.19 (6.91)	16.47 (4.12)^{d}	10.85 (3.37)^{e}	11.76 (3.50)^{d}	15.66 (4.02)^{d}	10.11 (3.26)^{d}	7.47 (2.82)^{d}	11.28 (3.43)^{e}	13.84 (3.79)^{b}	12.18	78.50
Diafenthiuron 50 WP	1.0	47.41 (6.92)	14.42 (3.86)^{e}	9.74 (3.20)^{d}	11.58 (3.48)^{d}	15.46 (3.99)^{d}	6.14 (2.58)^{f}	7.53 (2.83)^{d}	9.79 (3.21)^{d}	15.53 (4.00)^{e}	11.27	80.10
Fenpyroximate 5 EC	1.0	41.66 (6.49)	14.51 (3.87)^{e}	9.40 (3.05)^{d}	10.41 (3.30)^{e}	12.94 (3.67)^{e}	8.25 (2.96)^{e}	3.23 (1.93)^{e}	6.98 (2.73)^{e}	10.14 (3.26)^{e}	9.48	83.26
Cyenopyrafen 30 SC	0.8	49.07 (7.04)	13.55 (3.75)^{e}	8.05 (2.92)^{e}	7.81 (2.88)^{f}	9.54 (3.17)^{f}	5.85 (2.52)^{f}	2.71 (1.79)^{e}	6.40 (2.63)^{e}	9.27 (3.13)^{e}	7.90	86.06

Ethion 50 EC	2.5	41.32 (6.46)	19.79 (4.50)^{b}	16.27 (4.10)^{b}	15.82 (4.04)^{b}	20.02 (4.53)^{b}	14.72 (3.90)^{b}	9.36 (3.14)^{c}	13.12 (3.69)^{d}	16.85 v(4.17)^{b}	16.18	71.43
Control	-	44.15 (6.68)	43.53 (6.63)^{a}	45.14 (6.76)^{a}	50.06 (7.11)^{a}	57.58 (7.62)^{a}	67.15 (8.00)^{a}	74.32 (8.65)^{a}	62.74 (7.95)^{a}	64.95 (8.09)^{a}	56.65	-
CD (p=0.05)		NS	0.29	0.45	0.45	0.30	0.46	0.51	0.58	0.35	-	-
CV (%)		-	8.98	9.87	8.74	14.58	14.99	15.87	14.87	12.58	-	-

DBS: Day before spray; DAS: Day after spray; NS: Non significant; Figures within the parentheses indicates √x+0.5 transformed values;
Treatment means with the letter(s) in common are not significant by DMRT at 5% level of significance.

Table 2.Bio-efficacy of acaricides against two spotted spider mite, *Tetranychus urticae* in rose under field condition (2022-23)

Treatments	Dosage ml/g/l	Mean number of mites per leaf									Mean	Per cent reduction
		1st spray					2nd spray					
		DBS	3DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS		
Spiromesifen 240 SC	0.8	43.65 (6.64)	14.09 (3.82)^{c}	9.63 (3.18)^{c}	17.32 (4.22)^{c}	21.44 (4.68)^{c}	11.28 (3.43)^{c}	11.98 (3.53)^{c}	19.62 (4.49)^{c}	26.44 (5.19)^{c}	16.48	69.21
Chlorfenapyr 10 SC	1.0	45.17 (6.76)	14.54 (3.88)^{c}	6.24 (2.60)^{e}	12.69 (3.63)^{d}	18.81 (4.39)^{d}	8.47 (2.99)^{d}	10.23 (3.28)^{d}	17.78 (4.28)^{d}	23.93 (4.94)^{d}	14.09	73.67
Diafenthiuron 50 WP	1.0	43.99 (6.67)	10.85 (3.37)^{e}	9.56 (3.17)^{c}	10.95 (3.38)^{e}	14.41 (3.86)^{e}	7.51 (2.83)^{e}	7.09 (2.75)^{e}	10.48 (3.31)^{f}	16.27 (4.10)^{f}	10.89	79.65
Fenpyroximate 5 EC	1.0	50.54 (7.14)	9.35 (3.14)^{d}	5.15 (2.38)^{f}	9.56 (3.17)^{f}	13.66 (3.76)^{f}	6.25 (2.60)^{f}	6.66 (2.68)^{f}	11.4 (3.45)^{e}	17.58 (4.25)^{e}	9.95	81.40
Cyenopyrafen 30 SC	0.8	49.14 (7.05)	6.74 (2.69)^{f}	7.03 (2.74)^{d}	6.98 (2.73)^{g}	9.25 (3.12)^{g}	2.35 (1.69)^{g}	3.14 (1.91)^{g}	7.66 (2.86)^{g}	10.71 (3.35)^{g}	6.73	87.42
Ethion 50 EC	2.5	44.67 (6.72)	17.19 (4.21)^{b}	15.41 (3.99)^{b}	19.6 (4.48)^{b}	26.77 (5.22)^{b}	14.23 (3.84)^{b}	20.04 (4.53)^{b}	26.44 (5.19)^{b}	33.86 (5.86)^{b}	21.69	59.46
Control	-	46.90 (6.88)	53.18 (7.32)^{a}	48.25 (6.98)^{a}	55.25 (7.47)^{a}	58.35 (7.67)^{a}	63.25 (8.17)^{a}	61.59 (7.88)^{a}	50.27 (7.13)^{a}	44.55 (6.71)^{a}	53.51	-
CD (p=0.05)		NS	0.36	0.27	0.46	0.48	0.38	0.34	0.24	0.31	-	-
CV (%)		-	11.06	9.88	12.76	13.49	15.69	14.49	12.79	9.80	-	-

DBS: Day before spray; DAS: Day after spray; NS: Non significant; Figures within the parentheses indicates √x+0.5 transformed values;
Treatment means with the letter(s) in common are not significant by DMRT at 5% level of significance.

The pooled data of 2021-22 and 2022-23 indicated that of mean mite population did not vary significantly one day before imposition of treatments, indicating the uniform distribution of mites throughout the experimental field (Table 3). All the acaricides molecules tested proved their superiority in significantly suppressing the spider mite population compared to untreated control up to 14 days of the first and second application of acaricides. The lowest number of the mean mite was recorded in cyenopyrafen @ 0.80 ml/L followed by fenpyroximate @ 1.0 ml/L and diafenthiuron 50 WP @ 1.0 g/L which are on par with each other. The least reduction in mite population was observed in ethion 50 EC @ 2.50 ml/L followed by spiromesifen 240 SC @ 0.80 ml/L and chlorfenapyr 10 SC @ 1.0 ml/L. However, the highest number of mean mite population was observed in the untreated control. The chemicals, cyenopyrafen @ 0.80 ml/L and fenpyroximate @ 1.0 ml/L recorded 87.04 and 82.73 per cent reduction, respectively over untreated control. Next best treatment was diafenthiuron 50 WP

@ 1.0 g/L with 80.98 per cent reduction over control followed by chlorfenapyr 10 SC @ 1.0 ml/L (77.93 per cent). The lowest per cent reduction of mite population was observed in the treatment ethion 50 EC @ 2.5 ml/L (69.09 per cent) followed by spiromesifen 240 SC @ 0.80 ml/L (75.93 per cent). The B: C ratio calculated indicated that cyenopyrafen 30 SC recorded the highest B: C ratio of 2.54 followed by fenpyroximate 5 EC (2.42) and diafenthiuron 50 WP (2.25). The least B: C ratio was recorded for the control treatment with 1.31.

Our findings are in conformation with findings of Bajya and Ranjith (2016) who reported cyenopyrafen's effectiveness against the yellow mite, *Polyphagotarsonemus latus* in chili plants achieving an impressive reduction of 89.15 per cent compared to other treatments. Cyenopyrafen stands out as a newer acaricide capable of targeting early larvae, nymphs and adults by inhibiting mitochondrial electron transport at complex II. Its dual action through contact and ingestion renders cyenopyrafen highly effective against a diverse array of pests, including those that might be hidden within various plant structures. Present research findings are in line with the findings of Rajashekharappa *et al.* (2023) wherein the effectiveness of various acaricides was assessed against *T. urticae* infestations in yard long beans. They reported a remarkable reduction of 84.49 per cent in plots treated with diafenthiuron. These results also corresponds with the research findings of Kumar *et al.* (2010) who assessed the efficacy of specific acaricides against *T. urticae* on brinjal and stated that fenpyroximate 5 SC exhibited a reduction of 78.73% in the overall mite population. Similarly, our current study findings are in line with the observations made by Prakash *et al.* (2022) wherein the bio-efficacy and persistence of acaricides were examined against *T. urticae* in cucumber. Their results demonstrated a significant reduction of 79.61 per cent in plots treated with fenpyroximate 5 SC. In terms of bio-efficacy, considering the per cent reduction of the total mite population compared to the untreated control, the order is: cyenopyrafen 30 SC > fenpyroximate 5 EC > diafenthiuron 50 WP > chlorfenapyr 10 SC > spiromesifen 240 SC and > ethion 50 EC.

Table 3. Bio-efficacy of acaricides against two spotted spider mite, *Tetranychus urticae* in rose under field condition (Pooled)

Treatments	Dosage ml/g/l	Mean number of mites per leaf									Mean	Percent reduction	B:C ratio
		1st spray					2nd spray						
		DBS	3DAS	7 DAS	10 DAS	14 DAS	3 DAS	7 DAS	10 DAS	14 DAS			
Spiromesifen 240 SC	0.8	43.18 (6.57)	3.79 (2.07)^{de}	10.31 (3.28)^{c}	15.40 (3.98)^{c}	19.16 (4.43)^{c}	12.15 (3.55)^{c}	11.20 (3.42)^{c}	15.36 (3.98)^{c}	16.51 (4.12)^{f}	12.63	75.93	2.16
Chlorfenapyr 10 SC	1.0	46.68 (6.83)	5.06 (2.35)^{c}	8.54 (3.00)^{de}	12.22 (3.56)^{d}	17.23 (4.21)^{d}	9.29 (3.12)^{d}	8.85 (3.05)^{d}	14.53 (3.87)^{c}	14.09 (3.81)^{c}	11.58	77.93	2.23
Diafenthiuron 50 WP	1.0	6.20 (6.79)	3.56 (2.01)^{de}	9.65 (3.18)^{cd}	11.26 (3.42)^{de}	14.93 (3.92)^{e}	6.82 (2.70)^{e}	7.31 (2.79)^{e}	10.13 (3.26)^{d}	11.07 (3.40)^{d}	9.98	80.98	2.25
Fenpyroximate 5 EC	1.0	46.60 (6.82)	3.85 (2.08)^{d}	7.27 (2.78)^{f}	9.98 (3.23)^{e}	13.30 (3.71)^{f}	7.25 (2.78)^{e}	4.94 (2.33)^{f}	9.19 (3.11)^{d}	10.62 (3.33)^{d}	9.06	82.73	2.42
Cyenopyrafen 30 SC	0.8	49.61 (7.04)	2.53 (1.74)^{e}	7.54 (2.83)^{ef}	7.39 (2.80)^{f}	9.39 (3.14)^{g}	4.10 (2.14)^{f}	2.92 (1.84)^{g}	7.03 (2.74)^{e}	6.65 (2.67)^{e}	6.80	87.04	2.54
Ethion 50 EC	2.5	42.99 (6.59)	6.44 (2.63)^{b}	15.70 (4.02)^{b}	17.71 (4.26)^{b}	23.39 (4.88)^{b}	14.47 (3.86)^{b}	14.70 (3.89)^{b}	19.78 (4.50)^{b}	20.44 (4.57)^{b}	19.51	69.09	1.86
Control	-	45.52 (6.85)	48.15 (6.68)^{a}	46.69 (6.86)^{a}	52.65 (7.29)^{a}	57.96 (7.64)^{a}	65.20 (8.10)^{a}	67.95 (8.27)^{a}	56.50 (7.54)^{a}	31.71 (5.67)^{a}	52.48	-	1.31
CD (p=0.05)		NS	0.88	3.15	3.46	3.64	4.78	5.08	3.80	1.83	-	-	
CV (%)		-	8.81	11.75	10.78	9.21	15.76	16.96	11.29	6.51	-	-	

DBS: Day before spray; DAS: Day after spray; NS: Non significant; Figures within the parentheses indicates √x+0.5 transformed values;
Treatment means with the letter(s) in common are not significant by DMRT at 5% level of significance.

ACKNOWLEDGEMENT

The authors acknowledge the Director of Research, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India for providing facilities and support.

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MS Received: 23 October 2024
MS Acceptance: 15 December 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 303-311 (2024)
DOI Number : 10.5958/0974-4541.2024.00045.3

Insect pest diversity on mango in the nursery under humid tropics of Gujarat, India

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ABSTRACT: Studies were conducted at Navsari Agricultural University (NAU), Navsari during May, 2022 to April, 2023 to study the Arthropods infesting mango in nursery under humid tropics. Results revealed that total thirty-one insect-pests damaging mango mother plants in nursery. Twelve leaf eating caterpillars or defoliator *viz*., leaf- webber, common baron, leaf miner, tussock hairy caterpillar, flush caterpillar, lymantrid caterpillar, slug caterpillar, looper, leaf-roller, leaf cutter, yellow tail moth, and different grasshopper spp. were found damaging new young leaves and shoots. Three shoot damaging insect pests *viz*., shoot borer, stem miner, and shoot midge were observed. Thirteen sucking insect-pests *viz*., mango hoppers, thrips, plant hopper, leaf gall midges, mealybugs and scales; three leaf defoliating beetles and weevils *viz*., the leaf cutting weevil**,** grey or ash weevil and leaf beetle were observed infesting mango plants in nursery. Pest calendar was also prepared based on their period of activity throughout the year.

Keywords: Mango, Arthropods, Diversity, Nature of damage, Nursery, Shoot feeders

INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most widely grown fruits in tropical and subtropical regions of the world. In India, the area under mango cultivation is 2350 thousand ha with a production of 20772 thousand MT (Anon., 2022). In Gujarat, the area under mango cultivation is 173517 ha with production of 960172MT (Anon., 2023). At the global level, mango is attacked by 492 species of insects, 17 species of mites and 26 species of nematodes (Tandon and Verghese, 1985). Among them, 188 insect species have been reported from India (Srivastava, 1997). Approximately 127 of these species are foliage feeders or shoot feeders (Pena *et al.*, 1998; Kannan and Rao, 2006; Preetha, 2013; Sathe *et al*., 2015; Anant, 2016; Munj *et al*., 2019 and Vanitha, 2020; Khimani and Chavan, 2023). Commercial cultivation of mangoes, characterized by the area expansion, changing cropping patterns, varietal replacements, increased chemical interventions, has altered the pest complex and pest community structures significantly (Reddy *et al.,* 2018). Very little information is available on status of insect-pests of mango in nursery from South Gujarat. Considering the importance of pests of mango in nursery and to fill the gaps in the literature regarding the diversity and nature of damage of shoot feeders of mango in nursery from humid tropics of South Gujarat, the present study was conducted.

MATERIALS AND METHODS

The studies on shoot feeders of mango was conducted at Model Nursery, ASPEE College of Horticulture, Navsari Agricultural University (NAU), Navsari ($20^0$55'27.43 N latitude and $72^0$53'31.85 E longitude) during three different seasons pre-monsoon season (February to May, 2022); monsoon season (June-September, 2022) and post-monsoon season (October, 2022 to January, 2023) under humid tropics**.**Ten mother plants of mango (> 10 years old) irrespective of the variety were selected randomly.The occurrence of the insect-pests on leaves and shoots was recorded, collected and documented. The different life stages were collected from the field was brought to the Post Graduate Laboratory, Department of Entomology, N. M. College of Agriculture, Navsari Agriculture University, Navsari for rearing. Fresh food in form of mango leaves, shoot was provided regularly. The observations on their external morphology, nature of damage and behaviour were also recorded. Based on their nature of damage in field and also in laboratory, these pests were categorized as leaf eating caterpillars or defoliator, insect-pest damaging shoots, sucking pests and leaf eating beetles and weevils. Mango rootstocks grow in polythene bags and prepared softwood grafts in green shade-net house and poly-tunnel were also observed regularly. Based on the available literature and with the help of taxonomist, efforts have also been made to identify these insects up to genus and species level. Pest calendar was also prepared based on their period of activity throughout the year.

RESULTS AND DISCUSSION

During present study total thirty-one Arthropods were reported as shoot feeder of mango in nursery (Table-1).

A. *Leaf and shoot defoliators*

Incidence of leaf webber, *Orthega exvinacea* Hampson (Fig. I-1) was observed during September to March. Larvae were greenish in color with slender body. Early instar fed by scrapping the leaf surface, later webbed the leaves and fed inside. On heavy feeding, only midribs with network of veins were left and webbed bunches of leaves were found dried. Several caterpillars were found in a single web. Earlier the incidence of leaf webber (*O. exvinacea*) was recorded during mid-July to mid-March (Kavitha, 2004) and peak activity during August to October (Reddy and Sreedevi, 2016). This is also the major pest of mango in Nepal (Shrestha *et al*., 2022). Likewise, incidence of flush or shoot caterpillar, *Penicillaria jocosatrix* Guenée (Fig. I-2 to 5) was observed during July to September and March to April (Table 2). The larva was stout, centrally wide, smooth, and green with small blotches. The head was also green with spots. Mature larva becomes purple. The forewings were dull purple with several darker stripes and a dark-grey purple spot near the apical end. The hind wings are white with a central black spot and a broad dark border. The resting position of moth is different, with the abdomen curled up over the body, and the wings found wavy. Munj *et al*. (2019) from Konkan region of Maharashtra observed the infestation of this pest on root stocks in mango nursery.

The infestation of common baron, *Euthalia aconthea* Cramer (Fig. I- 6 to 8) was observed during July to September (Table 2). This is greyish brown butterfly with black and white markings on wings. The underside was also brown with a black marginal spots on the hind wings. The caterpillar was green with a yellowish dorsal stripe. Spines with branching pattern were observed beyond the caterpillar's body. The pupa was quadrangularin shape and dark green initially which turn brownish black. This is an important pest on mango in Jammu region (Tara and Gupta, 2016). Recently it has been reported as a pest of mango in the Andaman and Nicobar Islands, India (Purthi *et al*., 2023). Incidence leaf miner, *Acrocercops syngramma* Meyrick(Fig. I- 9 to 12) was observed during September to December and March to April (Table 2). Mature larva of leaf miner was reddish in color with slender body. Pupation takes place mostly in the soil and occasionally in the leaf-folds in a thin cocoon. The adult have red eyes and silver grey in colour. Larvae were found mining and feeding on leaf tissues, resulted in white papery spots on leaves which were filled with excreta. Average three to four larvae were also seen in single leaf house. In past, *A. syngramma* reported as a major pest of mango and damages to newly emerged flushes of mango plants during August to November (Kanhar *et al*., 2016; Kannan and Rao, 2006 and Vanitha, 2020).

Tussock hairy caterpillar (*Euproctis* sp.) (Fig. I- 13 to 15) is a polyphagous pest observed on new flushes of mango from March to April and July to September (Table 2). The fully grown caterpillar was yellowish to greyish with red stripes on the prothorax. Paired lateral tufts of hair were also observed on each segment of the body. Tail like brownish hairy tuft is also observed on the last abdominal segment. Mature larva pupatein cocoon made of silk which was elongated with tapering ends. Moth is yellow with pale transverse lines and black spots on the forewing. Hairy Lymantrid caterpillar, *Lymantria* sp. (Fig. I- 16 to 17) was observed during June to October. Female laid eggs in mass covered with yellowish/ brown hairs. The female was sluggish with rudimentary wings, whereas male had well developed wings and bipectinate antennae. The caterpillar was preferred 2-3 week old leaves which had distinctly colored spots along its back, five pairs of blue spots behind the head, and six pairs of red spots to the rear. Earlier Kannan and Rao (2006) and Preetha (2013) also reported this pest on young plants as shoot feeders of mango in Andhra Pradesh and Kerala respectively.

Table 1. Arthropods infesting mango in nursery from humid tropics of South Gujarat

Common name	Scientific name	Order: Family
Leaf eating caterpillars or defoliators		
Leaf Webber	*Orthaga exvinacea* Hampson	Lepidoptera: Pyralidae
Common baron	*Euthalia aconthea* Cramer	Lepidoptera: Nymphalidae
Leaf miner	*Acrocercops syngramma* M.	Lepidoptera: Gracillariidae
Tussock hairy caterpillar	*Euproctis*sp.	Lepidoptera: Nolidae
Flush caterpillar	*Penicillaria jocosatrix* G.	Lepidoptera: Noctuidae
Lymantrid caterpillar	*Lymantria* sp.	Lepidoptera: Erebidae

Slug caterpillar	*Latoia lepida* Cramer	Lepidoptera: Limacodidae
Looper	*Perixera illepidaria* Guenée	Lepidoptera: Geometridae
Leaf roller	*Dudua aprobola* Meyrick	Lepidoptera:Tortricidae
Leaf cutter	*Palumbina glaucitis*	Lepidoptera: Gelechidae
Yellow tail moth		Lepidoptera: Lymantriidae
Different grasshopper spp.		Orthoptera
Shoot damaging pests		
Shoot borer	*Chlumetia transversa* Walker	Noctuidae: Lepidoptera
Stem miner	*Spulerina* sp.	Lepidoptera: Gracillariidae
Shoot midge	*Erosomya indica* Felt.	Diptera: Cecidomyiidae
Sucking Pests		
Mango hopper	*Amritodus atkinsoni* Lethierry	Homoptera: Cicadellidae
	Idioscopus clypealis L.	Homoptera: Cicadellidae
Thrips	*Scirtothrips dorsalis* Hood	Thysanoptera: Thripidae
Plant hopper	*Scolypopa* sp.	Homoptera: Ricaniidae
Leaf gall midge	*Procontarinia matteiana* K.	Diptera: Cecidomyiidae
Mealy bug and scale	*Drosicha mangiferae* Green	Hemiptera: Pseudococcidae
	Icerya seychellarum W.	Hemiptera: Monophlebidae
	Rastococcus spinosus R.	Hemiptera: Pseudococcidae
	Rastrococcus iceryoides G.	Hemiptera: Pseudococcidae
	Phenacoccus sp.	Hemiptera: Pseudococcidae
	Aulacaspis tubercularis N.	Hemiptera: Coccidae
	Philephedra tuberculosa H.	Hemiptera: Coccidae
	Ceroplastes sp.	Hemiptera: Coccidae
Leaf eating beetles and weevils		
Leaf cutting weevil	*Deporaus marginatus* Pascoe	Coleoptera: Curculionidae
Grey weevil	*Myllocerus* spp.	Coleoptera: Curculionidae
Leaf beetle	*Basilepta* sp.	Coleoptera:Cerambycidae

The young larvae of slug caterpillar, *Latoia lepida* Cramer (Fig. I- 18 to 20) was observed during October to March and fed on the lower epidermis of the leaf. As they mature, the whole leaf blade was eaten leaving the midribs. Egg were flat shiny eggs on the under surface of leaves. Larva had greenish body with white lines.The pupa was very hard and formed in chocolate brown shell like silken cocoon. Later on, it converted into dark ash colour. The population of *Parasa lepida* was reported from May to December on mango with maximum infestation of 26.4 per cent during fourth week of August (Chaudhary *et al*., 2018). Preetha (2013) also reported this pest as shoot feeders of mango in Kerala.

Table 2. Pest calendar of Arthropods infesting mango in nursery during 2022-23

Name of the pest	Plant part affected	Pre-monsoon season 2022				Monsoon season 2022				Post-monsoon season 2022-23			
		Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.
O. exvinacea	L	+	+	-	-	-	-	-	+	+	+	+	+
E. aconthea	L	-	-	-	-	-	+	+	+	-	-	-	-
A. syngramma	L	-	+	+	-	-	-	-	+	+	+	+	-
P. jocosatrix	L & S	-	+	+	-	-	+	+	+	-	-	-	-
Euproctis sp.	L	-	-	-	-	-	+	+	+	-	-	-	-
Lymantria sp.	L	-	-	-	-	+	+	+	+	+	-	-	-
L. lepida	L	+	+	-	-	-	-	-	-	+	+	+	+
P. illepidaria	L	-	-	-	-	-	-	-	+	+	+	+	-
D. aprobola	L	-	+	+	+	-	-	-	+	+	+	+	-
E. similis	L	-	-	-	-	-	-	+	+	+	-	-	-
Grasshoppers	L	+	+	+	+	+	+	+	+	+	+	+	+
Leaf cutter	L	-	-	-	-	-	+	+	+	-	-	-	-
C. transversa	L	+	+	-	-	-	-	-	+	+	+	+	+
Spulerina sp.	L	-	-	-	-	-	-	-	+	+	+	+	-
E. indica	S	-	+	+	-	-	-	-	-	+	+	+	-
A. atkinsoni	L & S	+	+	+	-	-	-	-	-	+	+	+	+
I. clypealis	L & S	+	+	+	-	-	-	-	-	+	+	+	+
S. dorsalis	L	+	+	+	+	-	-	-	-	+	+	-	-
Scolypopa sp.	L & S	-	-	-	-	-	+	+	+	-	-	-	-
P. matteiana	L	+	+	-	-	-	-	-	+	+	+	+	+
P. tuberculosa	L	+	+	+	-	-	-	-	-	-	-	-	+
Ceroplastes sp.	L	+	+	+	-	-	-	-	-	-	-	-	+
R. spinosus	L	+	+	+	-	-	-	-	-	-	+	+	+
R. iceryoides	L	+	+	+	-	-	-	-	-	+	+	-	-
I. seychellarum	L	+	+	+	+	-	-	-	-	-	+	+	-
*Ceroplastes*sp	L	+	+	+	-	-	-	-	-	-	+	+	+
*Phenacoccus*sp	L	+	+	+	+	-	-	-	-	-	-	-	+
D. marginatus	L	-	-	-	-	+	+	+	+	+	-	-	-
Myllocerus spp.	L	-	-	-	-	+	+	+	+	+	+	-	-
Basilepta sp.	L	-	-	-	-	+	+	+	+	-	-	-	-

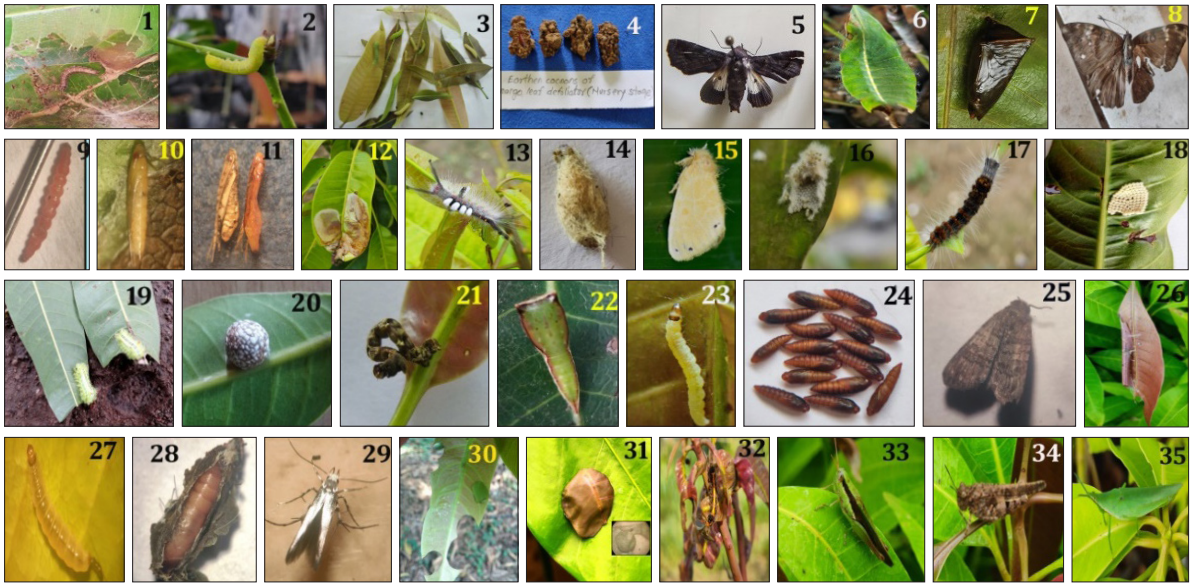
L: leaves, **S:** shoots, '**–**'**:** Incidence absent, '**+**'**:** Incidence present

The incidence of looper*, Perixera illepidaria* Guenée (Fig. I-21 to 23)was observed during September – December. There was much variation in the colour of larvae of different instars from black to dark brown with bands. The larvae made silken threads that descended vertically between tree branches and some larvae were seen hanging from them. Silken threads allowed larval movement from damaged twigs to healthy leaves. Larvae

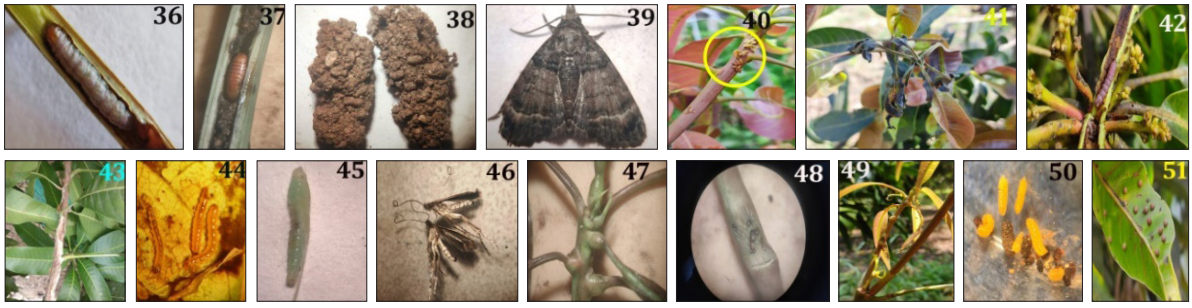
mostly fed on young leaves. The pupae were green and turned brown before adult emergence. *P. illepidaria* was first reported on litchi in Bihar (Kumar *et al*., 2014). This is an emerging pest on mango, mainly infests mango inflorescence (Soumya *et al*., 2021).

Similarly incidence of leaf roller, *Dudua aprobola* Meyrick (Fig. I-24 to 26) was observed during September to December and March to May when new vegetative flush appeared. Eggs were laid in axils of leaves. The young larvae tunneled into the axil and damaged new leaves. The mature larvae are yellowish green, except for the black head.The brown pupa is formed in a cocoon in a curled leaf. The adult is pale brown with dark markings, and a wingspan up to 20 mm.In later stages the larvae rolled the leaves inward from edges and fed from inside. Soumya *et al*. (2017) at Bengaluru recorded the incidence of *D. aprobola* from October to May and peaked in November and December, when new vegetative flush appeared and panicle initiation began.

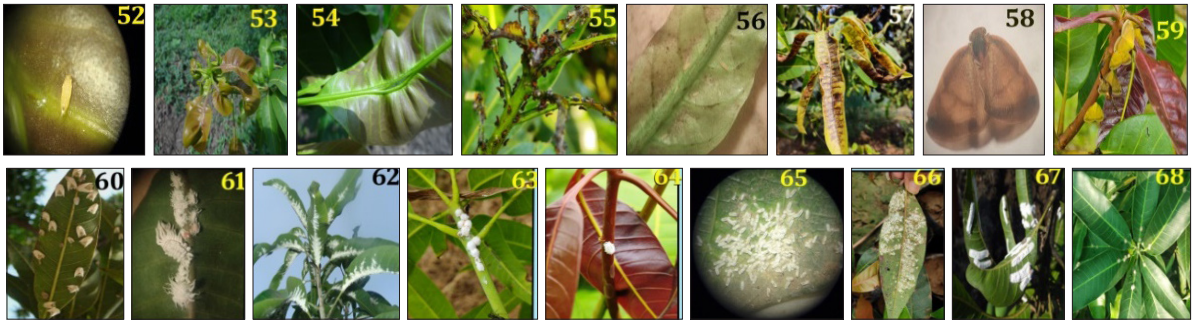
Leaf Defoliators



Pests Damaging Shoots



Sucking Insect Pests



Leaf Eating Beetles and Weevils

Fig. 1 Shoot feeders of mango in nursery under humid tropics

Leaf cutter, *Palumbina glaucitis* (Meyrick, 1907) (Fig. I-27 to 31) also occurred from July to October in scattered manner on new shoots. Green larva with brown head makes a portable leaf cases by cutting the leaf along the edges into small irregularly shaped pieces (mostly circular and semi-circular). Later, many small leaf pieces (4 to 8) were aggregated and stacked into a compact and circular leaf case. The larvae live and feed inside the case and can move from one place to another by carrying it. Pupation also occurs inside it. The adult emerges by leaving the pupal exuvia inside the case. Adult is silver-grey coloured with white marking on forewings and hind wings with broad hairy margins.

Incidence of black Yellow tail moth (*E. similis*) (Fig. I- 32) caterpillar with yellowish longitudinal band and red strip dorsally was observed during August to October. Numerous long hairs and minute white spots were present on body. Caterpillars were found biting leaves. Earlier, Preetha (2013) and Anant (2016) reported yellow tail moth (*E. similis*) on mango. Incidence of nymphs and adults of different grasshoppers (Fig. I- 33 to 35) were also observed to fed on margins of the leaf blade throughout the year.

A. Arthropods Damaging Shoots

Larva of shoot borer, *Chlumetia transversa* Walker (Fig. I- 36 to 42) was dark pink in color with brown head tunneling the tender shoots and excreta were found at the entry point and the shoot becomes hollow. Heavy infestation results in leaf abscission and wilting of shoots. Pupation occurs at damaging site (shoot tunnel) and also in soil in form of earthen cocoon.Adult moths are stout grayish brown in colour with wings having wavy lines. Incidence was observed during October to December and January to March. Choudhury (2015) observed maximum population of shoot borer during May to October. Munj *et al*. (2019), Kannan and Rao (2006) and Vanitha (2020) recorded infestation of *C. transversa* in root stocks in nursery.

Characteristic, papery white to dirty white mines due the infestation of stem miner, *Spulerina* sp. (Fig. I- 43 to 46) were observed at the bases of young shoots and emerging flushes of mango. The larvae were yellowish white and had a distinctive, segmented appearance. The larvae remain hidden inside the mines and continue to feed and come out just before pupation. Pupation took place inside transparent silken cocoons on leaves. The adult moth is narrow and elongate. The forewings are covered with brownish scales. They fed under the epidermis at the bases of young shoots and flushes of mango resulted in the formation of characteristic whitish, papery thin mines. Incidence was observed during October to December. Poorani and Thanigairaj (2022) recorded the incidence of mango stem miner *S. pulerinai sonoma* (Meyrick), a poorly known pest, is recorded from Tamil Nadu, India.

Incidence of shoot gall midge, *Erosomya indica* Felt. (Fig. I-47-50) was observed during October to December and March to April. Infested mango buds and shoots found with small raised galls containing a yellow larva. Small blackish emergence holes were found on galls. Affected plant parts got shriveled and died.Ahmed *et al*. (2005) reported that mango midge (*E. indica*) has become a major pest of mango and is found in all mango growing countries of the world. Sixteen species of midges are known to attack mango in Asia where this plant is indigenous. The midge infests and damages the crop at three different stages.

B. Sucking Arthropods

Incidence of mango hopper, *A. atkinsoni* and *Idioscopus* sp. (Fig. I- 22 to 55) was observed during October to November and during March to April. Adults of mango hopper were possessed wedge shaped body with broad head and scutellum. Eggs were found in slits, which were made in midrib on underside of leaves. Nymphs and adults both were found aggregated on leaves and suck the sap. Besides, they secreted honey dew and resulted in development of black sooty mold on leaves. Likewise incidence of Thrips, *S. dorsalis*(Fig. I- 56 to 57) was observed during October to November and February to May. Both nymphs and adults suck the

sap from the new flush and tender shoots which resulted in shiny silver and upward curled brown leaf edges and stunted growth. In Past Kavitha (2004) Preetha (2013), Sharma (2015), Choudhury (2015), Reddy and Sreedevi (2016), Anant (2016), Munj*et al*. (2019) and Bana *et al*. (2019) reported the incidence of hopper and thrips in mango.

Adults plant hopper, *Scolypopa*sp. (Fig. I- 59) were found resting on young leaves and also on the new shoots of mango and sucks the sap. Adults possessed yellowish forewings with dark brown patches at the base and margin. Black spots were present at each side of posterior margin in the forewings. Incidence was observed during July to October. Leaf gall midge, *P. matteiana* (Fig. I- 51) incidence was observed during July to November. Yellowish, minute larvae were found in raised galls. Infestation was resulted in dropping of leaves.

Different species of mealybugs viz., mealy bugs and scales, *Drosicha mangiferae* Green (Fig.I-60), *Icerya seychellarum* West wood (Fig.I-61), *Rastococcus spinosus* Robinson (Fig.I-62), *Rastrococcus iceryoides* Green (Fig.I-63), *Phenacoccus* sp. (Fig.I-64), *Aulacaspis tubercularis* Newstead (Fig.I-65,66), *Philephedra tuberculosa* Hawaii (Fig.I-67), and *Ceroplastes* sp.(Fig.I-68) were observed during January to April and November to December. Nymph and adults of mealy bugs were found sucking the sap from young leaves and new shoots. Development of sooty mold was observed due to honey dew secretion followed by drying of leaves. Sharma (2015) recorded infestation of mealy bug during January to May with peak in March in mango. Munj *et al*. (2019) and Reddy and Sreedevi (2016) also reported mealy bug infesting mango.

C. Leaf Eating Beetles and Weevils

Mango leaf cutting weevil, *D. marginatus* (Fig.I-69 to 72) infestation was observed during June to October. Adults were found shiny black with reddish orange head and prothorax. Adults of both sexes were observed infesting young leaves by scrapping, which resulted in curling and drying of leaves. However, female adults were found cutting young leaves from the base after ovipositing eggs singly in leaf tissue by making pouch parallel to the midrib. Fully grown third instar grubs exited leaf galleries by rupturing the epidermal layer of fallen infested mango leaves. Pupae were shiny white in color with visible pair of large black compound eyes. Infestation was resulted in defoliation of new flushes of mango. Earlier infestation of *D. marginatus* was reported by different workers all over the country (Kannan and Rao, 2006; Preetha, 2013; Sathe *et al*., 2015; Reddy and Sreedevi, 2016; Anant, 2016; Balaji and Kumar, 2018; Munj *et al*., 2019 and Vanitha, 2020).

Likewise incidence of grey weevil/ ash weevil, *Myllocerus* spp. (Fig.I-73 to 74) was observed during June to November. Ashy grey to whitish adults with stout body were observed. Adults were found feeding by biting leaf lamina. According to Kannan and Rao (2006) and Vanitha (2020) ash weevil is also a major pest in Nursery. Leaf beetle, *Basilepta* sp. (Fig.I-75) incidence was observed during June to September. The scrapping type of damage was caused by adults of this beetle which was same as caused by leaf cutting weevils. Windowpanes (papery patches) and numerous holes on leaves were produced. Damaged leaves lose vigor, curled upward, became brownish and finally dried.

Earlier, Aye (2020) documented 17 species of insect-pests of mango *viz*., *Leptocentrus taurus*, *I. Clypealis* and *I. nitidulus, Dictyophara pannonica, Lawana conspersa, Ricania* sp., *Scolypopa australis*, *Aphis gossypii, Myzuspersicae, I. Aegyptica* and *I. seychellarum, A. tubercularis, P. longispinus, B. rufomaculata, Hypomeces squamosus*, *Sternochetus mangiferae* and *B. dorsalis*. The present finding are more or less in coformity with earlier workers.

Considering the ensuing climate change and entry of invasives, a continuous monitoring and vigil on pest scenario is essential.

ACKNOWLEDGEMENTS

The authors are greatly thankful to Director of Research, Navsari Agricultural University, Navsari, Gujarat (India) for providing necessary facilities for conducting the present research work and Dr. Sunil Joshi, Dr. G. Mahendiran, Senior Scientist (Agril. Entomology), Division of Germplasm Collection and Characterization, ICAR- NBAIR, Bangaluru; Dr. K.D. Prathapan, Kerala Agricultural University, Vellayani, Kerala and Dr. P. R. Shashank, Scientist, Division of Entomology, ICAR-Indian Agricultural Research Institute New Delhi for correct identification of the specimen

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MS Received:20 October 2024
MS Acceptance:25 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 312-319 (2024)
DOI Number : 10.5958/0974-4541.2024.00046.X

Bioefficacy and phytotoxicity evaluation of insecticides against insect pests of chilli under field conditions in Haryana

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ABSTRACT: The study was aimed to evaluate the bioefficacy and phytotoxicity of insecticides against thrips (*Scirtothrips dorsalis*), fruit borer (*Helicoverpa armigera*) and tobacco caterpillar (*Spodoptera litura*) on chilli crop. Among the treatments, Cyantraniliprole 10.26% OD @ 750 and 600 ml/ha resulted in the low populations of thrips 1.60 and 1.93/plant at 3 days after first spray (DAFS), which declined to 0.27 and 0.47/plant, respectively by 14 days after second spray (DASS), respectively. Similarly, the low larval population of fruit borer and tobacco caterpillar 1.07 and 1.20/plant and 0.87 and 1.13/plant, respectively were recorded at 3 DAFS, which reduced to 0.13 and 0.20/plant, and 0.33 and 0.47/plant, respectively by 14 DASS. Cyantraniliprole 10.26% OD @ 750 and 600 ml/ha also showed low fruit infestation and high yield as compared to other treatments. Lambda cyhalothrin 4.9% CS @ 500 ml/ha, emamectin benzoate 5% SG @ 200 g/ha, lufenuron 5.4% EC @ 600 ml/ha and cyantraniliprole 10.26% OD @ 450 ml/ha were relatively less effective. The products were eco-friendly, since no phytotoxicity to chilli crop and no adverse impact on prevailing natural enemies, spiders and coccinellid in crop ecosystem was observed.

Keywords: Bioefficacy, chilli, thrips, fruit borer, tobacco caterpillar

INTRODUCTION

The chilli (*Capsicum annuum* L.) is one of the most valuable vegetable and spice crops. Its specific characteristics of pungency, aroma, colour, flavour and nutritive enrich make it to hold a critical part of ingredients used in the preparation of various food cuisines worldwide and preferred equally by rich as well as poor families. The major constraints in profitable production of chilli are diseases and insect pests, which attack the crop at vegetative as well as reproductive growth phases. The major insect pests hampering the crop growth at vegetative phase are sucking insect pests like leaf hoppers, whitefly, thrips, aphids and red spider mites which feed on the cell sap resulting in crinkling and curling of the leaves. At reproductive phase of the crop, direct damage to the chilli fruits is caused by fruit borer (*Helicoverpa armigera*) and tobacco caterpillar (*Spodoptera litura*) by initially feeding on leaves and later boring in to fruiting bodies thereby declining the quality fruit yield. Thrips (*Scirtothrips dorsalis*) not only damage the crop, also serve as one of the vectors of transmitting viral diseases. The chilli fruit production is significantly affected by sap-sucking pests and fruit borers, leading to considerable monetary losses to growers. Effective pest management strategies implication in time is therefore, becomes crucial for optimal crop production. The excessive and indiscriminate use of conventional and synthetic pyrethroid insecticides often, leads to the development of undesirable problems like suppression of natural enemies, loss of bioeffectiveness, development of pest resurgence and resistance, and even failure of pest control (Nagia *et al*., 1990, Goel *et al*., 1992, Ukey and Sarode, 2001, Kumar *et al*., 2006, Latha and Hunumanthraya, 2018). Thus, it becomes necessary to evaluate new molecules for the effective control of pests with no phytotoxicity to crops and no harm to consumer and environment. Keeping such issues in view, a field trial was conducted to evaluate bioefficacy, phytotoxicity and safety to natural enemies of insecticides Cyantraniliprole 10.26% OD, Lufenuron 5.4% EC, Lambda cyhalothrin 4.9% CS and Emamectin benzoate 5% SG on chilli crop against thrips, fruit borer and tobacco caterpillar pests.

MATERIALS AND METHODS

A field experiment was conducted at the IPFT Experimental Research Farm, Gurugram, Haryana (Latitude 28^{o} 50' 53.34" N, Longitude 77^{o} 09'34.11" E and 217 masl) during *kharif* 2022-23 to evaluate the bioefficacy and phytotoxicity of insecticides against the insect pests of chilli crop. The chilli crop var. Sakata 653 was planted in randomized block design (RBD) plots of 5 m x 4 m size and at a spacing of 30 cm x 50 cm. All the recommended agronomic practices for the

crop like irrigation, weeding, nutrient management, etc. were followed at regular intervals. With the initiation of incidence of pests on the crop, spray schedule was planned and application of treatments was done twice at 15 days interval. The treatments Cyantraniliprole 10.26% OD @ 450, 600, 750 and 1200 ml/ha, Lufenuron 5.4% EC @ 600 ml/ha, Lambda cyhalothrin 4.9% CS @ 500 ml/ha and Emamectin benzoate 5% SG @ 200 g/ha were applied using knapsack sprayer fitted with hollow cone nozzle and using 500 l/ha spray volume. The observations for the population of pests were made before first spray and further at 3, 7 and 14 days after each spray. To record the observations on thrips population, randomly selected three upper tender leaves per plant and ten plants per replicated plot were observed. However, for the larval population of fruit borer and tobacco caterpillar recording ten random plants per replicated plot were observed. The per cent fruit infestation by fruit borer and tobacco caterpillar was recorded before first spray and further at 10 days after first spray (DAFS) and at 10 and 20 days after second spray (DASS) by observing 50 random fruits per plot, and based on the data per cent fruit infestation was calculated.

The observations were also recorded visually for the phytotoxicity symptoms *viz*. Leaf injury on tips/ surface, Wilting, Vein clearing, Necrosis, Chlorosis, Stunting, Epinasty and Hyponasty after 3, 7, 10 and 14 days of each spray following 0-10 phytotoxicity rating scale (where 0=0%, 1=1-10%, 2=11-20%, 3=21-30%, 4=31-40%, 5=41-50%, 6=51-60%, 7=61-70%, 8=71-80%, 9=81-90%, 10=91-100%). To assess the impact of applied treatments on natural enemies, the population of spiders and coccinellids were recorded before first spray and at 3 and 7 days after each spray on randomly selected ten plants per plot. The crop yield was recorded at each harvest and cumulative yield expressed in terms of q/ha. The experimental data were analyzed statistically after subjecting to angular/ square root transformation as per the requirement.

RESULTS AND DISCUSSION

Control of thrips (*S. dorsalis*)

The population of thrips recorded at each time interval has been presented in Table 1. It was recorded that before first spray the population of thrips was ranging from 8.30 to 9.03/plant and the difference was not significant. The post treatments data recorded at 3, 7 and 14 days after first and second spray showed that all the treatments effectively controlled thrips population as compared to untreated control. Among the treatments, Cyantraniliprole 10.26% OD @ 750 ml/ha was found to be highly effective and closely followed by

Table: 1. Effectiveness of treatments against thrips, *Scirtothrips dorsalis* on chilli crop

Treatment	Formulation dose	Thrips population per plant						
		Before first spray	Days after first spray			Days after second spray		
			3 days	7 days	14 days	3 days	7 days	14 days
Cyantraniliprole 10.26% OD	450 ml/ha	8.47 (2.99)	4.23 (2.17)	3.90 (2.10)	6.20 (2.59)	3.73 (2.04)	2.87 (1.83)	1.60 (1.45)
Cyantraniliprole 10.26% OD	600 ml/ha	8.70 (3.03)	1.93 (1.56)	1.33 (1.35)	2.57 (1.75)	1.97 (1.57)	1.17 (1.29)	0.47 (0.98)
Cyantraniliprole 10.26% OD	750 ml/ha	8.57 (3.01)	1.60 (1.45)	1.17 (1.28)	2.23 (1.65)	1.80 (1.52)	1.03 (1.24)	0.27 (0.87)
Lufenuron 5.4% EC	600 ml/ha	9.03 (3.09)	4.63 (2.27)	3.47 (1.99)	6.47 (2.64)	4.30 (2.19)	3.43 (1.98)	2.13 (1.62)
Lambda cyhalothrin 4.9% CS	500 ml/ha	8.90 (3.07)	3.07 (1.89)	2.07 (1.60)	4.93 (2.33)	2.30 (1.67)	2.17 (1.63)	0.97 (1.21)
Emamectin benzoate 5% SG	200 g/ha	8.53 (3.01)	3.43 (1.98)	2.30 (1.67)	5.43 (2.44)	2.83 (1.82)	2.53 (1.74)	1.07 (1.25)
Untreated Control	-	8.30 (2.97)	9.50 (3.16)	12.07 (3.54)	19.20 (4.44)	14.53 (3.87)	12.90 (3.66)	8.87 (3.06)
S Em±		0.03	0.04	0.05	0.04	0.09	0.05	0.04
CD at 5%		NS	0.13	0.17	0.12	0.28	0.14	0.13

NS – Non significant, Figures in parentheses are square root transformed values (x + 0.5)

Table 2. Effectiveness of treatments against fruit borer, *Helicoverpa armigera* on chilli crop

Treatment	Formulation dose	Fruit borer larval population per plant						
		Before first spray	Days after first spray			Days after second spray		
			3 days	7 days	14 days	3 days	7 days	14 days
Cyantraniliprole 10.26% OD	450 ml/ha	2.43 (1.71)	2.10 (1.61)	1.73 (1.49)	1.90 (1.55)	1.47 (1.40)	0.80 (1.14)	0.67 (1.08)
Cyantraniliprole 10.26% OD	600 ml/ha	2.33 (1.68)	1.20 (1.30)	0.63 (1.06)	1.10 (1.26)	0.60 (1.05)	0.37 (0.93)	0.20 (0.83)
Cyantraniliprole 10.26% OD	750 ml/ha	2.30 (1.67)	1.07 (1.25)	0.57 (1.03)	0.87 (1.17)	0.47 (0.98)	0.27 (0.88)	0.13 (0.79)
Lufenuron 5.4% EC	600 ml/ha	2.47 (1.72)	1.67 (1.47)	1.40 (1.38)	1.57 (1.44)	1.20 (1.30)	0.87 (1.17)	0.57 (1.03)
Lambda cyhalothrin 4.9% CS	500 ml/ha	2.20 (1.64)	1.53 (1.43)	1.23 (1.31)	1.47 (1.40)	1.03 (1.24)	0.60 (1.05)	0.47 (0.98)
Emamectin benzoate 5% SG	200 g/ha	1.93 (1.56)	1.70 (1.48)	1.07 (1.25)	1.30 (1.34)	1.10 (1.26)	0.67 (1.08)	0.50 (1.00)
Untreated Control	-	2.10 (1.61)	3.97 (2.11)	6.17 (2.58)	6.60 (2.66)	5.87 (2.52)	4.37 (2.21)	3.80 (2.07)
S Em±		0.05	0.05	0.06	0.04	0.05	0.04	0.05
CD at 5%		NS	0.15	0.17	0.11	0.15	0.12	0.14

NS – Non significant, Figures in parentheses are square root transformed values (x + 0.5)

its lower dose 600 ml/ha at each observation time. The population at 14 days after second spray in the treatment Cyantraniliprole 10.26% OD @ 750 ml/ha reduced to 0.27/plant, which was closely followed by lower dose 600 ml/ha (0.47/plant). Rest of the treatments Lambda cyhalothrin 4.9% CS @ 500 ml/ha, Emamectin benzoate 5% SG @ 200 g/ha, Cyantraniliprole 10.26% OD @ 450 ml/ha and Lufenuron 5.4% EC @ 600 ml/ha with 0.97 to 2.13/plant were next in order of effectiveness and significantly superior to untreated control (8.87/plant). The per cent reduction in thrips population over control based on mean data of two sprays resulted that treatments Cyantraniliprole 10.26% OD @ 750 ml/ha and 600 ml/ha were highly effective at each time interval as compared to other treatments with 82.52 to 92.29% and 79.78 to 90.66% mean reduction in thrips population.

The present studies corroborate the findings of Sahani and Mondal (2020) from Bhirbhum, West Bengal, Italiya *et al*. (2023) and Kakadiya *et al.* (2024) from Anand, Gujarat, Layek *et al*. (2024) from Nadia West Bengal and Poornima *et al.* (2024) from Raichur, Karnataka that Cyantraniliprole 10.26% OD effectively controlled thrips in chilli crop. Cyantraniliprole 10.6% OD is also reported to be effective against sucking insect pests in watermelon crop (Layek *et al*., 2023). Reduction in chilli leaf curl disease transmitted by whitefly has also been reported by Daunde and Khandare (2020) with the application of Cyantraniliprole 10.6% OD @ 1.2 ml/L. Similarly, Cyantraniliprole 10.26% OD @ 90 g a.i/ha was found effective in controlling thrips in pomegranate orchard (Satyanarayana *et al*., 2024). Additionally, Priyanka *et al*. (2023) also reported Cyantraniliprole 300 g/L OD @ 70 and 90 g a.i./ha to be most effective in controlling thrips in grapes.

Control of fruit borer *(H. armigera)*

The larval population of fruit borer recorded at each time interval has been presented in Table 2. It was recorded that before first spray the fruit borer larval population was ranging from 1.93 to 2.47/ plant in different plots and the difference was not significant. The post treatments data recorded at 3, 7 and 14 days after first and second spray showed that at each observation time all the treatments effectively controlled fruit borer larval population on chilli crop as compared to untreated control. It is evident from the data that the treatment

Cyantraniliprole 10.26% OD @ 750 ml/ha was highly effective and closely followed by its lower dose 600 ml/ha at each observation time. The larval population at 14 days after second spray showed that Cyantraniliprole 10.26% OD @ 750 ml/ha was most effective with 0.13 larvae/ plant followed by lower dose 600 ml/ha (0.20 larvae/ plant). Rest of the treatments Lambda cyhalothrin 4.9% CS @ 500 ml/ha, Emamectin benzoate 5% SG @ 200 g/ha, Lufenuron 5.4% EC @ 600 ml/ha and Cyantraniliprole 10.26% OD @ 450 ml/ha with 0.47 to 0.67 larvae/ plant were next in order of effectiveness and significantly superior to untreated control (3.80 larvae/ plant). The per cent reduction in fruit borer larval population over control calculated for mean data of two sprays revealed that Cyantraniliprole 10.26% OD on application @ 750 and 600 ml/ha was highly effective as compared to other treatments for reducing the mean fruit borer larval population at each observation time by 85.38 to 92.67% and 83.06 to 90.66%, respectively.

The present findings are in conformity with Layek *et al*. (2024) reporting from Nadia, West Bengal that Cyantraniliprole 10.26% OD @ 120 g a.i./ha was efficient in controlling larval population of *H. armigera* in chilli crop. Likewise, Sahu and Mandal (2019) reported from Bhubaneswar, Odisha that Cyantraniliprole 10.26% OD @ 70 g a.i./ha was most effective followed by Emamectin benzoate 5% SG @ 10 g a.i./ha to control the larval population of *H. armigera* in capsicum. On okra crop Cyantraniliprole 10.26% OD on application @ 120 g a.i./ha and 90 g a.i./ha was also found equally effective against *H. armigera, Aphis gossypii, Earias vitella* and *S, litura* (Patel and Rahaman, 2021). Additionally, the Cyantraniliprole 10.26% OD @ 600 ml/ha and as a combination product Cyantraniliprole 7.3% w/w + Diafenthiuron 36.4% w/w SC @ 750 and 625 ml/ha were evaluated against sucking and fruit borer pests of okra crop by Kalyan and Kalyan (2022). They have reported that the combination product @ 750 and 625 ml/ha doses was equally effective against jassids, whitefly, mites, *H. armigera* and *Earias* spp. and superior to solo formulation Cyantraniliprole 10.26% OD @ 600 ml/ha.

Control of tobacco caterpillar *(S. litura)*

The larval population of *S. litura* recorded at each time interval has been presented in Table 3. It was recorded that before first spray the larval population of *S. litura* was ranging from 3.40 to 3.87/ plant in different plots and the difference was not significant signifying that

Table 3. Effectiveness of treatments against tobacco caterpillar, *Spodoptera litura* on chilli crop

Treatment	Formulation dose	Tobacco caterpillar larvae per plant						
		Before first spray	Days after first spray			Days after second spray		
			3 days	7 days	14 days	3 days	7 days	14 days
Cyantraniliprole 10.26% OD	450 ml/ha	3.67 (2.04)	2.03 (1.59)	1.77 (1.51)	2.47 (1.72)	1.80 (1.52)	1.33 (1.35)	0.90 (1.18)
Cyantraniliprole 10.26% OD	600 ml/ha	3.40 (1.97)	1.13 (1.28)	0.50 (0.99)	0.93 (1.20)	0.77 (1.12)	0.60 (1.04)	0.47 (0.98)
Cyantraniliprole 10.26% OD	750 ml/ha	3.53 (2.01)	0.87 (1.16)	0.37 (0.93)	0.87 (1.16)	0.63 (1.06)	0.53 (1.02)	0.33 (0.90)
Lufenuron 5.4% EC	600 ml/ha	3.83 (2.08)	1.53 (1.43)	1.30 (1.34)	2.20 (1.64)	1.47 (1.40)	1.07 (1.25)	0.67 (1.08)
Lambda cyhalothrin 4.9% CS	500 ml/ha	3.87 (2.09)	1.67 (1.47)	1.13 (1.28)	2.33 (1.68)	1.17 (1.29)	1.10 (1.26)	0.73 (1.10)
Emamectin benzoate 5% SG	200 g/ha	3.43 (1.98)	1.40 (1.38)	1.07 (1.25)	1.63 (1.46)	1.03 (1.24)	0.87 (1.17)	0.83 (1.15)
Untreated Control	-	3.73 (2.06)	6.53 (2.65)	6.17 (2.58)	6.80 (2.70)	6.53 (2.65)	6.23 (2.59)	4.60 (2.26)
S Em±		0.05	0.03	0.04	0.05	0.06	0.04	0.06
CD at 5%		NS	0.10	0.13	0.14	0.18	0.13	0.18

NS – Non significant, Figures in parentheses are square root transformed values (x + 0.5)

Table 4. Effectiveness of treatments on per cent fruit infestation by *Helicoverpa armigera* and *Spodoptera litura* and crop yield

Treatment	Formulation dose	Per cent fruits infested by *H. armigera*				Per cent fruits infested by *S. litura*				Chilli yield (q/ha)
		Before first spray	10 DAFS	10 DASS	20 DASS	Before first spray	10 DAFS	10 DASS	20 DASS	
Cyantraniliprole 10.26% OD	450 ml/ha	10.00 (18.85)	9.33 (18.26)	7.33 (16.22)	5.33 (13.82)	14.00 (22.35)	11.33 (20.11)	10.00 (18.85)	6.67 (15.31)	10.65
Cyantraniliprole 10.26% OD	600 ml/ha	10.67 (19.29)	6.67 (15.50)	4.00 (12.04)	2.00 (8.47)	10.00 (18.85)	8.00 (16.88)	4.67 (13.09)	3.33 (11.20)	13.83
Cyantraniliprole 10.26% OD	750 ml/ha	12.00 (20.66)	6.00 (14.66)	3.33 (11.20)	0.67 (5.74)	13.33 (21.75)	6.67 (15.50)	4.00 (12.04)	2.00 (8.47)	14.70
Lufenuron 5.4% EC	600 ml/ha	13.33 (21.79)	10.00 (18.85)	8.67 (17.60)	4.67 (13.09)	14.67 (22.85)	12.00 (20.66)	8.67 (17.60)	4.00 (12.04)	11.67
Lambda cyhalothrin 4.9% CS	500 ml/ha	12.67 (21.22)	8.67 (17.60)	8.00 (16.88)	4.00 (12.04)	10.67 (19.51)	10.00 (18.73)	7.33 (16.22)	5.33 (13.61)	11.45
Emamectin benzoate 5% SG	200 g/ha	10.67 (19.41)	8.00 (16.88)	6.00 (14.66)	3.33 (11.20)	12.67 (21.22)	9.33 (18.26)	5.33 (13.93)	4.67 (13.09)	11.02
Untreated Control	-	11.33 (19.94)	18.67 (25.92)	25.33 (30.50)	21.33 (27.82)	12.00 (20.66)	23.33 (29.14)	27.33 (31.82)	28.67 (32.63)	9.10
S Em±		1.66	1.10	1.20	1.68	1.22	1.24	1.04	1.93	0.62
CD at 5%		NS	3.38	3.68	5.18	NS	3.83	3.19	5.96	1.90

NS- Non significant, Figures in parentheses are angular transformed values (x + 0.5)

the larval population was more or less similar in all the experimental plots. The post treatment data recorded at 3, 7 and 14 days after first and second spray showed that at each observation time all the treatments effectively controlled larval population of tobacco caterpillar as compared to untreated control. Amongst the treatments Cyantraniliprole 10.26% OD @ 750 ml/ha was found to be highly effective closely followed by lower dose 600 ml/ha at each observation time. The larval population at 14 days after second spray showed that Cyantraniliprole 10.26% OD @ 750 ml/ha resulted in lowest population 0.33 larvae/ plant followed by lower dose 600 ml/ha with 0.47 larvae/ plant. Remaining treatments Lufenuron 5.4% EC @ 600 ml/ha, Lambda cyhalothrin 4.9% CS @ 500 ml/ha, Emamectin benzoate 5% SG @ 200 g/ha and Cyantraniliprole 10.26% OD @ 450 ml/ha with 0.67 to 0.90 larvae/ plant were next in order of effectiveness and significantly superior to untreated control (4.60 larvae/ plant). The per cent reduction in *S. litura* larval population calculated over untreated control based on mean data of two sprays for 3, 7 and 14 days showed that Cyantraniliprole 10.26% OD on application @ 750 and 600 ml/ha reduce the mean larval population of *S. litura* more efficiently 88.51 to 92.75% and 85.45 to 91.13%, respectively than other treatments.

It is on record that Cyantraniliprole 10.26% OD on application @ 120 g a.i./ha and 90 g a.i./ha on okra crop effectively controlled *H. armigera, Aphis gossypii, Earias vitella* and *S. litura*; and on application over cabbage crop @ 70 g a.i./ha and 60 g a.i./ha the product was effective to control *Brevicoryne brassicae, Lipaphis erysimi, Plutella xylostella* and *S. litura* (Patel and Rahaman, 2021). Tompe *et al*. (2020) conducted polyhouse trial in capsicum crop and reported that Cyantraniliprole 10.26% OD was most promising insecticide to control *S. litura* among the pesticides tested. Other treatments Chlorantraniliprole 18.5% SC, Lufenuron 50% EC, Flubendiamide 39.35% SC, Lambda cyhalothrin 5% EC, Spinosad 45% SC and Indoxacarb 14.5% SC were next in order of effectiveness. The studies carried out on soybean crop to control *S. litura* by Natikar *et al*. (2016) resulted that Flubendiamide 480 SC @ 0.2 ml/l was most effective treatment followed by Indoxacarb 15.8% EC @ 0.3 ml/l and Cyantraniliprole 10% OD @ 0.2 ml/l twice at 15 days interval. Similarly on groundnut crop Jagmohan *et al*. (2024) reported that Chlorantraniliprole 18.5% SC @ 30 g a.i./ha was most effective to control *H. armigera* and *S. litura* which was followed by Cyantraniliprole 10% OD @ 90 g a.i./ha whereas Lambda cyhalothrin 5% EC @ 25 g a.i./ha was comparatively less effective.

The higher efficacy of Cyantraniliprole compared to other tested insecticides in most of the cases may be due to the fact that Cyantraniliprole primarily acts through ingestion and secondarily through contact. As a result, the exposed insects exhibit lethargy and muscle paralysis and stop feeding, ultimately leading to insect death. The present study under Haryana agroclimatic conditions are in support of the results reported from other locations.

Control of fruit damage by *H. armigera* and *S. litura*

The per cent fruit infestation by *H. armigera* and *S. litura* recorded at each time interval has been presented in Table 4. It was recorded that before first spray the fruit infestation by *H. armigera* ranged from 10.00 to 13.33% whereas the fruit infestation by *S. litura* ranged from 10.00 to 14.67% in different plots and the differences were not significant. The post-treatment data recorded at 10 days after first spray and at 10 and 20 days after second spray, indicated that all the treatments were significantly more effective to control fruit infestation by both the pests as compared to untreated control. At 20 days after second spray, Cyantraniliprole 10.26% OD applied @ 750 ml/ha was most effective treatment with fruit infestations of 0.67% by *H. armigera* and 2.00% by *S. litura*. This was followed by Cyantraniliprole 10.26% OD @ 600 ml/ha, which showed fruit damage 2.00% by *H. armigera* and 3.33% by *S. litura*. Other treatments, Emamectin benzoate 5% SG @ 200 g/ha, Lambda cyhalothrin 4.9% CS @ 500 ml/ha, Lufenuron 5.4% EC @ 600 ml/ha and Cyantraniliprole 10.26% OD @ 450 ml/ha resulted in infestations ranging from 3.33 to 5.33% by *H. armigera* and 4.00 to 6.67% by *S. litura.*

Impact on crop yield

The chilli fruit yield recorded periodically and cumulative yield expressed in terms of q/ha has been presented in Table 4. The yield data showed that significantly increased yield was recorded in all the treatments as compared to untreated control except Cyantraniliprole 10.26% OD @ 450 ml/ha. The higher fruit yield 14.70 q/ha was recorded in Cyantraniliprole 10.26% OD @ 750 ml/ha treatment, which was closely followed by the lower dose of the product @ 600 ml/ha (13.83 q/ha). Other treatments Lufenuron 5.4% EC @ 600 ml/ha (11.67 q/ha), Lambda cyhalothrin 4.9% CS @ 500 ml/ha (11.45 q/ha) and Emamectin benzoate 5% SG @ 200 g/ha (11.02 q/ha) were next in order of effectiveness and significantly superior to untreated control. The least effective treatment in terms of fruit yield was Cyantraniliprole 10.26% OD @ 450 ml/ha with 10.65 q/ha, which was not significantly different from untreated control (9.10 q/ha). The relation between percent fruit damage by pests and yield is an indirect indicator for the efficacy of any chemical tested. The chilli yield with the application of Cyantraniliprole 10.26 OD @ 1.2 ml/l has been reported as high as 93.67 q/ha by Kakadiya *et al*. (2024). Patel and Rahaman (2021) reported the lowest (6.01%) mean okra fruit damage by fruit borer *H. armigera* which resulted in higher fruit yield (10.90 t/ha) with the application of Cyantraniliprole 10.26% OD @ 120 g a.i./ha. Higher chilli fruit yield with the application of Cyantraniliprole 10.26% OD has also been reported in comparison to untreated control (Sahani and Mondal, 2020, Kalyan and Kalyan, 2022, Italiya *et al*., 2023, Kakadiya *et al*., 2024).

Phytotoxicity evaluation on chilli crop

The observation for the phytotoxicity parameters recorded visually at 3, 7, 10 and 14 days after each application of treatments showed that no phytotoxicity symptoms were observed due to the application of Cyantraniliprole 10.26% OD @ 450, 600, 750 and 1200 ml/ha and other treatments at respective doses on chilli crop. On potato crop, Cyantraniliprole 10% OD @ 75, 150 and 300 g a.i./ha (Bojan, 2021) and Cyantraniliprole 10.26% OD @ 75 g a.i./ha (Subburaj and Bojan, 2023) have been reported to be non-phytotoxic. Also, Priyanka *et al*. (2023) observed no visible phytotoxicity symptoms on grapes with the application of Cyantraniliprole 300 g/L OD @ 70 and 140 g a.i./ha.

Impact on natural enemies

The prevailing population of natural enemies in the crop field recorded before first spray and at 3 and 7 days after each spray showed that spiders and coccinellids were most prevalent natural enemies in the experimental plots. There was no adverse impact of all the treatments on spiders and coccinellids at each observation time, since there was no significant difference in their populations. The investigations reporting biosafety of Cyantraniliprole to natural enemies like spiders and coccinellids under different crop agro ecosystems are on record. The safety to spiders and coccinellids with the application of Cyantraniliprole 10.26% OD @ 75 g a.i./ha on potato crop (Subburaj and Bojan, 2023) and Cyantraniliprole 300 g/L OD up to 90 g a.i./ha application on grapes (Prinyanka *et al*., 2023) has been reported. In another case sudden decline in coccinellids population with the application of Cyantraniliprole 10 OD @ 60, 75 and 90 g a.i./ha on potato crop has been reported by Bojan (2021), however gradual increase in population was observed thereafter. It is a common fact that the

population of natural enemies often tends to be decline after application of treatments. One of the main basic reasons may be insufficient food available for feeding (low pest population) and predators forced to migrate to other area in search of adequate food availability.

CONCLUSION

The treatment of Cyantraniliprole 10.26% OD on application @ 750 ml/ha and 600 ml/ha resulted to be effective in controlling the incidence of thrips, (*Scirtothrips dorsalis*), fruit borer (*Helicoverpa armigera*) and tobacco caterpillar (*Spodoptera litura*) in chilli crop with low pest population and higher per cent reduction in population over control. The low per cent fruit damage and higher crop yield were also recorded by using these two treatments. Other treatments Lufenuron 5.4% EC @ 600 ml/ha, Lambda cyhalothrin 4.9% CS @ 500 ml/ha, Emamectin benzoate 5% SG @ 200 g/ha and Cyantraniliprole 10.26% OD @ 450 ml/ha were also effective but to some lesser extent. No phytotoxicity to chilli crop and no adverse impact on predators like spiders and coccinellids were observed with the application of all the treatments, which indicated the biosafety and eco-friendly nature of the tested molecules.

ACKNOWLEDGEMENT

The authors are grateful to M/s GSP Crop Science Pvt. Ltd., Ahmedabad for sponsoring the trial and Director, IPFT, Gurugram for encouragement and providing the necessary facilities.

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MS Received: 23 October 2024
MS Acceptance: 28 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 320-325 (2024)
DOI Number : 10.5958/0974-4541.2024.00053.9

IPM modules against litchi fruit and shoot borer, *Conopomorpha sinensis* Bradley using safer and newer insecticides

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ABSTRACT: A field trial was conducted at ICAR-National Research Centre on Litchi, Mushahari, Muzaffarpur; Bihar to develop optimal combination of IPM modules for managing the litchi fruit and shoot borer (*Conopomorpha sinensis*; Lepidoptera: Gracillariidae) a major pest of litchi. At harvest stage, most of the treatments showed more than 85% efficacy on reduction in borer infestation over control. The highest reduction in borer infestation was found in flubendiamide (19.92%) + thiacloprid 19.92 % 480 SC(94.56%) followed by lambda cyhalothrin 5 EC(90.09%). The least infested fruit (1.50 kg/tree) and highest healthy fruit (24.99 kg/tree) was recorded with flubendiamide 19.92% + thiacloprid 19.92 % 480 SC followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (23.44 kg/tree), lambda cyhalothrin 5 EC (18.34 kg/tree) and chlorantranilprole 18.5 SC (16.67 kg/tree) against lowest (1.67 kg/tree) in control. Additionally, minimum yield loss (5.66%) was recorded with flubendiamide 19.92% + thiacloprid 19.92 % 480 SC followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (10.23%), lambda cyhalothrin 5 EC (14.09%) and chlorantranilprole 18.5 SC (16.67%) against maximum (90.46%) in control. Similarly, reduction in fruit infestation over control calculated on weight basis was also highest in flubendiamide 19.92% + thiacloprid 19.92 % 480 SC (90.53%) followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (83.14%), lambda cyhalothrin 5 EC (81.00%) and chlorantranilprole 18.5 SC (79.73%). Neonicotinoid based combination products containing flubendiamide, spirotetramat and/ or beta-cyfluthrin are recommended to manage the litchi shoot and fruit borer management in an effective way to achieve the maximum yield.

Keywords: Litchi fruit and shoot borer, *Conopomorpha sinensis*, insecticides, pest management

INTRODUCTION

Litchi, *Litchi chinensis* Sonn. belongs to family Sapindaceae, is one of the most important subtropical evergreen fruit crop. It is considered as queen of the subtropical fruits due to its attractive deep pink/red colours and flavoured juicy aril. The fruit has high nutritive value and excellent pulp (aril) quality known for its characteristics flavor and taste. India is the second largest producer of litchi in the world next to China. It is now an important commercial fruit crop in India due to its high market demand and export potential. Cultivation of litchi is widely spread in eastern India (Bihar, Jharkhand, West Bengal, and NE region) which provides livelihood opportunities to millions of people in the region (Kumar *et al.* 2014). This crop is also gaining momentum in Uttarakhand, UP, Himachal Pradesh, Jammu, Punjab, Orissa and non-traditional areas of southern states (Kerala, Karnataka and Maharashtra), owing to its high economic returns and ever increasing demand in the domestic markets. Insect-pests *viz*., fruit and shoot borer, litchi mite, bark eating borer, leaf folder, litchi looper, litchi weevils etc, which causes severe loss resulting in poor yield (Srivastava *et al*., 2015; Reddy *et al*., 2016; Srivastava *et al*., 2018)**.** Among insect-pests, litchi fruit and shoot borer, *Conopomorpha sinensis* (Lepidoptera: Gracillariidae)is one of the major threat to litchi growers, causing severe losses to fruit as well as young shoots, to the tune of 24-48% and 7-70%, respectively (Srivastava *et al*., 2017). The insects (larvae) damage the newly emerged shoot during September- October resulting in failure of shoot to bloom. Further, it punctures the peduncle of fruits (both developing as well as mature) during April-May resulting to severe loss through early fruit drop and appearance of excreta/larvae, when fruit is cut/opened after ripening. Like other crops, insecticides are most powerful and widely accepted for the control of pests in litchi and therefore, newer molecules with selective action, safer to non target organisms and environmentally sound may be explored to protect this precious crop (Srivastava *et al., 2004*; Srivastava *et al.,*

2005; Srivastava *et al.,* 2007; Kumar *et al*., 2014). Eco-friendly insect pest management is crucial for achieving sustainable food production. Several environmentally conscious and sustainable approaches to pest control should be prioritized to protect crops while minimizing negative impacts on pollinator bees and beneficial organisms. These methods include the use of botanicals (Divekar *et al*., 2022; Divekar *et al*., 2024), host plant resistance (HPR) (Divekar et al. 2019), plant secondary metabolites (Divekar *et al*., 2022), bio-control agents (Divekar P., 2023; Shinde *et al*., 2021), defense proteins (Divekar *et al*., 2023), and safer chemical control options (Kodandaram *et al*., 2024).

Insecticidal combinations are effective alternative to address the problem and to mitigate insecticide resistance. Combining insecticides with different properties such as nature action can be advantageous for containing both chewing and sucking pests simultaneously. Mixtures may enhance the overall target spectra allowing the control of a wide range of pests when they are present on the crop at the same time (Reddy *et al.*, 2018). Therefore, keeping in view the importance of litchi fruit and shoot borer, a field trial was conducted to evaluate the different optimal combination IPM modules against this key pest.

MATERIALS AND METHODS

Present study was conducted at experimental farm of ICAR-National Research Center on Litchi, Muzaffarpur, Bihar (latitude and longitude of 26°5'87"N and 85°26'64" E, respectively at altitude of 210m asl) during 2017-2018. Experiment was laid out in RBD with 6 treatments replicated 4 times (Table 1) in cv. Shahi. Good agronomical practices were followed as per recommended package of practices (Kumar *et al.,* 2015).

One foliar spray of neem based formulations was given at the time of panicle emergence before flowering to avoid egg laying by the moth. Three sprays of all the chemicals were applied at different interval during April-May. First spray was given at clove size fruit, second spray at cardamom size fruit (after fifteen days of first spray) while third spray was given at 10 days after second spray (about 15 days before harvest). Spraying was done on outer as well as inner canopy in all the direction on the tree with the help of power sprayer having hollow cone nozzles.

Observations were recorded on the basis of damaged fruit at early stage, mid stage and harvesting stage. To observe the borer infestation at early stage (clove size fruit) and mid stage (cardamom size fruit), the fallen fruits were collected from each treatments and cut/ open with the help of sharp knife. At fruit maturity, 100 fruits from each treatment were plucked randomly for recording observation. The peduncle of harvested fruit was removed and presence of larva or their excreta was considered as infested fruits. The damage was assessed based on the weight of total number of fruits and damaged fruits in the different treatments and the percent damage was worked out. The yield of litchi fruits was recorded from each plant on weight basis. Statistical analysis was carried out using SPSS software programme 24.0.

RESULTS AND DISCUSSION

All the treatments significantly reduced the fruit borer infestation in comparison to control during the period of experimentation. During 2017, no borer was observed at early stage in any treatment except spirotetramat 11.01% + imidacloprid 11.01% (1.33%) against 3.00 in control, that may be due to unfavorable environmental conditions (Table-1). At mid stage also, 0.00 borer infestation was observed in treatment with flubendiamide 19.92% + thiacloprid 19.92 which is closely followed by spirotetramat 11.01% + imidacloprid 11.01% (2.67%). Similar trend was observed at harvest stage too. During 2018, again no borer population was observed at early stage including control. At mid stage no population were recorded in two treatments namely, flubendiamide 19.92% + thiacloprid 19.92 % spirotetramat 11.01% + imidacloprid 11.01% followed by beta-Cyfluthrin 8.49 %+ imidacloprid 19.81 % (5.88%) against 47.78 % in control. At harvest stage again minimum infestation (3.88%) was observed in flubendiamide 19.92% + thiacloprid 19.92 % followed by lambda cyhalothrin (7.00%); chlorantraniliprole (9.33%) against 95.14% in control (Table 1).

Effect of different combination IPM modules on reduction of fruit borer infestation over control on litchi ecosystem are presented in Table 2. Data revealed that combined application of mixture insecticides with neem oil were found most effective in reducing borer population. During 2017, 100 per cent reduction over control of litchi fruit borer was recorded in flubendiamide 19.92% + thiacloprid 19.92 % followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (83.98%), chlorantranilprole 18.5 SC (65.99) at mid stage. At harvest stage, flubendiamide 19.92% + thiacloprid 19.92 % gave the maximum reduction over control (92.39 spirotetramat 11.01% + imidacloprid 11.01% (90.13%) and lambda cyhalothrin (86.04%). During 2018, again100 per cent reduction over control of litchi fruit borer was recorded in flubendiamide 19.92% + thiacloprid 19.92

Table 1. Efficacy of combination insecticides against litchi fruit and shoot borer infestation (%)

Treatments	Conc.	Early stage			Mid stage			Harvest stage		
		2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1-Lambda cyhalothrin 5 EC	0.003%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	6.33 (14.56)	6.67 (14.95)	6.50 (14.76)	8.33 (16.77)	7.00 (15.31)	7.67 (16.06)
T_2-Chlorantranilprole 18.5 SC	0.007%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.67 (13.75)	6.00 (14.14)	5.83 (13.95)	8.67 (17.11)	9.33 (17.75)	9.00 (17.44)
T_3-Beta-Cyfluthrin 8.49 %+ Imidacloprid 19.81 %	0.011%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	6.33 (14.56)	5.88 (14.00)	6.11 (14.29)	10.33 (18.71)	11.23 (19.56)	10.78 (19.15)
T_4-Flubendiamide 19.92% + Thiacloprid 19.92 % 480 SC	0.48%	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	4.54 (12.29)	3.88 (11.27)	4.21 (11.81)
T_5-Spirotetramat 11.01% + Imidacloprid 11.01% 240 SC	0.36%	1.33 (6.53)	0.00 (0.00)	0.67 (4.61)	2.67 (9.36)	0.00 (0.00)	1.33 (6.60)	5.89 (14.01)	9.67 (18.07)	7.78 (16.19)
T_6-Control		3.00 (9.88)	0.00 (0.00)	1.50 (6.97)	16.67 (24.07)	47.78 (43.71)	32.22 (34.57)	59.67 (50.56)	95.14 (77.38)	77.40 (61.61)
SEm (±)		0.27	-	0.14	0.43	0.72	0.36	0.60	0.62	0.40
CD (P=0.05)		0.87	-	0.43	1.37	2.30	1.13	1.92	1.98	1.26

*values in parenthesis are angular transformed

% along with spirotetramat 11.01% + imidacloprid 11.01% 240 SC followed by beta-Cyfluthrin 8.49 % + imidacloprid 19.81 % (87.69%) chlorantranilprole 18.5 SC (87.44%) at mid stage. Similar trend was also observed at harvest stage. The maximum reduction of borer over control (95.92%) was noticed in flubendiamide 19.92% + thiacloprid 19.92 % followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (89.84%) and chlorantranilprole 18.5 SC (90.19%) at harvest stage. Pooled data also revealed that at mid stage100 percent reduction of borer infestation over control was noticed in flubendiamide 19.92% + thiacloprid 19.92 % followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (95.87%), chlorantranilprole 18.5 SC (81.91%). However, at harvest stage, all the treatments showed more than 86 % efficacy on reduction in borer infestation over control. The highest reduction in borer infestation was found in flubendiamide 19.92% + thiacloprid 19.92% (94.56%) followed by lambda cyhalothrin (90.09%), spirotetramat 11.01% + imidacloprid 11.01% 240 SC (89.95%), chlorantranilprole 18.5 SC (88.37%) and beta-cyfluthrin 8.49 % + imidacloprid 19.81 % (86.07%).

All mixture as well as solo insecticides significantly influenced the borer infestation and fruit yield of litchi (Table 3). Weight of infested litchi fruits showed that application of these molecules reduced the damage of litchi fruits done by borer that contributed towards more marketable fruit yield as compared to control. Highest healthy fruit (24.99 kg/tree) was recorded with flubendiamide 19.92% + thiacloprid 19.92 % 480 SC followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (23.44 kg/tree), lambda cyhalothrin 5 EC (18.34 kg/tree), chlorantraniliprole 18.5 SC (16.67 kg/tree) and beta-cyfluthrin 8.49 % + imidacloprid 19.81 % (15.30 kg/tree against lowest (1.67 kg/tree) in control.

Additionally, minimum yield loss also (5.66%) was recorded with flubendiamide 19.92% + thiacloprid 19.92 % 480 SC followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (10.23%), lambda

Table 2. Efficacy of combination insecticides on reduction of litchi fruit and shoot borer infestation over control (%)

Treatments	Conc.	Early stage			Mid stage			Harvest stage		
		2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1-Lambda cyhalothrin 5 EC	0.003%	100.00	0.00	100.00	62.03	86.04	79.83	86.04	92.64	90.09
T_2-Chlorantranilprole 18.5 SC	0.007%	100.00	0.00	100.00	65.99	87.44	81.91	85.47	90.19	88.37
T_3-Beta-Cyfluthrin 8.49 %+ Imidacloprid 19.81 %	0.011%	100.00	0.00	100.00	62.03	87.69	81.04	82.69	88.20	86.07
T_4-Flubendiamide 19.92% + Thiacloprid 19.92 % 480 SC	0.48%	100.00	0.00	100.00	100.00	100.00	100.00	92.39	95.92	94.56
T_5-Spirotetramat 11.01% + Imidacloprid 11.01% 240 SC	0.36%	55.67	0.00	55.33	83.98	100.00	95.87	90.13	89.84	89.95
T_6-Control	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

cyhalothrin 5 EC (14.09%) and chlorantranilprole 18.5 SC (16.67%) against maximum (90.46%) in control. Similarly, reduction in fruit infestation over control calculated on weight basis was also highest in flubendiamide 19.92% + thiacloprid 19.92 % 480 SC (90.53%) followed by spirotetramat 11.01% + imidacloprid 11.01% 240 SC (83.14%), lambda cyhalothrin 5 EC (81.00%) and chlorantranilprole 18.5 SC (79.73%).

Highest reduction of litchi fruit borer infestation with combination insecticides, might be due to different properties. such as selective action as well as ovicidal action of these chemicals.

Further, combinations may enhance the overall target spectra allowing the control of a wide range of pests when they are present on the crop at the same time (Reddy *et al.*, 2018). Chlorantraniliprole is a new insecticide belonging to the anthranilic diamide class of chemistry and is intended for the control of Lepidopteran, Coleopteran, and some Dipteran pests. Chlorantraniliprole exhibits excellent differential selectivity for insect ryanodine receptors over mammalian ryanodine receptors (Bentley *et al*., 2010). Flubendiamide, a benzene dicarboxamide, is a new class of insecticide having a new biochemical mode of action, affecting ryanodine receptors in insects and is highly effective at very low dose against a broad spectrum of lepidopteran pests including resistance strains (Tohnishi *et al*., 2005; Sreedhar, 2019). From the study, it can be concluded that combination insecticides aremost effective against litchi borer and shoot borer. More infestation of litchi fruit andshoot borer noticed during harvest stage perhaps due to occurrence of intermittent rains during fruit growth and development, which might have created the congenial environment for borer survival (Srivastava *et al*., 2017).

Reddy *et al.* (2018) also reported that combination insecticides are more effective than solo once against variety of insect pests. Similarly, Srivastava *et al.* (2015) also observed flubendiamide, chlorantraniliprole, neonicotinoids and pyrethroids are highly effective against litchi pests. The results are also in line with the findings of Srivastava *et al.* (2016) who reported that the three spraying of flubendiamide and/or thiacloprid or chlorantraniliprole at recommended dose kept the litchi fruit borer infestation below threshold level and also care other insect pests with same spraying.

The finding of present investigation holds a good promise in litchi fruit borer management. However, further studies on effect of these combinations on natural enemies need to be undertaken so that such combination

Table 3. Efficacy of combination insecticides on fruit borer infestation and their impact on fruit yield of litchi

Treatments	Conc.	Weight of infested fruits in terms of unmarketable yield (kg/tree)			Weight of healthy fruits in terms of marketable yield (kg/tree)			Yield loss (%)			Reduction in fruit infestation over control on weight basis (%)		
		2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
T_1-Lambda cyhalothrin 5 EC	0.003%	3.10 (10.13)	2.91 (9.81)	3.01 (9.98)	18.56 (25.51)	18.11 (25.18)	18.34 (25.34)	14.31	13.84	14.09	76.15	84.41	81.00
T_2-Chlorantranilprole 18.5 SC	0.007%	3.10 (10.14)	3.32 (10.49)	3.21 (10.31)	17.11 (24.42)	16.23 (23.75)	16.67 (24.09)	15.34	16.98	16.15	76.15	82.22	79.73
T_3-Beta-Cyfluthrin 8.49 %+ Imidacloprid 19.81 %	0.011%	4.68 (12.49)	5.00 (12.91)	4.84 (12.71)	15.67 (23.31)	14.92 (22.71)	15.30 (23.01)	22.99	25.10	24.03	64.00	73.22	69.44
T_4-Flubendiamide 19.92% + Thiacloprid 19.92 % 480 SC	0.48%	1.67 (7.41)	1.33 (6.62)	1.50 (7.04)	24.31 (29.53)	25.66 (30.42)	24.99 (29.98)	6.43	4.93	5.66	87.15	92.88	90.53
T_5-Spirotetramat 11.01% + Imidacloprid 11.01% 240 SC	0.36%	2.00 (8.12)	3.33 (10.51)	2.67 (9.39)	25.21 (30.13)	21.66 (27.72)	23.44 (28.94)	7.35	13.33	10.23	84.62	82.16	83.14
T_6-Control	-	13.00 (21.13)	18.67 (25.59)	15.84 (23.44)	2.11 (8.34)	1.23 (6.36)	1.67 (7.42)	86.04	93.81	90.46	0.00	0.00	0.00
SEm (±)		0.10	0.15	0.10	0.30	0.15	0.14	-	-	-	-	-	-
CD (0.05)		0.33	0.49	0.31	0.96	0.48	0.45	-	-	-	-	-	-

can be more effectively utilized in future. Neonicotinoid based combination products having flubendiamide, spirotetramat and/ or beta-cyfluthrin are recommended to manage the litchi shoot and fruit borer management in a effective way with maximum yield.

ACKNOWLEDGEMENT

The authors would like to acknowledge the help of Director, ICAR-NRC Litchi, Muzaffarpur, for providing the necessary facilities required for the present investigation.

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MS Received: 25 September 2024
MS Acceptance: 15 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 326-329 (2024)
DOI Number : 10.5958/0974-4541.2024.00054.5

Bio-efficacy and economics of biopesticides against tobacco cutworm, *Spodoptera litura* Fab. on menthol mint

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ABSTRACT: A field experiment was conducted to study the bio-efficacy and economics of biopesticides against tobacco cutworm, *Spodoptera litura* Fab. on menthol mint during the *kharif* season of 2023 at Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur), Bihar. Among the treatments, *Bacillus thuringiensis* var. *kurstaki* applied @ 1 l/ha was found to be the most effective, reducing the mean larval population by 42.92 per cent. The next most effective treatment was *Beauveria bassiana* @ 2.5 kg/ha (38.08%) which was statistically comparable to *Metarhizium anisopliae* @ 1.5 l/ha (34.91%) and *Azadirachtin* (1500 ppm) at 0.75 l/ha (32.13%). The least effective treatments were Neem oil (2%) applied at 10 l/ha (28.02%) and NSKE (5%) at 25 kg/ha (24.76%), although both were more effective than the untreated control plot. The highest B:C ratio was observed for *Bacillus thuringiensis* var. *kurstaki* at 1 l/ha (1:1.52) followed by *Beauveria bassiana* at 2.5 kg/ha (1:1.32), *Metarhizium anisopliae* at 1.5 l/ha (1:1.29) and *Azadirachtin* (1500 ppm) at 0.75 l/ha (1:1.26). NSKE (5%) at 25 kg/ha and Neem oil (2%) at 10 l/ha yielded benefit-cost ratios of 1:0.76 and 1:0.70 respectively, while the untreated control plot had the lowest ratio of 1:0.61.

Keywords: Bio-efficacy, biopesticides, economics, tobacco cutworm, menthol mint

INTRODUCTION

Among different essential oils produced in India, *Mentha arvensis* (menthol mint) oil holds prominent position in terms of acreage, production and domestic consumption and export to the world market. India is the largest producer and exporter of natural menthol in the world. The annual turnover of the menthol industry has been in the range of ` 3,500–4,000 crores during the past one decade. Menthol mint is presently cultivated in more than 2.50 lakh hectares in North India. Uttar Pradesh contributes about 70–75% of the total national production of menthol mint oil. Menthol mint yields 130–150 kg mint oil/ha (single harvest) giving a net profit in the range of 60–70,000 in about 3 and a half months (Suryavanshi *et al.*, 2021). Taking the lesson of success of menthol mint cultivation from the farmers of UP, the area under mint is now spreading to other states in the country including Bihar, parts of Punjab.

Japanese Mint (*Mentha arvensis var piperascense*) is an aromatic perennial herb, grown as an annual in sub-tropical parts of north India. Mints belong to the genus *Mentha*, in the family Labiatae (Lamiaceae) which includes other commonly grown essential oil-yielding plants such as basil, sage, rosemary, marjoram, lavender, pennyroyal and thyme. Within the genus *Mentha* there are several commercially grown species, varying in their major chemical content, aroma and end use. Their oils and derived aroma compounds are traded world-wide. All are herbaceous plants, readily sending out runners (rainy season) and stolons (winter) which develop new roots and shoots at the nodes and form plants. The entire aerial shoots together with foliage is a source of essential oil rich in menthol, carvone, linalool and linanyl acetate having use in pharmaceutical preparations and flavour industry. Japanese mint is a perennial ascending herb growing about 60-80 cm. in height and under favourable conditions may attain a height upto 100 cm. It does not produce seed and propagation is through vegetative means only (Kumar *et al.*, 2019).

However, insect pests pose a significant constraint in the production and quality of menthol mint oil. Among these, the *Spodoptera litura* Fab., is a particularly severe pest, substantially reducing the overall herbage yield. It was initially considered a minor pest but now poses significant threat to mint crops and identified as a severe pest for *Mentha arvensis* (Kedar *et al.*, 2023). In order to find safer methods of management of *S. litura*, present studies were conducted to evaluate the bio-efficacy and economics of certain biopesticides.

MATERIALS AND METHODS

The field experiment was conducted on during the *kharif* season of 2023 in the agro-climatic zone of North Bihar, at the Herbal Garden of RPCAU, Pusa

(Samastipur), Bihar. The experiment comprise seven treatments replicated three times in a Randomized Block Design, using plots each measuring 40 cm x 40 cm and an overall plot size of 2m x 2m following the recommended package of practices, apart from insecticidal application. The variety used for the experiment was Kosi with seven different treatments *viz., Bacillus thuringiensis*var. *Kurstaki, Metarhizium anisopliae, Beauveria bassiana,* Neem oil 2 %, NSKE 5%, *Azadirachtin*1500 ppm and Untreated Control.

The foliar spray of all the treatments was done by knapsack sprayer of 15 litres capacity. All the liquid formulations were measured by measuring cylinder and solid formulations were weighed using weighing balance. The spray solution of desired concentration was formed accordingly. The biopesticides are scheduled for two applications throughout the crop season, the 1st at the onset of pest infestation and the 2nd fifteen days following the initial spray. The larval population of pest was recorded from five randomly chosen plants in each treatment before the foliar application. Similarly, the larval population of pest was recorded on 1, 3, 7 and 14 days after first and second spray in each treatment. The yield of the marketable leaves was recorded after harvest and the cumulative yield and economics of each treatment was worked out.

The data collected from the experiments were analyzed statistically according to the experimental requirements. The effectiveness of treatments was also assessed by working out the per cent reduction of larvae over control. The benefit-cost ratio was computed. To compute the benefit-cost ratio, the additional revenue generated over the control plot was divided by the extra cost incurred for pest management.

RESULTS AND DISCUSSION

The cumulative efficiency of different biopestide treatments for the management on tobacco cutworm infesting menthol mint was summarized in (Table 1). The results regarding overall mean of two sprays against tobacco cutworm revealed that the treatment *Bacillus thuringiensis* var. *kurstaki* @ 1 l/ha was counted to be more efficient treatment and the per cent reduction in *S. litura* larval population over control was 42.92 per cent, followed by efficient application was *Beauveria bassiana* @ 2.5 kg/ha, *Metarhizium anisopliae*@ 1.5 l/ha, Azadirachtin 1500ppm @ 0.75 l/ha, Neem oil 2% @ 10 l/ha and NSKE 5 % @ 25 kg/ha also the per cent reduction in *S. litura* larval population over control was 38.08, 34.91, 32.13, 28.02 and 24.76 per cent respectively which were better than control or untreated plot after two successive sprays of biopesticides.

Among the treatments evaluated *Bacillus thuringiensis*var. *kurstaki* applied at 1 l/ha emerged as the most effective, achieving a significant reduction in the mean larval population by 42.92 per cent. This finding aligns with earlier research conducted by Sharma (2000), which demonstrated that formulations

Table 1. Efficacy of biopesticide treatments against tobacco cutworm on mint

Treatments	Dose (kg or l/ha)	1st Spray	2nd Spray	Mean larval population	Per cent reduction over control
T_1-*Bacillus thuringiensis*var. *kurstaki*	1.00	5.42	2.67	4.04	42.92
T_2-*Metarhizium anisopliae*	1.50	5.50	3.42	4.46	34.91
T_3-*Beauveria bassiana*	2.50	4.58	2.42	3.50	38.08
T_4-Neem oil 2 %	10.0	5.50	4.33	4.92	28.02
T_5- NSKE 5%	25.0	5.00	3.50	4.25	24.76
T_6- Azadirachtin1500 ppm	0.75	4.58	3.33	3.96	32.13
T_7-Untreated Control		9.25	9.58	9.42	
SEm (±)		0.41	0.38		
CD at 5 %		1.27	1.20		
CV (%)		11.46	12.61		

of *Bacillus thuringiensis* could lead to mortality rates of 66.66% to 100% within 3 to 5 days, indicating its strong potential as a biopesticide in pest management strategies. *Beauveria bassiana*, applied at 2.5 kg/ha, was the second most effective treatment, reducing the larval population by 38.08 per cent. This is consistent with findings from Suganthy and Sakthivel (2013), who reported that *Beauveria bassiana* was effective in managing *S. litura* populations. The current study also found that *Metarhizium anisopliae* at 1.5 litres/ha and Azadirachtin at 1500 ppm were statistically comparable, with reductions of 34.91 per cent and 32.13 per cent, respectively. The effectiveness of Azadirachtin has been corroborated by Nathan and Kalaivani (2005), who noted its significant impact on the nutritional indices of *S. litura*, further supporting its use in integrated pest management. In contrast, Neem oil 2% @ 10 litres/ ha and NSKE 5% @ 25 kg/ha were the least effective treatments, yielding reductions of 28.02% and 24.76%, respectively. However, both treatments were still more effective than the untreated control plot. Previous studies, such as those by Singh *et al.* (2019), have shown that while neem-based products can manage *S. litura* populations, they may not be as effective as synthetic pesticides or other biopesticides. Singh *et al.* (2019) investigated the performance of various neem-based biopesticides in managing *S. litura* larvae that neem oil was the most effective among the neem products, while neem seed kernel and leaf extracts yielded comparable results. Sumanjali *et al.* (2020) conducted a thorough study, monitoring *S. litura* larvae populations at 3, 5, and 7 days after both the first and second sprays and found that *Bacillus thuringiensis* showed better efficacy with larval population reductions of 54.17% and 74.58%. Chandrayudu *et al.* (2015) carried out a field trial over two consecutive *Rabi* seasons to assess botanical and microbial insecticides against *S. litura* and reported that *Bacillus thuringiensis* (*Bt*) spray was highly effective in reducing both larval populations and leaf damage. NSKE (5%) and neem oil at 2 ml/litre were also effective, though to a lesser extent. Swami *et al.* (2019) evaluated various biopesticides against the tobacco caterpillar and found that all treatments significantly reduced pest populations compared to the control, resulting in NSKE and neem oil were less effective, with mean larval populations of 4.97larvae/plant.

Economics of various biopesticide treatments against tobacco cutworm infesting menthol mint

The field efficacy of different biopesticides tested by application of foliar sprays and the economics of treatments on menthol mint estimated which revealed that best returns are obtained which varied from 175 to 102 q/ha and the highest yield obtained from the treatment *Bacillus thuringiensis* var. *kurstaki* @ 1 l/ha (175 q/ha) followed by *Beauveria bassiana* @ 2.5 kg/ ha (169 q/ha), *Metarhizium anisopliae* @ 1.5 l/ha (162 q/ha), Azadirachtin 1500ppm @ 0.75 l/ha (158 q/ha), Neem oil 2% @ 10 l/ha (153 q/ha),NSKE 5 % @ 25 kg/ ha (127 q/ha) and the untreated check recorded (102 kg/ ha) as given in (Table 2).

The net profits calculated by deducting the initial cost of land preparation, biopesticide cost and the labour charge the after that the economics of various treatments the highest ratio was obtained from the treatment *Bacillus thuringiensis* var. *kurstaki* @ 1 l/ha (1:1.52) followed by *Beauveria bassiana* @ 2.5 kg/ha (1:1.32), *Metarhizium anisopliae* @ 1.5 l/ha (1:1.29), Azadirachtin 1500ppm @ 0.75 l/ha (1:1.26), NSKE 5 % @ 25 kg/ha (1:0.76), Neem oil 2% @ 10 l/ha (1:0.70) and the untreated check was recorded (1:0.61) as given in (Table 2).

Table 2: Effect of biopesticides on foliage yield of menthol mint

Biopesticides	Dose (kg or l/ha)	Mean foliage yield (q/ha)	Increased yield over control (q/ha)	Increase in yield over control (%)	B:C Ratio
T_1-*Bacillus thuringiensis* var. *kurstaki*	1.00	175	73	71.57	1.52
T_2-*Metarhizium anisopliae*	1.50	162	60	58.82	1.29
T_3-*Beauveria bassiana*	2.50	169	67	65.69	1.32
T_4-Neem oil 2 %	10.0	153	51	50.00	0.70
T_5-NSKE 5%	25.0	127	25	24.51	0.76
T_6-*Azadirachtin* 1500 ppm	0.75	158	56	54.90	1.26
T_7-Untreated Control	-	102	0	0.00	0.61

CONCLUSION

The effectiveness of different biopesticide treatments against tobacco cutworm infesting menthol mint revealed that *Bacillus thuringiensis* var. *kurstaki* applied at 1 l/ha was the most effective treatment, reducing the mean larval population by 42.92%. The next most effective treatment was *Beauveria bassiana* at 2.5 kg/ha (38.08%), which was statistically comparable to *Metarhizium anisopliae* at 1.5 l/ha (34.91%) and azadirachtin (1500 ppm) at 0.75 l/ha (32.13%). The highest B:C ratio was recorded with *Bacillus thuringiensis* var. *kurstaki* at 1 l/ha (1:1.52), followed by *Beauveria bassiana* at 2.5 kg/ha (1:1.32), *Metarhizium anisopliae* at 1.5 l/ha (1:1.29), and Azadirachtin (1500 ppm) at 0.75 l/ha (1:1.26).

ACKNOWLEDGEMENT

The authors would like to express their heartfelt and sincere thanks to the Head, Department of Entomology, Post Graduate College of Agriculture, Dr. Rajendra Prasad Central Agricultural University, Pusa (Samastipur) Bihar for extending their facilities to conduct these studies smoothly.

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MS Received: 30 August 2024
MS Acceptance: 20 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 330-336 (2024)
DOI Number : 10.5958/0974-4541.2024.00055.1

Major insect pests and natural enemies on brinjal in the *Tarai* region of Uttarakhand, India in relation to weather parameters

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ABSTRACT: The present study was conducted to document major insect pests and natural enemies on brinjal grown under natural farming in the tarai region of Uttarakhand, India during *kharif* 2022-23. Major insect-pests found on the brinjal crop were brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenee (Lepidoptera: Pyralidae), leafhopper, *Amrasca biguttula biguttula* Ishida (Hemiptera: Cicadellidae), white fly *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae), hadda beetle, *Henosepilachna vigintioctopunctata* Fabricius (Coleoptera: Coccinellidae), leaf roller *Eublemma olivacea* Walker (Lepidoptera: Erebidae) and stink bug *Nezara viridula* (Hemiptera: Pentatomidae). Among natural enemies, *Coccinella* sp. (Coleoptera: Coccinellidae) and spider were recorded in present studies. Population peaks of various insect pests and natural enemies were recorded in the following pattern, whitefly was recorded in 3rd week of August (34th SMW), peak in the population of leafhopper was recorded in 4th week of August (35th SMW), leafroller in 5th week of August (35th SMW), Brinjal shoot and fruit borer in 2nd week of September (37th SMW), bugs in 2nd week of September (37th SMW), hadda beetle in 4th week of August (34th SMW), Coccinella in 1st week of October (40th SMW) and spider in 3rd week of September (38th SMW).

Keywords: Brinjal, *Leucinodes*, whitefly, hadda beetle, coccinellids, weather parameters

INTRODUCTION

Brinjal (*Solanum melongena* Linnaeus) belongs to the family Solanaceae and chromosome number (2n = 24) and is also known as eggplant. It is one of the most popular and important vegetable crops worldwide (Gleddie *et al.,* 1986) and also a popular vegetable cultivated across India. Together with the potato, it is the second most eaten vegetable in the country (Mammoun *et al.,* 2004). Brinjal occupies an area of 74.9 million ha with a production of 12874 million tonnes in India. Major brinjal growing states in India are West Bengal, Orissa, Gujarat, Bihar, Madhya Pradesh, Chattisgarh, Andhra Pradesh, Tamil Nadu, Maharashtra, Assam (https://agriexchange.apeda.gov.in**,** 2023). It is an important vegetable grown all year round, because of its short duration, high yield, nutritional richness, economic viability, and potential on-farm and off-farm jobs, vegetables are significant components of Indian agriculture and nutritional security (Samota *et al.,* 2014). The most crucial element of a balanced diet is vegetables, which also serve as a form of nutrition. Therefore, unripen fruits of brinjal are generally eaten as vegetables due to their high nutritional content, which includes minerals like iron, phosphorus, calcium, and vitamins like A, B, and C. The fruit can be added to stews or used as garnish. It can also be eaten raw or prepared as a baked, grilled, fried, or boiled vegetable. According to reports, it is used in Ayurvedic treatment for diabetes. Moreover, it functions well as an aphrodisiac, a cardiac tonic, a laxative, and an anti-inflammatory (Kalawate *et al.,* 2012). However, brinjal yield remains lower than predicted due to various restrictions, the most significant of which are insect and non-insect pests that attack the crop at various physiological growth phases from nursery to harvest causing upto 70 to 92 per cent of crop losses (Chakraborti and Sarkar, 2011).

There are 26 insect pests species and few non insect pest species infesting brinjal of which Shoot and fruit borer, *Leucinodes orbonalis* Guenee (Lepidoptera: Pyralidae), white fly, *Bemisia tabaci Gennadius* (Hemiptera: Aleyrodidae), leafhopper, *Amrasca biguttula biguttula* Ishida (Hemiptera: Cicadellidae), hadda beetle, *Henosepilachna vigintioctopunctata* Fabricius (Coleoptera: Coccinellidae), leafroller *Eublemma olivacea Walker* (Lepidoptera: Erebidae), stink bug *Nezara viridula* (Hemiptera: Pentatomidae), and non-insect pests like red spider mite, *Tetranychus* spp are commonly known to infest brinjal crop (Vevai, 1970). *Leucinodes orbonalis* G., the brinjal shoot and fruit borer (BSFB), is often regarded as the most dangerous pest of the fruit. It has also significantly hampered output in all nations where the fruit is grown (Alam *et al.,* 2003).

Sucking pests of brinjal *viz.,* whitefly and leafhopper results in major crop losses, both directly and indirectly,

by sucking the cell sap with their piercing and sucking mouth parts and by transmitting viral diseases by forming sooty mold by whitefly and aphid and little leaf by leafhopper (Kunbhar *et al.,* 2018). Studying the population densities of insect pests that affect brinjal is crucial for efficient pest control (Sundareshwari *et al.,* 2017). Therefore, in this present study, the seasonal incidence of major insect pests and natural enemies of brinjal crop along with their relation with the various abiotic factors which is very important for formulating further management strategies.

MATERIALS AND METHODS

The field experiment was carried out at Vegetable Research Centre (VRC), G.B..U.A& T, Pantnagar, Uttarakhand during the *kharif* season of 2022. Incidence of insects was recorded per plot on randomly selected five plants. Observations were recorded once from the untreated plots in a standard week. Data was recorded 21 days after transplanting. The population estimation of brinjal shoot and fruit borer was recorded by counting the number of withered terminal shoot and infested fruits in the later stage of the crop. Sucking pests *viz.,* Leafhopper (*Amrasca biguttula biguttula, Ishida*) and whitefly (*Bemisia tabaci*) were recorded from three leaves top, middle, and bottom leaves of five randomly selected plants in the field using the method proposed by Rawat *et al.,* (1973). In case of insect pests such as *H. vigintioctopunctata* (adult and grub), pentatomid bugs, leafroller and natural enemies such as coccinellid beetles and spiders the data was recorded from entire plant in five randomly selected plants.

RESULTS AND DISCUSSION

The data collected on the insect pests infesting brinjal and associated natural enemies and their correlation with different weather factors during *kharif* crop season 2022 is presented below.

Insect- pests of brinjal

The insect pests *viz.,* brinjal shoot and fruit borer *Leucinodes orbonalis* Guenee (Lepidoptera: Pyralidae), leafhopper *Amrasca biguttula biguttula* Ishida (Hemiptera: Cicadellidae), white fly *Bemisia tabaci Gennadius* (Hemiptera: Aleyrodidae), grub and adult of hadda beetle *Henosepilachna vigintioctopunctata* Fabricius (Coleoptera: Coccinellidae), leafroller *Eublemma olivacea Walker* (Lepidoptera: Erebidae), stink bug *Nezara viridula* (Hemiptera: Pentatomidae) and natural enemies such as *Coccinella sp.* (Coleoptera: Coccinellidae) and spider were recorded in present studies.

Leafhopper, *Amrasca biguttula biguttula* Ishida (Hemiptera: Cicadellidae)

The leafhopper infestation was initiated during 4th week of July as foliage started in the crop (30th Standard Meteorological Week), with 3.60 number of leafhoppers per plant (Table. 4.1). The leafhopper population started increasing gradually with maximum number (17.40 per 3 leaves) during 4th week of August (35th Standard week) as the crop was in the vegetative stage. After that, as the crop reached maturity, the leafhopper population started decreasing with a minimum number of leafhoppers (0.80/ plants) recorded in the second last week of October (43rd

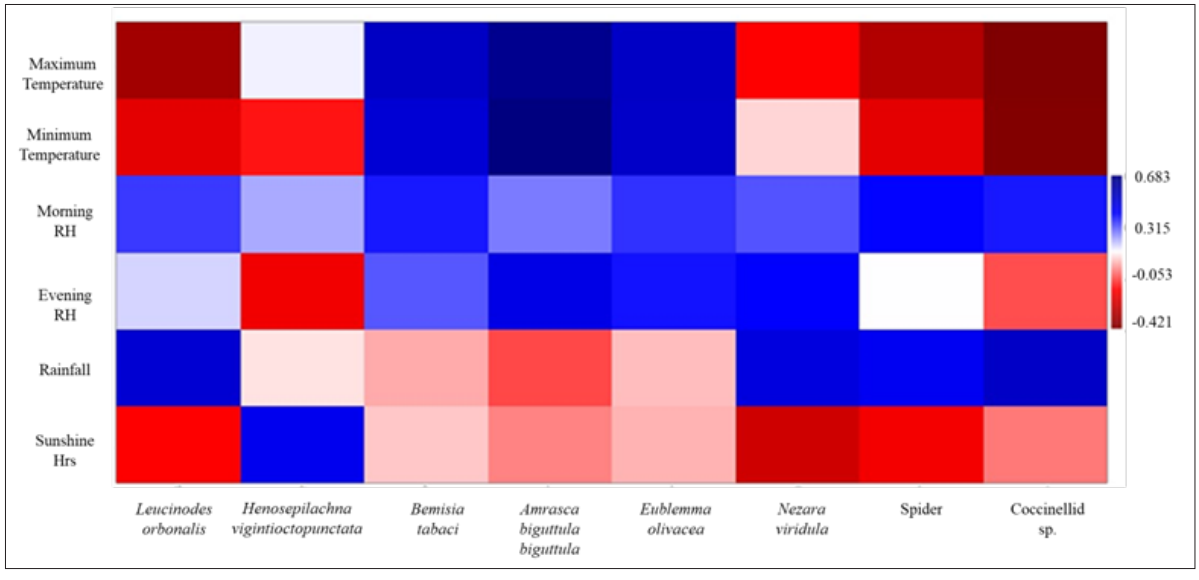

Fig. 1. Mosaic plot demonstrating the correlation between various insect pestas and natural enemies with different weather parameters

standard week). This is in keeping with Ajabe *et al.* (2019) findings who stated that the leaf hopper population grew along with the crop until it reached its highest of 11.80 leaf hoppers per 3 leaves in the second week of September (37th SMW), after which the population steadily declined.

White fly, *Bemisia tabaci Gennadius* (Hemiptera: Aleyrodidae)

The white fly infestation initiated during 4th week of July (30th standard week), with average population of 1.50 white fly per 3 leaves. The white fly population started increasing gradually with maximum number (24.70 /3 leaves) during 3rd week of August (34th standard week) due to availability of sufficient nutrition as tender foliage during vegetative stage of the crop. According to the data collected by Kumar and Sharma (2022), the presence of *B. tabaci*, was first observed in the beginning of August (33rd SMW) with initial population of 3.40 per 3 leaves. The population peaked at 60.80 whiteflies per 3 leaves in the fourth week of September (41st SMW).

Stink Bug, *Nezara viridula* Linnaeus (Hemiptera: Pentatomidae)

The stink bug (*Nezara viridula*) infestation was commenced during 1st week of August (32nd SMW) with mean population of 0.10 bugs per plant. The bug population started increasing gradually with increase in foliage as the vegetative stage proceeded with maximum number of up to 9.60 bugs per plant during 2nd week of September (37th SMW) as fruit set commenced. Later the bug population started decreasing gradually as crop reached maturity with minimum number of bugs (0.50 /plant) recorded during the 4th week of October (43rd SMW).

Brinjal shoot and fruit borer on shoot infestation

The shoot infestation of brinjal shoot and fruit borer commenced from the 1st week August with an initial population of 0.50 larvae per plant as the plant growth continued and was observed until last week of October, 2022 as crop continued to grow until maturity with a final population of 6.50 larvae per plant. The shoot infestation occurred at its peak for the first-time during 2nd week of September (37th SMW) with 22.30 larvae per plant. The shoot infestation recorded was ranging from 0.50 per cent to 22.30 per cent during the cropping period.

According to a study conducted by Sharma *et al.* (2017), the presence of brinjal shoot and fruit borer infestation was observed to begin in the 34th week, averaging at 0.64, and it reached its highest point at 5.21 during the 41st week.

Hadda beetle, *Henosepilachna vigintioctopunctata* (Coleoptera: Coccinellidae)

The hadda beetle infestation commenced during 4th week of July (30th SMW), 2022 with start of foliage with 0.15 mean of beetles per plant. The beetle population started increasing gradually as the crop growth proceeded with maximum number of 5.20 per plant recorded during 4th week of August (34th SMW). After that the beetle population started decreasing as flowering and fruiting commenced with 2.40 beetles per plant recorded in 3rd week of September (38th SMW), it again increased (4.30 beetles /plant) on 1st week of October (40th SMW) as crop attained maximum growth stage and finally decreased (2.20 beetles /plant) during 4th week of October (43rd standard week as crop reached maturity.

According to a study conducted by Sharma and Tayde (2017), the *kharif* season of 2016 began in the 30th week with an average of 1.2 hadda beetles per plant. Over time, the beetle population steadily increased and reached its highest level of 3.6 beetles per plant in the 35th week. However, by the 41st week, no hadda beetles were observed.

Leafroller, *Eublemma olivacea Walker* (Lepidoptera: Erebidae)

The leafroller infestation started 5th week of July (31st SMW) with an initial population of 1.00 larvae per plant as plant started its vegetative phase. Later, the leafroller population started increasing gradually with maximum number (7.60 larvae /plant) during 5th week of August (35th SMW) during maximum growth stage of the crop. Later, the leafroller population gradually started decreasing as crop reached maturity reaching a minimum of 0.20 larvae per plant which was recorded in the 4th week of October (43rd SMW).

NATURAL ENEMIES

Coccinellid beetle

The population of predatory coccinellids ranged between 0.60 to 4.90 beetles per plant in brinjal crop during August to October, 2022. The coccinellids were first observed in 1st week of August (32nd SMW) with appearance of sucking pests like aphids and leaf hoppers with 0.60 beetles per plant. The maximum population (4.90 /plant) of coccinellids was noticed during 1st week of October (40th SMW) after that the population was gradually decreasing as the crop reached the fruiting stage and maturity by 1st week of October (43rd SMW) with 2.70 beetles per plant.

Table 1. Temporal distribution of insect pests and natural enemies associated with brinjal crop (*kharif* 2022)

Date	SMW	*Leucinodes orbonalis*	*Henosepilachna epilachna*	*Bemisia tabaci*	*Amrasca biguttula biguttula*	*Eublemma olivacea*	*Nezara viridula*	Spider	*Coccinellid* sp.
23-07-2022	30	0.00	0.15	1.50	3.60	0.00	0.00	0.00	0.00
30-07-2022	31	0.00	0.20	4.30	6.50	1.00	0.00	0.00	0.00
06-08-2022	32	0.50	0.25	7.40	9.10	3.10	0.10	0.25	0.60
13-08-2022	33	3.10	5.20	11.30	12.40	4.50	1.30	0.43	0.88
20-08-2022	34	5.00	5.20	24.70	16.80	7.30	2.20	0.80	2.40
27-08-2022	35	9.50	3.30	22.50	17.40	7.60	3.80	2.45	2.75
03-09-2022	36	13.40	3.10	18.60	15.90	6.20	6.20	3.60	3.20
10-09-2022	37	22.30	1.60	12.25	13.50	6.10	9.60	4.20	3.90
17-09-2022	38	19.70	2.40	10.80	10.20	4.80	9.30	4.80	4.50
24-09-2022	39	20.60	2.40	10.60	8.70	3.70	8.80	2.85	4.65
01-10-2022	40	17.25	4.30	7.20	5.75	3.60	5.20	2.93	4.90
08-10-2022	41	14.50	3.70	5.40	2.60	1.50	3.70	2.60	4.40
15-10-2022	42	10.00	3.50	3.70	1.50	0.80	1.60	2.20	3.50
22-10-2022	43	6.50	2.20	0.70	0.80	0.20	0.50	1.85	2.70

Sarta *et al.* (2022) found that coccinellids up to 1.25 insects per plant were first spotted in the first week of August 2018 (32nd SMW). Coccinellids reached their peak population (2.25 /plant) in the last week of August (34th SMW).

Spider

The predatory spider count ranged between 0.25 to 4.80 spiders per plant in brinjal crop during August to October, 2022. The spiders were first observed in 1st week of August (32nd SMW) with appearance of sucking pests like aphids, thrips, and leaf hoppers with 0.25 spiders per plant with the maximum population (4.80 spiders /plant) noticed during 3rd week of September (38th SMW)

The predatory spiders were initially observed on the brinjal crop during the second week of August (32nd SMW), according to Sarta *et al.* (2022), at a rate of 2.75 per plant. Then, during the first week of September (36th SMW), the spider population increased and peaked at 3.0 per plant.

Correlation studies of weather parameters on insect pests and natural enemies in brinjal

The correlation coefficient between the mean number of insects and the climatic factors *i.e.,* maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours were worked out and are presented in table 1.

Leafhopper, *Amrasca biguttula biguttula* Ishida (Hemiptera: Cicadellidae)

The leafhopper population showed positive and significant correlation with maximum temperature (r = 0.649*) and minimum temperature (r = 0.683**). Whereas the correlation was positive but non-significant with morning relative humidity (r = 0.273) and evening relative humidity (r = 0.463). The correlation was found negative and non-significant with rainfall (-0.067) and sunshine hours (-0.003).

The correlation studies of Soren *et al.* (2019) indicated that there was negative and non- significant

with sunshine hours (r = -0.242) and rainfall (r = -0.159). The result showed positive and significant correlation by Tupe *et al.* (2022) minimum temperature (r = 0.68*) and maximum temperature (r = 0.71**).

White fly, *Bemisia tabaci Gennadius* (Hemiptera: Aleyrodidae)

The white fly population showed positive and significant correlation with maximum temperature (r = 0.534*). Correlation was positive but non- significant with minimum temperature (r = 0.498), morning relative humidity (r = 0.381), evening relative humidity (r = 0.312), rainfall (r = 0.041) and sunshine hours (r = 0.072).

The study by Kumar and Sharma (2022) revealed a significant and positive correlation with maximum temperature (r = 0.759**) and minimum temperature with positive and non-significant correlation (r = 0.227). Berani *et al.* (2020) reported positive and significant with maximum temperature (r = 0.533*, 0.572**) in 2018-19 and 2019-20 respectively.

Stink Bug, *Nezara viridula* Linnaeus (Hemiptera: Pentatomidae)

The bug population showed positive and significant correlation with minimum temperature (r = 0.086), morning relative humidity (r = 0.317), evening relative humidity (r = 0.407) and rainfall (r = 0.479). Whereas correlation was negative with maximum temperature (-0.31) and sunshine hours (-0.25).

Brinjal shoot and fruit borer

The correlation studies showed that the non-significant positive correlation with the morning relative humidity (r = 0.345), evening relative humidity (r = 0.177), and rainfall (r = 0.504). Whereas it showed non-significant negative correlation with maximum temperature (r = -0.346), minimum temperature (r = -0.202), and sunshine hours (r = -0.148).

Gupta *et al.* (2021) found negative and non-significant correlated with sunshine hours (r = -0.195), and positive and non- significantly correlated with rainfall (r = 0.236). Saran *et al.* (2018) reported negative and non- significant correlation with minimum temperature (r = -0.286), and positive and non-significant correlation with morning relative humidity (r = 0.126).

Hadda beetle, *Henosepilachna vigintioctopunctata* (Coleoptera: Coccinellidae)

The hadda beetle population showed positive and non- significant correlation with maximum temperature (r = 0.146), morning relative humidity (r = 0.222), rainfall (r = 0.101) and sunshine hours (r = 0.444). whereas, negative and non- significantly correlated with minimum temperature (r = -0.124) and evening relative humidity (r = -0.175).

Sharma *et al.* (2017) found that weather showed positive and non- significant correlation with rainfall (r

Table 2. Correlation between weather parameters and mean number of insect pests and natural enemies in brinjal during kharif 2022

Weather parameters	*Leucinodes orbonalis*	*Henosepilachna vigintioctopunctata*	*Bemisia tabaci*	*Amrasca biguttula biguttula*	*Eublemma olivacea*	*Nezara viridula*	Spider	*Coccinellid* sp.
Maximum temperature	-0.346	0.146	0.535*	0.649*	0.531	-0.149	-0.31	-0.421
Minimum temperature	-0.202	-0.124	0.498	0.683**	0.527	0.086	-0.205	-0.414
Morning RH	0.345	0.222	0.381	0.273	0.353	0.317	0.404	0.38
Evening RH	0.177	-0.175	0.312	0.463	0.387	0.407	0.132	-0.06
Rainfall mm	0.504	0.101	0.041	-0.067	0.06	0.479	0.434	0.528
Sunshine hrs	-0.148	0.444	0.072	-0.003	0.049	-0.25	-0.169	-0.014

= 00.781). Singh *et al.* (2023) reported positive and non-significant correlation with rainfall (r = 0.172), sunshine hour (r = 0.073).

Leafroller, *Eublemma olivacea Walker* (Lepidoptera: Erebidae)

The leafroller population showed positive and significant correlation with every weather parameter *viz.,* maximum temperature (r = 0.531), minimum temperature (r = 0.527), morning relative humidity (r = 0.353), evening relative humidity (r = 0.387), rainfall (r = 0.06) and sunshine hours (r = 0.049).

NATURAL ENEMIES

Coccinellid beetle

The population of coccinellids showed positive and non-significant correlation with morning relative humidity (r = 0.38) and rainfall (r = 0.528). The correlation with maximum temperature (r = -0.421), minimum temperature (-0.414), evening relative humidity (r = -0.06) and sunshine hours (r = -0.014) was negative and non- significant.

In their investigation, Chandrakumar *et al.* (2008) discovered that there was a strong negative association (r = -0.641) between the density of coccinellids and the highest temperature. Kumar and Sharma (2022) found negative and non- significant correlation with minimum temperature (r = -0.222), rainfall (r = -0.356).

Spider

The population of spider showed positive and non-significant correlation with morning relative humidity (r = 0.404), evening relative humidity (r =0.132) and rainfall (r = 0.434). Whereas it was negatively non-significant correlation with maximum temperature (-0.31), minimum temperature (-0.251) and sunshine hours (r = -0.169). Singh *et al.* (2023) reported negative and non- significant correlation with minimum temperature (r = -0.065).

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MS Received: 10 October 2024
MS Acceptance: 25 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 337-343 (2024)
DOI Number : 10.5958/0974-4541.2024.00056.8

Validation of a species-specific *mtCOI* marker for the identification of cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae)

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ABSTRACT: The invasive mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae), has emerged as a serious pest of the cassava crop, with its recent incursion into India prompting heightened concerns. This study validated a species-specific *mtCOI* marker (SS-*mtCOI*) to identify *P. manihoti* during its nymphal stage. A comprehensive survey was conducted across several districts of Kerala to collect specific samples of *P. manihoti* nymphs from cassava and alternative host plants. Subsequently, the SS-*mtCOI* marker was employed to evaluate the efficacy of this marker across various populations of *P. manihoti* in Kerala, utilizing extracted DNA and polymerase chain reaction (PCR) analysis for validation. This marker successfully identified all developmental stages (egg, first, second, third instar, and adult female), even at low DNA concentrations. This validation of the SS-*mtCOI* marker through PCR assay provides a quick, clear, and reliable method for identifying *P. manihoti*, eliminating the need for traditional slide mounting.

Keywords: Cassava Mealybug, *Phenacoccus manihoti*, species specific marker, PCR

INTRODUCTION

Cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae), is native to South America and a major pest of cassava (*Manihot esculenta* Crantz) around the world (Cox & Williams 1981; Löhr *et al.,* 1990; Bellotti *et al.,* 1999). It causes about 80% reduction in yield, leading to annual economic losses surpassing $2B dollars (Herren 1981; Herren and Neuenschwander 1991; Neuenschwander *et al.,*1988; Nwanze, 1982). It successfully invaded at least 47 countries across South America, Africa and Asia, devastating cassava crops (Cabi, 2022; Morales *et al.,* 2016)). In Asia, it was first observed in Thailand in 2008 (Muniappan *et al*., 2009) and later spread to Cambodia, Indonesia, Laos, Vietnam (Bellotti *et al.,* 2012; Parsa *et al.,* 2012; Winotai *et al.,* 2010) and India in 2020 (Joshi *et al*., 2020) where it is causing a notable decline in cassava production. The thelytokous parthenogenesis reproduction in *P. manihoti* allows a single individual to establish a successful invasion (Parsa *et al.,* 2012). Its rapid spread, averaging 150 km per year, is facilitated by the attachment of eggs or ovisacs to carriers, along with the wind dispersal of both nymphs and adults over long distances (Liebhold and Tobin 2008; Winotai *et al.,* 2010). Along with cassava, Indeed, *P. manihoti* exhibits a broad palate, showing a preference for plants across nine different families (Cox and Williams, 1981; Morales *et al.,* 2016; Le Ru and Tertuliano, 1993). *P. manihoti* oligophagous behaviour allows it to thrive in various ecosystems, threatening cassava and ornamental plants. Its ability to spread quickly necessitates effective identification strategies for control measures (Parsa *et al.,* 2012). Identifying species through morphological features is mainly possible with adult females, while nymphs and ovisacs are challenging due to similarities among related species (Wang *et al.,* 2019). An urgent need exists for an effective diagnostic tool to manage further spread. The SS-*mtCOI* Marker PCR assay provides a straight forward solution for identifying species at any nymph stage, even for non-specialists (Jiang *et al.,* 2013; Rugman-Jones *et al.,* 2006; Zhang *et al.,* 2012). A PCR method was employed to monitor and identify *P. solenopsis* (Tian *et al.,* 2013) and *P. manihoti* (Wang *et al*., 2019) using *mtCOI* markers. Similarly, our study validated a specific *P. manihoti* marker for effectively identifying immature stages across various host plants and geographic areas.

MATERIALS AND METHODS

Mealybug collection

A survey was undertaken in different districts of Kerala with the aim of collecting *P. manihoti*

specimens from cassava, *Manihoti esculenta* and other alternative hosts (Table 1 and Fig 1). Immature and adult stages of *P. manihoti* were collected from Indoor rearing at Kerala Agricultural University, Thrissur. *P. manihoti* specimens were identified and validated by morphological characteristics as described by (Williams and de Willink 1992; Parsa *et al.,* 2012; Joshi *et al.,* 2020). The other mealybug species were also collected and recognized by taxonomic keys before molecular research (Tang, 1992). All samples were preserved in 95% ethanol at -20°C until the DNA was isolated, and voucher specimens were deposited at the Kerala Agricultural University, Thrissur.

Table 1. Collection Details and Host Plant Information of *Phenacoccus manihoti*

District	Latitude	Longitude	Host plant
Thrissur	10.54931	76.28319	*Manihot esculenta, Talinum triangulae, Blumea lacera, Synedrella nodiflora, Lantana camera*
Ernakulam	10.14697	76.35342	*Manihot esculenta*
Kannur	11.79556	75.57417	*Manihot esculenta*
Palakkad	10.68221	76.51466	*Manihot esculenta*
Malappuram	10.98425	76.18517	*Manihot esculenta*
Kottayam	9.534239	76.53211	*Manihot esculenta*
Alappuzha	9.145715	76.5367	*Manihot esculenta, Grass*
Pathanamtittha	9.304222	76.73044	*Manihot esculenta*
Trivandrum	8.334488	77.09431	*Manihot esculenta*
Kollam	8.842853	76.75152	*Manihot esculenta*
Kozhikode	11.33821	75.92294	*Manihot esculenta*
Idukki	9.822318	76.69965	*Manihot esculenta*
Kasargod	12.34186	75.112	*Manihot esculenta, Alternenthera sessilis*

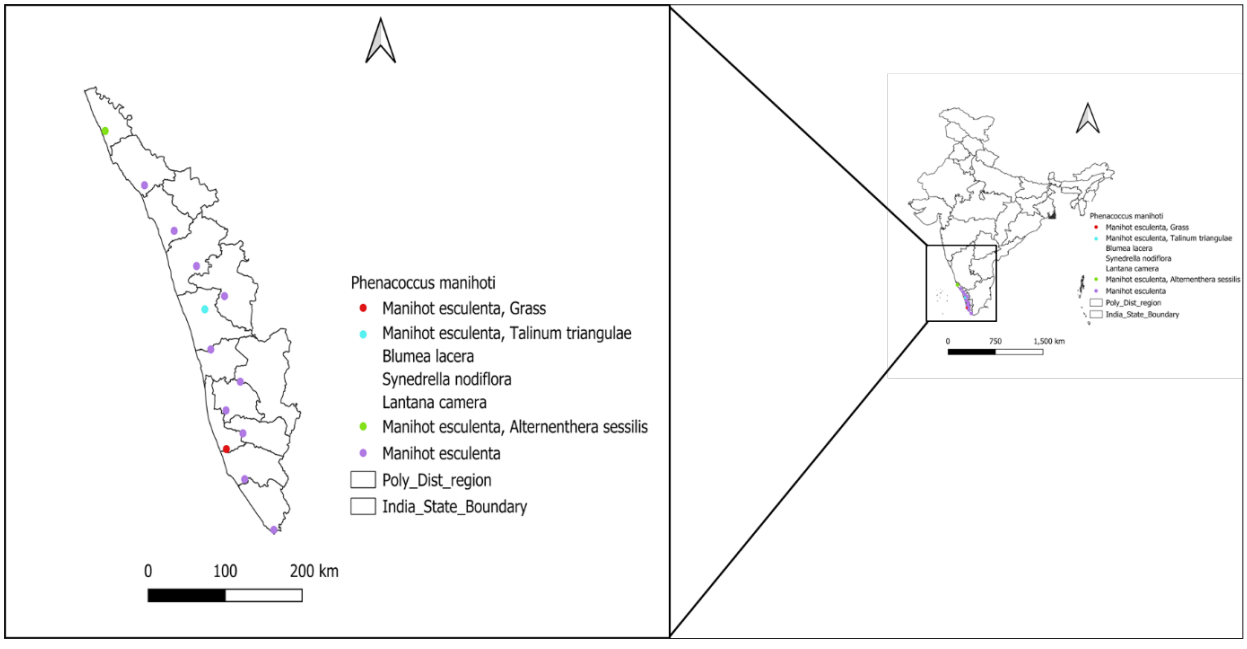

Fig.1. Collection Details of *Phenacoccus manihoti* in Kerala

DNA extraction

The genomic DNA from *P. manihoti* was extracted using the DNeasy® Blood & Tissue kit protocol (Qiagen, Germantown, MD, USA; catalog # 69504). The extracted DNA was then assessed by running it on a 1.2% agarose gel electrophoresis setup with 1 x TAE buffer (40 mM Tris-acetate, 1 mM EDTA) for 30 minutes. Ethidium bromide (0.5 mg/ml) was added during its preparation. The gel was then visualized and documented using a Bio-Rad Gel EZ Imager.

Amplification and sequencing

We amplified the DNA using a Veriti 96-Well PCR Thermal Cycler (Applied Biosystems). A total of 20µL reactants were used, which includes PCR-grade water (7.8µL), master mix (2X EmeraldAmp Takara with Dye) (10µL), forward and reverse primers (0.6µL each), and DNA template (1µL). The pair of *mtCO1* primers used FP (5'-CTTGATAAAACAGGAATTGAG-3') and RP (5'-CCTTTGATGATTTCTTCTTCT-3') (Wang et al., 2019). The PCR process involved the following steps: initial denaturation for 2 min at 95°C, then 30 cycles of denaturation (94°C-30 sec), annealing (50°C-30 sec), and chain extension (72°C-30 sec). There will be a final extension at 72 °C lasting for five minutes. The 5 µL PCR products were resolved in a 1.2% agarose gel at 80 V for 30 min. We sequenced each positive product in both directions at Gene Spec Pvt. Ltd., Cochin, India, to verify that the products amplified by the specific markers originated from the gene *mtCOI*.

RESULTS AND DISCUSSION

Molecular analysis of *P. manihoti* and its immature stages from cassava

Genomic DNA extracted from adult and immature stages of *P. manihoti* (including 3rd, 2nd, and 1st instar nymphs and eggs) was amplified using the SS-*mtCOI* marker. Gel electrophoresis revealed a consistent presence of a 355 bp targeted fragment of *P. manihoti* across entire replicates, even at small concentrations. The band for *P. manihoti* (mtDNA) from various mature and immature stages is illustrated in lanes 1 to 5 in (Fig. 2).

SS-*mtCOI* marker specificity and stability in *P. manihoti* across Kerala

Genomic DNA extracted from *P. manihoti* specimens and other mealybugs of cassava collected from thirteen districts of Kerala was examined to assess its specificity and stability. The SS-*mtCOI* marker successfully amplified DNA from all samples, consistently producing a 355 bp fragment in gel electrophoresis, even at low concentrations (Fig 5.). Because of the marker's specificity, it was unable to detect other mealybug species (Fig 3.).

Specificity of SS-*mtCOI* marker from alternative hosts of *P. manihoti*

The DNA extracted from *P. manihoti* found on alternative hosts *(Alternanthera sessilis*, *Talinum triangulare*, *Blumea lacera*, *Synedrella nodiflora*, *Lantana camara*, and grass) was amplified, resulting in the detection of a 355 bp product (Fig 4.).

SS-*mtCOI* marker analysis

The DNA band observed in the PCR products indicated the presence of the CO1 gene, spanning 355 base pairs in length (Fig 2,3,4 and 5.) The BLAST analysis of the CO1 gene sequence revealed a perfect match with 100% identity and coverage. The sequences have been submitted to GenBank under the accession numbers (PP660149.1, PP660148.1, and PP660147.1). The sequences of mealybug samples are cent per cent identity with sequences from India (MT895817 and MW039322), china (KY611346, KY611348, KY611347 and KY611349) and also with other accessions OK172179 OK173048, OK172562, OK172342, OK174324, OK172561).

Fig.2. SS-*mtCOI* Marker PCR amplification across *P. manihoti* developmental stages

M, marker; 1–5, samples feeding on cassava from Kerala; 1-female Adult; 2-3rd instar nymph 1st instar nymph; 3, 2nd instar nymph; 4, 1st instar nymph; 5, egg

Fig.3. SS-*mtCOI* amplification in *P. manihoti* and other mealybug species from cassava

(M- Ladder; 1- P. *manihoti*; 2- *P. marginatus*; 3- *P. solenopsis*; 4- *F. virgata*; 5- *P. jackbeadslyi*)

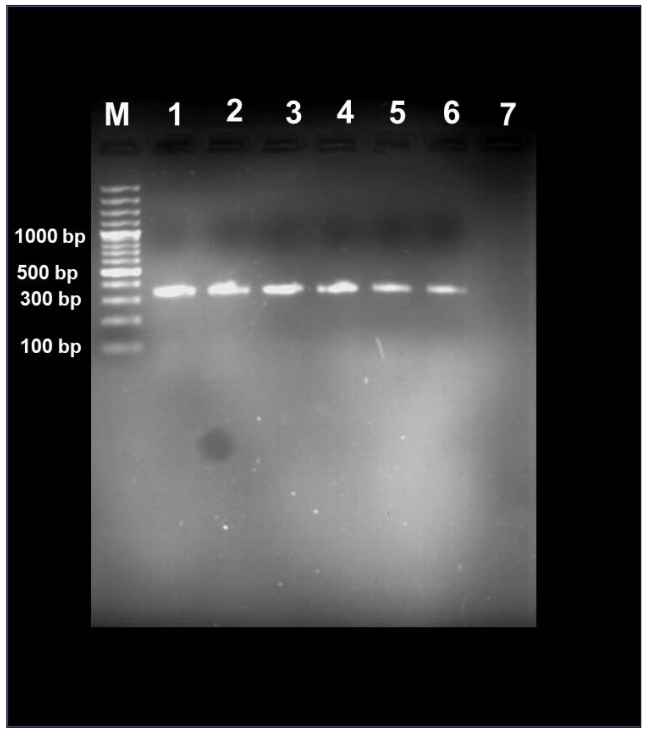

Fig.4. SS-*mtCOI*marker amplification pattern in *P. manihoti* from alternative hosts

(M- ladder; 1- Alternentherasessilis; 2- Talinum triangulae; 3- Blumealacera; 4- Synedrella nodiflora; 5-Lanatana camera; 6-Grass)

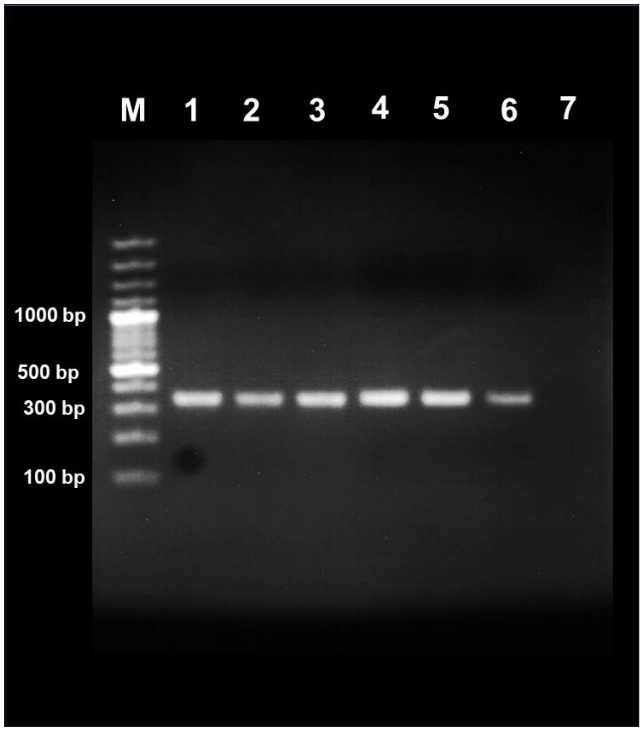

Fig.5. SS-*mtCOI* marker amplification in *P. manihoti* developmental stages from various districts of Kerala

(M – Ladder; 1-Thrissur; 2-Palakkad; 3-Ernakulam; 4-Malappuram; 5- Kozhikode; 6- Kannur; 8-Kottayam; 9-Alappuzha; 10- Pathanamthitta; 11- Kollam; 12- Idukki; 13- Thiruvananthapuram districts; 7 and 14 - blank.

Invasive insects pose significant threats to agriculture, contributing to global food shortages. Pacheco *et al.* (2014) also found that a multiplex PCR was a quick and cheap way to identify *P. solenopsis*, *Dysmicoccus brevipes*, *Pseudococcus viburni*, *Planococcus citri*, and *P. ficus*. Similarly, *P. manihoti*, an invasive pest with significant repercussions for cassava crops, is adept at long-distance dispersal, often through international trade (Parsa *et al.,* 2012). There is an urgent need for a rapid method to identify *P. manihoti* due to its significant impact. The PCR assay developed in this study utilizes the SS-*mtCOI* marker for accurate, species-specific detection. This method is fast, sensitive, and reliable, completing the process in 2.5 hours using DNA from any growth stage. A 353-bp segment confirms the presence of *P. manihoti*. Additionally, the assay eliminates the need for slide preparation, sequencing, or restriction digestion, making it accessible for non-specialists during plant quarantine inspections. Species-specific PCR with an SS-marker is a rapid tool for identifying species by detecting specific gel electrophoresis bands. It is effective for various species, including mealybugs (Zhang *et al.,* 2012; Saccaggi *et al.,* 2008).

Notably, multiplex PCR differentiated *Planococcus citri*, *P. ficus*, and *Pseudococcus longispinus* (Saccaggi *et al.,* 2008), while specific markers were developed for *P. comstocki*, *P. viburni*, and *P. citri* (Hosseini and Hajizadeh, 2011).Wang *et al.* (2019) evaluated the specificity of the SS-*mtCOI P. manihoti* marker set was thoroughly tested against 21 closely related mealybug species commonly encountered in Chinese ports or fields, including several quarantine pests and congeners. Encouragingly, no cross-reaction was observed with non-target species, confirming the primer pair's specificity. Moreover, this method proved effective across various developmental stages and different *P. manihoti* populations, and it consistently performed well across different PCR thermal cycler models, showcasing its stability.

This included four quarantine pests (*P. solenopsis*, *D. neobrevipes*, *P. lilacinus*, and *P. minor*), as well as three congeners (*P. madeirensis*, *P. solani*, and *P. solenopsis*). The absence of cross-reaction with non-target species, as indicated by the results shown in (Fig. 3), confirms the primer pair's specificity. Moreover, this approach precisely detected all stages of development and diverse populations of *P. manihoti* (see Fig. 2). Successful with a detection limit as low as 50pg µL–1 of DNA, this PCR assay demonstrates high sensitivity in identifying *P. manihoti*, surpassing the limitations of repeatability and reliability associated with RAPD analysis. Consequently, it presents a superior alternative for detecting *P. manihoti* in imported cassava sets and tubers, which may harbour various developmental stages and females, often resembling closely related species morphologically.Crucially, this approach is easy to apply and does not necessitate a deep understanding of taxonomy or molecular biology. However, in order to guarantee that the primer pair can be used in a wider range of similar mealybug species, it is advisable to conduct further tests to confirm its specificity.

CONCLUSION

In conclusion, developing a stage-independent identification method for *P. manihoti* utilizing species-specific markers holds significant promise for both invasion prevention and the management of other mealybug species. By employing markers that are not contingent on specific developmental stages, such as eggs or nymphs, this approach offers a versatile and robust means of accurately identifying *P. manihoti* across all life stages. Such precision in identification is crucial for implementing timely and targeted interventions to prevent invasions and mitigate the potential damage caused by this pest. Moreover, the applicability of species-specific markers extends beyond *P. manihoti*, providing a valuable tool for the identification and management of related mealybug species. This advancement represents a vital step forward in enhancing our capacity to safeguard agricultural and horticultural systems from the threats posed by invasive pests, ultimately contributing to the sustainability and resilience of global ecosystems.

ACKNOWLEDGEMENT

We sincerely thank Kerala Agricultural University (KAU), Thrissur and the Kerala State Biodiversity Board (KSBB), Thiruvananthapuram for their invaluable support and funding. Their assistance and resources have been instrumental in successfully completing this research endeavour. This is a part of my Ph.D. dissertation.

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MS Received: 20 September 2024
MS Acceptance: 12 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 344-349 (2024)
DOI Number : 10.5958/0974-4541.2024.00057.4

Baseline toxicity evaluation of new insecticide molecules against *Spodoptera litura* (F.) (Lepidoptera: Noctuidae) in cole crops

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ABSTRACT: *Spodoptera litura* (F.), poses a significant threat to the productivity and quality of cole crops such as cabbage, cauliflower, and broccoli. In this study evaluated the baseline toxicity of seven novel insecticides was evaluated against *S. litura* populations from the F_1 and F_6 generations using the leaf dip bioassay method. The insecticides evaluated were emamectin benzoate, indoxacarb, spinosad, Lambda cyhalothrin, chlorfenapyr, cyantraniliprole, and chlorfluazuron. Among the F_1 generation, emamectin benzoate exhibited the highest toxicity (LC_{50}: 0.93 µg/mL), followed closely by Spinosad (LC_{50}: 1.03 µg/mL) and Indoxacarb (LC_{50}: 1.13 µg/mL), whereas Lambda cyhalothrin showed the lowest toxicity (LC_{50}: 60.21 µg/mL). In the F_6 generation, indoxacarb emerged as the most toxic insecticide (LC_{50}: 0.39 µg/mL), followed by emamectin benzoate (LC_{50}: 0.57 µg/mL) and Cyantraniliprole (LC_{50}: 0.68 µg/mL), with Lambda cyhalothrin remaining the least effective (LC_{50}: 34.76 µg/mL). The baseline toxicity data generated contributing to resistance management programs.

Keywords: *Spodoptera litura*, cole crops, baseline toxicity, insecticides, bioassay

INTRODUCTION

Cole crops such as cabbage, cauliflower, kale, and broccoli, belonging to the family Brassicaceae, are extensively cultivated in temperate and tropical regions worldwide, including India. Among the states, West Bengal ranks first in cole crop production. Bihar, another significant producer, ranks sixth in cabbage production. However, the cultivation of these economically important crops is hampered by severe pest infestations that occur from the early stages of crop growth to harvest. In India, cole crops are attacked by a total of 37 insect pests. Notable among these are the cabbage leaf webber (*Crocidolomia binotalis* Zell), painted bug (*Bagrada hilaris* Burmeister and *Bagrada cruciferarum* Kirk.), cabbage butterfly (*Pieris brassicae* L.), cabbage semilooper (*Trichoplusia ni* Hubner), diamond back moth (*Plutella xylostella* L.), and tobacco cutworm (*Spodoptera litura* Fabricius). Overall, pest infestations in cole crops can result in yield losses ranging from 7% to 90% (Choudhuri *et al*., 2001; Rao & Lal, 2005). These pests not only reduce yield but also degrade produce quality through mining, skeletonization, and discoloration of leaves.

Spodoptera litura (Fabricius) is one of the most polyphagous and economically important pests. Belonging to the family Noctuidae, it infests over 120 host plants globally, including tobacco, peanuts, tea, cotton, pulses, cauliflower, cabbage, potatoes, castor, sunflower, and tomato. Despite the widespread use of insecticides, the pest has developed resistance to conventional and novel insecticides with diverse modes of action, resulting in frequent outbreaks and control failures (Ahmad *et al*., 2011).

To combat the rising issue of insecticide resistance, insecticidal resistance management (IRM) strategies are crucial. These include the rotation and combination of insecticides from different chemical groups with distinct modes of action. Synergists such as piperonyl butoxide, diethyl maleate, and triphenyl phosphate can enhance insecticide efficacy by inhibiting metabolic resistance mechanisms. Piperonyl butoxide blocks mixed-function oxidases, diethyl maleate inhibits glutathione S-transferase, and triphenyl phosphate acts as an esterase inhibitor (Raffa and Priester, 1985). Despite these measures, the need for alternative pesticides with low resistance potential, minimal environmental impact, and reduced risks to human health remains critical. Given the economic importance of cole crops and the significant impact of pests like *S. litura*, it is imperative to conduct baseline toxicity studies. These studies assess the susceptibility of pest populations to various insecticides, providing critical data for developing effective pest management strategies and delay resistance development. Establishing baseline susceptibility levels enables the monitoring of resistance trends over time and informs the selection of appropriate control measures to ensure sustainable crop production.

MATERIALS AND METHODS

Collection and rearing of *Spodoptera litura*

Fifth and sixth instar larvae of *Spodoptera litura* were collected from fields of cabbage, cauliflower, and broccoli (cole crops) through a zigzag sampling method, ensuring representation of populations from different non-identical localities. The larvae were transferred to glass jars for rearing under controlled laboratory conditions (26°C and 65% RH). Fresh food was provided daily, and the larvae's excreta was removed to maintain hygiene and prevent diseases. After pupation, adult moths were transferred to transparent plastic jars with mesh on one side to ensure proper ventilation. The moths were fed a 10% sugar solution, supplemented with methyl-4-hydroxybenzoate (2 g/L) and vitamins, soaked in cotton wool balls. After mating, moths laid eggs, which were then hatched under optimal conditions. This process continued upto the F_6 generation.

Leaf dip bioassay

The baseline toxicity of various newer insecticides was assessed using the leaf dip bioassay method. Third-instar larvae (weighing 0.06–0.08 g and measuring 0.8–1.0 cm in length) from the F_1 and F_6 generations were used for the bioassay. Newer insecticides recommended by the CIBRC for the control of *S. litura* on cole crops, including emamectin benzoate 5% SG, indoxacarb 14.5%, spinosad 2.8% EC, Lambda cyhalothrin 5% EC, chlorfenapyr 10% SC, cyantraniliprole 10.26% OD, and chlorfluazuron 5.4% EC, were used for the study (Table 1). The bioassay procedure followed the FAO-recommended methods for resistance monitoring (FAO Plant Protection Bulletin, FAO Method No. 17, 18, 1979).

Initially, a preliminary assay was conducted by applying arbitrary concentrations of each insecticide without replication to identify the concentration range that caused 0–100% mortality. Serial dilutions of six concentrations, with one control (water), were then prepared for each insecticide (Table 1), and three replications were made for each concentration. In each replication, ten larvae were used.

Fresh, pesticide-free leaves from cabbage, cauliflower, and broccoli plants were collected from the field. Leaf discs (4–5 cm in diameter) were cut on both side of the midrib using a sterilized punch, taking care to avoid contamination. Test concentrations were prepared through serial dilution, and the leaf discs were immersed in the solutions for approximately 1 minute. Excess liquid was removed by air drying. After drying, the leaf discs were placed in separate Petri dishes using sterilized forceps. A total of ten third-instar larvae were placed in each Petri dish, which was then covered with white muslin cloth and labelled according to the diluted concentrations. This procedure was repeated for three replicates of each concentration.

Larval mortality was recorded 24 hours after treatment. Larvae were considered dead if they showed signs of growth retardation, such as cessation of feeding, body size reduction, or the inability to return to an upright position when poked (moribund). The LD_{95} values of the F_6 generation were considered as the discriminative dose value for every tested insecticide.

Data Analysis

The mortality data were analysed using probit analysis through the POLOPLUS program (LeOra Software,

Table 1. Insecticides used, along and their concentrations upon serial dilution

Treatment	Insecticides	Dose (ml/L)	Concentration (in PPM)	Toxicity labels
T1	Emamectin Benzoate 5% SG	0.002	8, 4, 2, 1, 0.5, 0.25, 0	Blue
T2	Indoxacarb 14.5% SC	0.003	8, 4, 2, 1, 0.75, 0.50, 0	Yellow
T3	Spinosad 2.8% EC	0.003	24.32, 12.16, 6.08, 3.04, 1.52, 0.076, 0	Blue
T4	Lambda cyhalothrin 5 % EC	0.6	960, 480, 240, 120, 60, 30, 0	Yellow
T5	Chlorfenapyr 10 % SC	0.02	72, 36, 18, 9, 4.5, 2.3, 0	Blue
T6	Cyantraniliprole 10.26 % OD	0.01	10.08, 5.04, 2.52, 1.26, 0.63, 0.315, 0	Green
T7	Chlorfluazuron 5.40% EC	0.01	50, 30, 10, 7, 5, 3, 0	Green
T8	Control (with water)	-	-	-

2003), based on Finney's (1971) method. The following formulae were used to calculate the susceptibility index and rate of resistance decline.

- Susceptibility index = LC_{50} or LD_{95} of 1st generation/ LC_{50} or LD_{95} of last generation
- Rate of resistance decline (R) = log(final LC_{50}) – log(intial LC_{50}) / n
  (where, n = no. of generation)
- Generation (G) = 1/R

RESULTS AND DISCUSSION

The LC_{50} values and toxicity ratios of various insecticides against the F_1 and F_6 generation populations of *S. litura* are presented in tables 2 and 3, respectively. The chi-square analysis of mortality data confirmed a good fit to the probit regression model, validating accuracy of our estimates. In the F_1 generation, population of *S. litura*, the pest was highly susceptible to emamectin benzoate and least susceptible to Lambda cyhalothrin. Emamectin benzoate exhibited the highest toxicity with the LC_{50} value of 0.93 µg/mL, making it 65 times more toxic than the least toxic insecticide. The LC_{50} values of spinosad, indoxacarb, cyantraniliprole, chlorfluazuron, and chlorfenapyr were 1.03, 1.13, 1.34, 7.58, and 9.22 µg/mL, respectively, and these were 58.45, 53.28, 45.00, 8.00, and 6.60 times more toxic than least toxic insecticide. Lambda cyhalothrin recorded as the least toxic insecticide, with the LC_{50} value of 60.21 µg/mL.

In the F_6 generation, population of *S. litura*, the pest showed highsusceptibility to Indoxacarb and low susceptibility to Lambda cyhalothrin. Indoxacarb was the most toxic insecticide, with an LC_{50} value of 0.39 µg/mL, making it 89.12 times more toxic than the least toxic insecticide. The LC_{50} values of emamectin benzoate, cyantraniliprole, spinosad, chlorfluazuron and chlorfenapyr were 0.57, 0.68, 0.85, 5.28, and 6.76 µg/mL, respectively, which were 61.00, 51.00, 41.00, 6.10,

Table 2. Dosage mortality response of *S. litura* against different insecticides through leaf dip method in F_1 generation at 24 h

	Treatments	LC_{50} (µg/ml)	Fiducial LD_{50} limit (ppm)		X^2	Slope ±SE	LD_{95} (µg/ml)	Fiducial LD_{95} limit (ppm)		Toxicity ratio
			Lower	upper				Lower	Upper	
T1	Emamectin Benzoate 5% SG	0.93	0.62	1.32	1.30	1.351±0.215	15.47	7.92	51.89	65.00
T2	Indoxacarb 14.5% SC	1.13	0.77	1.53	3.51	1.475+-0.260	14.74	7.71	52.64	53.28
T3	Spinosad 2.8% EC	1.03	0.31	2.18	4.3	0.941+-0.143	57.78	18.50	778.20	58.45
T4	Lambda cyhalothrin 5 % EC	60.21	26.94	97.06	1.3	1.007±0.206	2590	1033.1	19872	1.00
T5	Chlorfenapyr10 % SC	9.22	6.97	11.95	0.82	1.929±0.253	65.65	42.33	131.69	6.60
T6	Cyantraniliprole 10.26 % OD	1.34	0.56	2.63	5.52	1.038±0.200	30.58	11.65	301.95	45.00
T7	Chlorfluazuron 5.40 % EC	7.58	5.76	9.72	1.36	1.924±0.288	54.28	33.89	122.98	8.00

Note: LC50.: Lethal concentration 50, LD95.: Lethal dose 95, SE.: Standard error, X2.: Chi sqaure

Table 3: **Dosage mortality response of *S. litura* against different insecticides through leaf dip method in F_6 generation at 24 h**

	Treatments	LC_{50} (µg/ml)	Fiducial LD_{50} limit (ppm)		X^2	Slope ±SE	LD_{95} (µg/ml)	Fiducial LD_{95} limit (ppm)		Toxicity ratio
			Lower	upper				Lower	Upper	
T1	Emamectin Benzoate 5% SG	0.57	0.39	0.76	1.99	1.773±0.258	4.82	3.06	10.2	61.00
T2	Indoxacarb 14.5% SC	0.39	0.10	0.68	0.57	1.093±0.274	12.63	5.56	119	89.12
T3	Spinosad 2.8% EC	0.85	0.31	1.66	3	0.993±0.146	38.75	14.94	254.91	41.00
T4	Lambda cyhalothrin 5 % EC	34.76	9.05	64.67	0.61	0.8930.209	2420.1	883.15	3102	1.00
T5	Chlorfenapyr 10 % SC	6.76	4.13	10.15	1.2	1.185+0.210	50.68	77.38	774	5.10
T6	Cyantraniliprole 10.26 % OD	0.68	0.35	1.05	2.37	1.117+0.211	20.33	9.17	103.7	51.00
T7	Chlorfluazuron 5.40 % EC	5.28	2.47	8.17	5.13	1.764+0.295	45.28	22.58	340	6.10

Note: LC50.: Lethal concentration 50, LD95.: Lethal dose 95, SE.: Standard error, X2.: Chi sqaure

Table 4: Susceptibility index and rate of resistance decline based on F_1 and F_6 generationsat 24 h

Treatments	Generation	LC_{50} (µg/ml)	LD_{95} (µg/ml)	Susceptibility index		Rate of resistance decline and generation	
				LC_{50} (µg/ml)	LD_{95} (µg/ml)	R	G
T_1 Emamectin Benzoate 5% SG	F_1	0.93	15.47	1.64	3.20	-0.03	27.70
	F_6	0.57	4.82	1.00	1.00		
T_2 Indoxacarb 14.5% SC	F_1	1.13	14.74	2.86	1.16	-0.07	13.13
	F_6	0.39	12.63	1.00	1.00		
T_3 Spinosad 2.8% EC	F_1	1.03	57.78	2.60	1.49	-0.01	74.86
	F_6	0.85	38.75	1.00	1.00		
T_4 Lambda cyhalothrin 5 % EC	F_1	60.21	2590	1.72	1.07	-0.03	25.14
	F_6	34.76	2420	1.00	1.00		
T_5 Chlorfenapyr10 % SC	F_1	9.22	65.65	1.36	1.29	-0.02	43.40
	F_6	6.76	50.68	1.00	1.00		
T_6 Cyantraniliprole 10.26 % OD	F_1	1.34	30.58	1.96	1.50	-0.01	55.74
	F_6	0.68	20.33	1.00	1.00		
T_7 Chlorfluazuron 5.40 % EC	F_1	7.58	54.28	1.43	1.19	-0.02	38.35
	F_6	5.28	45.28	1.00	1.00		

Note: LC50.: Lethal concentration 50, LD95.: Lethal dose 95, R.: Rate of resistance decline, G..: No. of generations

and 5.10 times more toxic than least toxic insecticide. Lambda cyhalothrin emerged as the least toxic insecticide, with an LC_{50} value of 34.76 µg/mL.

Indoxacarb showed the highest susceptibility index (2.86 µg/mL), followed by spinosad (2.60), cyantraniliprole (1.96), Lambda cyhalothrin (1.72), emamectin benzoate (1.64), chlorfluazuron (1.43), and chlorfenapyr (1.36). Our findings indicate that indoxacarb requires 13.13 generations to reduce resistance by 0.07-fold. Lambda cyhalothrin requires 25.14 generations to reduce resistance by 0.03-fold. Emamectin benzoate necessitates 27.70 generations for a 0.03-fold decrease in resistance. Chlorfluazuron requires 38.35 generations to reduce resistance by 0.02-fold. Chlorfenapyr needs 43.40 generations to decrease resistance by 0.02-fold. Cyantraniliprole requires 55.74 generations to reduce resistance by 0.01-fold. Finally, Spinosad requires 74.86 generations for a 0.01-fold reduction in resistance (Table 4).

Previous research, including Ishtiaq *et al*. (2012), has indicated that indoxacarb and emamectin benzoate are more toxic than Spinosad, and our study corroborates these findings. In our results, Indoxacarb and emamectin benzoate exhibited significantly higher toxicity than Spinosad against *S. litura*, corroborating Ishtiaq *et al*. (2012) findings on *S. exigua*. These results highlight the higher efficacy of newer insecticides, such as indoxacarb and emamectin benzoate, compared to older insecticides like Spinosad, which is widely used but less effective in our study.

Li *et al*. (2015) reported that spinosad is highly effective in controlling Lepidopteran pests, including *Plutella xylostella*, but in our study, emamectin benzoate and indoxacarb outperformed spinosad in terms of toxicity. Similarly, findings by Karuppaiah *et al*. (2017) and Bird (2015) support the higher toxicity of emamectin benzoate in several pest species. The discrepancy in our study can likely be attributed to different experimental conditions, such as pest populations and environmental factors.

Cyantraniliprole, which was introduced for the control of Lepidopteran pests, also demonstrated good efficacy, though it was less toxic than the aforementioned insecticides. Sang *et al*. (2016) found that cyantraniliprole had moderate efficacy against *S. litura* in China, which is similar with our results where it was less effective than indoxacarb and emamectin benzoate but still more

effective than older insecticides like Lambda cyhalothrin. Other studies, such as by Sang *et al*. (2016), have also reported that cyantraniliprole is an effective alternative to conventional insecticides, although its toxicity varies depending on the pest species and resistance levels.

Dash *et al*. (2020) reported that chlorfluazuron is less effective than emamectin benzoate and Indoxacarb in controlling *S. litura*, suggesting that insecticides in the same chemical class, such as chlorfenapyr, may have limitations in pest control.This observation aligns with our findings, as both chlorfluazuron and chlorfenapyr exhibited relatively low toxicity in both F_1 and F_6 generations.Previous studies by Su and Sun (2014), have similarly highlighted that the effectiveness of chlorfluazuron is often compromised due to the development of pest resistance.

Furthermore, Lambda cyhalothrin emerged as the least toxic insecticide in both F_1 and F_6 generations, consistent with the results of Sreelakshmi *et al*. (2019), who found reduced efficacy of Lambda cyhalothrin against *S. litura*. The reduced effectiveness of Lambda cyhalothrin in our study may be attributed to the overuse of pyrethroids in pest management, leading to resistance development in pest populations, as reported by Guillem□Amat *et al*. (2022). This variability in insecticide effectiveness underscores the need for continuous monitoring of pest susceptibility and resistance levels. Our findings, in line with previous studies (Ahmad *et al*., 2018; El-Sheikh., 2015), highlight the importance of establishing baseline susceptibility in pest populations before implementing long-term pest management strategies.

CONCLUSION

This study highlights the baseline toxicity of various insecticides against *Spodoptera litura* in cole crops. Indoxacarb and emamectin benzoate demonstrated superior efficacy in controlling pest populations, with significantly higher toxicity compared to other insecticides tested. These findings underscore the importance of integrating effective, low-resistance insecticides into pest management strategies. Continuous monitoring of insecticide susceptibility is essential to mitigate resistance development and ensure the sustainable cultivation of cole crops. The baseline data provided will serve as a valuable reference for future resistance management and pest control efforts.

ACKNOWLEDGEMENTS

The authors are highly thankful to the Department of Entomology, Dr. Rajendra Prasad Central Agricultural University for facilitating to utilize the laboratory facilities. This research is part of Sathur Nandini' M.Sc. dissertation.

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MS Received: 16 August 2024
MS Acceptance: 25 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 350-356 (2024)
DOI Number : 10.5958/0974-4541.2024.00058.0

First report of root-knot nematode, *Meloidogyne enterolobii* on watermelon in India

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ABSTRACT: Root-knot nematode, *Meloidogyne enterolobii* is a devastating species of *Meloidogyne*. This nematode was restricted only to guava. However This paper reports the occurrence of *M. enterlobii* on watermelon at Perur village, Coimbatore district, Tamil Nadu, India and it is the first record of new host of this species. Soil and root samples showed very high population (536 J_2 / 250g soil; 123±10 adult female / 5g root). Young seedlings of watermelon showed multiple compound galls on the root. Seedlings expressed stunted growth and pale yellow leaves. The species was confirmed by comparing with the original description and using molecular characterization. The morphological characters of adult females, males and second stage juveniles were measured using micrometers. Female nematodes recorded with a average body length including neck 687.8 µm; body width 425.3 µm; stylet length 13.8 µm; stylet knob height 2.8 µm; stylet knob width 4.5 µm; dorsal oesophageal gland orifice 4.90 µm and the distance from the excretory pore to head end 63.45 µm. Morphometric characters of female were similar to that of native population from guava and original descriptions.

Keywords: *Meloidogyne enterolobii*, watermelon, morphometrics, guava, first report, compound galls

INTRODUCTION

Plant parasitic nematodes are a major threat to agricultural productivity. Among major plant parasitic nematodes, root-knot nematodes act as obligate sedentary endoparasites, distributed worldwide (Jones *et al.*, 2013) and pose a major threat to about 3,000 plant species (Abad *et al*., 2021). The highest global multifariousness of the genus *Meloidogyne* occurs in Asia, where 45 species have been reported (Subbotin *et al*., 2021) while fourteen species of root-knot nematodes are recorded in India. Among identified *Meloidogyne* spp. the four major species include *M. incognita, M. javanica*, *M. arenaria* and *M. hapla* which cause economic losses in major cultivable crops (Manjunadha *et al.*, 2017). Recent report indicated that *Meloidogyne enterolobii* is becoming an emerging threat to horticultural crops due to its global distribution with a wide host range including other important economic cultivable crops (Ye *et al*., 2013; Galbieri *et al*., 2020). Moreover, this nematode has an ability to reproduce on tomato genotypes carrying Mi resistance genes (Moens *et al*., 2009; Castagnone-Sereno, 2012). In India, the first report of *M. enterolobii* was by Poornima *et al*. (2016) in guava from Ayakudi village of Dindigul district in Tamil Nadu. Later, the species diversity in Coimbatore district was morphologically and molecularly confirmed and described by Suresh *et al*. (2019) and Ashokkumar *et al*. (2019). The host range of this species was restricted only to guava till 2022 in India but, its infection was recorded first time in watermelon in a village at Coimbatore distract of Tamil Nadu, India. This paper describes the morphometric characters of this species and comparison with the native population collected from guava.

MATERIALS AND METHODS

Collection of soil and root samples

A composite of soil samples was collected from one month old watermelon field situated at Perur (Latitude: 10°58'30.32"N Longitude: 76°54'55.87"E), Coimbatore district, Tamil Nadu. A composite group of soil sample of about 200g of soil and galled roots were collected from the infested field. Similarly, soil samples from *M. enterolobii* infected guava field situated at the same location was also collected for comparison and confirmation of the nematode species. Collected soil samples were processed using Cobb's decanting and sieving method (Cobb, 1918). The infective juveniles and male nematodes were extracted using Modified Baermann's technique (Schindler, 1961).

Morphological studies

The collected infective juveniles and males were examined under compound microscope and the morphological identification was done using the generic characters described in Mai and Lyon (1975). The nematodes within the infected roots were examined using Acid fuchsin – Lactophenol method (Bybd Jr *et al*., 1983). Matured adult females were visualized under

binocular stereo zoom microscope. Permanent mounts of infective juveniles, male and posterior cuticular pattern (PCP) were processed by Seinhorst method (Seinhorst, 1959). Microscopic documentation was done using inverted research microscope (Nickon Ti2 Ecllipse).

Molecular characterization

DNA was extracted from female root-knot nematodes using worm lysis buffer (WLB; 50 mMKCl, 10 mM Tris ph 8.2, 2.5 Mm $MgCl_2$, 20 µg/ ml proteinase K, 0.45 % Tween 20 and 0.01% gelatine) as described by Castagnone-Sereno *et al.* (2012). Single female nematode was picked and transferred to 1.5 ml microfuge tube. The tube containing single nematode was added with 25 µl worm lysis buffer and crushed with needle or micropipette tips. The tubes were centrifuged at 12,000 rpm for 2 minutes and supernatant were stored at -80°C for 30 min (Adam *et al.*, 2007). The extracted DNA were subjected for PCR amplification of the 28s r RNA gene using NEM 28s F 5'-CGGATAGAGTCGGCGTATC-3' and NEM 28s R5'-GATGGTTCGATTAGTCTTTCGCC-3'primers as described by (Ye *et al.*, 2015). The reaction was executed with a total volume of 25 µl reaction which contains 2.0 µl of DNA, 1.0 µM primer (Forward and Reverse), 2.5 µl of 10X buffer, 2.5 µl 200-mM of each dNTP and 2 units of Taq polymerase enzyme and made upto 25 µl. The PCR cycles are followed by initial denaturation of 94°C for 2 min, and 40 cycles of 94°C for 30 sec, 50°C for 1 min, and 72°C for 30 sec. The reaction was terminated with 72°C for 7 min. gel was viewed in an UV transilluminator and photographed using Alpha imager TM1200 documentation and analysis system (Alpha Innotech Corporation, San Leandro, California).The PCR products were sequenced at the Yaazh Xenomics, Coimbatore.

RESULTS AND DISCUSSION

Species Description

Morphometric description of mature females

Shape of the matured females varied from pear to globular and differentiable in size, prominent neck with varying size without any posterior protuberance. Head region continuous with enlarged body (Fig. 1a). Females were white in colour. The excretory pore situated near the metacarpus and slightly varying in position depending on the size of the nematode. Annules are distinct and visible, visualized at the posterior region of the nematode body. Stylet was thin and strong with conus curved slightly at the dorsal side, knobs were distinct with a slight curve at anterior part. DOGO varies from 4.1 to 5.5 µm in length from the base of the stylet. Oesophageal gland comprises of one large uninucleate dorsal gland and two small nucleated sub-ventral glands with variability in shape, size and glandular position. The glandular lobes overlaps the intestine ventrally. The measurements of matured females were listed in Table 1. Adult females recorded an average body length of 687.8 µm; body width 425.3 µm; neck length 275.4 µm; stylet length 13.8 µm; stylet knob height 2.8 µm; stylet knob width 4.5 µm; dorsal oesophageal gland orifice 4.90 µm and the distance from the excretory pore to head end 63.45 µm. Perennial pattern located at the posterior region is oval in shape with coarse and fine striae, dorsal arch moderate to high, most probably rounded in adequate specimens (Fig.1b). Lateral lines indistinct, presence of striae in lateral sides of the vulva with prominent tail tip. Though, the size of organelles were comparatively smaller it falls within the range of native guava population and original description.

Table 1. Morphometrics of mature female *M.enterolobii* of water melon and guava populations from India

Characters	Watermelon (Present population)	Guava (Present population)	Original Description (Yang and Eisenback, 1983)
Body length	663.4±68.3 (580.2-854.3)	692.4±63.1 (524.5-765.3)	735.0±92.8 (541.3-926.3)
Body width	415.0±68.3 (390.5-530.8)	435.8±63.9 (375.1-581.6)	606.8±120.5 (375.7-809.7)
Neck length	254.3±56.8 (179.6-311.9)	271.3±52.4 (224.3-395.2)	218.4±74.1 114.3-466.8)
Stylet length	15.25±1.58 (11.5-19.0)	13.7±0.6 (13.0-14.4)	15.1±1.35 (13.2-18.0)
Stylet knob height	2.18±0.48 (1.5-2.8)	2.6±0.47 (2.2-3.3)	2.4±0.26 (1.9-3.1)

Stylet knob width	4.5±0.25 (4.0-5.1)	4.7±0.31 (4.2-5.3)	4.9±0.39 (4.1-5.6)
DOGO	4.9±0.22 (4.5-5.5)	4.8±0.4 (3.6-5.5)	4.9±0.78 (3.7-6.2)
Excretory pore to head end	60.3±4.8 (54.3-65.3)	64.8±4.2 (55.1-69.3)	62.9±10.5 (42.3-80.6)
Vulval length	29.0±1.50 (25.0-32.3)	25.8±1.3 (22.9-28.3)	28.7±2.0 (25.3–32.4)
Vulva anus distance	20.4±1.0 (18.2-20.7)	22.4±1.3 (19.1-25.3)	22.2±1.8 (19.7-26.6)
A	1.2±0.1 (1.1-1.7)	1.5±0.1 (1.1-1.8)	1.2±0.2 (0.9-1.9)

Figures in parenthesis are value range

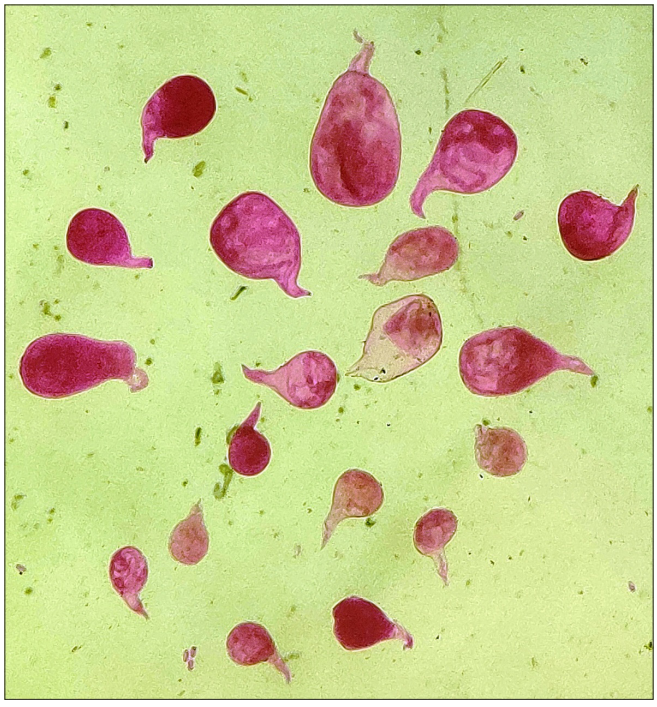

Fig.1a. Adult female nematode

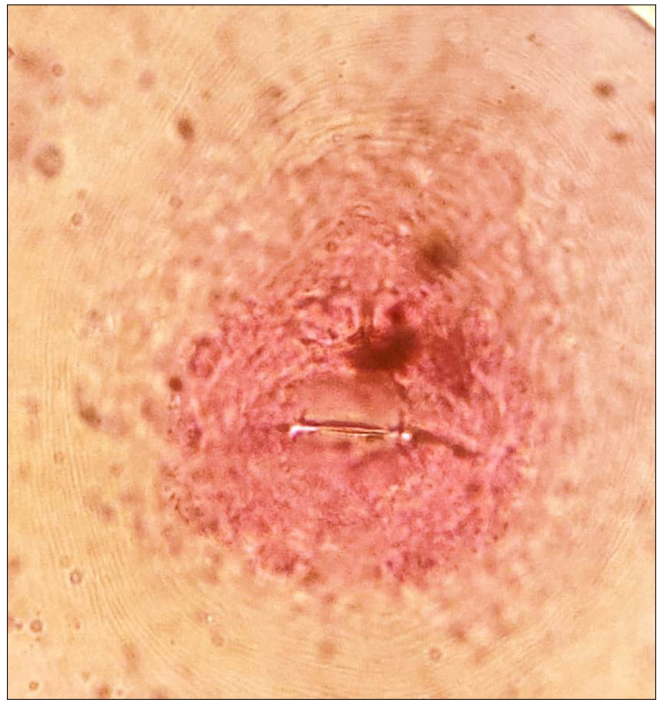

Fig.2. Posterior cuticular pattern of female

Male nematode

Males were vermiform in shape with long, slender and transparent body, tapering towards both the ends. Head region was slightly offset with moderate cephalic framework whereas the tail end was more rounded. Presence of strong and robust stylet, straight conus with cylindrical shaft with round and bigger knobs was recorded. Amphidal openings were slit like without annulations, whereas distinct annulations were present in body region. In some specimens, each knobs divided into two by a groove and the DOGO distance varied accordingly. Anterior region consists of a distinct procarpus, oval to round shaped with elongated metacarpus. Average body length was 1,234.50 µm; body width 34.70 µm; stylet length 22.23 µm; stylet knob height 2.92 µm; stylet knob width 4.98 µm; dorsal esophageal gland orifice 4.60 µm; excretory pore to head end 142.65 µm; tail length 10.45 µm and spicule length 28.88 µm (Table 2).

Table 2. Morphometrics of male *M.enterolobii* malesfrom water melon and guava populations

Characters	Watermelon (Present population)	Guava (Present population)	Original Description (Yang and Eisenback, 1983)
Body length	1584.35±85.5 (1452.6-1672.4)	1214.7±176.6 (850.1-1351.9)	1599.8±159.91 (1348.6-1913.3)
Body width	41.40±3.96 (37.4-47.5)	33.1±3.1 (27.9-39.2)	42.3±3.5 (37.0-48.3)
Tail length	10.48±2.77 (7.4-14.6)	10.57±3.15 (7.5-14.9)	12.5±2.24 (8.6-20.2)
Stylet length	23.40±1.43 (21.8-25.7)	21.5±1.4 (19.6-25.8)	23.4±0.96 (21.2-25.5)
Stylet knob height	3.05±,0.47 (2.4-3.7)	3.1±0.3 (2.4-3.6)	3.3±0.33 (2.6-3.9)
Stylet knob width	5.15±0.60 (4.5-5.8)	4.7±0.3 (3.7-7.4)	5.4±0.34 (4.5-5.8)
DOGO	3.98±0.51 (3.3-4.7)	5.4±1.2 (3.7-6.5)	4.7±0.4 (3.7-5.3)
Excretory pore to head end	170.85±2.98 (166.8-174.4)	138.4±31.7 (92.4-195.9)	178.2±11.2 (159.7-206.2)
Spicule length	30.83±2.46 (27.8-34.3)	27.8±3.2 (20.1-33.4)	30.4±1.2 (27.3-32.1)
Gubernaculum length	5.85±0.49 (5.2-6.5)	7.3±0.6 (5.7-8.4)	6.2±1.0 (4.8-8.0)
Testis length	807.03±98.17 (674.2-922.8)	302.7±86.5 (230.6-436.1)	-
A	38.43±1.97 (35.21-40.53)	36.7±4.0 (30.1-42.3)	37.9± 3.2 (34.1-45.5)
C	159.65±31.87 (114.55-196.30)	114.9±41.9 (89.5-165.8)	131.6±24.1 (72.0-173.4)

Figures in parenthesis are value range

Second stage juvenile (J_2)

Second stage juveniles was vermiform and very slender. Body length was about 425.55µm; body width 14.53µm; stylet length 11.93µm; stylet knob height 1.58µm; stylet knob width 2.64µm; dorsal esophageal gland orifice 3.25µm; excretory pore to head end 83.43µm and tail length 53.85µm (Table 3).

Diagnosis of *M. enterolobii* infestation can be challenging due to morphological similarities between it and other root-knot nematode species (Blok and Powers, 2009; Castagnone-Sereno *et al.*, 2012; Min *et al*., 2012). Later, the taxonomic status was re-entered by Karssen *et al.* (2012) and concluded it as a Synonym of *M. mayaguensis* (Rammah and Hirschmann, 1988). The morphometric measurements were similar to the original description illustrated by Yang and Eisenback (1983). They have originally described the species *M. enterolobii* parasitizing Pacara Earpod tree in China. The description derived from the second stage juvenile of collected samples were similar to the originaldescription given by (Rammah and Hirschmann, 1988).

Table 3: Morphometric dimensions of *M.enterolobii* second stage juvenile of watermelon population and in comparison with guava population from India

Characters	Morphometric dimensions of J_2 of *M. enterolobii*		
	Watermelon (Present population)	Guava (Present population)	Original Description (Yang and Eisenback, 1983)
Body length	436.50±7.13 (428.6-447.3)	413.5±26.7 (375-460)	436.6±16.6 (405.0-472.9)
Body width	15.180±45 (14.7-15.9)	13.9±1.5 (12.3-17.1)	15.3±0.9 (13.9-17.8)
Tail length	51.0±1.70 (48.6-53.4)	50.1±7.0 (42.7-75.1)	56.4±4.5 (41.5-63.4)
Excretory pore to head end	91.40±2.35 (88.4-94.6)	78.9±4.3 (73.1-92.1)	91.7±3.3 (84.0-98.6)
Stylet length	11.30±0.68 (10.6-12.4)	12.1±0.4 (11.4-12.3	11.7±0.5 (10.8-13.0)
Stylet knob height	1.88±0.19 (1.6-2.1)	-	1.6±0.1 (1.9-1.8
Stylet knob width	2.68±0.22 (2.4-3.0),8.09	-	2.9±0.2 (2.4-3.4)
DOGO	3.08±0.33 (2.7-3.6)	2.8±0.3 (2.3-3.8)	3.4±0.3 (2.8-4.3)
A	28.78±0.39 (28.13-29.16)	30.0±3.2 (24.1-35.2)	28.6±1.9 (24.0-32.5)
C	8.56±0.16 (8.38-8.82)	8.3±1.0 (6.1-10.6)	7.8±0.7 (6.8-10.1)

Figures in parenthesis are value range

Molecular characterization

Nucleotide sequence of PCR product was subjected to BLAST analysis and the results revealed 90 –100% similarities with the existing *M. enterolobii* isolates available in NCBI database. These sequence result confirmed the identity of the species as *M. enterolobii*.

***M. enterolobii* infection in watermelon**

Infected plants showed yellowing of leaves and stunted growth (Fig.2). The height of plants was about 25cm±2 cm while it was about 60cm in uninfected plants. Root showed compound galls with an average of 123±10 female nematodes per 5g root. Soil samples recorded with 536 second stage juvenile (J_2) / 250g soil. Kiewnick *et al*. (2008) reported infection of *M. enterolobii* in tomato for the first time from Mexico. First report on occurrence of this nematode in cotton was recorded by Galbieri *et al.* (2020) from Brazil. Present study revealed that the root-knot gall formation on the infected roots of watermelon were almost similar as that was reported by Poornima, *et al*. (2019) from India. These reports and present investigation confirms that the *M. enterolobii* adopts itself as a strong parasite to most of the agriculturally important crops.

Fig.2a. *M. enterolobii* infected watermelon seedling

Fig.2b. *M. enterolobii* infected root

Fig.2c. Healthy seedling

CONCLUSION

Guava root-knot nematode, *M. enterolobii* has a wide host range. In India, it was recorded only in guava and found to be introduced through infected seedling. The present study reported the damage caused by this nematode in watermelon crop for the first time in India. The crop was infected at the seedling stage itself and become completely yellow with prominent root-knot galls on the root. Molecular and morphological studies of the nematode confirmed the species. The current study is a caution to farmers and nematologists that native guava population becoming a pest of other economically important crops also. Suitable management strategy have to be formulated to combat this malady.

ACKNOWLEDGEMENT

Authors express their gratitude for laboratory facilities provided by the Department of Nematology, TNAU, Coimbatore and financial support provided by the AICRP (N) scheme, ICAR, New Delhi to conduct this study.

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MS Received: 02 August 2024
MS Acceptance: 15 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 357-359 (2024)
DOI Number : 10.5958/0974-4541.2024.00040.1

RESEARCH NOTE

Do ants pollinate cashew flowers? An observation on flower damage and nectar thieving by *Crematogaster subnuda* Mayr.

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ABSTRACT: Ant-plant associations are greatly diverse leading to mutualistic and/or antagonistic interactions between them. In general, ants are considered as minor pollinators. Ant pollination is rare and restricted to a few plant species. The cashew trees are consistently visited by diverse species of ants. During a survey in the cashew plantations, damage to the reproductive parts of cashew flowers was observed and the ants were noticed in such damaged flowers. This document presents details about nectar thieving by *Crematogaster subnuda* in the cashew flowers and the damage caused to the reproductive parts.

Keywords: Crematogaster, cashew, flowers, nectar

The cashew (*Anacardium occidentale* L.) is an important tree nut crop and is cross-pollinated. Cashew is visited by plenty of ant species throughout its different phenological stages and 49 species have been recorded by Vanitha *et al*. (2015). Ants can be seen on trunk, leaves, shoots, nuts and fruits (cashew apples) and even in fallen rotting apples. Ant species are chiefly attracted to the extra floral nectarines (EFN) present on cashew leaves, shoots, flowers and developing nuts (Rickson and Rickson, 1998). Some predatory species are also recorded on cashew (Peng *et al.*, 2014, Vanitha *et al*., 2015, Mohapatro *et al*., 2015). According to earlier reports, the role of ants as pollinators is speculative as ants move to the base of flowers and buds for the EFN and rarely touches the reproductive parts of the flowers (Bhattacharya, 2004). Ants crawl continuously on the flowers making them unattractive to the foraging bees and are assumed to feed on pollen fluids causing pollen damage and non-viability (Bhattacharya, 2004). However, during the recent floral observations at ICAR-DCR, we noticed the damage on the reproductive floral parts (absence of stamens and style) with the ants in such damaged flowers. Thus, this present investigation was carried out to document the flower damage and nectar thieving by *Crematogaster subnuda* Mayr.

In an experimental plot of ICAR-DCR, Puttur, a total of 98 cashew trees (9 years old) were observed for the presence of ants during March-May 2024. The ant species observed on the trees especially on the flowers were recorded. Insecticidal sprays were avoided in the plot during the observation period. The trees having damaged flower parts were tagged (N=10), and in each tagged tree, five inflorescences were labelled and observed for the activity of ants on cashew flowers at fortnight intervals. A total of 50 inflorescences were observed at fortnight intervals. The number of damaged flowers was recorded twice a day i.e., once at 11.30 am (when an thesis of majority of the male and hermaphrodite flowers had occurred) and at 3.30 pm to have complete data on damaged flowers and the extent of flower damage. The nut set was recorded in those inflorescences and also in the other trees where floral damage was not present.

A total of 1310 fresh flowers were observed during the study. The common ant species noticed on the cashew flowers during the observation include *Anoplolepisgracillipes* (Smith), *Camponotus compressus* (Fab.), *Tapinoma melanocephalum* (Fab.) and *Crematogaster* spp. Majority of these ants were seen foraging on EFNs present on cashew leaves, shoots, flowers and tender nuts. The ant species causing damage to the cashew floral parts was determined as *Crematogaster subnuda* Mayr. using the morphological keys (Fig. 1c-insert). ***C. subnuda*** is a common acrobat ant widely distributed throughout India (Bharti ***et al***., 2016). This species is bright chestnut red coloured (3 to 3.5 mm in length) with the heart shaped gaster, dark or nearly black in colour, it raises its gaster high up vertically in the air while foraging hence known as cocktail ants. Out of 94 cashew trees observed, *C. subnuda* was present only in 10 trees (10.6 %); and in two such trees, the ants were

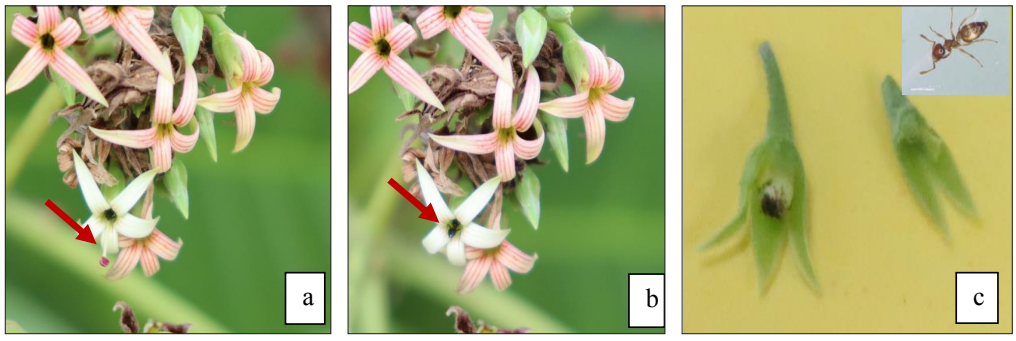

Fig. 1. *C. subnuda* damage in cashew flowers a. long stamen seen in a male flower (arrow) with ant inside, b. long stamen severed in same flower c. dissected damaged male (right) and hermaphrodite flowers (left) showing damaged stamens and style, insert- *C. subnuda*

seen entering into the dried sticks which might be their nests. In the two trees seen with *C. subnuda* nests, 25 and 37 percentage of inflorescences were without damage by *C. subnuda*. As per the report of Galen (1983), more than 25% damage by *Formica neorufibaris gelida* was noticed in the flowers of *Polemonium viscosum* Nutt. *C. subnuda* did not touch the anthers of long stamen, but entered inside and started chewing the base of the stamens in male flowers and stamens and style in hermaphrodite flowers throwing out the chewed floral parts (Fig. 1a, b and c).

Similar observation on severing the base of style or chewing through the ovary during nectar foraging has been reported in *P. viscosum* by *F. n. Gelida* (Galen, 1983). The percentage of fresh flowers damaged by the ants in an inflorescence ranged between 25 and 100 % indicating severity of the damage (N=200). The damage was more on male flowers (74.46 % of the total male flowers) compared to hermaphrodite flowers (47.26 % of the total hermaphrodite flowers). The extent of damage observed at fortnight intervals from March to April indicated the percentage of damaged flowers was higher in the afternoon hours (Fig. 2).The buds were also damaged by these ant species but only to the extent of less than 0.5 %. Due to damage by ants, the flowers dried away subsequently. It was noticed that the damaged flowers were subsequently visited by the ants, sometimes even on second or third day of opening indicating that foraging reward of *C. subnuda* is nectar and not the pollen grains.

An ant spent approximately around 2.87±0.68 minutes/flower during its first visit to fresh flower, and during subsequent visit to the same flowers, the time spent was 0.89 ±0.39 minutes/ flower (Table 1). A maximum of 4.21 minutes was spent in a fresh flower by an ant. The nut set in the inflorescences where *C. subnuda* was present was significantly less (0.86) compared to 2.07 in the inflorescences without damage of ants ($P<0.005$).

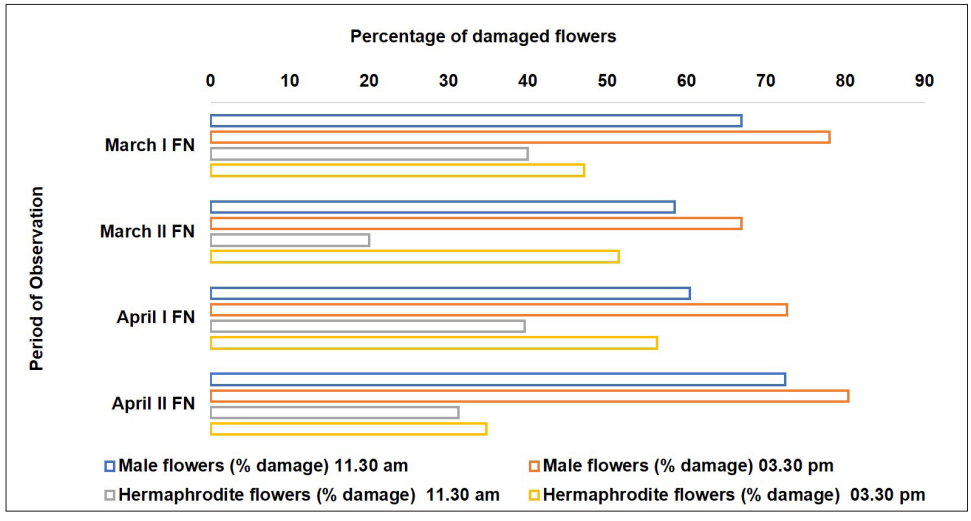

Fig.2. Extent of damaged male and hermaphrodite flowers in morning (FN) and evening (AN) hours in tagged inflorescences, I- first fortnight, II- second fortnight

Additionally, it was observed that the foraging activity of bee species was very less in the inflorescences where *C. subnuda* were present (0.2 bees/10 inflorescences/5 min) compared to other trees (0.6 bees/10 inflorescences/5 min) which could be due to lower foraging reward available to the bees due to damage by ants leading to poor pollination and nut set in those inflorescences. Ants generally repel pollinators by their aggressive nature (Junker *et al*., 2010). There are several evidences to show that ants behave as floral nectar thieves and disrupts plant-pollinator mutualism (Cembrowski *et al*., 2014, Hanna *et al*., 2015, Sinu *et al*., 2017).

Table 1: Time spent/ flower by *C. subnuda* and nut set in cashew

Details of activities	Mean ±SEM
Mean time spent on a fresh flower by *C. subnuda*	2.87 ±0.68 minutes
Mean time spent on a fresh damaged flower by *C. subnuda* in subsequent visits	0.89 ±0.39 minutes
Nut set/inflorescence in trees with *C. subnuda*	0.86 ±0.74 No.
Nut set/inflorescence in trees without *C. subnuda* but with other ant species	2.07 ±1.28 No.

These observations on nectar thieving by *C. subnuda* in the cashew flowers emphasize on monitoring and documentation of different ant species and their role for better understanding of ant-cashew relationship. Ants can threaten cashew-bees mutualism and thus understanding the factors influencing pollination will aid in implementing better management measures.

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MS Received: 10 September 2024
MS Acceptance: 29 November 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 360-363 (2024)
DOI Number : 10.5958/0974-4541.2024.00059.7

RESEARCH NOTE

Efficacy of biopesticides and botanicals against *Carpomyia vesuviana* Costa on ber

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ABSTRACT: A field experiment on the relative efficacy of botanical and biopesticides against *Carpomyia vesuviana* Costa on ber was conducted in 2021-22. The results revealed that Spinosad45 SC was most effective, followed by azadirachtin 0.03 EC and NSKE (5%) whereas, *Neem* oil and *Karanj oil* were least effective. The treatment of *Beauveria bassiana* 1.15 WP and *Metarhizium anisopliae* 1.15 WP were found moderately effective against ber fruit fly.

Keywords: *Carpomyia vesuviana*, ber, biopesticides, azadirachtin, Karanj oil

The ber (*Ziziphus mauritiana* L.) also known as 'desert apple' is an important fruit crop in arid and semi-arid regions of Rajasthan, Haryana, Punjab, Gujarat, and other part of India. The low productivity of ber has been attributed to various abiotic and biotic factors the major factors that contributes towards low yield of ber is the damage done by a number of insect pests and diseases. Ber trees have been reported to be attacked by about over 100 species of insect- pests (Butani, 1979; Lakra and Singh, 1985). Among them ber fruit fly, *Carpomyia vesuviana* Costa is the most serious one (Sharma *et al.,* 1998, Lal *et al,.* 1993) and found everywhere in India where ber is grown. In serious cases, it causes severe yield loss up to 80 per cent or even up to 100 per cent damage (Sharma *et al.,* 1998; Karuppaiah, 2014). The use of botanicals and biopesticides for management of *Carpomyia vesuviana* is a part of this work for effective management of this pest and avoiding harmful effect to the predators.

A field experiment was laid out in a randomized block design (RBD) with eight treatments and replicated thrice. The ber variety 'Gola' recommended for this region was used andplant to plant distance of 8 m × 8 m. The treatments included were azadirachtin 0.03 EC, NSKE (5%), Neem oil (1%), *Metarhizium anisopliae* 1.15 WP, *Beauveria bassiana* 1.15 WP and spinosad and untreated control. Neem seed kernel extract was prepared by grinding known weight of kernel into a fine powder. The resulting powder was then socked overnight in sufficient quantity of water. The desired concentration of NSKE on kernel weight to volume (of water) basis was obtained by filtering the extract in a fine muslin cloth with repeated washing in the next morning. The volume was made up by adding the required quantity of water to get 5 per cent solution (Kumar *et al.,* 2000). Sandoval used one ml per liter of spray solution used as surfactant. The required quantity of different bio-pesticide was sprayed by using foot sprayer. Overall two sprays were done. The first spray was done at the peanut stage and second spray was done 30 days after the first spray. The fruit fly damage was recorded from each tree by observing hundred fruits randomly from bulk at each commercial picking (Patel *et al.*, 1989). Three pickings were taken during the season at ten days intervals. In all these treatments fruits were brought the laboratory and dissected with a knife and those possessing gallery, maggot or exit hole was taken as the fruit fly infestation. The yield of healthy fruits was recorded at each picking and mean fruit yield per tree was worked out.

The data as given in Table 1 indicate that the treatment of spinosad 45 SC was most effective having 11.61 per cent fruit infestation. This was followed by azadirachtin 0.03 EC having 23.72 per cent infestation. The treatment of *Beauveria bassiana* 1.15 WP and *Metarhizium anisopliae* 1.15 WP were found next effective treatments and resulted in 26.78 and 27.66 per cent infestation, respectively and at par to each other. The maximum infestation (30.86%) was recorded in *Karanj* oil followed by *Neem* oil (28.80%) treated plots which were found at par to each other. However, it was superior over control having 35.75 per cent fruit infestation. The treatments tested in the present study were not evaluated

earlier against ber fruit fly. Hence, the efficacy of these treatments tested on other crops discussed to support the present findings. In the present findings the efficacy of spinosad are conformity with that of Nehra *et al* (2019*)* and Rifat Alam *et al*. (2021) reported thet among the treatments, spinosad 45 SC performed the best based on minimum percent fruit infestation on both number and weight basis. Diksha *et al*. (2019) reported that among biopesticides, spinosad and azadirachtin though inferior over the synthetic pyrethroid, were as effective over neem and pongamia oil, *Beauveria bassiana*, clay and also over the recommended insecticide malathion. *Neem* oil, *B*. *bassiana*, Pongamia oil, clay and Neemastra treatments were not found much effective though these were superior over control. Bhowmik *et al*. (2014) reported that Neemazal and *karanj* oil were the least effective insecticide in reducing the fruit infestation by melon fruit fly.

Table 2 reveals that the maximum net profit of Rs. 625.04 per tree was recorded from the treatment of spinosad followed by azadirachtin (448/tree) and NSKE (379/tree). The lowest net profit of Rs. 193.80 per tree was obtained from *Karanj* oil which was followed by *Metarhiziumanisopliae* with net profit of Rs. 253.40 per trees. The net profit of Rs. 297.80 per trees was obtained from the treatment of *Neem*oil. The treatment of *Beauveria bassiana*, the net profit of cost of management of fruit fly was found 333.00. The highest cost benefit ratio of 1:4.03 was recorded from treatment of spinosad followed by *Beauveria bassiana,*

Table 1: Efficacy of different biopesticide against *C. vesuviana* on ber during 2021-22

Treatments	Formulation	Conc./ Dosage	Per cent fruit infestation at			Mean
	1.15 WP		10 DAT	20 DAT	30 DAT	
Beauveria bassiana		1g/l	24.60	26.78	29.00	26.78
			(29.82)	(31.12)	(32.57)	(31.14)
Karanj oil		1.5ml/l	28.00	31.80	32.80	30.86
	1.15 WP		(31.92)	(34.29)	(34.92)	(33.72)
Metarhizium anisopliae		1g/l	25.35	27.27	30.37	27.66
	Lab. prepared		(30.18)	(31.43)	(33.42)	(31.70)
NSKE		5.0%	23.37	25.80	28.00	25.72
	-		(28.86)	(30.48)	(31.93)	(30.44)
Neem oil		1 .5ml/l	25.80	29.40	31.20	28.80
	0.03 EC		(30.43)	(32.77)	(33.94)	(32.44)
Azadirachtin		5ml/l	21.38	23.50	26.30	23.72
	45 SC		(27.46)	(28.92)	(30.83)	(29.11)
Spinosad		0.01 %	10.38	11.47	13.00	11.61
	-		(18.68)	(19.71)	(21.11)	(19.90)
Untreated control		-	34.83	35.77	36.66	35.75
			(36.13)	(36.65)	(39.18)	(36.70)
S.Em.±			**0.51**	**0.61**	**0.81**	**0.26**
CD (p=0.05)			**1.57**	**1.88**	**2.50**	**0.80**

Figures in the parentheses are angular transformed value.
DAT = days after treatment

Table 2. Economics of different biopesticide applied for the management of *C. vesuviana* during 2021-22

Biopesticides	Formulation	Conc. (%)/ Dose	Marketable yield (kg/ tree)	Yield gain over control	Value of yield gain (Rs.)	Cost of treatment (Rs.)	Net profit/ tree (Rs.)	Incremental cost benefit ratio
Beauveria bassiana	1.15 WP	1 g/l	33.00	11.50	460.00	127.00	333.00	1:2.62
Karanj oil	-	1.5 ml/l	29.40	07.90	316.00	122.20	193.80	1:1.58
Metarhizium anisopliae	1.15 WP	1 g/l	31.00	09.50	380.00	126.60	253.40	1:2.0
NSKE	Lab prepared	5.0%	35.35	13.85	554.00	175.00	379.00	1:2.16
Neem oil	-	1.5 ml/l	32.00	10.50	420.50	122.20	297.80	1:2.41
Azadirachtin	0.03 EC	5 ml/l	37.00	15.50	620.00	172.00	448.00	1:2.60
Spinosad	45 SC	0.01%	41.00	19.50	780	154.96	625.04	1:4.03
Untreated			21.50	-	-			-

Market price ber: Rs. 40/kg

azadirachtin, *Neem* oil *and* NSKErecording the ratio of 1:2.62, 1:2.60 and 1:2.41 and 1:2.16 respectively. Cost benefit ratio obtained from the *Metarhizium anisopliae*was 1:2.00. The least cost benefit ratio was recorded in *Karanj* oil with 1:58. Diksha *et al*. (2019) who reported that among biopesticides, the BCR value of B. *bassiana* is 1:1.21 and Hosagoudar *et al*. (1999) reported that cost benefit ratio was maximum in Nimbicidine and NSKE with 1:3.00 and 1:3.24, respectively.

Effect of different treatments on marketable yield of ber fruits on weight basis

The data presented in Table 2 revealed that the weight of marketable fruits harvested from treated trees was recorded higher than control. Maximum weight of marketable yield of 41 kg ber per tree was recorded from the treatment of spinosad followed by azadirachtin and NSKE producing 37.00 and 35.35 kg per tree, respectively. The weight of marketable fruits in the treatments of *Beauveria bassiana*(33 kg/tree) and *Neem* oil (32kg/tree) respectively. Minimum weight of marketable fruit (29.40 kg/tree) was recorded from *Karanj* oil, followed by *Metarhiziumanisopliae* with and 31.00 kg fruits per tree, respectively. However, it was 21.50 kg per tree in untreated control. Hosagoudar *et al.* (1999) reported that lowest healthy fruit yield of ber was 12.76 and 13.53 kg/tree from Nimbicidine (0.03%) and NSKE (5%), respectively and shivbhagvan*et.al*. reported that lowest healthy fruit yield of ber was 17.20 and 18.45 kg/tree from Neem oil (1.5 ml/l) and NSKE (5%), respectively.

Effect of different treatments on loss due to ber fruit fly on weight basis

The data presented in Table 2 and revealed that the weight of fruits was also reduced due to the infestation of fruit fly *C. vesuviana*. The minimum loss in fruit weight (6.27 kg/tree) was recorded in the treatment of spinosad followed by azadirachtin, NSKE and *Neem* oil with loss of 09.92, 10.80 and 10.87 kg per tree, respectively. The loss in weight of fruit in the treatments of *Metarhizium anisopliae and Beauveria bassiana* was 10.90 and 11.00 kg per tree. The maximum loss in weight of fruits (12 kg/tree) was recorded from the treatment of *Karanj* oil. In control the loss in weight of fruits was recorded 13.50 kg per tree. Hosagoudar et al. (1999) reported that maximum fruit yield loss of 10.25 and 9.45 kg/tree as recorded from treatments of Nimbicidine (0.08%) and NSKE (5.0%), respectively. Shivbhagvan *et al*., reported that maximum fruit yield loss of 9.13 and 8.98 kg/tree as recorded from treatments of NSKE (5.0%) and Neem oil (1.5 ml/l), respectively.

The study showed that using spinosad resulted in the lowest total and percentage of avoidable losses, as well as the highest benefit-cost ratio. These results indicate that this biopesticide is effective in reducing fruit fly presence in ber fields while maintaining economic viability.

ACKNOWLEDGEMENT

The senior author thanks the Dean, SKN College of Agriculture, Jobner (Sri Karan Narendra Agriculture University, Jobner) Jaipur, Rajasthan for providing facilities.

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MS Received:09 November 2024
MS Acceptance:15 December 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 364-367 (2024)
DOI Number : 10.5958/0974-4541.2024.00060.8

RESEARCH NOTE

Eco friendly management of fruit fly, *Zeugodacus cucurbitae* infesting bottle gourd

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ABSTRACT: Field trials were conducted to evaluate the efficacy of seven botanicals to manage melon fly, *Zeugodacus cucurbitae* (Coquillett) infesting bottle gourd. Out of seven botanicals azadirachtin (0.03%) was found most effective against fruit fly followed by NSKE. The maximum yield of bottle gourd (282 q ha^{-1}) was obtained from the plots treated with azadirachtin 0.03% followed by NSKE (280 q ha^{-1}) while the minimum fruit yield was obtained with *karanj* oil (268q ha^{-1}). The maximum incremental benefit-cost ratio was obtained from the plot treated with *tumba* crude extract (9.91) while the minimum benefit cost ratio (2.20) in *karanj* oil.

Keywords: Fruit fly, azadirachtin, NSKE, *karanj* oil, bottle gourd

Bottle gourd [*Lagenaria siceraria* (Molina) Standley], a white-flowering annual plant from the Cucurbitaceae family, is widely spread in tropical regions and plays an important role in local economies. It is grown during the spring, summer, and wet seasons. It is consumed as a vegetable. Bottle gourd is susceptible to the attack of several insect pests during different stages of crop growth like melon fly, *Zeugodacus cucurbitae* (Coquillett), red pumpkin beetle, *Raphidopalpa foveicollis* (Lues); hadda beetle, *Epilachna dermurili* Mulsent; whitefly, *Bemisia tabaci* Gennadius; aphid, *Aphis gossypii* Glover; leaf miner, *Liriomyza trifoli;* and mirid bug*, Nesidiocoris cruentatus* (Ballard). Among them, the melon fruit fly *cucurbitae* has been observed to cause serious damage to bottle gourd fruits. Maggots feed on pull inside the fruits. Losses to may reach 100 per cent if control measures are not applied (Vayssieres and Carel., 1999). In order to find safer means of managing fruit fly, the present study evaluated the efficacy of botanicals for the management of fruit fly infesting bottle gourd.

The present investigations were carried out at the Instructional Farm of the College of Agriculture, Jodhpur, Rajasthan, during the *kharif*, 2023. The experiment was conducted in a simple randomized block design with eight treatments including control and each replicated three times. The seeds of bottle gourd variety Pusa Naveen were sown on 12th August 2023 keeping row to row and at a spacing of 3 x 0.75 m2. The recommended package of practices was followed to raise the crop.

The spraying was done by using pre-calibrated knapsack sprayer. The first foliar spray of each treatment was commenced at the fruit setting stage on 16th October during 2023 when oviposition marks were noticed in bottle gourd fruits and the second spray was given on was given just after observing ETL. The quantity of water at the rate of 500 l/ha was used in each spray application. The observations on the total number of fruits and infested fruits in each plot were recorded regularly before and 4, 7, 10, 13, and 16 days after each spray application.The percentage of fruits infestation was worked out. The fruit yield per plot (kg) was recorded at three days interval and at the end of crop season of all the pickings per plot were cumulated and converted to hectares basis and then statistically analysed. To ascertain the cost-effective treatment. Incremental Cost Benefit Ratio (ICBR) was worked out by taking into account the expenditure on individual botanical treatment and the income from yield.

Effect of botanical treatments on fruit fly infestation

Four days after the first spray, all treatments significantly reduced fruit fly infestation compared to the control, with azadirachtin 0.03% showing the lowest infestation (14.47%) followed by NSKE (14.67%), which were comparable. Other effective treatments included moringa leaves and bark extract (20.20%), *Tumba* crude extract (20.83%), and castor oil (21.27%). Castor oil was at par with Thar Jaivik 41EC (25.37%), while

Karanj oil exhibited the highest infestation (27.43%). After seven days, azadirachtin 0.03% (12.87%) and NSKE (13.67%) remained the most effective, with no significant difference between them. Moringa leaves and bark extract (18.47%), *Tumba* crude extract (19.20%), and Castor oil (19.23%) were moderately effective, while Karanj oil (27.43%) remained the least effective. At 10 days, azadirachtin (14.17%) and NSKE (15.13%) continued to show the lowest infestation, followed by moringa leaves and bark extract (20.40%), *Tumba* crude extract (21.10%), and Castor oil (21.03%). At 13 days, azadirachtin (15.07%) and NSKE (15.63%) were again the most effective, with Moringa leaves and bark extract (21.30%), *Tumba* crude extract (22.27%), and castor oil (24.07%) showing moderate efficacy, and *Karanj* oil (30.83%) exhibiting the highest infestation. After 16 days, the infestation ranged from 15.90% (azadirachtin 0.03%) to 31.01% (karanj oil), with azadirachtin and NSKE continuing to show the lowest levels of infestation, followed by Moringa leaves and bark extract (22.57%), *Tumba* crude extract (23.10%), and Castor oil (24.77%), while *Karanj* oil (31.01%) remained the least effective. Overall, azadirachtin 0.03% and NSKE consistently performed the best, followed by Moringa leaves and bark extract, *Tumba* crude extract, and castor oil, with *Karanj* oil being the least effective treatment for managing fruit fly infestation.

Second spray

In the second spray application, all treatments significantly reduced fruit fly infestation compared to the control. Four days post-application, azadirachtin 0.03% exhibited the lowest infestation (13.87%), followed by NSKE (15.70%), both of which were comparable in effectiveness. The next most effective treatments included Moringa leaves and bark extract (20.73%), *Tumba* crude extract (21.43%), and castor oil (21.97%), with Castor oil being at par with Thar Jaivik 41EC (27.40%). *Karanj* oil showed the highest infestation (29.07%), indicating its lower efficacy. A similar pattern was observed seven, ten, and thirteen days after the second spray, with Azadirachtin 0.03% and NSKE consistently demonstrating the lowest infestation. Sixteen days post-application, Azadirachtin 0.03% (17.07%) and NSKE (18.57%) remained the most effective, followed by Moringa leaves and bark extract (25.83%), *Tumba* crude extract (26.70%), and castor oil (27.03%). Castor oil was also comparable to Thar Jaivik 41EC (28.40%), while *Karanj* oil continued to show the highest infestation (33.80%). Overall, azadirachtin 0.03% and NSKE were the most effective treatments in controlling fruit fly infestation, with *Karanj* oil proving to be the least effective.The order of effectiveness after sixteen days of application was azardiractin 0.03% > NSKE > moringa leaves and bark extract > *Tumba* crude extract > castor oil>thar jaivik 41EC > *Karanj* oil.

These observations are also supported by the findings of Khursheed and Desharaj (2012) who reported that spraying with azadirachtin was superior over malathion for controlling melon fruit fly with less per cent fruit damage. Sawai *et al*. (2014) reported that treatment of azadiractin was at par with DDVP and emamectin benzoate. Pal *et al.* (2015) reported that malathion 50EC @ 1ml/l provided maximum reduction in fruit infestation followed by NSKE. Ali *et al*. (2011) reported that minimum per cent fruit damage (41.94%) by fruit fly in bitter gourd was noticed in neem seed kernel extract treatment and was superior over other plant extract treatments.

Economics of the treatments

The maximum yield was recorded in the plot treated with azadiractin 0.03% with 282 q ha^{-1}followed by NSKE 280 q ha^{-1}fruit yield.The minimum fruit yield was obtained karanj oil (268q ha^{-1}) followed by Thar jaivik 41EC (270 q ha^{-1}).The maximum incremental benefit-cost ratio of 9.91 was recorded in tumba crude extract followed by 9.35 in azardiractin 0.03% and 7.57 in castor oil.The lowest benefit-cost ratio was computed in the plot treated with *karanj* oil (1:2.20) followed by moringa leaves and bark extract (4.33) (Table 2).

The study highlights the efficacy of various botanical insecticides in managing the fruit fly, *Z. cucurbitae*, in bottle gourd. Among the treatments evaluated, azadiractin at 0.03% emerged as the most effective in reducing fruit fly infestation, followed by NSKE and moringa leaves and bark extract. Economically, azadirachtin and NSKE proved to be highly cost-effective, showcasing favourable incremental cost-benefit ratios. These findings suggest that adopting botanical insecticides like azadirachtin and NSKE can be beneficial for sustainable pest management in bottle gourd production.

Table 1. Management of fruit fly infesting bottle gourd using botanicals pesticides (First spray)

Treatments	Dose	Per cent fruit infestation					
		Before spray	4 DAS	7 DAS	10 DAS	13 DAS	16 DAS
Azadirachtin 0.03%	5 ml/litre	20.07 (26.59)	14.47 (22.14)	12.87 (20.91)	14.17 (21.95)	15.07 (22.73)	15.90 (23.47)
NSKE	5 ml/litre	19.60 (26.23)	14.67 (22.52)	13.67 (21.63)	15.13 (22.79)	15.63 (23.25)	16.57 (23.90)
Moringa leaves & bark extract	10 ml/ litre	23.20 (28.74)	20.20 (26.66)	18.47 (25.44)	20.40 (26.70)	21.30 (27.42)	22.57 (28.30)
Tumba crude extract	5 ml/litre	22.27 (28.03)	20.83 (27.13)	19.20 (25.91)	21.10 (27.31)	22.27 (28.13)	23.10 (28.63)
Castor oil	2 ml/litre	23.93 (29.24)	21.27 (27.34)	19.23 (25.97)	21.03 (27.23)	24.07 (29.37)	24.77 (29.84)
Thar jaivik 41EC	4 ml/litre	27.87 (29.24)	25.37 (30.19)	25.17 (30.10)	27.10 (31.37)	30.47 (33.50)	30.60 (33.17)
Karanj oil	2 ml/litre	29.10 (32.64)	27.43 (31.57)	25.60 (30.38)	27.53 (31.62)	30.83 (33.70)	31.01 (33.44)
Untreated control		25.83 (30.54)	28.37 (32.18)	31.13 (33.90)	36.63 (37.24)	42.50 (40.67)	44.43 (41.79)
S.Em.±		1.34	1.34	1.23	1.32	1.34	1.35
C.D at (P= 0.05)		4.08	4.08	3.74	4.00	4.07	4.11

Figures in parenthesis are arcsine values
DAS: Days After Spraying

Table 2. Management of fruit fly infesting bottle gourd using botanicals pesticides (Second spray)

Treatments	Dose	Per cent fruit infestation						Mean yield (q ha^{-1})	Incremental Benefit cost ratio
		Before spray	4 DAS	7 DAS	10 DAS	13 DAS	16 DAS		
Azadirachtin 0.03%	5 ml/ litre	15.90 (23.47)	13.87 (2177)	13.50 (21.45)	14.63 (22.36)	16.23 (23.67)	17.07 (24.39)	281.7	9.35
NSKE	5 ml/ litre	16.57 (23.90)	15.70 (23.24)	14.97 (22.70)	16.23 (23.71)	16.87 (24.20)	18.57 (25.51)	280.0	5.67
Moringa leaves & bark extract	10 ml/ litre	22.57 (28.30)	20.73 (27.01)	19.07 (25.89)	21.57 (27.66)	22.43 (28.25)	25.83 (30.49)	278.0	7.57
Tumba crude extract	5 ml/ litre	23.10 (28.63)	21.43 (27.55)	19.77 (26.39)	22.50 (28.27)	23.77 (29.16)	26.70 (31.09)	274.7	2.20
Castor oil	2 ml/ litre	24.77 (29.84)	21.97 (27.92)	20.30 (26.72)	23.53 (29.02)	24.13 (29.36)	27.03 (31.25)	271.7	5.67

Thar jaivik 41EC	4 ml/ litre	29.93	27.40	25.40	26.17	27.43	28.40	262.0	9.91
		(33.17)	(31.56)	(30.24)	(30.75)	(31.55)	(32.17)		
Karanj oil	2 ml/ litre	20.37	29.07	26.73	29.50	31.07	33.80	267.3	4.33
		(33.44)	(32.60)	(31.09)	(32.88)	(33.87)	(35.54)		
Untreated control		44.43	47.87	44.53	42.20	40.83	35.56	259.7	
		(41.79)	(43.78)	(41.86)	(40.50)	(39.69)	(36.60)		
S.Em. ±		1.38	1.36	1.35	1.24	1.34	1.34	37.17	
C.D at (p= 0.05)		4.19	4.14	4.10	3.78	4.08	4.09	118.82	

Figures in parenthesis are arcsine values
DAS: Days After Spraying

ACKNOWLEDGEMENTS

The authors are grateful to the Dean, College of Agriculture, Jodhpur, for providing the necessary facilities.

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MS Received:14 September 2024
MS Acceptance: 25 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 368-370 (2024)
DOI Number : 10.5958/0974-4541.2024.00061.4

RESEARCH NOTE

Management of fruit fly, *Bactrocera dorsalis* (Hendel) through fruit bagging in custard apple

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ABSTRACT: An investigation on "Assessment of hybrid custard apple (*Annona* spp.) genotypes for Fruit fly (*B. dorsalis*) infestation and control strategies"was carried out at AICRP, Arid Zone Fruit, MPKV, Rahuri during 2023. Seasonal incidence study of fruit fly (*B. dorsalis*) on twelve hybrid genotypes of custard apple, it was observed that the genotypes Hy-06, Hy-07, Hy-08, Hy-20, Hy-21, Hy-22, and Annona-7 showed no incidence of fruit fly maggots. Moderate infestation was found in the genotypes Balanagar and Phule Janaki, while NMKG, NMK-3, and Arka Sahan were significantly more susceptible to fruit fly attacks compared to the other genotypes. Among the seven treatments against fruit fly control on the NMKG genotype, the white wax-coated bag proved the most effective, showing no maggots in the fruit. It was at par to the polypropylene white bagand the brown-colored wax coated bag. Then next effective treatment was the brown paper bag which was on par with the methyl eugenol trap and karanj + neem oil spray showed higher levels of infestation compared to other treatments while untreated control had the highest infestation.

Keywords: Fruit fly, *B. dorsalis*, custard apple pests

The custard apple (*Annona* spp.) is a tropical fruit crop belonging to the Annonaceae family. The major custard apple-producing states are Maharashtra, Gujarat, Andhra Pradesh, Uttar Pradesh, Madhya Pradesh, Bihar, Assam, Rajasthan, Odisha and Tamil Nadu. Maharashtra being the top producer of custard apple cultivation, covers over 17,080 hectares, out of a total of 52,000 hectares nationwide, with a production of 1,39,230 MT in Maharashtra and 4,60,100 MT across the country (Anonymous, 2023).

Among different insect pests attacking custard apple, Oriental fruit fly, *Bactrocera dorsalis* (Hendel) is emerging as a serious pest of custard apple particularly in hybrid cultivars compared to *Annona squamosa.* The fruit fly infests semi-ripened fruit by laying eggs, maggots feeds on flesh by bore into the fruit, puncturing the skin and causing direct damage. Integrated management strategies include destroying infested fruits, ploughing around trees to eliminate pupae and using mass trapping with methyl eugenol traps to monitor and manage the pest population. Recently fruit bagging is being advocated to prevent fruit fly damage in different fruit crops. However no systematic studies were conducted on efficacy of different types of bags to cover Annona fruits. Hence present study was conducted to evaluate bags made of different materials for fruit fly management.

The experiment was conducted at the Institutional Research Orchard, MPKV Rahuri, in a Randomized Block Design (RBD) using the cv. NMKG hybrid of custard apple, with three replications for each treatment. The materials tested included polypropylene bags (white), white wax-coated bags, brown paper bags and brown wax-coated bags, all sized 6 x 5 inches, alongside methyl eugenol traps and a mixture of karanj oil (1%) and neem oil (99%) at 3 ml/lit. Fruits were bagged one month before harvest (Karim, 1989) when they reached the size of a cricket ball as it shows a preference for laying eggs on fruits between 30 to 40 days before harvest fruit based on maturity indices. After ripening, the number of maggots in the fruits was counted by cutting them horizontally and the surviving maggots per fruit were recorded from each treatment replicate. This data was used for further analysis, which was performed using the technique of analysis of variance (ANOVA), with significance determined according to the method by Panse and Sukhatme (1978) for Randomized Block Design.

Table 1. Evaluation of different treatment against fruit fly (*B. dorsalis*) on hybrid custard apple

Tr. No.	Name of the treatment	Size/ Dose	Av. no. of maggots observed per three fruits	Per cent fruit damage
T_1	Polypropylene white bag	6 x 5”	0.4 (0.92)	13.3
T_2	White wax coated bag	6 x 5”	0.0 (0.71)	0.0
T_3	Brown paper bag	6 x 5”	1.7 (1.49)	56.7
T_4	Methyl eugenol Trap	1 trap	2.1 (1.61)	70.0
T_5	Brown color wax coated bag	6 x 5”	0.9 (1.20)	30.0
T_6	Spraying of Karanj oil + Neem oil	3 ml/lit+ 3 ml/lit	2.8 (1.81)	93.0
T_7	Untreated control	-	4.0 (2.13)	133.0
SE(m)±			0.07	-
Cd at 5%			0.23	-

Figures in the parenthesis indicates $\sqrt{x + 0.5}$transformed values

The data presented in table 1 reveal that all four types of bagging materials effectively protected against fruit fly infestation, with untreated control(T_7) fruits averaging 3.67 maggots per fruit. Notably, the white wax-coated bag (T_2) exhibited superior performance, showing no maggots in the fruit. This result positions it as the most effective treatment among the options tested. It was at par to the polypropylene white bag (T_1) registered an average of 0.4 maggots per fruit (13.3% damage) and the brown color wax-coated bag (T_5) had an average of 0.9 maggots per fruit (30% damage). The brown paper bag (T_3) was also effective, recording an average of 1.7 maggots per fruit (56.7% damage), which was at pat to the methyl eugenol trap treatment (T_4), showing 2.1 maggots per fruit (70% damage). Additionally, the treatment involving a karanj and neem oil spray (T_6) resulted in 2.8 maggots per fruit (93.5% damage), which, while exhibiting more maggots than the other treatments, was still lower than the untreated control, which had 4.0 maggots per fruit (133% damage). The current findings are consistent with research by Begum *et al.* (2013), who tested five bagging techniques over two fruiting seasons, including perforated polythene and paper bags. They found that perforated white polybags nearly eliminated fruit fly infestation, producing almost 100% non-infested fruits. Similarly, Mondal *et al.* (2015) studied fruit wrapping methods, reporting infestation rates between 1.32% and 17.31%, with transparent polypropylene bags and partial paper covers yielding the lowest loss at 1.66%. Both studies emphasize the effectiveness of bagging in reducing fruit fly infestations and enhancing fruit quality. Bagging fruits with white wax-coated bags, and another polypropylene white bags, emerged as the most effective management strategy, substantially reducing infestation levels.

These results underscore the efficacy of various bagging materials and highlight the potential for implementing these strategies in custard apple cultivation to manage fruit fly infestations effectively.

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MS Received: 05 September 2024
MS Acceptance: 15 October 2024

Pest Management in Horticultural Ecosystems
Vol. 30, No.2 pp 371-372 (2024)
DOI Number : 10.5958/0974-4541.2024.00062.0

RESEARCH NOTE

Record of severe infestation of root-knot nematode (*Meloidogyne incognita*) in the Mangalore Spinach (*Basella alba)* in and around Bengaluru, India

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ABSTRACT: Mangalore spinach (*Basella alba*) is a widely cultivated leafy vegetable known for its nutritional benefits. During a field survey in and around Bengaluru rural areas, it was observed that *B. alba* was severely affected (60-80% plants) by the root-knot nematode (*Meloidogyne incognita*). It warrants an integrated approach to manage the root knot nematode to protect this economically important crop. Different cultural, physical and biological means of management are discussed.

Keywords: *Basella alba*, spinach, root knot nematode, biopesticides

Mangalore spinach (*Basella alba*) is a widely cultivated leafy vegetable known for its nutritional benefits. However, its cultivation is often hampered by the root-knot nematode (*Meloidogyne incognita*), which causes significant damage to the plants. A survey conducted in and around Bengaluru revealed a notable increase in nematode infestation following rainfall. Infested plants exhibited symptoms such as stunted growth, yellowing, and drying up. One of the most telling signs of nematode presence is the formation of galls or knots on the roots, which disrupts the plant's ability to absorb water and nutrients effectively. These symptoms collectively hinder the overall health and productivity of the plants, necessitating timely and effective management strategies.

Soil samples were collected from the rhizosphere of infested plants from four locations *viz.*, Varadenahalli, Kodihalli, Mandibelle, (Bengaluru Rural District) and Gundligurki, from Chikkaballapur District, Karnataka.The Baermann funnel technique was used for nematode extraction. Soil samples were placed on a mesh or tissue paper supported by a funnel filled with water. The setup was allowed to sit for 24-48 h, enabling nematodes to migrate out of the soil and into the water. Nematodes were collected from the water and counted under a microscope to assess infestation levels.

In every plot examined, 14 out of 20 vines (70%) in the first plot, 16 out of 20 vines (80%) in the second plot, 12 out of 20 vines (60%) in the third plot, and 13 out of 20 vines (65%) in the fourth plot were affected by the root-knot nematode infestations. To manage root-knot nematode infestations in Mangalore spinach, several strategies were employed. Solarization involved uprooting affected plants and exposing the soil to direct sunlight, which helped reduce nematode populations by heating the soil to lethal temperatures for nematodes and other soil-borne pathogens. Organic treatment included mixing Rashvee liquid herbal soap (at 1ml/l of water) with neem cake (50g/plant) and applying it to the soil after uprooting. This method effectively eliminated nematodes without harming beneficial microorganisms, as neem cake acted as a natural nematicide and the herbal soap enhanced its efficacy. Biological control was achieved by using nematode-trapping fungi such as *Purpureocillium lilacinum*, which parasitize nematodes and reduce their population in the soil. This eco-friendly approach maintained soil health and biodiversity. Additional measures included crop rotation with non-host crops to break the nematode life cycle, using nematode-resistant varieties of Mangalore spinach if available, incorporating organic matter such as compost or green manure to improve soil health and suppress nematode populations, and applying organic mulch to maintain soil moisture and temperature, which helped reduce nematode activity.

Fig. 1 *Meloidogyne incognita* infected roots of *Basella alba*

The management of root-knot nematodes in Mangalore spinach requires an integrated approach combining cultural, organic, and biological methods. Solarization is effective in reducing nematode populations by utilizing high soil temperatures, which are lethal to nematodes. Organic treatments, such as the application of neem cake and herbal soap, provide a sustainable alternative to chemical nematicides, preserving beneficial soil microorganisms. By adopting these integrated pest management strategies, Mangalore spinach cultivation can be sustained, promoting eco-friendly home garden practices. These methods not only manage nematode infestations effectively but also enhance soil health and productivity.

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MS Received: 20 November 2024
MS Acceptance: 10 January 2025

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Printed at : Shreya Printers & Publishers, Mobile: 9538186800